SHURA Energy Transition Center

The external cost of fossil fuel use in power generation, heating and road transport in Turkey

About SHURA Energy Transition Center
SHURA Energy Transition Center, founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University, contributes to decarbonisation of the energy sector via an innovative energy transition platform. It caters to the need for a sustainable and broadly recognized platform for discussions on technological, economic, and policy aspects of Turkey's energy sector. SHURA supports the debate on the transition to a low-carbon energy system through energy efficiency and renewable energy by using fact-based analysis and the best available data. Taking into account all relevant perspectives by a multitude of stakeholders, it contributes to an enhanced understanding of the economic potential, technical feasibility, and the relevant policy tools for this transition.

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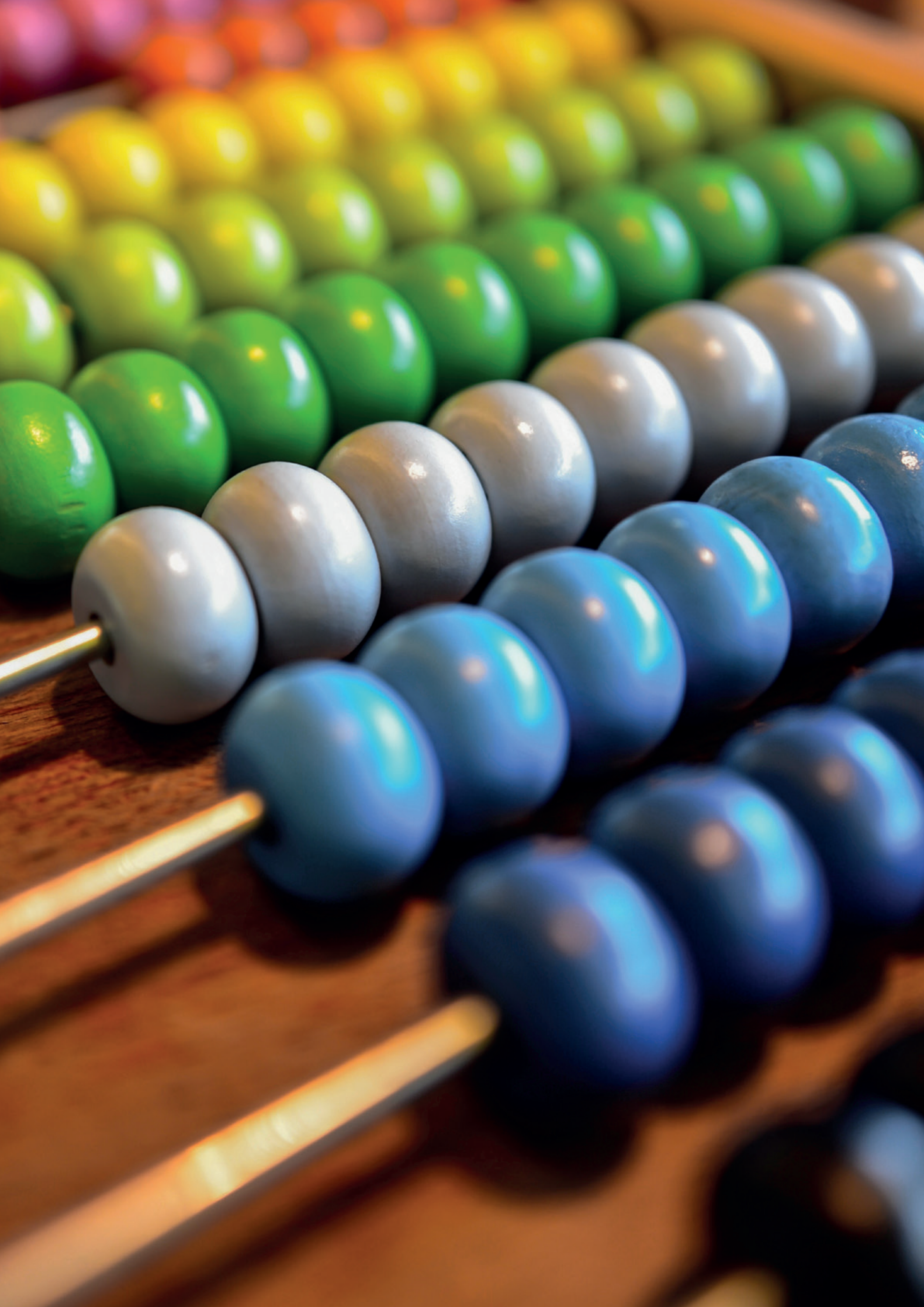
Disclaimer
This report and the assumptions made within the scope of the study have been drafted based on different scenarios and market conditions as of the end of 2019. Since these assumptions and the market conditions are subject to change, it is not warranted that the forecasts in this report will be the same as the actual figures. The institutions and the persons who have contributed to the preparation of this report cannot be held responsible for any commercial gains or losses that may arise from the divergence between the forecasts in the report and the actual values.

The external cost of fossil fuel use in power generation, heating and road transport in Turkey



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LIST OF ABBREVIATIONS

AQLI	Air Quality Life Index
CASES	Cost Assessment for Sustainable Energy Systems
CH_4	Methane
CIEMAT	Centre for Research on Energy, Environment and Technology (University of Granada)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DALY	Disability Adjusted Life Years
€	Euro
EDGAR	Energy Data for Global Atmospheric Research
ECU	European Currency Unit
EAF	Electrical Arc Furnace
EF	Emission Factors
EİGM	General Directorate of Energy Affairs (Elektrik İşleri Genel Müdürlüğü)
EPİAŞ	Turkish Energy Exchange Inc. (Enerji Piyasaları İşletme Anonim Şirketi)
ETS	Emissions Trading System
EU	European Union
EU-27	The 27 member countries of the European Union
ExternE	External Costs of Energy Project
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HEI	Health Effects Institute
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
Ktoe	kilotons of oil equivalent
Kton	kiloton
LHV	Low Heating Value
m	Mass of fossil fuel
MW	Megawatt
N_2O	Nitrous Oxide
NGCC	Natural Gas Combined Cycle
NIR	National Inventory Report
NMVOC	Non-methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
O_3	Ozone

OECD	Organisation for Economic Cooperation and Development
PM	Particulate matter
Ppb	Parts per billion
PP	Power plant
PPP	Purchasing Power Parity
PPS	Purchasing Power Standard
SO_x	Sulphur Oxide
toe	tons of oil equivalent
TÜİK	Statistics Institution of Turkey (Türkiye İstatistik Kurumu)
TÜPRAŞ	Petroleum Refineries of Turkey Inc. (Türkiye Petrol Rafinerileri Anonim Şirketi)
TWh	Teravat-saat (trilyon KWh)
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
US$	United States Dollar
VOC	Volatile Organic Compounds
VSL	Value of Statistical Life
WHO	World Health Organisation
YLD	Years Lived with Disability
YOLL	Years of Life Lost

Executive Summary

This report aims to provide a first attempt at quantifying the unpriced, or external, costs of fossil fuel use for energy consumption in Turkey. While various studies exist for estimating the external costs of fossil fuels on a global basis or for some individual countries and regions, such as the EU, an in-depth study for Turkey, covering power generation, heat and road transport, is being published for the first time. While there are previous studies for individual sectors, such as power generation or road transport, the present study is unique in its coverage of both sectors and types of pollutants.

Fossil fuel pricing is an area generally referred to as "market failure" by economists since many of the costs associated with fossil fuel consumption, such as adverse effects on air, soil, forests, human health and climate are not reflected by market prices. In other words, the market prices do not include the social costs of using fossil fuels for energy generation. Thus, the price of energy generation from fossil fuels based only on market prices does not reflect the true cost of fossil fuel consumption. Basing investment and consumption decisions for energy generation from fossil fuels on market prices without attention to external costs is misleading from a social perspective. In the case of costs of emissions that cause climate change, the social costs are not just national or regional but also global. Estimating the external costs of fossil fuel consumption and reflecting it in actual costs, either through taxes or emissions trading, has thus become part of the international agenda. In case of Turkey, where emissions trading, carbon or fossil fuel taxes are not yet implemented nationally, European Union countries are preparing to impose border taxes on their imports of Turkish products based on the carbon content production.

In the current context, the recent economic slowdown due to COVİD-19 measures since the beginning of 2020, has resulted in reduced emissions and improved air quality. Besides, the slump in economy, trade and transport caused a sharp decline in the price of oil and other fossil fuels. Temporarily improved air quality and declining fossil fuel prices brings in the question of immediate action for climate change issues and raises concerns of shifting priorities. On the other hand, the current situation is also raising awareness of the possibilities for improvement and increasing demand on governments for intensifying their efforts for the general wellbeing on a national and global scale. Therefore, discussing the real cost of fossil fuels and focusing on the long-term is now timelier and more relevant than ever.

This study, covering fossil fuel use in power generation, heating, and road transport sectors in Turkey, constituting 89% of total fossil fuel use, was performed with 2018 data. Results are presented by sectors for each of the seven geographical regions of Turkey, distributed by type of fuel and pollutant. **Total annual external costs of fossil fuel use in Turkey, based on the emissions calculated for each sector, is estimated to be around 10 billion Euros (11 billion US$). The magnitude of the external costs of fossil fuel consumption corresponds to about 1.5 percent of GDP and about 1/3 of total annual health expenditures. The estimated external cost of fossil fuel use is three times the level of subsidies provided to fossil fuels in Turkey.**

With 2.9 billion Euos/year, power generation has the highest external cost from fossil fuel consumption followed by the transport sector with a cost of 2.7 billion Euos/year. Fossil fuel consumption in industry (including oil refineries, iron & steel, cement, ceramics, food and textiles) has an external cost of 2.4 billion Euos/year, whereas the external cost in buildings is 1.6 billion Euos/year. **These values indicate that, from a health and environment perspective, while reducing emissions from power generation is clearly top priority, emissions from other sources come close and cannot be overlooked.**

A breakdown of external costs by fuel type shows that 56% arise from coal use (of which about 60% comes from lignite used for electricity generation and heating) and 33% from petroleum products. Natural gas use constitutes 11% of external costs of fossil fuels. This study does not take into account external costs that may arise as a result of biofuel or biomass consumption.

Regionally, the Marmara region with its concentration of population, industrial production and energy consumption has the highest level of external costs of fossil use with a 28% share. The Aegean and Mediterranean regions, with 18% share each, are the most exposed after the Marmara region.

According to the calculations in this report, external costs of air pollution constitute 60% of total external costs from fossil fuel use while the share of greenhouse gases (mainly carbon dioxide- CO_2) is 40%. These percentages are indicative and could vary substantially depending on assumptions related to emissions and unit social costs. After CO_2, the highest cost stems from nitrogen oxides (No_x) and particulate matter (PM) emissions, accounting for about half the external costs caused by fossil fuel use. While NO_x emissions in Turkey arise mainly from the transport sector, PM emissions come predominantly from power generation. Developments related to energy efficiency and electrification in these sectors will provide opportunities for reducing fossil fuel consumption.

The results of the study reveal that the magnitude of fossil fuel costs not reflected in prices is considerably high. If external costs were taken into account, the cost of power generation would be 8% higher than market costs for natural gas, 26% higher for hard coal and 58% higher for lignite. Taking into account quality of life and welfare effects, calculations clearly justify replacement of fossil fuels with renewables in power generation. With further research and technological development, similar comparisons could be made for the heating and transport sectors.

The externality cost figures calculated for Turkey in this study should be considered a low-end estimate in the light of higher figures implied in other studies. Comparison with emissions estimates in Emissions Data for Global Atmospheric Research (EDGAR) of the European Commission Joint Research Centre suggests that **the upper bound of the external costs for sectors included in this study may reach 20 billion Euros. Expanding the coverage of the study to sectors not currently included, such as mining, construction, agriculture, and industrial sectors other than those covered in this study would further increase this sum.**

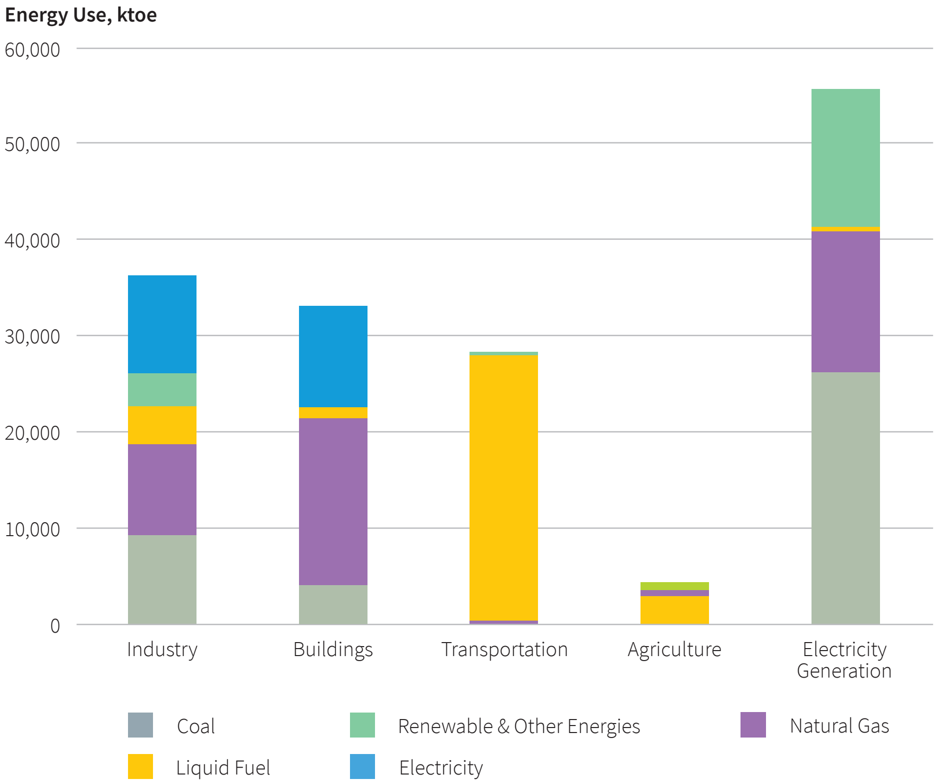
In sum, the potential socioeconomic benefits of avoiding the costs of fossil fuel use can be substantial and need to be further studied and incorporated into the design of energy and economic development policies of Turkey.

1. Introduction

Objectives and scope

Turkey's energy demand is increasing 3-4% on average per year. The country continues to largely rely on fossil fuels comprising just below 90% of its primary energy supply. The share of fossil fuels is lower for the power generation sector which is at around 75% in 2018 as seen in Figure 1 (Enerji İşleri Genel Müdürlüğü, 2019).

Figure 1: *Sector breakdown of energy use by fuel type in Turkey, 2018*



Source: EİGM, 2019

Growing energy demand with continuing reliance on fossil fuels creates adverse effects on the environment and human health.

Growing energy demand with continuing reliance on fossil fuels create adverse effects on the environment and human health. Sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), mercury, arsenic, fluorine are among the pollutants generated due to the combustion of fossil fuels. These pollutants can cause serious health effects in addition to other impacts such as reduced agricultural yields and forest damage. Moreover, effects of each individual particle are exacerbated by overall exposure to a mixture of particles, especially fine particles of SO_x, NO_x and other emissions. Major air pollutants and their effects on human health caused by fossil fuel consumption are summarized in Table 1.

***Table 1:** Major Air pollutants and effects on human health*

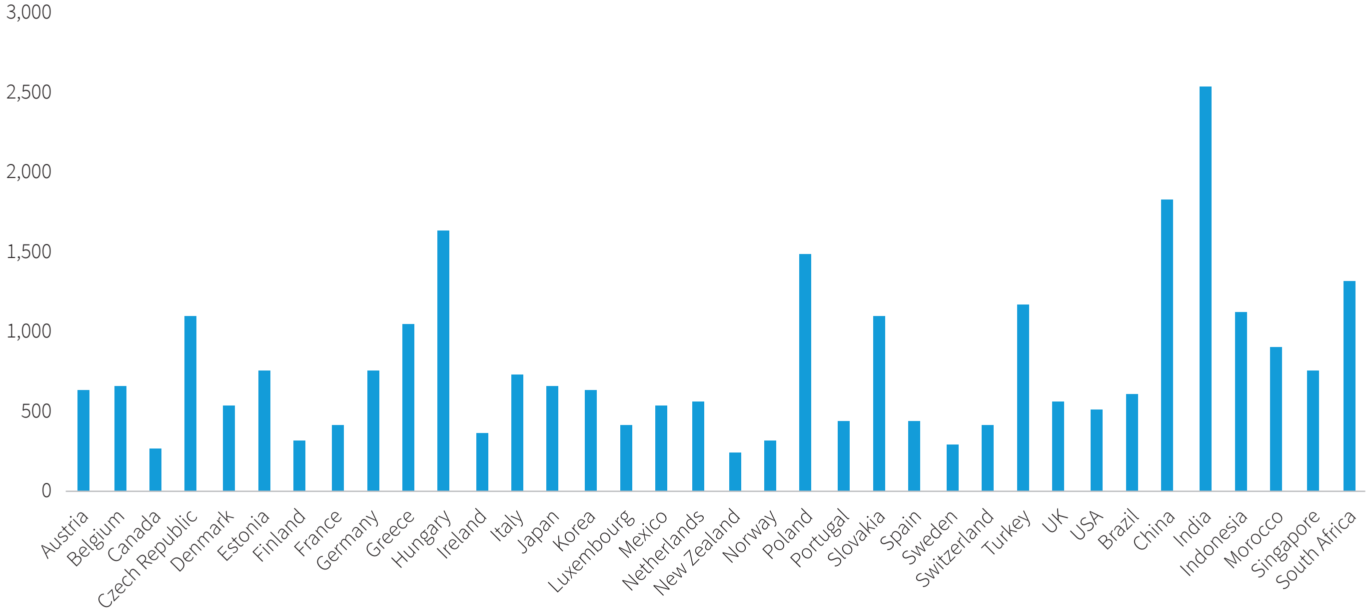
Nitrogen Oxides (No_x)	NO, NO_2 caused by the combination of nitrogen in the air with oxygen when fossil fuels are burned, resulting in acid rain and fog.	Cardiovascular diseases, asthma exacerbation, chronic obstructive pulmonary disorder, other respiratory diseases
Sulphur Oxides (So_x)	SO_2 is mainly caused by industrial processes, combustion engines and power generation from fuels with sulphur content. Sulphur also combines with oxygen, causing acid rain.	Eye, nose and throat irritation, exacerbation of chronic respiratory conditions; increased risk of infection.
Ozone (O_3)	Ground level ozone caused by reaction of NOx with volatile organic compounds resulting in fog.	Chest pain, throat irritation, inflammation of the airways, lung function impairment, exacerbation of symptoms of bronchitis, emphysema and asthma
Particulate Matter (PM)	Extremely small particles and liquid droplets in the atmosphere.	Respirable particles cause various adverse effects in airways and lungs.
PM_{10}	Ultrafine particles with a diameter ≤ 10 µ	Inhalable particles can lodge in the respiratory tract and may cause respiratory disorders and cancers
$PM_{2.5}$	Ultrafine and other particles with an aerodynamic diameter ≤ 2.5 µ	Particles are respirable and are small enough to reach the gas exchange region of the lungs, may cause respiratory disorders and cancers

Source: WHO, 2020

According to data and analysis published by the World Health Organisation (WHO) in 2016, there were 4.2 million premature deaths globally attributable to ambient air pollution (WHO, 2018a). About 91% of premature deaths due to ambient air pollution occur in low and middle income countries. Premature deaths are only one aspect of air pollution; illnesses resulting from related chronic and infectious diseases add to the burden of disease caused by air pollution. WHO reports that among diseases attributable to ambient air pollution are acute lower respiratory infections, lung cancer, chronic obstructive pulmonary disease, ischaemic heart disease, and stroke. The burden of disease is measured by disability adjusted life years (DALYs[1]) and years of life lost (YLD[2]). Measured by DALYs per 100,000 population, Turkey is among the countries most effected by health problems attributable to ambient air pollution. In terms of burden of disease related to ambient air pollution, Turkey ranks the third after Hungary and Poland among OECD countries (WHO, 2018b).

[1] DALY: The sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.
[2] YLD or YLL: YLL are calculated from the number of deaths multiplied by a standard life expectancy at the age at which death occurs. YLD is defined as years lived with disability.

Figure 2: *Ambient Air Pollution Attributable DALYs per 100,000 Population, OECD and Affiliated Countries, 2016*

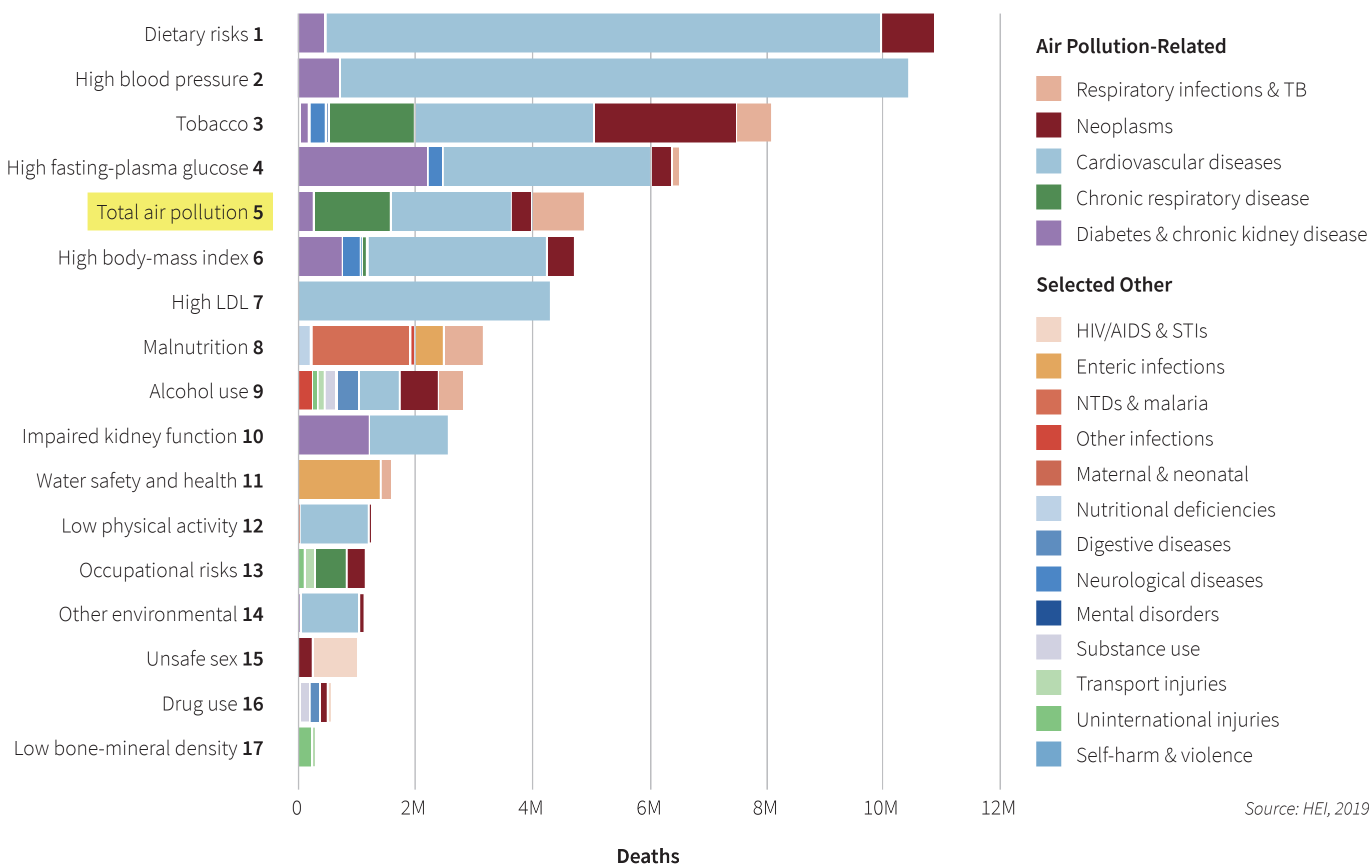


**Affiliated countries are Brazil, China, India, Indonesia, Morocco, Singapore and South Africa*

Source: WHO, 2018b

According to the State of Global Air 2019 report published by the Health Effects Institute (HEI), air pollution is among the leading causes of death in the world in 2017 (HEI, 2019). The report indicates that air pollution is the fifth leading risk factor for mortality worldwide.

Figure 3: *Global ranking of risk factors by total number of deaths from all causes, all ages, both sexes, 2017*



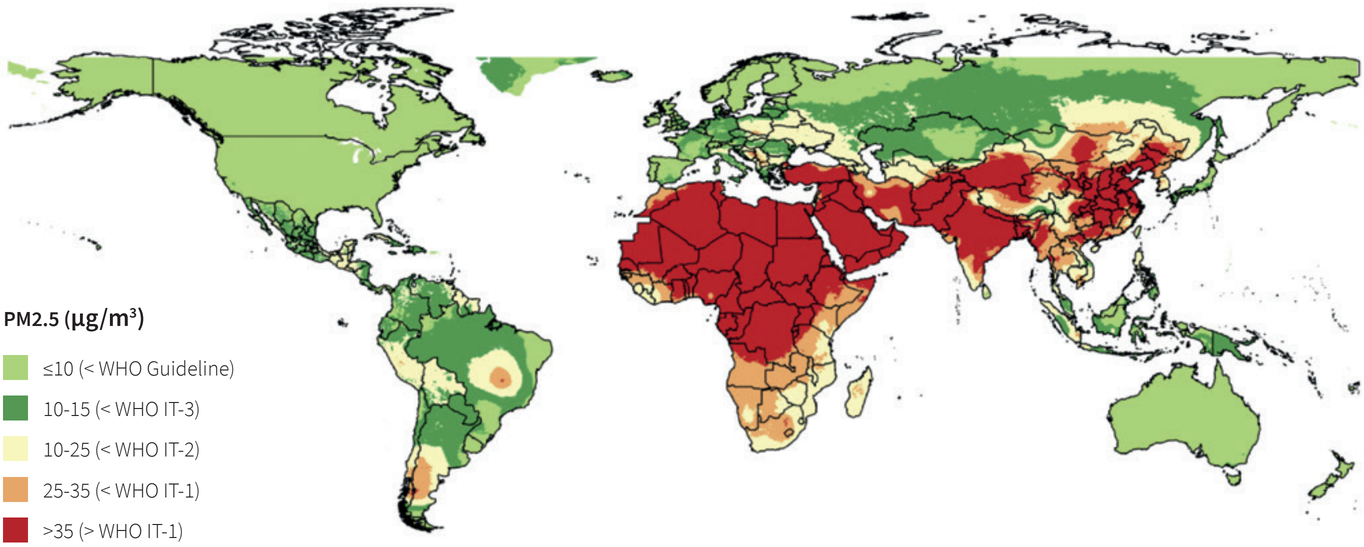
Source: HEI, 2019

Ambient air pollution is not only one of the leading causes of mortality, but also one of the fastest growing global health risks.

Up to date information provided by the Lancet Global Health Metrics on the global burden of disease indicates that ambient air pollution is not only one of the leading causes of mortality, but also one of the fastest growing global health risks. According to the annualised rate of change (ARC) reported by the Lancet in exposure to selected risks, ambient particulate matter pollution ranks among top three fastest growing risk factors together with high body mass index and high fasting plasma glucose. During 2010-2019, the annualised rate of growth in exposure to ambient particulate matter pollution was 1.47% (The Lancet, 2020).

HEI measures air pollution by exposure data focusing on ozone and fine particulate matter ($PM_{2.5}$). According to the report, more than 90% of the world population live in areas that exceed the WHO guideline for healthy air and over half live in areas that do not even meet WHO's least stringent air quality target. Turkey is exposed to particularly high levels of fine particulate matter with exposure exceeding WHOs lowest interim target (WHO IT-1) of 35 u/m^3. Ozone concentrations in Turkey are placed at the fourth highest range of 58-65 population weighted parts per billion (ppb). While fine particulate matter is a more pronounced problem in Turkey compared to ozone, monitoring of ozone exposure is still important for Turkey as risk of exposure to ozone tends to increase with higher levels of per capita income and development.

Figure 4: *Annual Average $PM_{2.5}$ Concentrations Relative to the WHO Guideline, 2017*



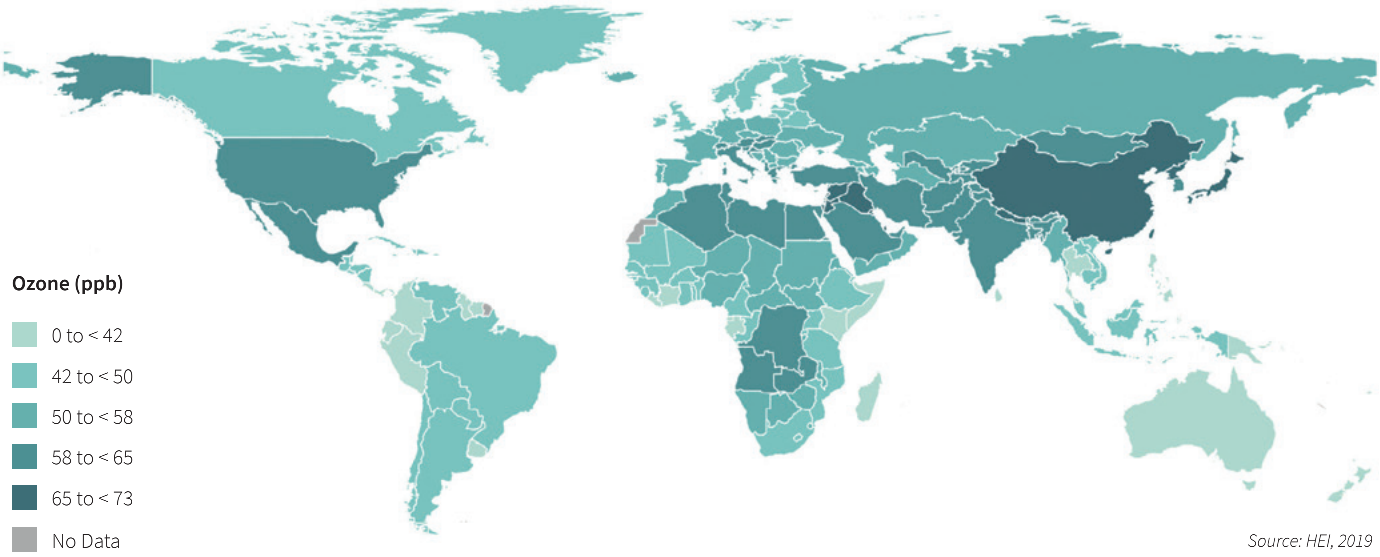
PM2.5 (µg/m³)

- ≤10 (< WHO Guideline)
- 10-15 (< WHO IT-3)
- 10-25 (< WHO IT-2)
- 25-35 (< WHO IT-1)
- >35 (> WHO IT-1)

(IT= Interim Target)

Source: HEI, 2019

Figure 5: *Population-Weighted Seasonal Average (8-Hour Max) Ozone Concentrations, 2017*



Source: HEI, 2019

According to the latest annual report published by the Turkish Chamber of Environmental Engineers, as of 2019, none of the urban provincial centers in Turkey can meet the air quality standards set by the WHO. The report also states the around 75 million people (over 90% of the population) are exposed to air pollution and pollution level has been increasing steadily since 2003. The amount of particulate matter (aerosols) in Turkey's atmosphere was 5.6% higher than that of Europe in 2003 while the difference has increased to 31% in 2019 (TMMOB, 2020). The health impact of deviating from the WHO norms can be assessed through the Air Quality Life Index (AQLI) developed by the University of Chicago. The AQLI Annual Update indicates that annual life expectancy in Turkey would be 0.4 years higher if Turkey conformed to the WHO standard for $PM_{2.5}$ (Greenstone & Fan, 2020). Similar findings are reported by the Turkey Right to Clean Air Platform (Karababa, et.al., 2020).

In Turkey 75 million people (over 90% of the population) are exposed to air pollution and pollution level has been increasing steadily since 2003.

In addition to emissions causing air pollution, fossil fuel use is associated with carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions which are regarded as the driver of the global climate change problem. CO_2 emissions may not cause immediate and direct health effects per se; however, it is important to assess the impacts associated with climate change. In this context, several approaches have been in place since the early 2000s, to price carbon emissions. To date, some 40 countries and more than 20 cities, states and provinces use carbon pricing mechanisms, and more are planning to implement them in the future. Carbon pricing schemes now in place cover about half their emissions, which translates to about 13 percent of annual global greenhouse gas emissions (World Bank, 2019).

Pricing carbon emissions intends to reflect the external costs associated with carbon emissions as a price to be paid by those who are responsible for the emissions. There are two mechanisms used for carbon pricing: emissions trading system (ETS) or carbon tax. An ETS, also known as a "cap and trade" system, caps the total level of emissions and allows those with low emissions to sell their extra allowances to larger emitters. Voluntary and mandatory carbon markets based on a "cap and trade" mechanism have been established in many parts of the world. A carbon tax, on the other hand, sets a price on carbon by defining a tax rate on greenhouse gas emissions or on the carbon content of fossil fuels.

The effectiveness of the existing mechanisms in capturing the social cost of carbon is widely debated. The social cost of carbon is defined as the quantifiable cost of emitting one additional ton of CO_2 in terms of damages to the environment caused by $CO2_2$. This value can be used to weigh the benefits of reduced warming (in other words, the "social cost of carbon") against the costs of cutting emissions (CarbonBrief, 2020). Carbon pricing mechanisms, especially carbon markets, may be ridden with some of the same "market failure" issues that fossil fuel pricing faces. For instance, the EU carbon trading system, one of the most established systems in the world, experienced a major slump after the 2008 financial crisis with carbon prices dropping to a fraction of their pre-crisis levels. This major slump along with the continued growth in global emissions has brought to the forefront the gap between the "true social cost of carbon" and the existing carbon prices.

The social cost of carbon may also be defined as the external cost of carbon that this study attempts to estimate for Turkey. Compared to other pollutants, quantifying the effect of an additional ton of CO_2 on climate change is more complex and uncertain since the effects are global and long-term. There is currently no carbon tax or ETS in Turkey; an actual carbon price for Turkey does not exist. However, since 2013 Turkey has been involved in the Partnership for Market Readiness (PMR) launched in 2011 by the World Bank to support developing countries' efforts to reduce greenhouse gas emissions through effective use of market-based instruments. Phase 1 of the PMR program in Turkey comprising analytical studies has been completed in November 2019, and Phase II comprising pilot studies and implementation has begun in January 2020 (Çevre ve Şehircilik Bakanlığı & Dünya Bankası, 2020).

Studies reveal that the benefits of adopting the climate pledges or other alternative policies for mitigation outweigh the costs.

Despite the uncertainties in pricing externalities, modelling studies to measure the benefits of avoided health and environmental costs arising from airborne emissions against the cost of adopting the necessary measures are becoming more common. Such studies reveal that the benefits of adopting the Paris Agreement pledges or other alternative policies for mitigation outweigh the costs. A study published in 2014 to measure the costs and benefits of the EU Clean Air Package (2005) concluded that the net benefits (benefits minus costs) of achieving the targets would result in annual net benefits of 28 billion € (in terms of 2005 €) despite limitations in fully measuring the benefits (Holland, 2014). More recent studies with more detailed modelling, focusing on the cost and benefits of achieving the climate pledges, also report significant net benefits, especially health benefits, as a result of mitigation measures (Markandya, et al., 2018; Vandyck, T et al., 2018). Switching from fossil fuels to renewable energy is an important component of the measures evaluated in these studies.

This study aims to develop a reference document for Turkey to present the external costs of fossil fuel use for power generation, building, transportation, and for some major manufacturing sectors. The external costs estimated in this report include the costs of environmental degradation and health problems caused by the emissions of air pollutants and greenhouse gasses due to fossil fuel consumption. Additionally, the external costs of the emissions from industrial processes in iron & steel, cement and ceramics are also covered in this study.

International institutions, such as (IRENA), International Monetary Fund (IMF) and International Energy Agency (IEA), have published studies on the global cost of externalities of fossil fuel use. IRENA places the global external effects of energy supply and use related to climate change and air pollution as 2.2 trillion US$ to 5.9 trillion US$

per year and compares it to the global cost of energy supply which is 5 trillion US$ per year (IRENA, 2016). The IMF estimates a cost of 5.3 trillion US$, including not only the damages on health and environment, but the cost of fossil fuel subsidies (Coady et al., 2015). The IEA, on the other hand, focuses not on externalities but fossil fuel subsidies, and places the annual cost of fossil fuel subsidies at around 300 billion US$ (IEA, 2018). A recent study published by Greenpeace entitled Toxic Air: The Price of Fossil Fuels (Greenpeace, 2020) estimates that the average global cost of health and economic impacts of air pollution caused by fossil fuels in 2018 is 2.5 trillion US$, ranging from 1.8 trillion US$ to 3.4 trillion US$.

At regional or national levels, there are various studies that quantify the damage costs of air pollutant emissions and their economic value. Developed countries such as Germany, Unites States, and some other European Union (EU) countries have funded research projects to determine country and fuel specific external costs (CASES, 2008; CIEMAT, 2000; National Academies of Sciences, Engineering, Medicine, 2009; World Nuclear Association, 2017). While damage costs due to fossil fuel power generation for the EU is estimated at US$ 70 billion in 1990, which is about 1% of GDP for EU in 1990; the external costs of power generation in the USA was estimated as $120 billion in 2005 (CASES, 2008; CIEMAT, 2000; World Nuclear Association, 2017) with almost similar share in GDP (World Bank, 2020).

The damage costs from power generation in Germany in 1990, excluding global warming effects, were estimated as about 30 billion Euro, nearly 1% of Germany's 1990 GDP (CIEMAT, 2000). An extensive study on the cost-benefit analysis of the EU Clean Air Package was published in 2014 (IIASA TSAP, 2014). The study compares the costs of abatement to the benefits based on avoided costs of health and non-health impacts assuming achievement of specified air quality standards by 2025 and 2030. According to the study, the annual avoided health costs for the EU-27 in 2005 prices is in the range of 543 to 742 billion euros. Detailed information on the aforementioned studies are provided in the following sections and these studies are used as references in this study.

The social cost of carbon, on the other hand, is widely debated and several recent international studies have attempted to quantify the costs on the environment and translate it into a unit cost or carbon price. A major and widely cited global study is the International Panel on Climate Change (IPCC) Report on Global Warming where the costs of 1.50C global warming above average pre-industrial levels are discussed. According to the report, the price of carbon varies substantially among models and scenarios and the values increase with mitigation efforts. The report surveys various studies and concludes that discounted values for social cost of carbon vary between 10 to 100 USD/ton depending on scenarios and discount rates (IPCC, 2019). This study, as will be shown in Section 2, assumes a value of 32€ for Turkey.

Estimating the external costs of fossil fuel consumption and reflecting it in actual costs, either through taxes or emissions trading, has become part of the international agenda.

In the case of costs of emissions that cause climate change, the social costs are not just national or regional but also global. Estimating the external costs of fossil fuel consumption and reflecting it in actual costs, either through taxes or emissions trading, has thus become part of the international agenda. Accounting for the external costs of fossil fuels used for electricity generation, heating and transport will be of paramount importance for Turkey in the context of trade agreements with countries and regions that set carbon neutrality in the core of their transition agendas. Under the European

Under the European Green Deal that aims to make the region carbon-neutral by 2050, a border carbon adjustment system, where the EU could potentially impose a carbon tax on imported goods, is being considered.

Green Deal that aims to make the region carbon-neutral by 2050, the border carbon adjustment under consideration could potentially put a carbon tax on imported goods. The strategy intends to eliminate the entry of goods that are produced more carbon intensive than in the EU, where social costs are not reflected in the price of goods (SHURA, 2020). The European Union (EU) is the largest trade partner of Turkey where the region represents about half of its total exports of 171 billion US$ in 2019 (TÜİK, 2020). A study conducted by the Turkish Industry & Business Association (TÜSİAD) found that a carbon border tax in the range of 30€ to 50€ per tonne carbon dioxide (CO_2) to be imposed by the EU would cost carbon-intensive exporting sectors between 800 million to 1.8 billion Euro annually and proposes that the tax be implemented nationally with the proceeds to be used for decarbonisation investments (Yeldan, et.al., 2020).

Previous studies on Turkey have concentrated on fossil fuel subsidies rather than external costs. One exception is the recent Greenpeace study which reports an average of 21 billion US$, ranging from 14 billion US$ to 30 billion US$ for the external costs of air pollution from fossil fuels in Turkey (Greenpeace, 2020). This report aims to provide a first attempt in quantifying the unpriced or external costs of fossil fuel use for energy consumption in Turkey. The present study is unique in its coverage of both sectors and types of pollutants. In addition, the emissions and their external costs in this report are estimated based on the location of the emission sources to be able to determine the major air pollutant and GHG costs associated with the fossil fuel combustion and processes related to production at seven geographical regions of Turkey, namely Marmara, Central Anatolia, Aegean, Mediterranean, Black Sea, Southeast Anatolia, and Eastern Anatolia regions. In the next section of the report, the estimated externalities of the major pollutants and GHGs by regions and sectors are presented.

This report aims to provide a first attempt in quantifying the unpriced or external costs of fossil fuel use for energy consumption in Turkey.

This report is accompanied with a detailed methodology annex. Where relevant, this annex has been referred to provide the reader with insights on the details of the methodology, background data sources and assumptions. The Annex is available at www.shura.org.tr and provides the following information:

- Methodology to estimate emissions based on Turkey's energy balances at sector level and the methodology to allocate emissions between Turkey's seven geographical regions
- Methodology, data (e.g. emissions per fuel type, fuel demand by region, efficiency of technologies used, air pollution reduction technologies) and assumptions concerning each sector of the energy system, namely power generation, buildings, manufacturing industry (including petroleum refining) and transport
- Methodology to estimate the external costs per pollutant based on the ExternE (CIEMAT, 2000) and CASES (CASES, 2008) projects and how costs of other countries have been adapted for the case of Turkey
- More detailed results than presented in the main report on the basis of sectors, fuel types, regions and emissions

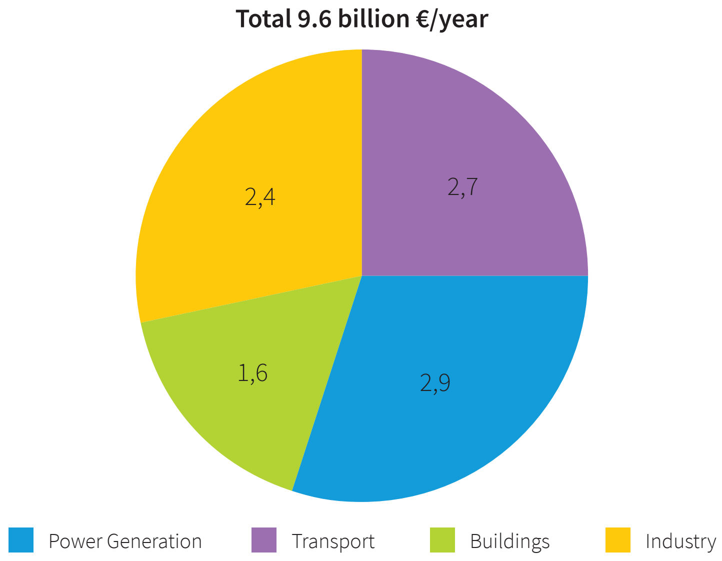
2. Results and Discussion

In this section, estimated emissions and the external costs of air pollutants and GHG due to processes and fossil fuel combustion by sectors and by regions are presented. An overview of results reveals that the external cost of emissions from fossil fuel use resulting from combustion and process use in power generation, transport, buildings and selected energy intensive industries (petroleum refineries, iron & steel, cement, ceramics, textiles, and food) is 9.6 billion euros annually on average. This represents a conservative low-end figure compared to the emission and externality figures quoted for Turkey in other international studies and databases as detailed in Section 2.3. The main difference between this study and other studies is the usage of actual power generation data rather than assumptions based on installed capacity, and higher emission control assumptions based on regulations and existing technology in this study. As such, the unseen and unpriced cost of fossil fuel use amounts to 1.4% of Turkey's GDP and 32% of annual national health expenditures.

Power generation constitutes about 30% of the external cost of fossil fuels followed by transport (28%), industry (25%) and buildings (17%).

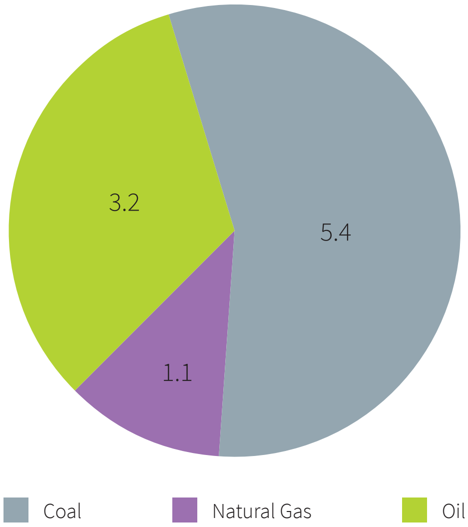
Power generation constitutes about 30% of the external cost of fossil fuels followed by transport (28%), industry (25%) and buildings (17%). These values indicate that, from a health and environment perspective, while reducing emissions from power generation clearly has the top priority, emissions from other sources come close and cannot be overlooked.

Figure 6: *Sectoral Breakdown of the External Costs of Fossil Fuel Use, 2018*



A breakdown of external costs by fuel type shows that 56% arises from coal use (of which about 60% comes from lignite use for power generation and heating) and 33% from petroleum products. Natural gas use constitutes 11% of external costs of fossil fuels.

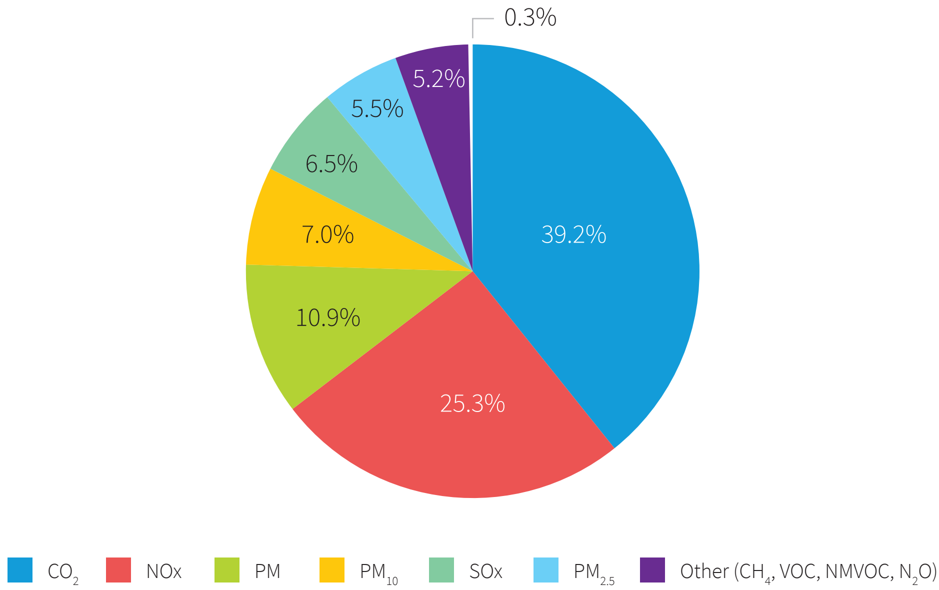
Figure 7: *Breakdown of the External Costs of Fossil Fuel Use by Fuel Types, 2018*



> *The external cost breakdown by pollutants shows that climate change impacts account for nearly 40% of the total value.*

As discussed in detail in the remainder of this section, the above external cost breakdown by fuel types and sectors is a direct result of the cost of pollutants emitted by combustion and processes using fossil fuels. The external cost breakdown by pollutants shows that climate change impacts (i.e. CO_2 emissions) account for nearly 40% of the total value. Outdoor air pollution represents the remaining 60%. NO_x emissions have the highest share among all air pollutants with a 25% share in the total value of externalities followed by all types of particulate matter emissions whose combined value constitutes another 23%. The remainder is constituted mainly by SO_x and CO, each of which account for about 6% of the total value of external costs.

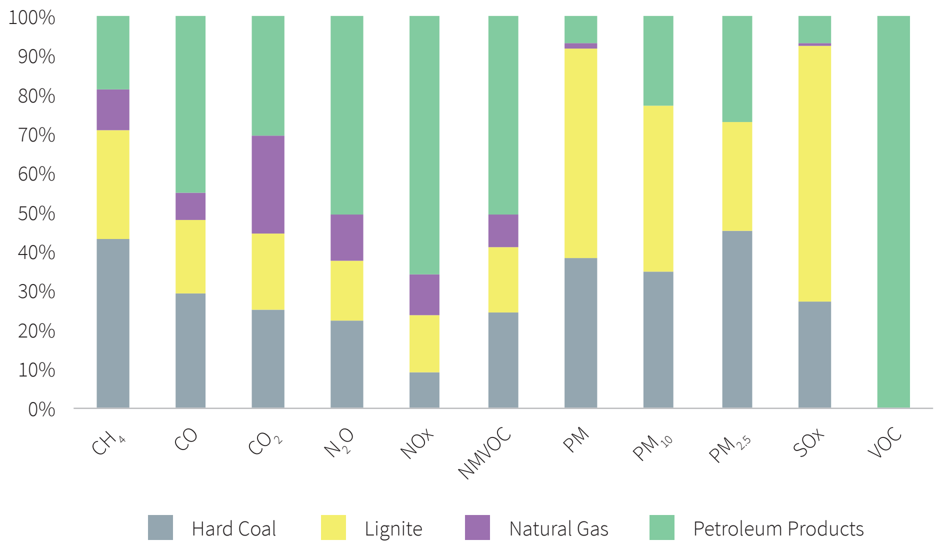
Figure 8: *Breakdown of the External Costs of Fossil Fuel Use by type of Pollutants, 2018*



A significant portion of emissions from pollutants with a high share in total external costs arises from coal used for power generation and heating and petroleum products used in transport.

As shown in Figure 9, a significant portion of emissions from pollutants with a high share in total external costs arises from coal (hard coal and lignite) used for power generation and heating and petroleum products used in transport. Coal accounts for about 45% of CO_2 emissions, 48% of CO emissions, over 90% of SO_x and PM emissions, and about 75% of PM_{10}, and $PM_{2.5}$ emissions whereas petroleum products account for 66% of NO_x emissions, 45% of CO emissions and 30% of CO_2 emissions. Natural gas accounts for around 10% or less of emissions from major pollutants except for CO_2 where its share is 25%.

Figure 9: *Fuel Share of Emissions by Type of Pollutant, 2018*

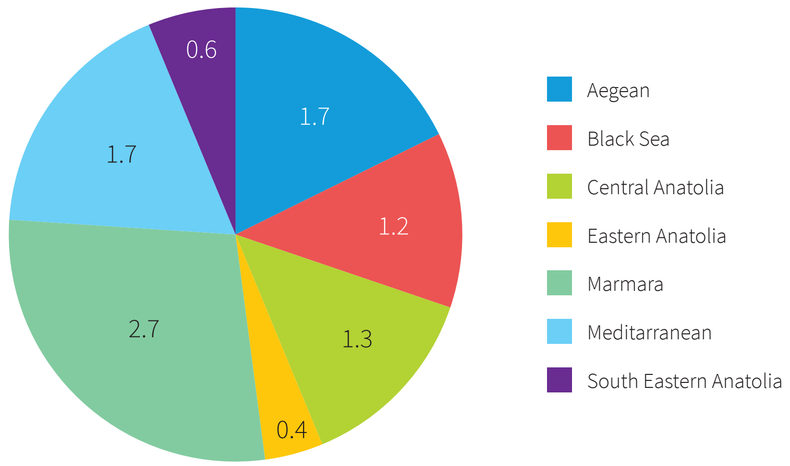


The Marmara region is the most impacted, constituting 28% of total external costs, followed by Aegean and Mediterranean regions with about an 18% share each.

In addition to quantifying the overall external costs of fossil fuel use in Turkey, the study shows regional distribution of impacts by the seven geographical regions of the country. As shown in Figure 10, the Marmara region is the most impacted, constituting 28% of total external costs, followed by Aegean and Mediterranean regions with about an 18% share each. These results are in line with the intensity of economic activity and population in Turkey's seven geographical regions.

Regional distribution of costs was calculated separately by sectors, taking into account regional distribution of fossil fuel power plants for power generation, regional distribution of iron & steel plants, petroleum refineries, cement and ceramics factories. For regional distribution of impacts from textiles and food industries, which are smaller in scale and have a wider geographic distribution, industrial GDP percentages by regions was used. Regional distribution of external costs for transport and buildings sectors were calculated according to regional population shares.

Figure 10: *Regional breakdown of the external costs of fossil fuel use, 2018*



2.1. Sectoral Emissions

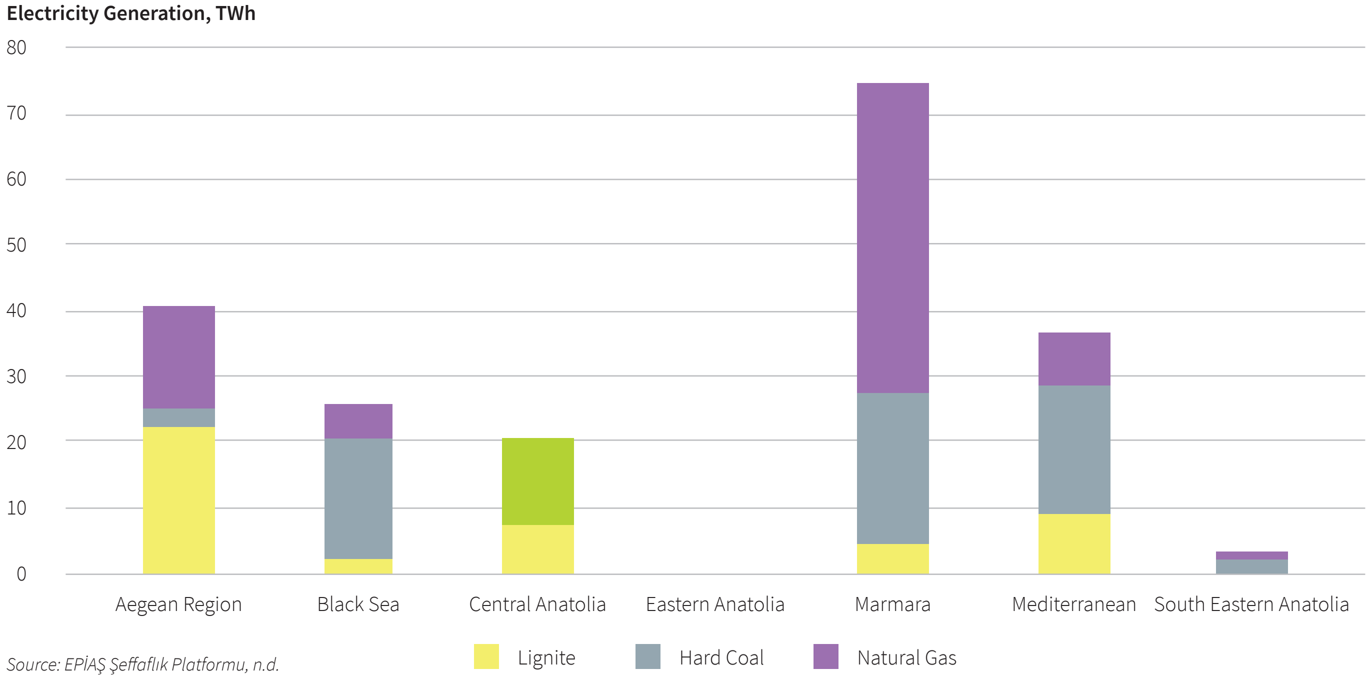
The estimated emissions of air pollutants and GHG due to processes and fossil fuel consumption by sectors and by regions are presented in this section. **Detailed results are presented in Section 2.1 of the separate Methodology Document.**

The methodology report covers the specific assumptions behind the estimation of emissions from each fuel type based on the appropriate emission factors for each sector. The sources of data for emission factors, individual plants and technologies (where available) are also provided in the Methodology Document.

2.1.1. Power Generation

This study covers the emissions from 262 power plants in operation in 2018, of which 220 are natural gas fuelled, 26 are lignite fuelled, 15 are hard coal fuelled, and one is asphaltite fuelled, as obtained from The Energy Atlas (Enerji Atlası, n.d.). The hourly power generated at each of these 262 power plants in 2018 is obtained from EPİAŞ (EPİAŞ Şeffaflık Platformu, n.d.). In addition to these large scale plants, an estimate was made, as explained in the methodology document, for the power generated at about 50 natural gas power plants (mostly with capacities < 10 MW) whose data was not available from EPİAŞ. The total installed capacity of such plants is less than 2.5% of total natural gas-fuelled power generation capacity. The regional distribution of fossil fuelled power plants is shown in Figure 11.

Figure 11: *Distribution of regional fossil fuelled power generation, 2018*

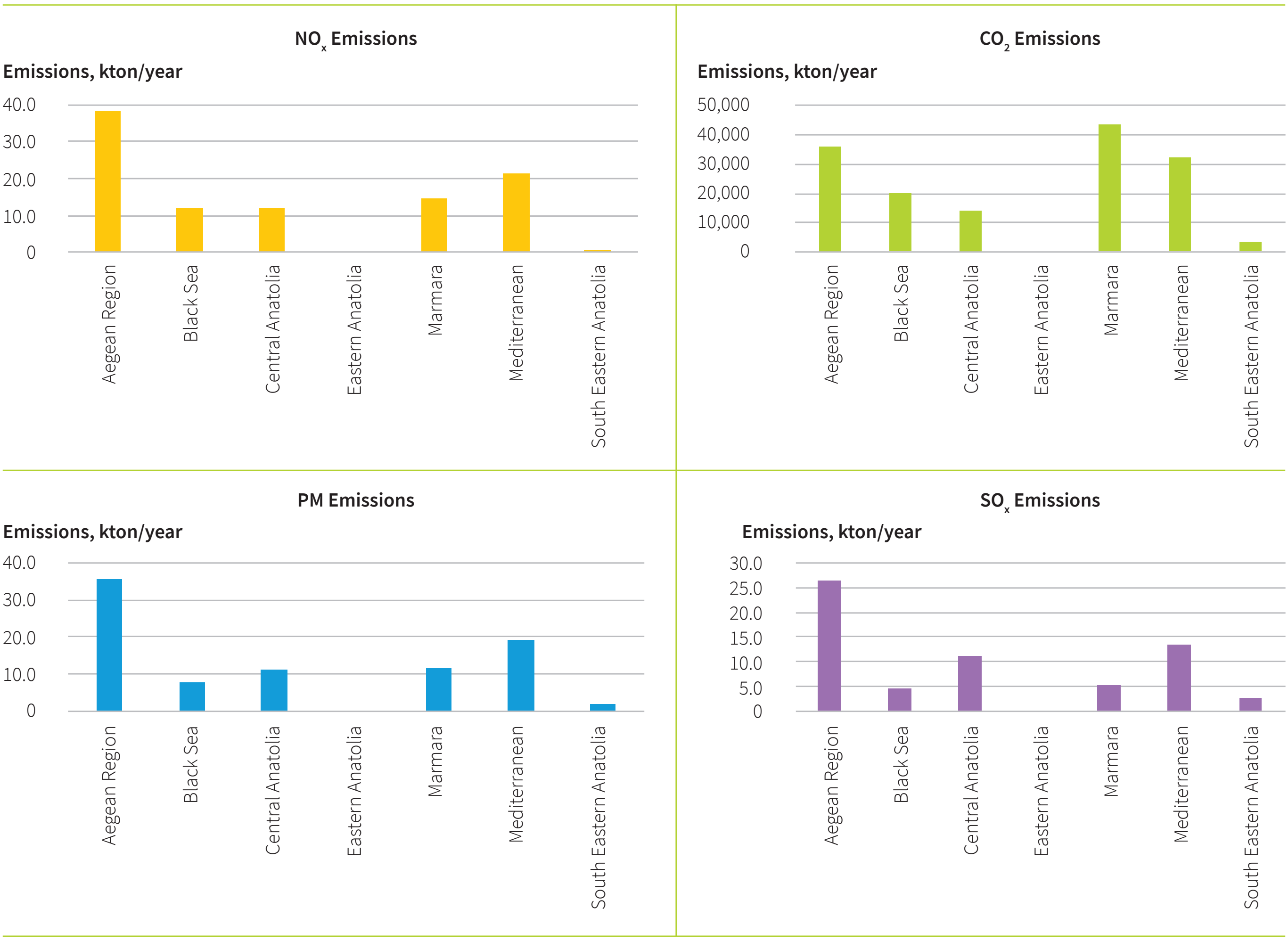


Source: EPİAŞ Şeffaflık Platformu, n.d.

The assumptions and calculations related to the emissions from power generation are presented in detail in Section 2.1.1 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.2 of the Methodology Document.

The regional distribution of NOx, CO_2, PM and SO_x emissions are presented in Figure 12. As can be seen, the NOx, PM and SO_x emissions at Aegean Region are the highest due to the high share of lignite fuelled power plants in this region, as shown in Figure 11. As stated before, Marmara Region has the highest fossil fuelled power plant electricity generation. Thus, the CO_2 emissions in this region is the highest among seven regions.

Figure 12: *Regional distribution of major air pollutants and CO_2 emissions*



The emissions by pollutant and type of plant are presented in Figure 13. As shown in the figure, the data reveal that lignite fuelled power plants emit 60% of NOx, 70% of PM, and 82% of SO_x gases in the power generation sector. When hard coal plants are added, the share of coal plants in emissions of major pollutants reaches 90% for NOx, 97% for PM and nearly 100% for SO_x. Fine particulate matter emissions PM_{10} and $PM_{2.5}$, having particularly severe human health impacts, come entirely from coal fired power plants, with 78% of PM10 coming from lignite fired plants and 58% of $PM_{2.5}$ resulting from hard coal fired plants. The impact of natural gas fired power plants, on the other hand, is mainly on CO and NMVOC where their share of emissions is 70% and 53% respectively with the remainder evenly divided between coal and lignite. In terms of overall impact, the share of coal fired power plants in total emissions is more significant than natural gas fired power plants.

An assessment of greenhouse gas emissions from power generation reveals that coal fired power plants emit 76% of total CO_2 in the sector.

An assessment of greenhouse gas emissions from power generation reveals that coal fired power plants emit 76% of CO_2 (36% lignite, 40% hard coal) and 64% of CH_4 (28% lignite, 36% hard coal). The role of natural gas fired plants in greenhouse gas emissions is also significant, though it is less pronounced than coal fired plants.

Figure 13: *Distribution of major air pollutants and CO_2 emissions based on power plant type*

The CO_2, N_2O, and CH_4 emissions due to the fossil fuel consumption in power generation sector in 2017 are presented in Turkish GHG National Inventory Report (NIR) (UNFCCC, 2019) and shown in Table 2. The emissions presented in NIR for CO_2 and CH_4 are close to the estimates presented in this study for 2018; however, N_2O emissions are almost three times higher than the ones presented here due to employment of higher emission factors for N_2O in NIR (i.e. NIR uses 61 kg N_2O/TJ for lignite combustion at fluidized bed technology, the emission factor used in this study is 1.5 kg N_2O/TJ). Thus, the 2018 CO_2 and CH_2 emission estimates are comparable to the ones presented in NIR for 2017; however, the N_2O emission estimates are about 2/3 lower. Since internationally accepted emissions factors are used in this study, the emissions estimated for these GHGs can be deemed as more reliable than those reported in NIR.

Table 2: *Comparison of CO_2, N_2O, and CH_4 emissions from NIR in power sector*

GHG	2018 Emission in This Study, kton	2017 Emissions in NIR, kton
CO_2	146,050	144,814
N_2O	1.7	4.6
CH_4	1.7	1.9

Source: UNFCCC, 2019.

The emission factors are in ranges based on the technology of the power plants and/or the composition/properties of the fuel. The emissions presented above are based on average emission figures assumed depending on the plant technology and characteristics. Thus, the estimated emissions are expected to lie in a range based on the range of the emission factors. For example, if the minimum and maximum values of the CO_2 emission factors presented in the Methodology document were used, the CO_2 emissions would be between 43,991 kton and 55,460 kton for lignite fired power plants, between 58,524 kton and 59,483 kton for hard coal fired power plants, and between 33,933 kton and 36,433 kton for natural gas fired power plants. Due to the wide range of the CO_2 emission figures presented for the lignite fired power plants, the estimated emissions based on the maximum CO_2 emission figure is 26% higher than the one based on the minimum CO_2 emission figure. Therefore, a range of 127 to 165 million tons emerges for CO_2 emissions assuming +/- 13% deviation from the mean value.

2.1.2. Road Transport

In this study, the estimation of major pollutants and GHGs from the road transportation sector including passenger cars, light duty vehicles, heavy duty trucks, and busses is covered. There is a total of 17.2 million road transport vehicles in Turkey, 72% of which are automobiles, 22% light duty vehicles, 5% heavy duty trucks and 1% buses. The estimates for emissions resulting from these vehicles in 2018 were obtained from a study conducted at Hacettepe University (Hacettepe University, 2018).

The assumptions and calculations related to the emissions from road transport are presented in detail in Section 2.1.2 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.2 the Methodology Document.

The emissions are calculated taking into account the fuel type of the vehicle (gasoline, diesel, LPG, and electric), vehicle engine displacement, vehicle age and standard (Conventional, Pre-Ece, Euro 1, Euro 3, Euro4, Euro5, and Euro6), and vehicle mileage for all vehicle categories. The regional distribution of emissions is estimated in parallel to regional share of population. Regional distribution of transport sector emissions is presented in Figure 14.

Figure 14: *Regional distribution of air pollutants and CO_2 emissions associated with the transport sector*

The CO_2, N_2O, and CH_4 emissions from the road transport sector in 2017 are presented in NIR (UNFCCC, 2019) and given in Table 3. The emissions presented in NIR for CO_2 is close to the estimated emissions presented in this study; however, CH_4 and N_2O emissions differ due to use of different emission factors.

Table 3: *Comparison with Transport Sector CO_2, N_2O, and CH_4 emissions from NIR, 2017*

GHG	2018 Emission in This Study, kton	2017 Emissions in NIR, kton
CO_2	78,502	77,094
N_2O	2.5	4.1
CH_4	4.8	15.2

Source: (UNFCCC, 2019)

2.1.3. Buildings

The residential and commercial building sector in Turkey consumes about 31% of total energy supply as of 2018 (General Directorate of Energy Affairs, 2019). Pollutant emissions arising from the use of hard coal, lignite, and natural gas for space and domestic hot water heating purposes in the residential and commercial buildings sector based on the type fuel consumed in the buildings are covered in this part of the report.

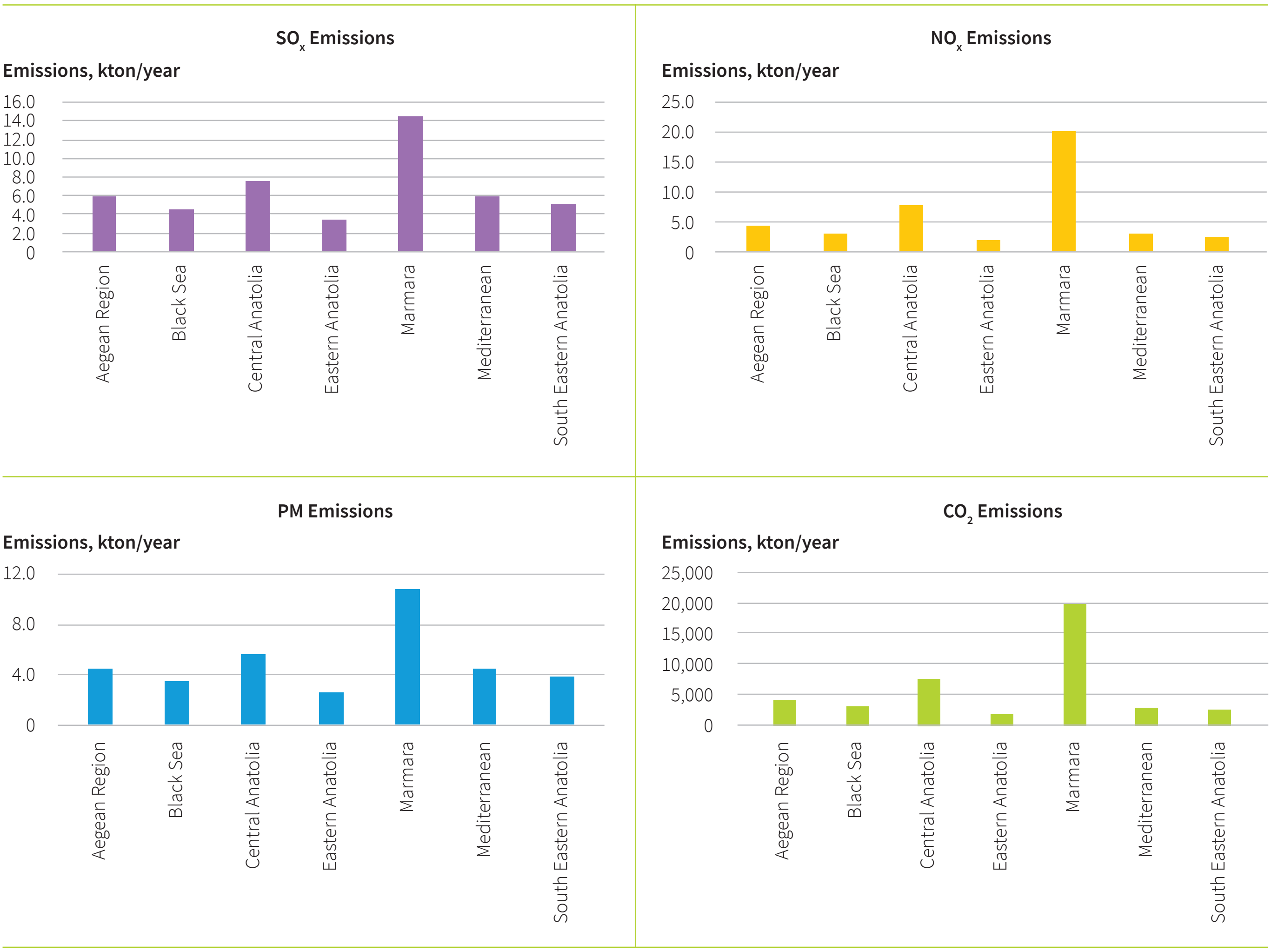
The assumptions and calculations related to the emissions from buildings are presented in detail in Section 2.1.3 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.3 the Methodology Document.

The regional emissions of SO_x, NO_x, PM, and CO_2 are presented in Figure 15. Similar to the transportation sector, the emissions of these major pollutants and CO_2 are at the highest levels in the Marmara region due to the high share of population and thus the number of buildings in this region.

While the share of coal consumption in buildings is significantly lower than natural gas, most of the major pollutants in the buildings sector, such as PM, CO and NMVOC is caused by hard coal and lignite combustion.

The predominant fuel used in buildings is natural gas with a share of 74% in total fossil fuel consumption by buildings. Natural gas is followed by hard coal (13%), lignite (8%) and oil products (5%). While the share of coal consumption in buildings is significantly lower than natural gas, most of the major pollutants in the buildings sector, such as PM, CO and NMVOC is caused by hard coal and lignite combustion. The share of coal in the emissions of these pollutants in the building sector is in the range of 85-100%. Coal consumption also has a role in greenhouse gas emission by buildings, emitting 89% of CH_4 and 23% of CO_2.

Figure 15: *Regional emissions of major pollutants and CO_2 from the buildings sector*



2.1.4. Petroleum Refining

In Turkey, TUPRAŞ has four refineries which are located in Izmit, Izmir, Kırıkkale, and Batman with a total refining capacity of 28.1 million tons/year crude oil as given in Table 4 (Tüpraş, 2018). A new refinery plant, STAR Refinery Plant, is in operation since October 2018. Since its operation data was not yet available at the time the study was conducted, the plant is not included in the analyses.

Table 4: *Location and capacity of the petroleum refineries in Turkey, 2018*

Plant Name	Region	Province	Capacity (million tons/year)
TÜPRAŞ İzmit Refinery	Marmara	İzmit	11
TÜPRAŞ İzmir Refinery	Aegean	İzmir	11
TÜPRAŞ Kırıkkale Refinery	Central Anatolia	Kırıkkale	5
TÜPRAŞ Batman Refinery	Southeastern Anatolia	Batman	1.1

Source: TÜPRAŞ, 2018

All units in petroleum refinery require process heaters using variety of fossil fuels to supply required heat to the system. The combustion of these fuels generate mainly CO_2, SO_x, and NO_x emissions which are then discharged to atmosphere through stacks (Choudhari, n.d.).

The assumptions and calculations related to the emissions from petroleum refineries are presented in detail in Section 2.1.4 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.4 the Methodology Document.

According to General Energy Balance Table 2018 (Enerji İşleri Genel Müdürlüğü, 2019), there are two main fossil fuel types used in petroleum refineries namely, crude oil and natural gas with consumption of 24,815 and 753 ktoe, respectively. The consumption of these fuels on a regional basis are determined by distributing the total amount depending on the refining capacities of the plants.

Generally, the fuel combusted to provide the process heat and steam required for the refining processes is taken as 6 to 10 percent of the total fuel input to the refinery (Gómez et al., 2006). Therefore, the amount of crude oil to be combusted is taken as 6 percent of the value given in the General Energy Balance Table 2018 (General Directorate of Energy Affairs, 2019). Moreover, it is considered that the entire natural gas input to the petroleum refinery is used for combustion. Amounts of fuel combusted are given in Table 5.

Table 5: *Amount of fuel combusted in oil refineries by regions in 2018, ktoe*

Region	Amount of fuel combusted, ktoe	
	Crude Oil	Natural Gas
Marmara	615	295
Central Anatolia	279	134
Aegean	615	295
Southeastern Anatolia	61	29
Total	1570	753

Crude oil and natural gas related emission figures used to determine the emissions from petroleum refineries are given in Table 6 (Alyüz, 2012).

Table 6: *Emission factors of petroleum refining*

Pollutant	Emission Figure (g/GJ)	
	Crude Oil	Natural Gas
PM	20	1
SO_x	653	NA
CO	14	39
NO_x	194	88
CO_2	73,300	56,100
N_2O	1.5	0.3
NMVOC	2.3	2.6
CH_4	3.0	NA

Petroleum refining emissions are calculated by Tier 1 Method of IPCC Guideline (Gómez et al., 2006). In this method, the emission factors given in Table 6 are multiplied by the fuel consumption data. The estimated controlled emissions are calculated by taking into account the controlling of SO_x, PM and NO_x emissions with 95%, 98%, and 75% abatement efficiencies, respectively.

The regional emissions of some major pollutants and CO_2 from petroleum refining is presented in Figure 16. As can be seen, Aegean and Marmara regions have the highest emissions since majority of the petroleum refining plants are in these regions.

Figure 16: *Regional emissions of SO_x, CO, NO_x, and CO_2 from petroleum refining*

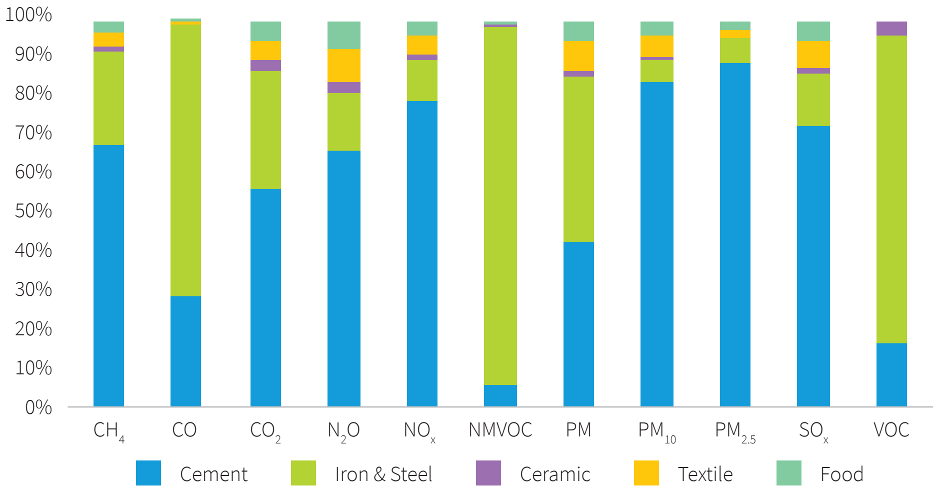
2.1.5. Industrial Sectors

The estimated emissions from the cement industry, iron & steel production, ceramic production, textile and leather production, and food industry are presented in this section of the report.

The assumptions and calculations related to the emissions from industrial sectors are presented in detail in Section 2.1.5 of the Methodology Document.

Emissions of cement, iron & steel, ceramic, textiles & leather and food industries consuming a major part of the energy in Turkey are covered in this study. Cement and iron & steel industries constitute the majority of industrial emissions for most pollutants and greenhouse gases. The industrial sectors covered by this study account for 70% of total industrial consumption of fossil fuels. As the sectors included tend to be energy intensive, coverage of industrial emissions by the report is expected to exceed 70%.

Figure 17: *Breakdown of Industrial Emissions by Industries and Pollutants*



2.1.5.1. Cement Industry

There are two aspects of cement production that result in pollutants and GHG emissions. The first is the so-called "process" emissions that contribute about 5% of total anthropogenic CO_2 emissions excluding land use change. The second source of emissions is the combustion of fossil fuels to generate the significant energy required to heat the raw ingredients to well over 1000 °C, and these are called "energy" emissions (Andrew, 2018).

Cement industry operates in all regions of Turkey and 2018 production by regions is shown in Table 7 (Türkiye Çimento Müstahsilleri Birliği, n.d.). In 2018, total production decreased by 10% compared to 2017.

Table 7: *Turkey's cement industry capacity and production in 2018, ktons*

	Capacity, ktons/year		Capacity Utilization (%)		2018 Production, ktons	
	Clinker	Cement	Clinker	Cement	Clinker	Cement
Marmara	20,068	29,117	94	67	18,854	19,590
Aegean	9,444	13,777	66	43	6,225	5,894
Mediterranean	22,929	33,964	86	50	19,662	16,930
Black Sea	8,672	18,359	92	49	7,991	9,031
Central Anatolia	15,025	22,315	82	58	12,359	12,951
Eastern Anatolia	7,447	13,176	68	47	5,083	6,223
Southeastern Anatolia	6,273	11,164	75	47	4,712	5,248
Total	**89,862**	**141,876**	**83**	**53**	**74,889**	**75,870**

Source: TÇMB - Turkish Cement Manufacturers' Association.

The assumptions and calculations related to the emissions from the cement industry are presented in detail in Section 2.1.5.1 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.5 the Methodology Document.

The emissions calculations for the cement industry are based on the production figures presented in Table 7. The regional distribution of some major pollutants and CO_2 emissions resulting from fossil fuel combustion and processes, based on regional distribution of clinker and cement production of existing plants, are shown in Figure 18. The cement industry, like other industrial activities, is strictly regulated via national and international legislation regarding environmental protection. Therefore, the figure represents controlled emissions, assuming required controls are performed. The resulting regional emissions concentrate in Marmara and Mediterranean regions since most of the cement plants are located in these regions.

The combination of fossil fuels used in cement production makes the cement sector one of the major industrial emitters of pollutants such as SO_x, NO_x and fine particulate matter, as well as greenhouse gases such as CO_2 and CH_4.

Various fossil fuels may be used for energy and process needs in cement production. Some of the fuels can be used interchangeably where price and availability are among the determinants of the type of fuel used. Recent consumption data from Turkey indicates that petroleum products (mainly petroleum coke) constitute 57%, hard coal and lignite 40% and natural gas and other gases 3% of the energy consumption in the cement sector. As shown in Figure 17, the combination of fossil fuels used in cement production makes the cement sector one of the major industrial emitters of pollutants such as SO_x, NO_x and fine particulate matter, as well as greenhouse gases such as CO_2 and CH_4.

Figure 18: *Regional distribution of some major pollutants and CO_2 emissions from the cement industry*

2.1.5.2. Iron & Steel Industry

There are two main routes to produce steel, integrated and recycling routes. Integrated route is based on the production of iron from iron ore, while recycling route uses scrap iron as the main iron-bearing raw material in electric arc furnaces. In both cases, the energy consumed comes from fuel (mainly coal and coke) and electricity. Recycling route consumes much less energy (about 80 %) than the integrated route. Steel is produced from either iron ore in integrated steelworks or scrap in electrical arc furnaces (Energy Efficiency and CO_2 Reduction in the Iron & steel Industry In brief, n.d.). In Turkey, 74% of the steel is produced in electrical arc furnaces and 26% in integrated steelworks (Turkey Steel Producers' Association, 2016). The amount of steel produced in 2018 is 37.3 million tons (Turkey Steel Producers' Association, 2019) and the total is distributed according to production capacities of regions (Steel Exporters' Association, 2018) as seen in Table 8 .

Table 8: *Regional steel capacity and estimated production in Turkey in 2018*

Region	Capacity, ktons	Production, ktons
Marmara	7,350	5,441
Aegean	11,300	8,365
Mediterranean	10,700	7,921
Isdemir	5,300	3,923
Black Sea	8,400	6,218
Kardemir	3,500	2,591
Erdemir	3,850	2,850
Total	50,400	37,312

Source: Steel Exporters' Association, Turkish Steel Producers' Association

The integrated route relies on the use of coke ovens, sinter plants, blast furnaces, and Basic Oxygen Furnace converters (*Energy Efficiency and CO_2 Reduction in the Iron and Steel Industry In Brief, n.d.*). In Turkey there are three integrated steel plants; Kardemir (established in 1939, in Karabuk), Erdemir (established in 1965, in Eregli), and Isdemir (established in 1977 in Iskenderun). All of these plants include coke production units (Alyüz, 2012) and emissions of coke production are included in the total emissions reported in this study.

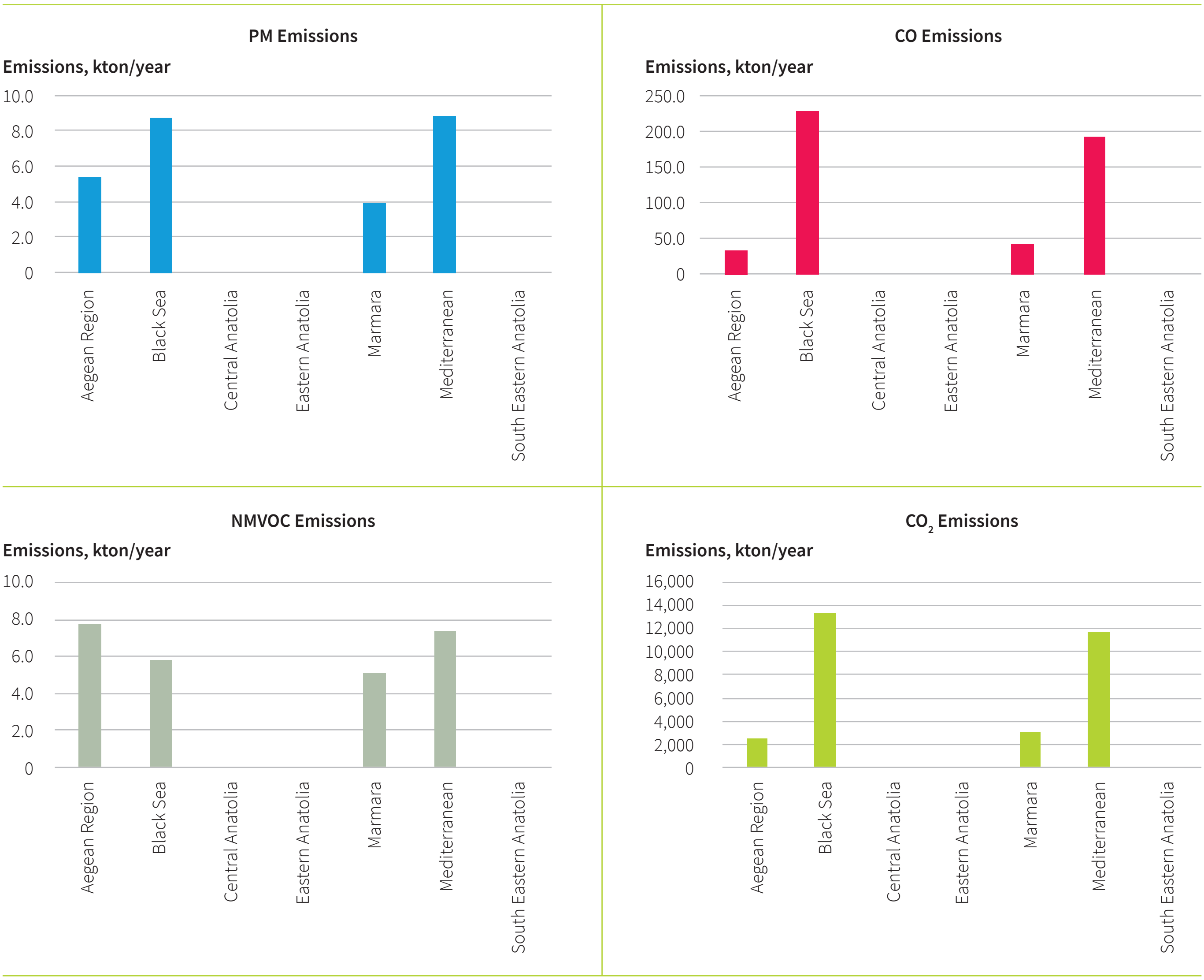
The assumptions and calculations related to the emissions from iron and steel production are presented in detail in Section 2.1.5.2 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.6 the Methodology Document.

The emissions calculations for the iron and steel industry are based on the production figures presented in Table 8, using the emissions figures provided in the Methodology Document separately for coke production (integrated route) and for steel production from the integrated recycling routes. The regional distribution of PM, CO, NMVOC, and CO_2 emissions resulting from fossil fuel combustion and industry related processes in the iron and steel industry are presented in Figure 19. The regions with high emissions for these pollutants are Black Sea and Mediterranean regions since the integrated plants with heaviest energy use are located in these regions. The iron & steel industry, like other industrial activities, is strictly regulated via national and international legislation regarding environmental protection. Therefore, the Figure represents controlled emissions assuming that required controls are performed.

Most emissions in the iron & steel sector arise from the use of coal in the coking process and in steel making in integrated plants.

Coal (hard coal) is the predominant fuel used in iron & steel production and most emissions arise from the use of coal in the coking process as well as in steel making through the integrated route. Of fossil fuel based pollutant emissions in the iron and steel sector, 80% of NO_x, nearly 100% of particulate matter emissions, and 45% of NMVOC emissions are caused by coal use. Natural gas use, on the other hand, accounts for 68% of CO and 55% of NMVOC emissions. Coal use is also the dominant factor in iron and steel industry greenhouse gas emissions, accounting for 65% of CO_2 and 51% of CH_4 emissions.

Figure 19: *Regional distribution of major pollutants and CO_2 emissions from iron & steel industry*



2.1.5.3. Ceramics Industry

The ceramic manufacturing industry in Turkey is divided into two large groups: ceramic coating production and sanitary ware production. In 2017, sanitary ware production was 352 thousand tons while the ceramic coating production reached to 5.47 million tons (Kocabaş and Ermurat, 2017). Ceramic plants in Turkey are mainly located at Marmara, Aegean, and Central Anatolia regions. Thus, the production has been assumed according to adjusted industrial GDP percentages considering the regions with ceramic production facilities. The regional distribution of ceramic production is given in Table 9.

Table 9: *Regional distribution of ceramic production, 2017*

Region	Industrial GDP	Adjusted GDP	Ceramic Coating (million tons/yr.)	Sanitary Ware (thousand tons/yr.)
Aegean	14%	16%	0.8874	57.11
Black Sea	6%	7%	0.3735	24.04
Central Anatolia	15%	18%	1.0063	64.75
Eastern Anatolia	0%	-	-	-
Marmara	49%	59%	3.2028	206.10
Mediterranean	0%	-	-	-
Southeastern Anatolia	0%	-	-	-
TOTAL	84%	100%	5.47	352

Source: Kocabaş and Ermurat, 2017

The assumptions and calculations related to the emissions from ceramics production are presented in detail in Section 2.1.5.3 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.7 of the Methodology Document.

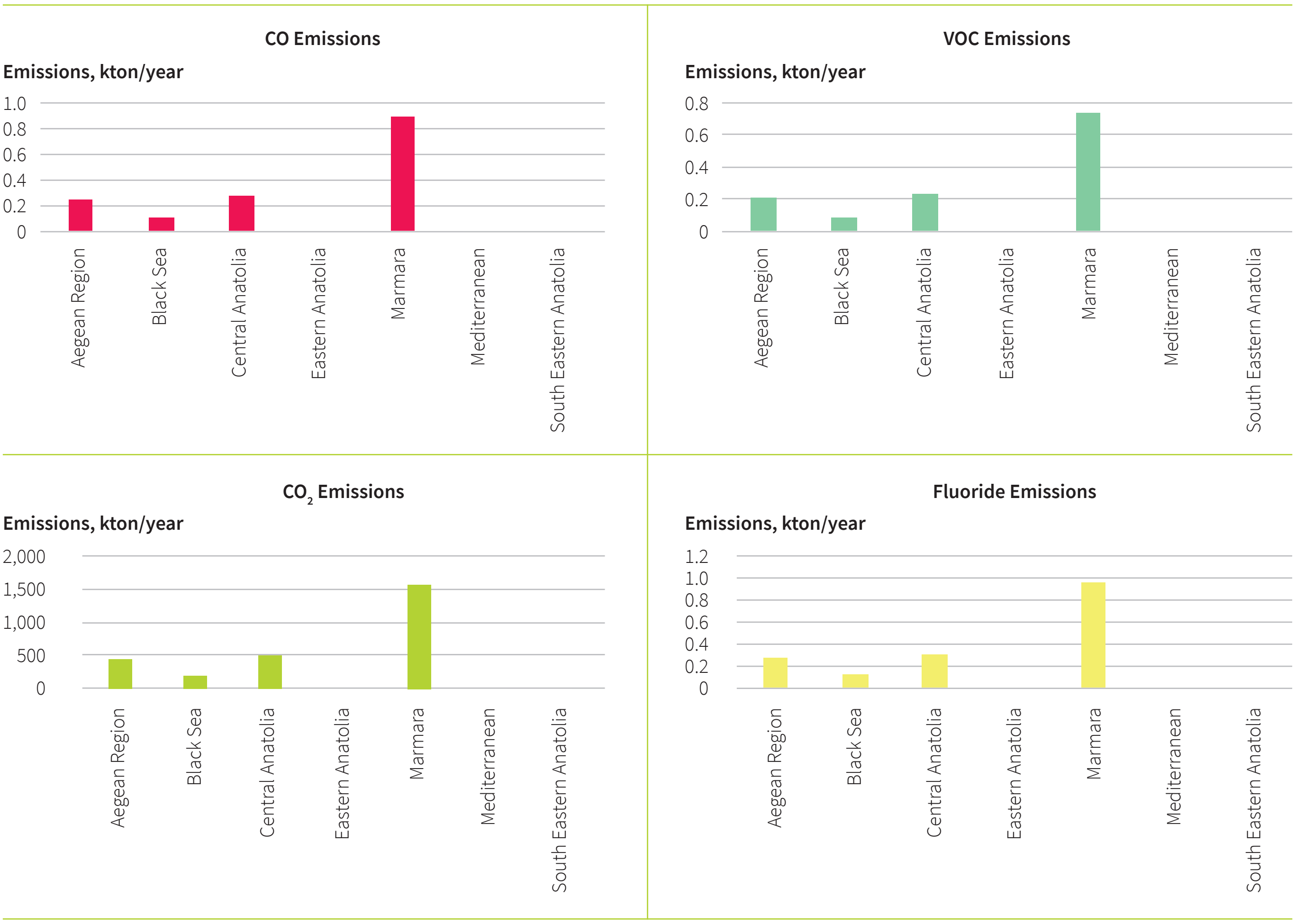
The emissions calculations for the ceramics industry and their regional distribution are based on the production figures presented in Table 9, utilizing the emissions figures provided in the Methodology Document and fuel consumption amounts provided in National Energy Balance Tables.

The regional distribution of major pollutants and CO_2 resulting from fossil fuel combustion and industry related processes in ceramic industry are presented in Figure 21. Ceramics industry, like other industrial activities, is strictly regulated via national and international legislation regarding environmental protection. Therefore, the figure represents controlled emissions assuming that required controls are duly performed. The region with the highest emissions for these pollutants is the Marmara region since most of the ceramic plants are located in this region.

Over 90% of emissions from major pollutants and 77% of CO_2 emitted by the ceramics industry are caused by natural gas use and the remainder by coal.

Natural gas is the predominant fuel used for processes and combustion in the ceramics industry for both coating and sanitary ware production. Smaller amounts of hard coal and lignite are also used for processes and other requirements. Over 90% of emissions from major pollutants and 77% of CO_2 emitted by the ceramics industry is caused by natural gas use and the remainder by coal.

Figure 20: *Regional major pollutant and CO_2 emissions from ceramic sector*



2.1.5.4. Textile and Leather Industry

The textile industry is spread all over the country with numerous plants of all sizes and separating the industry by provinces is not reliable due to limited data. The amount and type of fossil fuels used by the sector in 2018 are obtained from national energy balance tables and regional distribution is based on regional industrial GDP shares.

The assumptions and calculations related to the emissions from ceramics production are presented in detail in Section 2.1.5.4 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.8 of the Methodology Document.

The regional NO_x, CO_2, PM and SO_x emissions are presented in Figure 22. Similar to the other sectors presented above, the region with highest emissions for these pollutants is the Marmara region since most of the textile plants are located in this region.

While natural gas is the predominant fuel used in the textile industry, 80-100% of the emissions of major pollutants emitted by the sector, such as NO_x, SO_x and PM are caused by coal consumption.

The predominant fuel used in the textile industry is natural gas, having a share of 62% in total energy consumption. Coal, over 90% of which is lignite, has a share of 37% and the share of various types of liquid fuels is 1%. Nevertheless, 80-100% of the emissions of major pollutants emitted by the sector, such as NO_x, SO_x and PM (all types) are caused by coal consumption. In addition, coal accounts for 58% of CO_2 emissions and 42% of CH_4 emissions while the respective shares for natural gas are 42% and 56%.

Figure 21: *Regional distribution of major pollutants and CO_2 emissions from textile sector*

2.1.5.5. Food Industry

More than half the CO_2 emissions in the food industry stem from natural gas use while emissions of major pollutants such as SO_x, NO_x and PM come almost entirely from coal consumption.

Food industry consumes high amount of energy, about 8% of total industrial energy consumption, which is dominated by natural gas (General Directorate of Energy Affairs, 2019). Production plants are spread all over Turkey and distribution of energy is assumed to be based on regional GDP percentages. The emissions covered for the food industry in this study are combustion emissions only; process emissions are not included due to data limitations. Data on the amount and types of fossil fuels used by the sector, obtained from energy balance tables, reveal that natural gas is the predominant energy source (66%), followed by lignite (20%), hard coal (11%) and other fuels, coke and liquid fuels (3%).

The assumptions and calculations related to the emissions from the food industry are presented in detail in Section 2.1.5.5 of the Methodology Document. The details of the results in this section are provided in the tables in Section 3.9 of the Methodology Document.

The regional distribution of major pollutants and CO_2 resulting from food industry are given in Figure 23. The region with highest emissions for these pollutants is the Marmara region since most of the food processing plants are located in this region. The main pollutants and their emission figures resulting from food production are explained in section 2.1.5.5 and details provided in the tables in Section 3.9 of the

Methodology Document. Based on types of fuels used and emissions factors, it is estimated that coal consumption accounts for over 70% of NO_x emissions and nearly 100% of SO_x and PM emissions and a significant portion of CO_2 emissions. The share of coal in CO_2 emissions by the food industry is 47% while the share of natural gas is 52%. As in textiles, while energy consumption by the sector is dominated by natural gas, coal consumption has a more significant effect on emissions.

Figure 22: *Regional distribution of major pollutants and CO_2 emissions from food sector*

2.1.6. Total Emissions

Fossil fuel combustion and process based emissions of major pollutants and GHGs from power generation, transportation, buildings, petroleum refining, cement, steel and iron, ceramic, textile, and food industries and their totals are summed up and some of the pollutants and GHGs emissions by sectors are given in Table 10 and Figure 23, Table 11 and Figure 24, and Table 12 and Figure 25, respectively.

Table 10: *Sectoral distribution of fossil fuel combustion based total emissions, ton/year*

Pollutant / GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Buildings	Petro Refining	Cement	Steel Iron	Ceramic	Textile	Food	TOTAL
CH_4	476	617	626	4,847	25,804	169	1,505	103	43	70	71	34,331
CO	4,844	5,891	24,435	343,441	374,832	2,015	7,418	2,814	1,507	1,849	2,101	771,148
CO_2	52,372,568	58,618,322	35,058,649	78,501,802	41,638,434	5,895,463	24,084,831	7,859,082	2,694,662	5,276,302	5,019,205	317,019,318
N_2O	714	925	63	2,518	729	95	363	85	13	48	40	5,593
NO_x	58,900	28,574	10,181	306,843	43,278	3,424	10,668	4,131	1,168	3,428	2,798	473,393
NMVOC	798	622	1,600	47,074	43,395	211	1,604	233	104	149	160	95,951
PM	60,055	24,325	2,211	11,275	35,204	23	11,832	5,420	981	4,788	3,454	159,568
PM_{10}	20,281	5,595	0	18,785	32,123		2,716	1,238	231	1,130	810	82,910
$PM_{2.5}$	3,024	4,109	0	15,262	31,488		1,231	712	44	225	213	56,309
SO_x	51,522	11,085	175	8,638	46,841	1,839	8,188	4,100	553	2,731	2,089	137,761
VOC	0	0	0	51,920	0	0	0	0	0	0	0	51,920

Table 11: *Sectoral distribution of process based total emissions, ton/year*

Pollutant / GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Buildings	Petro Refining	Cement	Steel Iron	Ceramic	Textile	Food	TOTAL
CH_4							0	432	0			432
CO							189,469	492,718	0			682,188
CO_2							31,941,623	22,551,110	0			54,492,734
N_2O							0	0				0
NO_x							46,806	3,277	0			50,083
NMVOC							0	25,711				25,711
PM							15,402	21,405				36,807
PM_{10}							15,174	0	0			15,174
$PM_{2.5}$							8,346	0				8,346
SO_x							20,819	1,329	0			22,148
VOC							5,253	26,045	1,253			32,552

Table 12: *Sectoral distribution of total emissions, ton/year*

Pollutant / GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Buildings	Petro Refining	Cement	Steel Iron	Ceramic	Textile	Food	TOTAL
CH_4	476	617	626	4,847	25,804	169	1,505	535	43	70	71	34,763
CO	4,844	5,891	24,435	343,441	374,832	2,015	196,888	495,533	1,507	1,849	2,101	1,453,336
CO_2	52,372,568	58,618,322	35,058,649	78,501,802	41,638,434	5,895,463	56,026,454	30,410,193	2,694,662	5,276,302	5,019,205	371,512,052
N_2O	714	925	63	2,518	729	95	363	85	13	48	40	5,593
NO_x	58,900	28,574	10,181	306,843	43,278	3,424	57,474	7,408	1,168	3,428	2,798	523,476
NMVOC	798	622	1,600	47,074	43,395	211	1,604	25,944	104	149	160	121,662
PM	60,055	24,325	2,211	11,275	35,204	23	27,234	26,824	981	4,788	3,454	196,374
PM_{10}	20,281	5,595	0	18,785	32,123	0	17,890	1,238	231	1,130	810	98,084
$PM_{2.5}$	3,024	4,109	0	15,262	31,488	0	9,577	712	44	225	213	64,655
SO_x	51,522	11,085	175	8,638	46,841	1,839	29,007	5,429	553	2,731	2,089	159,909
VOC	0	0	0	51,920	0	0	5,253	26,045	1,253	0	0	84,473

Figure 23: *Sectoral distribution of some major pollutants and CO_2 due to combustion based emissions*

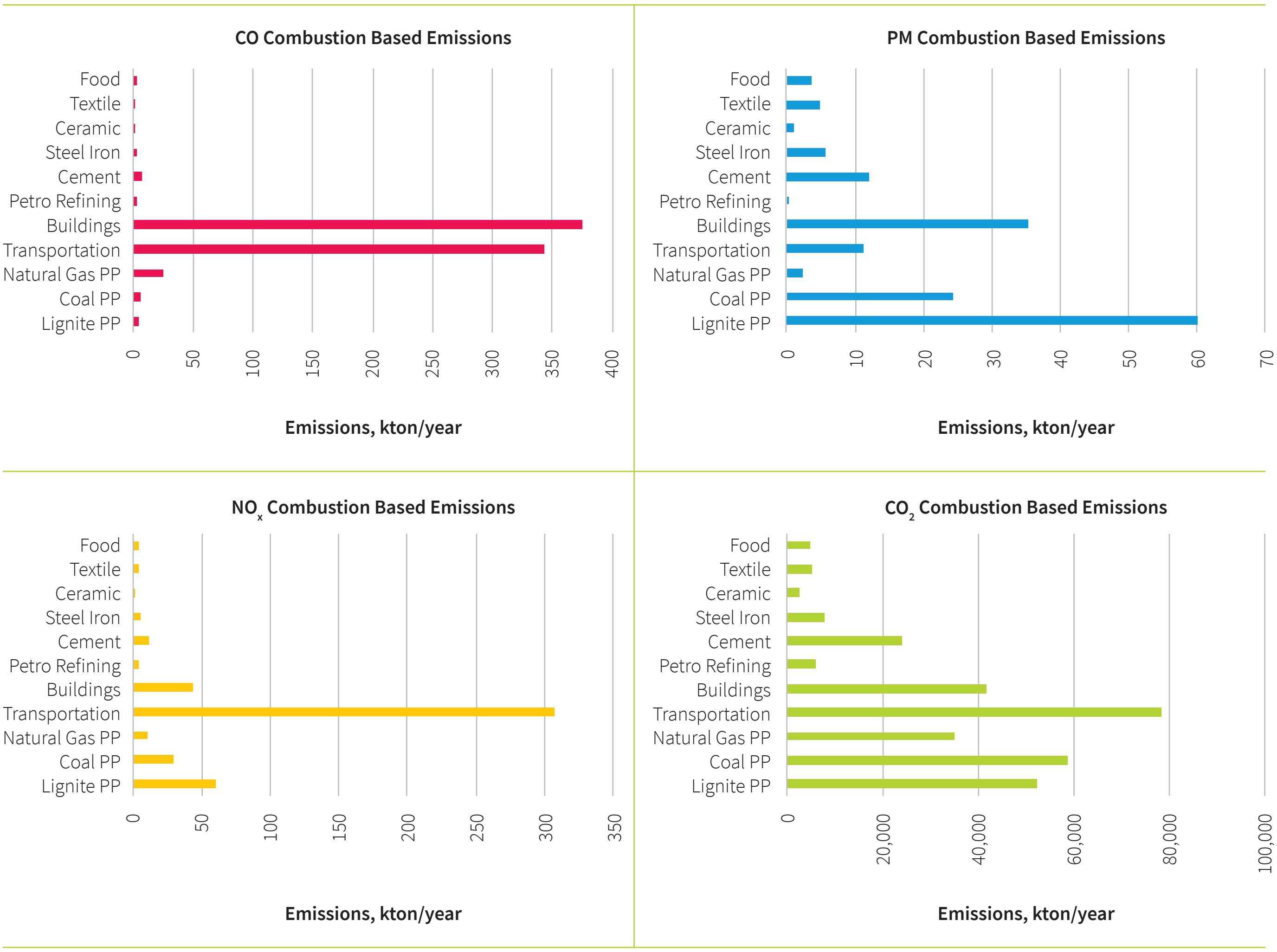


Figure 24: Sectoral distribution of some major pollutants and CO_2 due to process-based emissions

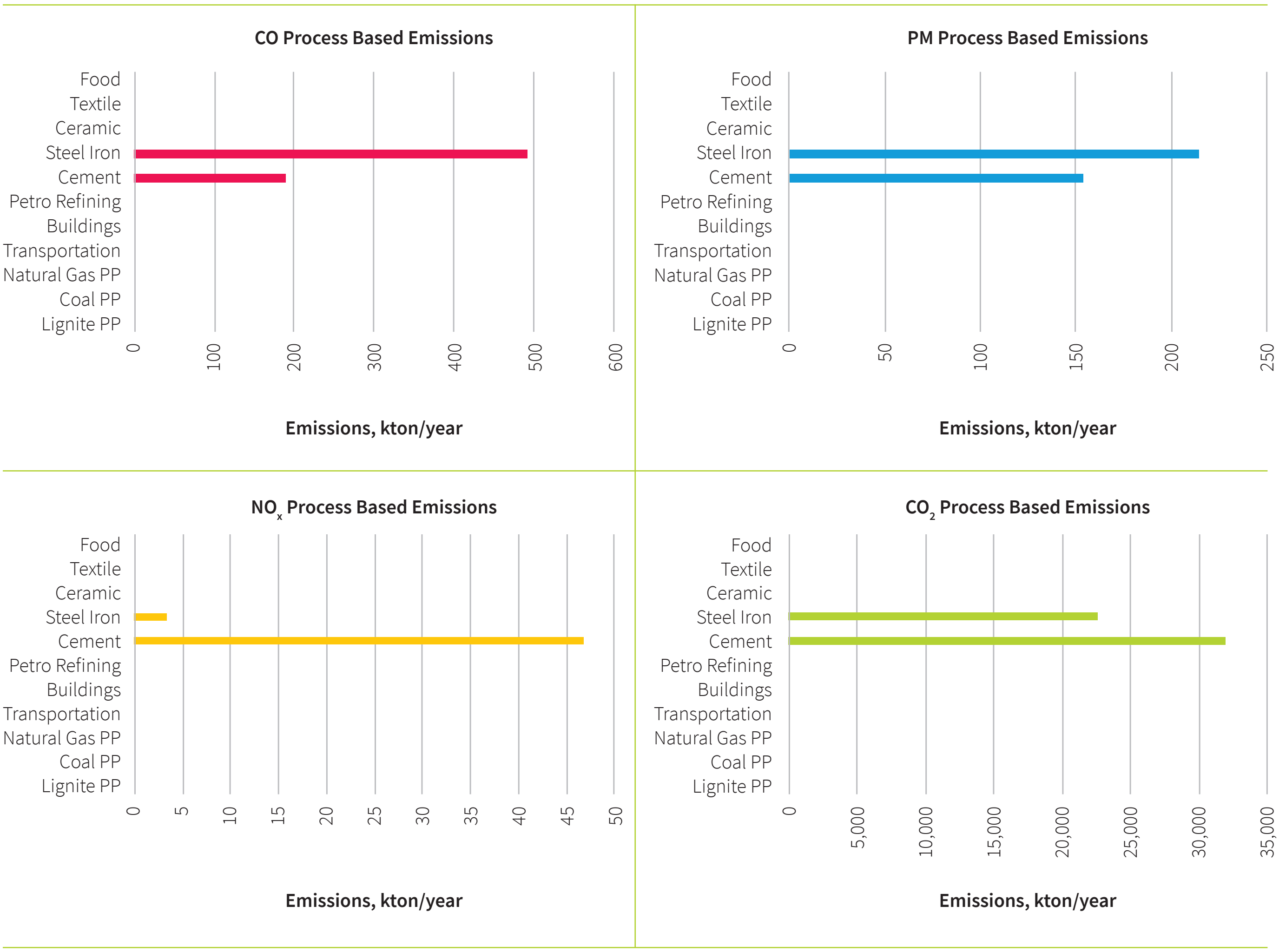
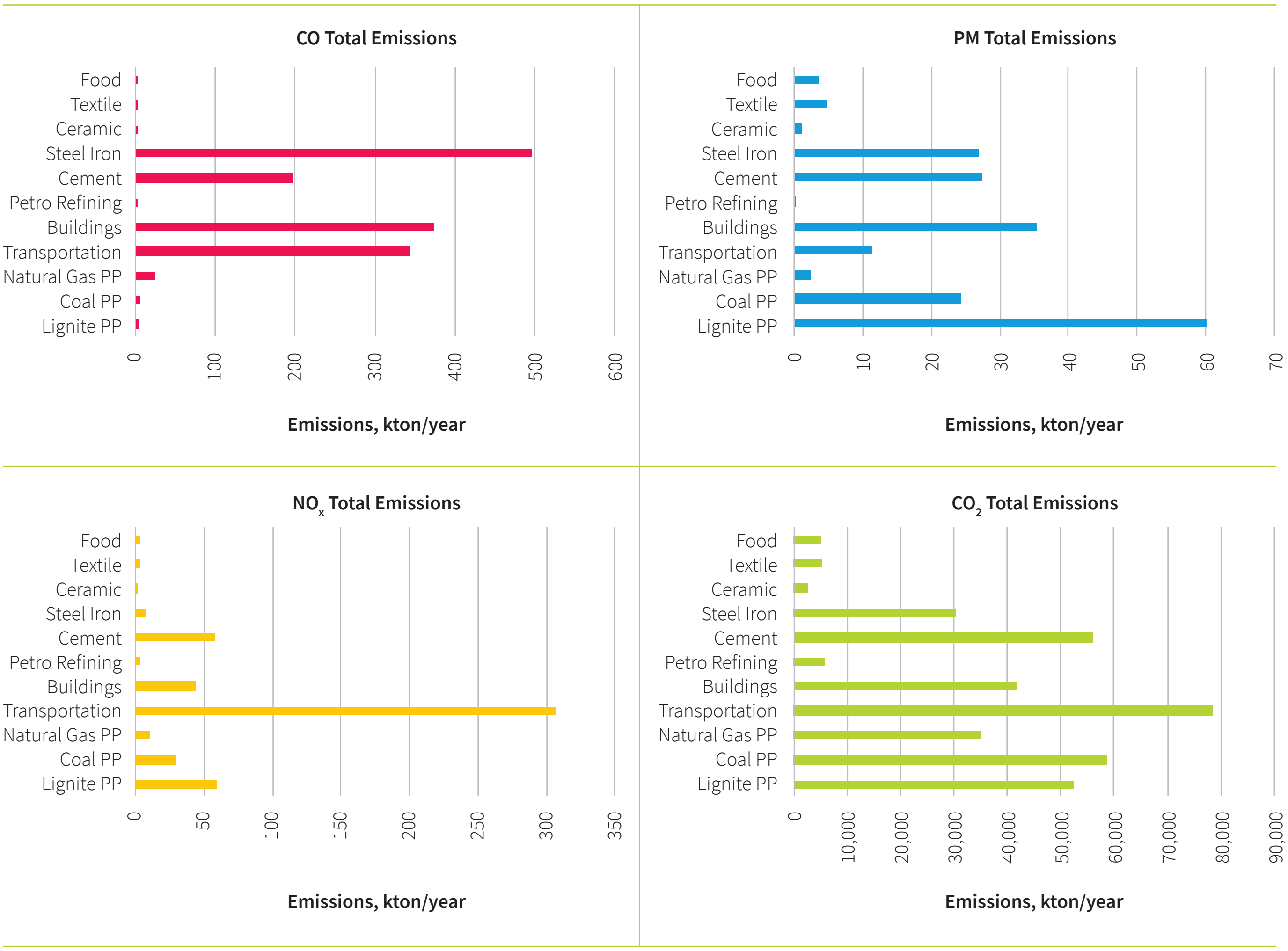


Figure 25: *Sectoral distribution of some major pollutants and CO_2 total emissions*



Transport, buildings, and lignite fired power plants are major sources of pollutants and GHGs.

As can be seen from these tables and figures, transport, buildings, and lignite fired power plants are major sources of pollutants and GHGs. The transport sector is responsible for about 65% of the combustion-based NO_x emissions due to the high share of diesel vehicles. The shares of building and lignite fuelled power plants is almost 60% of the total combustion-based PM emissions. The uncontrolled hard coal and lignite consumption in buildings is mostly responsible for the combustion based SO_x emissions. Similarly, over 90% of the combustion-based CO emissions arise from transportation and the buildings sector. Transport sector covers one fourth of the combustion-based CO_2 emissions, which is followed by lignite and hard coal fired power plants and the buildings sector.

Of the industries analysed in this study, process-based emissions are estimated for the cement, steel & iron, and ceramic production industries. As can be seen from Figure 25, the major pollutants estimated are NO_x, PM, and CO. More than 90% of the process-based NO_x are generated from the cement industry, whereas the majority of the PM and CO emissions are from steel and iron industry.

The regional distribution of some major pollutants and GHGs emissions arising from combustion and process-based power, transportation, buildings, petroleum refining, cement, steel and iron, ceramic, textile, and food industries and their totals are presented in Table 13 / Figure 26, Table 14 / Figure 27, and Table 15 / Figure 28, respectively.

Table 13: *Regional distribution of fossil fuel combustion based total emissions, ton/year*

Pollutant	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	4.448	3.305	5.452	2.284	11.171	4.411	3.260	34.331
CO	101.538	74.007	121.927	53.048	245.255	98.251	77.122	771.148
CO_2	57.665.399	36.192.340	40.871.723	9.901.750	103.012.427	53.229.072	16.146.607	317.019.318
N_2O	909	648	758	250	1.735	911	382	5.593
NO_x	86.087	47.631	72.071	25.658	137.214	67.613	37.119	473.393
NMVOC	12.461	9.099	15.328	6.594	30.888	12.061	9.521	95.951
PM	44.811	15.741	21.908	4.589	34.383	30.070	8.065	159.568
PM_{10}	17.909	7.632	12.021	4.024	20.726	14.435	6.163	82.910
$PM_{2.5}$	8.024	6.118	8.208	3.561	16.555	8.484	5.360	56.309
SO_x	36.396	12.298	22.583	4.865	28.256	23.826	9.537	137.761
VOC	6.672	5.000	8.286	3.831	15.944	6.620	5.567	51.920

Table 14: *Regional distribution of process based total emissions, ton/year*

Pollutant	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0	0	0	0	251	181	0	432
CO	49.213	246.423	31.270	12.860	89.468	241.031	11.923	682.188
CO_2	3.151.013	14.698.248	5.452.715	2.619.999	10.088.229	16.273.089	2.209.442	54.492.734
N_2O	0	0	0	0	0	0	0	0
NO_x	4.288	5.902	7.725	3.177	12.563	13.482	2.945	50.083
NMVOC	7.696	5.721	0	0	5.006	7.288	0	25.711
PM	5.379	8.861	2.629	1.263	7.098	10.511	1.065	36.807
PM_{10}	1.179	1.806	2.590	1.245	3.918	3.386	1.050	15.174
$PM_{2.5}$	648	993	1.425	685	2.155	1.862	577	8.346
SO_x	1.898	2.743	3.436	1.413	5.400	5.947	1.310	22.148
VOC	640	646	1.098	357	17.190	12.292	331	32.552

Table 15: *Regional distribution of total emissions, ton/year*

Pollutant	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	4.448	3.305	5.452	2.284	11.422	4.592	3.260	34.763
CO	150.751	320.430	153.197	65.909	334.723	339.281	89.045	1.453.336
CO_2	60.816.412	50.890.588	46.324.438	12.521.748	113.100.656	69.502.161	18.356.049	371.512.052
N_2O	909	648	758	250	1.735	911	382	5.593
NO_x	90.375	53.533	79.796	28.835	149.777	81.095	40.065	523.476
NMVOC	20.157	14.820	15.328	6.594	35.894	19.348	9.521	121.662
PM	50.190	24.602	24.537	5.853	41.480	40.581	9.131	196.374
PM_{10}	19.088	9.438	14.612	5.268	24.644	17.822	7.212	98.084
$PM_{2.5}$	8.672	7.112	9.632	4.245	18.710	10.347	5.937	64.655
SO_x	38.294	15.041	26.019	6.278	33.656	29.773	10.847	159.909
VOC	7.312	5.647	9.383	4.188	33.134	18.912	5.898	84.473

Figure 26: *Regional distribution of fossil fuel combustion-based emissions of major pollutants and CO_2*

Figure 27: *Regional distribution of process-based emissions of major pollutants and CO_2*

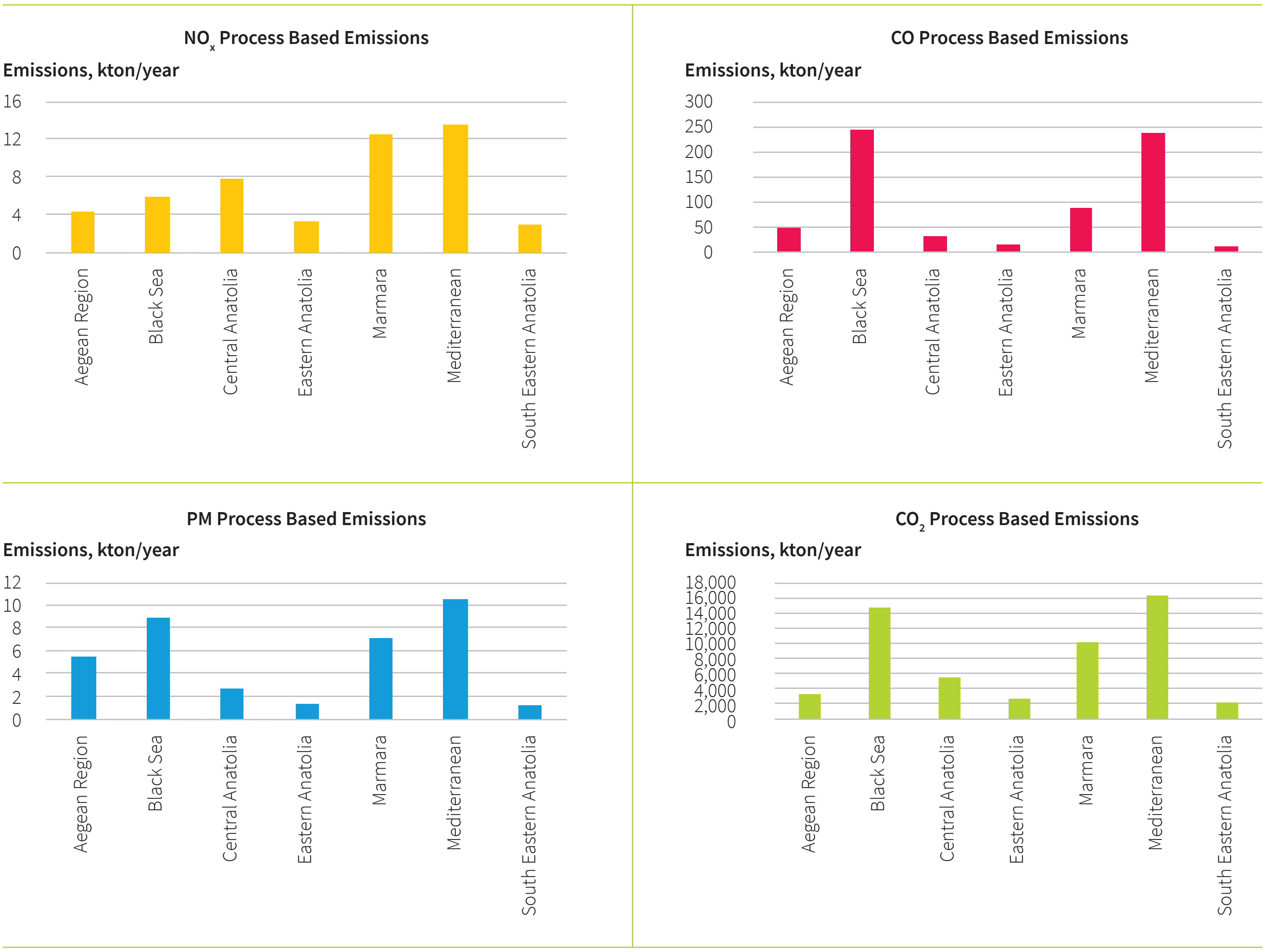


Figure 28: *Regional distribution of total emissions of major pollutants and CO_2*

Emissions of CO_2, CO and NO_x concentrate mainly in the Marmara and Mediterranean regions while combustion based SO_x and PM emissions are highest in the Aegean region.

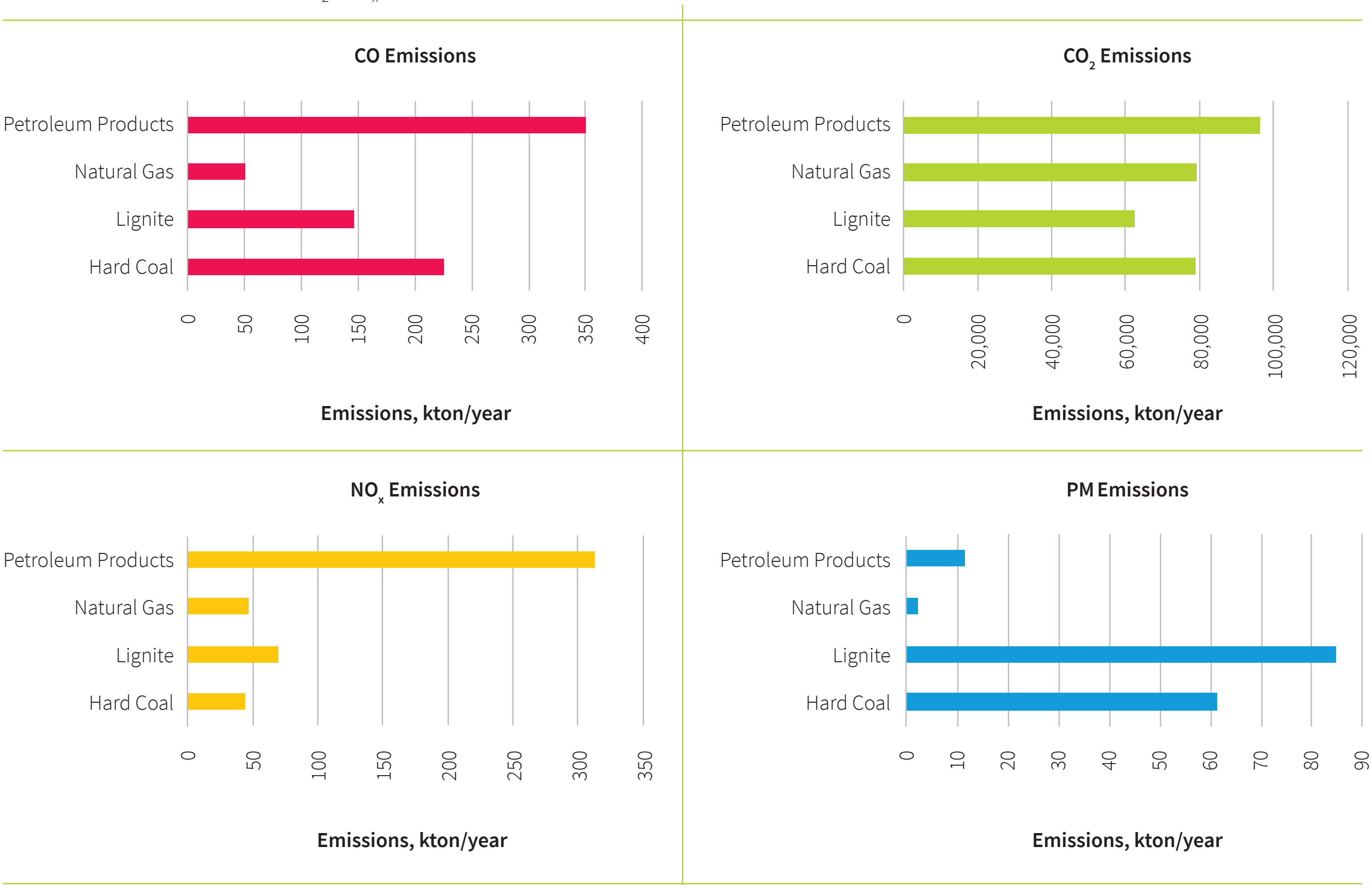
As can be seen from these tables and figures, the majority of combustion and process-based CO, NO_x, and CO_2 emissions are from Marmara and Mediterranean regions due the high population, and excessive number of vehicles, and numerous industrial plants located in these regions. The Aegean Region has the highest combustion based SO_x and PM emissions due to the high number of lignite power plants in this region as shown in Figure 11.

The fuel based emissions of some major pollutants and GHGs due to fossil fuel combustion at power, transport, buildings, petroleum refining, cement, iron & steel, ceramic, textile, and food industries are presented in Table 16 and Figure 29. As it can be seen below, NO_x and CO emissions are mainly from the combustion of petroleum products, mostly arising from the transport sector as shown in Figure 26. More than half of the PM emissions are due to lignite combustion, also shown clearly in Figure 26. The CO_2 emissions are almost evenly divided among the four fuel types.

Table 16: Emissions of major pollutants and GHGs based on the combustion of hard coal, lignite, natural gas and petroleum products, ton/year

Pollutant	Hard Coal	Lignite	Natural Gas	Petroleum Products	TOTAL
CH_4	14,876	9,363	3,676	6,416	34,331
CO	225,077	145,829	50,440	349,802	771,148
CO_2	79,034,493	62,428,247	79,072,358	96,484,220	317,019,318
N_2O	1,242	859	677	2,815	5,593
NO_x	44,312	69,469	46,507	313,105	473,393
NMVOC	23,583	15,609	8,167	48,592	95,951
PM	61,292	84,677	2,224	11,374	159,568
PM_{10}	28,708	35,416	0	18,786	82,910
$PM_{2.5}$	25,310	15,736	0	15,262	56,309
SO_x	37,211	89,579	464	10,507	137,761
VOC	0	0	0	51,920	51,920

***Figure 29:** Emissions of CO, CO_2, NO_x, and PM based on the combustion of hard coal, lignite, natural gas, and petroleum products*



2.2. Sectoral Externalities

In this section, external costs of air pollutants and GHG due to processes and fossil fuel consumption by sectors and regions are presented. Detailed results are presented in Section 2.2 of the separate Methodology Document. As explained in more detail in Section 2.2.3 and 2.2.4 of the Methodology Document, the external costs obtained from the ExternE Project have been used and adjusted to Turkey by applying the purchasing power parity (PPP) income multiplier.

Germany was selected as the main reference country whose external costs for each pollutant reported in ExternE were adopted. For pollutants that are not covered for Germany, such as PM, CO, CH_4, and N_2O, Austria is assumed as the reference country since it is the only country that evaluates these pollutants. Additionally, for $PM_{2.5}$ and VOC via Ozone the values of France are adopted.

The adopted unit cost for each type of pollutant and GHG is adjusted for Turkey using the purchasing power parity (PPP) income multiplier.

The wide range of external cost of CO_2, the main contributor of global warming, varies for each country between a minimum of 3.8 ECU (€)/tons to a maximum of 139 ECU (€)/tons. Disregarding these outliers, the external cost in the majority of the countries lies in the range of 18-46 ECU (€)/ton. Thus, the midpoint of 18 to 46 range is accepted as the reference value to be used for adjustment of the external cost of CO_2 to Turkey. The adopted unit cost for each type of pollutant and GHG is adjusted for Turkey using the purchasing power parity (PPP) income multiplier (please refer to Methodology Document section 2.2.3 for more detail). The calculated external costs for each pollutant are assumed to be the same for all regions of Turkey.

2.2.1. Power Generation

External costs of fossil fuel use in power generation are calculated based on the detailed emission estimates presented in section 3.1 of the Methodology Document, following the steps in Section 2 of the same document. The tables below provide the estimated regional external costs for power generation by pollutant type.

Table 17: *External cost of power generation from lignite fired power plants, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
CO	0.98	0.02	0.29	0.00	0.08	0.40	0.00	1.78
CO_2	278.82	17.55	86.74	0.00	43.49	105.54	0.00	532.13
N_2O	0.27	0.02	0.09	0.00	0.05	0.10	0.00	0.52
NO_x	161.66	1.82	47.90	0.00	9.66	53.37	0.00	274.41
PM	181.97	5.79	56.83	0.00	9.76	64.94	0.00	319.28
PM_{10}	71.30	2.89	21.21	0.00	7.77	36.00	0.00	139.16
$PM_{2.5}$	12.02	0.49	3.58	0.00	1.31	6.07	0.00	23.46
SO_x	100.19	2.44	43.20	0.00	11.95	42.33	0.00	200.11
TOTAL	807.20	31.01	259.83	0.00	84.07	308.74	0.00	1,490.88

Table 18: *External cost of power generation from hard coal fired power plants, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.03
CO	0.08	0.62	0.00	0.00	0.76	0.67	0.03	2.16
CO_2	22.09	158.47	0.00	0.00	207.72	183.21	24.11	595.59
N_2O	0.02	0.18	0.00	0.00	0.24	0.21	0.03	0.67
NO_x	7.67	50.88	0.00	0.00	32.20	41.11	1.27	133.12
PM	4.28	33.99	0.00	0.00	45.91	35.51	9.64	129.32
PM_{10}	1.27	10.09	0.00	0.00	13.63	10.54	2.86	38.39
$PM_{2.5}$	1.13	8.97	0.00	0.00	10.60	9.34	1.86	31.89
SO_x	1.66	14.58	0.00	0.00	7.21	9.04	10.56	43.06
TOTAL	38.20	277.77	0.00	0.00	318.26	289.62	50.35	974.24

Table 19: *External cost of electricity generation from natural gas fired power plants, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.03
CO	1.53	0.57	1.30	0.00	4.64	0.81	0.12	8.97
CO_2	60.29	22.62	51.77	0.00	184.81	32.12	4.61	356.22
N_2O	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.05
NO_x	8.11	3.01	6.88	0.00	24.56	4.27	0.61	47.43
PM	2.01	0.74	1.70	0.00	6.08	1.06	0.15	11.75
SO_x	0.12	0.04	0.10	0.00	0.35	0.06	0.01	0.68
TOTAL	72.07	26.99	61.76	0.00	220.46	38.31	5.50	425.13

Table 20: *External cost of power generation, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.02	0.01	0.01	0.00	0.03	0.02	0.00	0.08
CO	2.60	1.21	1.59	0.00	5.48	1.88	0.15	12.91
CO_2	361.21	198.64	138.51	0.00	436.02	320.86	28.72	1,483.95
N_2O	0.30	0.20	0.09	0.00	0.30	0.31	0.03	1.24
NO_x	177.44	55.70	54.78	0.00	66.42	98.75	1.88	454.96
PM	188.25	40.52	58.53	0.00	61.76	101.50	9.79	460.36
PM_{10}	72.57	12.98	21.21	0.00	21.40	46.54	2.86	177.55
$PM_{2.5}$	13.15	9.46	3.58	0.00	11.91	15.41	1.86	55.35
SO_x	101.97	17.06	43.30	0.00	19.52	51.43	10.57	243.85
TOTAL	917.48	335.77	321.59	0.00	622.80	636.67	55.85	2,890.24

As expected, Aegean, Mediterranean and Marmara regions have higher externalities than others due to high number of power plants located in these regions, as shown in Figure 29.

Figure 30: *Regional distribution of major air pollutants and CO_2 externalities from power sector*

The distribution of external costs by fuel type is given in Table 21. As can be seen, more than half of the external costs are due to lignite fuelled power plants.

Table 21: *External cost of power generation by fuel types, million Euro/year*

Pollutant/GHG	Lignite Power Plants	Hard Coal Power Plants	Natural Gas Power Plants	TOTAL
CH_4	0.02	0.03	0.03	0.08
CO	1.78	2.16	8.97	12.91
CO_2	532.13	595.59	356.22	1,483.95
N_2O	0.52	0.67	0.05	1.24
NO_x	274.41	133.12	47.43	454.96
PM	319.28	129.32	11.75	460.36
PM_{10}	139.16	38.39	0.00	177.55
$PM_{2.5}$	23.46	31.89	0.00	55.35
SO_x	200.11	43.06	0.68	243.85
TOTAL	1,490.88	974.24	425.13	2,890.24

The external costs of power generation for Turkey from lignite, hard coal, and natural gas power plants per MWh of power generated are calculated as 36.29 Euros (€), 14.62 Euros (€), and 4.70 Euros (€), respectively. These external costs are compared with those estimated by Georgakellos (2007) (Georgakellos, 2007) for Greece, Matsuki et al. (2010) (Matsuki & Brondazia, n.d.) for Ukraine, and Sakulniyomporn et al. (2011) (Sakulniyomporn et al., 2011) for Thailand, as presented in Table 22.

Table 22: *External cost comparison for power generation Euro/MWh*

Power Plant Type	This Study	Study Conducted for		
		Greece (2007) (Georgakellos, 2007)	Ukraine (2010) (Matsuki & Brondazia, n.d.)	Thailand (2011) (Sakulniyomporn et al., 2011)
Lignite PP	36.29	43.89		11.03
Hard Coal PP	14.62		55.15	4.51
Natural Gas PP	4.70	13.86		0.46

The external costs for lignite and natural gas based power generation estimated for Greece (Georgakellos, 2007) are respectively 1.3 and 2.9 times higher than those estimated in this study. The external costs estimated for lignite and hard coal based power plants in the study conducted for Thailand (Sakulniyomporn et al., 2011) are about 30% of those estimated in this study, whereas the external cost regarding natural gas based plants is only 10% of the one estimated here. On the other hand, the external costs for hard coal burning power plants in the study conducted for Ukraine (Matsuki & Brondazia, n.d.) is about 4 times the values estimated here. These differences are due to the economic and social characteristics of the countries and fuel properties used in power plants, as well as the disparity of the years these studies are conducted.

In another study, the environmental damage costs from fossil fuel based power generation in the EU was reported as US$ 70 billion for 1990, which is about 1% of GDP (CASES, 2008). Besides, in 2009 a US National Research Council report commissioned by the Congress quantified and analysed a total of $120 billion external costs of energy production in the USA in 2005 (National Academies of Sciences, Engineering, Medicine, 2009).

Since the external costs are estimated based on the emission estimates, which themselves are based on a wide range of emission figures, the external costs are also expected to lie on a range. For example, as stated in Section 3.1.1, if minimum and maximum CO_2 emission figures are used, the estimated CO_2 emissions would lie in a range. Accordingly, CO_2 external costs of lignite fuelled power plants are expected to be between 447 and 564 million Euros, CO_2 external costs of hard coal fuelled power plants are expected to be between 495 and 604 million Euros, and CO_2 external costs of natural gas fuelled power plants are expected to be between 345 and 370 million Euros. Thus, the external costs are expected to differ by about 26% for lignite power plants.

The external cost of power generation from fossil fuels, particularly coal, is quite high in comparison with the levelised cost of energy (LCOE) from these sources.

The external costs of power generation from fossil fuels, particularly coal, is quite high in comparison with the levelised cost of energy (LCOE) from these sources. LCOE reflects the market cost of generating electricity from fossil fuels while the external cost represents costs on health and environment that are not priced by the market. Below is a comparison of LCOE and external cost per MWh. When external costs are taken into account, the cost of power generation is 8% higher than market costs of natural gas, 26% higher for hard coal and 58% higher for lignite.

Table 23: *Market (LCOE) and External Costs of Power Generation from Fossil Fuels (€/MWh)*

Plant Fuel Type	LCOE	External Cost	Total Cost
Natural Gas	60.8	4.7	65.5
Hard Coal	56.1	14.5	70.7
Lignite	57.9	33.4	91.2

2.2.2. Road Transport

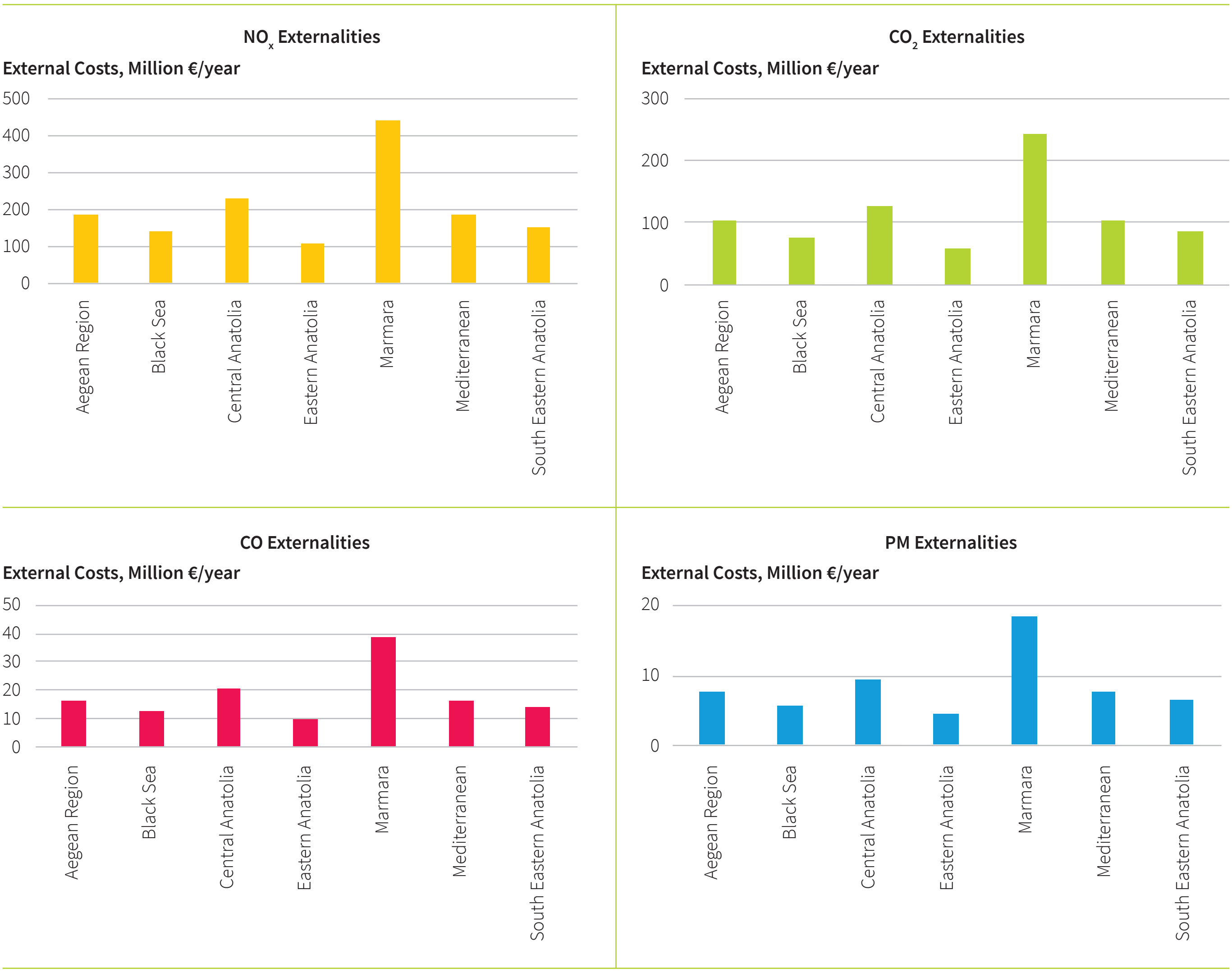
External costs of fossil fuel use in road transport are calculated based on the detailed emissions estimates presented in section 3.2 of the Methodology Document, following the steps in Section 2 of the same document. The external costs estimated for the transportation sector is presented in Table 24. NO_x, the major pollutant related with the sector is the main contributor of external costs for transportation industry. Vehicle ownership has a positive correlation with GDP and income rates of the regions. In the Marmara region transport related external costs are higher than other regions due to high GDP, population and thus high number of vehicles in this region.

Table 24: *Road Transport external costs, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.03	0.02	0.04	0.02	0.07	0.03	0.03	0.24
CO	16.20	12.14	20.12	9.30	38.72	16.08	13.52	126.07
CO_2	102.49	76.82	127.29	58.85	244.94	101.70	85.53	797.62
N_2O	0.23	0.18	0.29	0.13	0.56	0.23	0.20	1.83
NO_x	183.69	137.68	228.13	105.48	439.00	182.28	153.29	1,429.54
PM	7.70	5.77	9.57	4.42	18.41	7.64	6.43	59.94
PM_{10}	16.56	12.41	20.57	9.51	39.58	16.44	13.82	128.89
$PM_{2.5}$	15.22	11.41	18.90	8.74	36.37	15.10	12.70	118.43
SO_x	4.31	3.23	5.35	2.48	10.30	4.28	3.60	33.55
VOC	2.24	1.68	2.78	1.29	5.35	2.22	1.87	17.43
TOTAL	348.65	261.31	433.00	200.20	833.23	345.97	290.94	2,713.31

The regional distribution of the externalities of major pollutants and CO_2 are presented in Figure 31. The costs of these pollutants and CO_2 from the transportation sector have the highest shares as expected.

Figure 31: *Regional distribution of air pollutants and CO_2 emissions related with transportation sector*



The externalities estimated in this study covers the predicted emissions of 17,173,573 vehicles in 2018. Thus, the average external cost per vehicle is estimated as 158 Euros (€). This figure is 30% lower than the one calculated for Auckland New Zeland (Jakob et al., 2006) as seen in Table 25. The difference between these values can be due to the differences between the economic and social characteristics of the countries and number and type of vehicles in each country.

Table 25: *External cost comparison for road transportation*

Data	Turkey (This Study, 2018)	New Zealand (Jakob, et.al., 2006)
Number of vehicles	17,173,573	2,500,000
Total Cost of Road Transportation, Euros (€)	2,713,547,182	501,712,010
External Cost per Vehicle, Euros (€)	158	201

2.2.3. Buildings

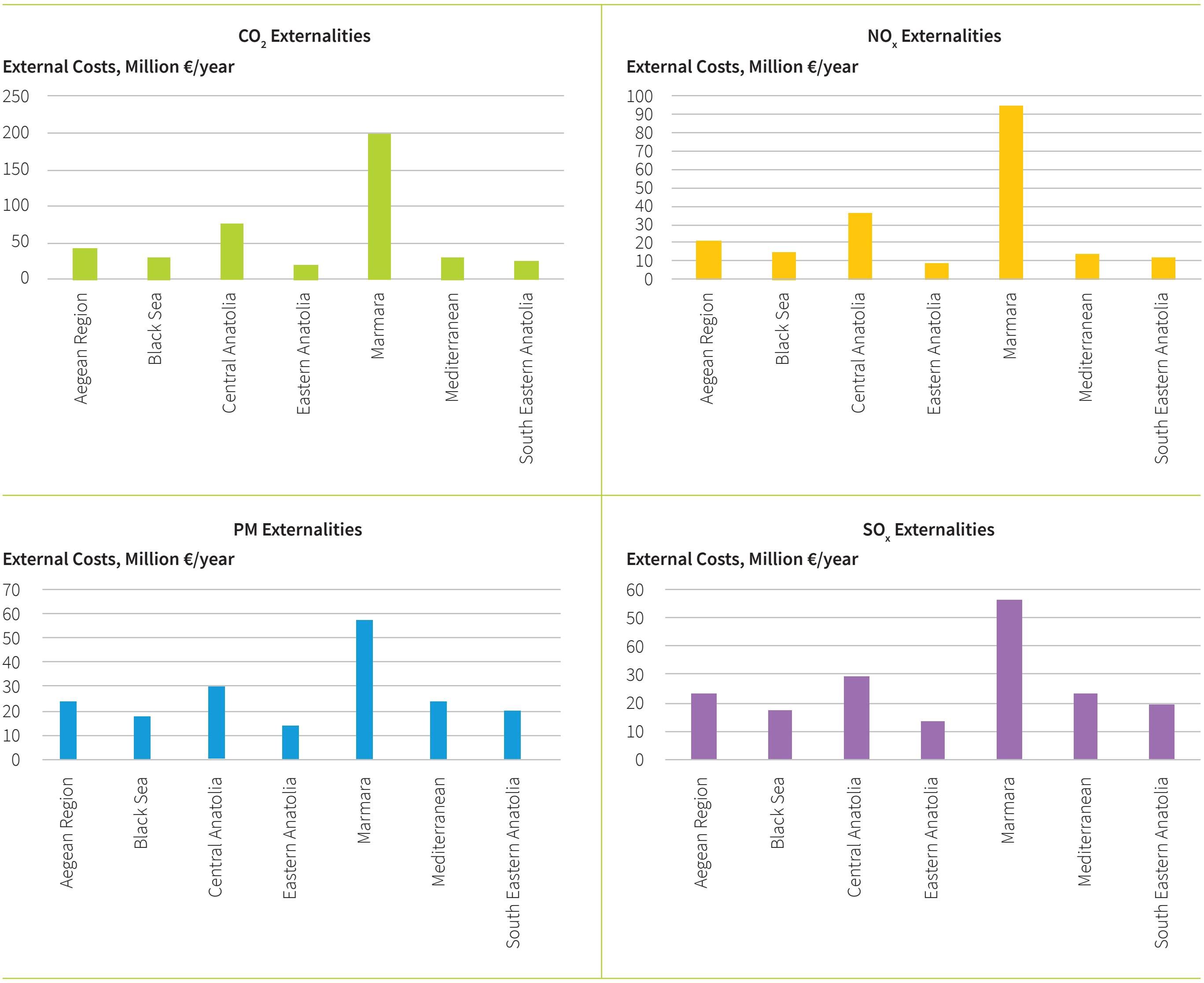
External costs of fossil fuel emissions from buildings are calculated based on the detailed emissions estimates presented in section 3.3 of the Methodology Document, following the steps in Section 2 of the same document. Among the cost of damages caused by the fossil fuel consumption in the residential and commercial building sector, CO_2 has the biggest portion, followed by SO_x as presented in Table 26.

Table 26: *Buildings external costs, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.16	0.12	0.21	0.09	0.42	0.15	0.13	1.27
CO	17.46	13.04	22.12	9.91	43.65	17.06	14.35	137.60
CO_2	43.11	30.31	75.81	19.28	199.81	29.56	25.20	423.07
N_2O	0.05	0.04	0.10	0.02	0.25	0.04	0.03	0.53
NO_x	20.67	14.56	36.04	9.32	94.48	14.35	12.22	201.63
PM	24.05	18.03	29.87	13.81	57.47	23.86	20.07	187.16
PM_{10}	28.32	21.23	35.17	16.26	67.69	28.10	23.63	220.41
$PM_{2.5}$	31.40	23.53	38.99	18.03	75.03	31.16	26.20	244.34
SO_x	23.34	17.49	29.06	13.38	56.11	23.11	19.44	181.93
TOTAL	188.56	138.33	267.37	100.11	594.92	167.39	141.27	1,597.93

The regional distribution of the externalities of the major pollutants and CO_2 are depicted in Figure 32. Due to high SO_x, NO_x, PM, and CO_2 emissions from the combustion of hard coal, lignite, and natural gas in buildings, the externalities of these pollutants and CO_2 are also high, especially in the Marmara Region which has highest number of buildings.

Figure 32: *Regional externalities of major pollutants and CO_2 from the buildings sector*



In buildings, hard coal, constituting 40% of the total cost, has the highest share in external costs while the remaining 60% is evenly divided between lignite and natural gas.

External costs by fuel types of the buildings sector is presented in Table 27. Hard coal, constituting 40% of the total cost, has the highest share while the remaining 60% is evenly divided between lignite and natural gas. The share of lignite and hard coal in external costs of fossil fuels is high compared to their share in the consumption of fossil fuels in buildings. The share of lignite and hard coal in total fossil fuel consumption in buildings is about 8% and 12% respectively.

Table 27: *External costs of the building sector based on fuel type, million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Total
CH_4	0.69	0.43	0.14	1.27
CO	79.51	51.55	6.53	137.60
CO_2	59.15	36.68	327.24	423.07
N_2O	0.06	0.04	0.43	0.53
NO_x	28.93	20.24	152.46	201.63
PM	113.91	73.25	0.00	187.16
PM_{10}	134.21	86.20	0.00	220.41
$PM_{2.5}$	148.67	95.67	0.00	244.34
SO_2	0.00	0.00	0.00	0.00
SO_x	55.87	124.95	1.11	181.93
TOTAL	621.01	489.01	487.91	1,597.93

2.2.4. Petroleum Refining

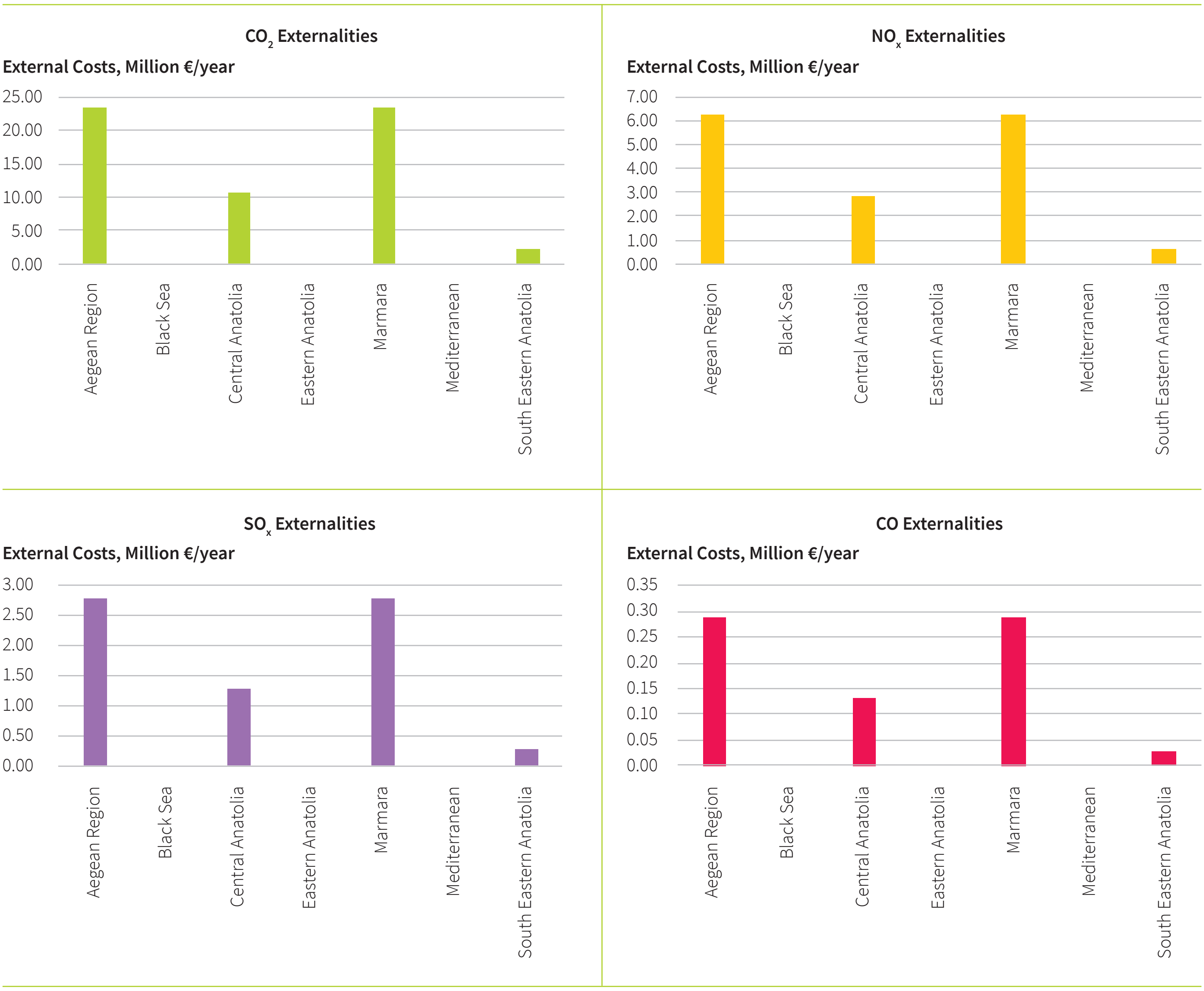
External costs of fossil fuel emissions from buildings are calculated based on the detailed emissions estimates presented in section 3.4 of the Methodology Document, following Section 2 of the same document. Similar to the buildings sector, the externalities due to the emissions of CO_2 result in the highest share of externalities in this sector (see Table 28). As detailed in Section 2.1.4, petroleum refining emissions are calculated by Tier 1 Method of IPCC Guideline.

Table 28: *Petroleum refining external costs, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
CO	0.29	0.00	0.13	0.00	0.29	0.00	0.03	0.74
CO_2	23.45	0.00	10.66	0.00	23.45	0.00	2.34	59.90
N_2O	0.03	0.00	0.01	0.00	0.03	0.00	0.00	0.07
NO_x	6.25	0.00	2.84	0.00	6.25	0.00	0.62	15.95
PM	0.05	0.00	0.02	0.00	0.05	0.00	0.00	0.12
SO_x	2.80	0.00	1.27	0.00	2.80	0.00	0.28	7.14
TOTAL	32.85	0.00	14.93	0.00	32.85	0.00	3.29	83.94

The regional distribution of the externalities of the major pollutants and GHGs from petroleum refining sector is presented in Figure 33. Almost 70% of the total externalities are from CO_2 emission, due to concentration of refineries in Marmara and Aegean Regions as presented below.

Figure 33: *Regional externalities of SO_x, CO, NO_x, and CO_2 emissions from petroleum refining*



Petroleum products constitute almost 75% of total external costs in refineries.

External costs of the petroleum refining sector by fuel types is presented in Table 29. External costs from the petroleum products cover almost 75% of the total external costs.

Table 29: *External costs of the petroleum refining sector by fuel types, million Euro/year*

Pollutants/GHGs	Petroleum Products	Natural Gas	Total
CH_4	0.01	0.00	0.01
CO	0.29	0.45	0.74
CO_2	41.94	17.96	59.90
N_2O	0.06	0.01	0.07
NO_x	12.72	3.23	15.95
PM	0.12	0.00	0.12
SO_x	7.14	0.00	7.14
TOTAL	62.28	21.65	83.94

2.2.5. Industrial Sectors

In this section, externalities due to the emissions based on fossil fuel consumption in cement, steel & iron, ceramics, textile & leather, and food industries are presented.

2.2.5.1. Cement Industry

External costs of fossil fuel emissions from cement production are calculated based on the detailed emissions estimates presented in section 3.5 of the Methodology Document, following Section 2 of the same document. External costs of cement industry are calculated for emissions from fossil fuel combustion and for emissions from processes. Table 30 shows damage costs calculated based on emissions of fossil fuel combustion in this industry. CO_2 emissions are the main contributor to the externalities for this industry due to the use of high amounts of petroleum products and hard coal during cement production.

Table 30: *Cement industry external costs due to fossil fuel combustion, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.07
CO	0.21	0.32	0.46	0.22	0.70	0.61	0.19	2.72
CO_2	19.01	29.13	41.78	20.07	63.19	54.61	16.93	244.72
N_2O	0.02	0.03	0.04	0.02	0.07	0.06	0.02	0.26
NO_x	3.86	5.92	8.48	4.08	12.83	11.09	3.44	49.70
PM	4.89	7.49	10.74	5.16	16.24	14.04	4.35	62.90
PM_{10}	1.45	2.22	3.18	1.53	4.81	4.16	1.29	18.63
$PM_{2.5}$	0.74	1.14	1.63	0.78	2.47	2.13	0.66	9.55
SO_x	2.47	3.79	5.43	2.61	8.21	7.10	2.20	31.80
TOTAL	32.66	50.03	71.75	34.47	108.52	93.79	29.07	420.37

In the cement industry, externalities from processes are almost 1.5 times higher than the externalities due to fossil fuel combustion.

External costs related to cement production processes are also calculated and given in Table 31. The emissions of SO_x and PM from processes involved in cement production have the highest externalities. Externalities from processes are almost 1.5 times higher than the externalities due to fossil fuel combustion in this sector. Total externalities of the emissions originating from this sector are presented in Table 32.

Table 31: *Cement industry external costs due to processes, million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CO	5.78	7.42	11.48	4.72	17.51	18.26	4.38	69.55
CO_2	25.22	38.63	55.40	26.62	83.80	72.42	22.45	324.54
NO_x	18.13	23.27	35.99	14.80	54.90	57.25	13.72	218.06
PM	6.36	9.75	13.98	6.72	21.14	18.27	5.66	81.88
PM_{10}	8.09	12.39	17.77	8.54	26.88	23.23	7.20	104.12
$PM_{2.5}$	5.03	7.71	11.06	5.31	16.72	14.45	4.48	64.76
SO_x	6.72	8.63	13.35	5.49	20.36	21.23	5.09	80.86
PVOC	0.15	0.19	0.29	0.12	0.44	0.46	0.11	1.76
TOTAL	75.48	107.99	159.31	72.32	241.76	225.59	63.09	945.54

Table 32: *Cement industry total external costs (combustion + processes), million Euro/year*

Pollutants/ GHGs	Aegean Region	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.07
CO	5.99	7.75	11.94	4.94	18.21	18.87	4.57	72.27
CO_2	44.23	67.77	97.18	46.69	146.99	127.03	39.38	569.26
N_2O	0.02	0.03	0.04	0.02	0.07	0.06	0.02	0.26
NO_x	21.99	29.19	44.47	18.88	67.73	68.34	17.16	267.76
PM	11.25	17.24	24.72	11.88	37.38	32.31	10.02	144.79
PM_{10}	9.54	14.61	20.95	10.07	31.69	27.39	8.49	122.75
$PM_{2.5}$	5.77	8.85	12.69	6.10	19.19	16.58	5.14	74.32
SO_x	9.19	12.41	18.77	8.10	28.57	28.33	7.29	112.66
VOC	0.15	0.19	0.29	0.12	0.44	0.46	0.11	1.76
TOTAL	108.13	158.03	231.06	106.79	350.28	319.38	92.17	1,365.84

The regional distribution of the total externalities of major pollutants and CO_2 from cement production is presented in Figure 34. As can be seen, almost half of the externalities are from Marmara and Mediterranean Regions where the majority of emissions are originated.

Figure 34: *Regional distribution of some major pollutants and CO_2 externalities from the cement industry*

Half of combustion-based external costs in the cement industry are due to hard coal use.

The combustion-based external costs by fuel types for the cement industry is presented in Table 33. Almost half of the external costs are due to hard coal combustion, followed by petroleum products.

Table 33: *Combustion-based external costs of the cement industry by fuel types, million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Petroleum Products	Total
CH_4	0.00	0.00	0.00	0.07	0.07
CO	0.52	0.06	0.11	2.04	2.72
CO_2	81.04	19.70	4.20	139.77	244.72
N_2O	0.09	0.02	0.00	0.15	0.26
NO_x	24.26	8.72	0.56	16.16	49.70
PM	45.15	17.34	0.00	0.41	62.90
PM_{10}	13.32	5.31	0.00	0.00	18.63
$PM_{2.5}$	8.66	0.89	0.00	0.00	9.55
SO_x	24.92	6.88	0.00	0.00	31.80
TOTAL	197.98	58.93	4.87	158.60	420.37

2.2.5.2. Iron & steel Industry

External costs of fossil fuel emissions from iron & steel production are calculated based on the detailed emissions estimates presented in section 3.6 of the Methodology Document, following Section 2 of the same document. Iron & steel industry is also an energy intensive sector requiring special assessment for both combustion and process related external costs. Fossil fuel use to meet energy demand results in external costs mainly due to CO_2 and PM emissions. Coke is the dominant fuel in this sector. Table 34 shows the cost of damages by region and pollutant arising from fuel combustion, whereas the process based externalities are presented in Table 35. The total external costs of the iron & steel industry are presented in Table 36.

Table 34: *Iron and steel industry external costs due to fossil fuel combustion, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
CO	0.23	0.32	0.00	0.00	0.15	0.33	0.00	1.03
CO_2	17.90	24.95	0.00	0.00	11.65	25.35	0.00	79.85
N_2O	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.06
NO_x	4.32	6.01	0.00	0.00	2.81	6.11	0.00	19.25
NO_x Via Ozone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	6.46	9.00	0.00	0.00	4.20	9.15	0.00	28.81
PM_{10}	1.91	2.66	0.00	0.00	1.24	2.70	0.00	8.50
PM_{25}	1.24	1.73	0.00	0.00	0.81	1.75	0.00	5.52
SO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_x	3.57	4.98	0.00	0.00	2.32	5.06	0.00	15.92
TSP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	35.64	49.67	0.00	0.00	23.18	50.46	0.00	158.95

In the iron & steel industry, externalities from process-based CO_2 and PM emissions are almost three times higher than those from combustion related emissions.

Externalities from process-based CO_2 and PM emissions are almost three times higher than those from combustion related emissions. Table 35 shows details and the Black Sea and Mediterranean regions exhibit higher external costs than other regions since integrated plants with heavy fossil fuel usage are located in these regions.

Table 35: *Iron and steel industry external costs due to processes, million Euro/year*

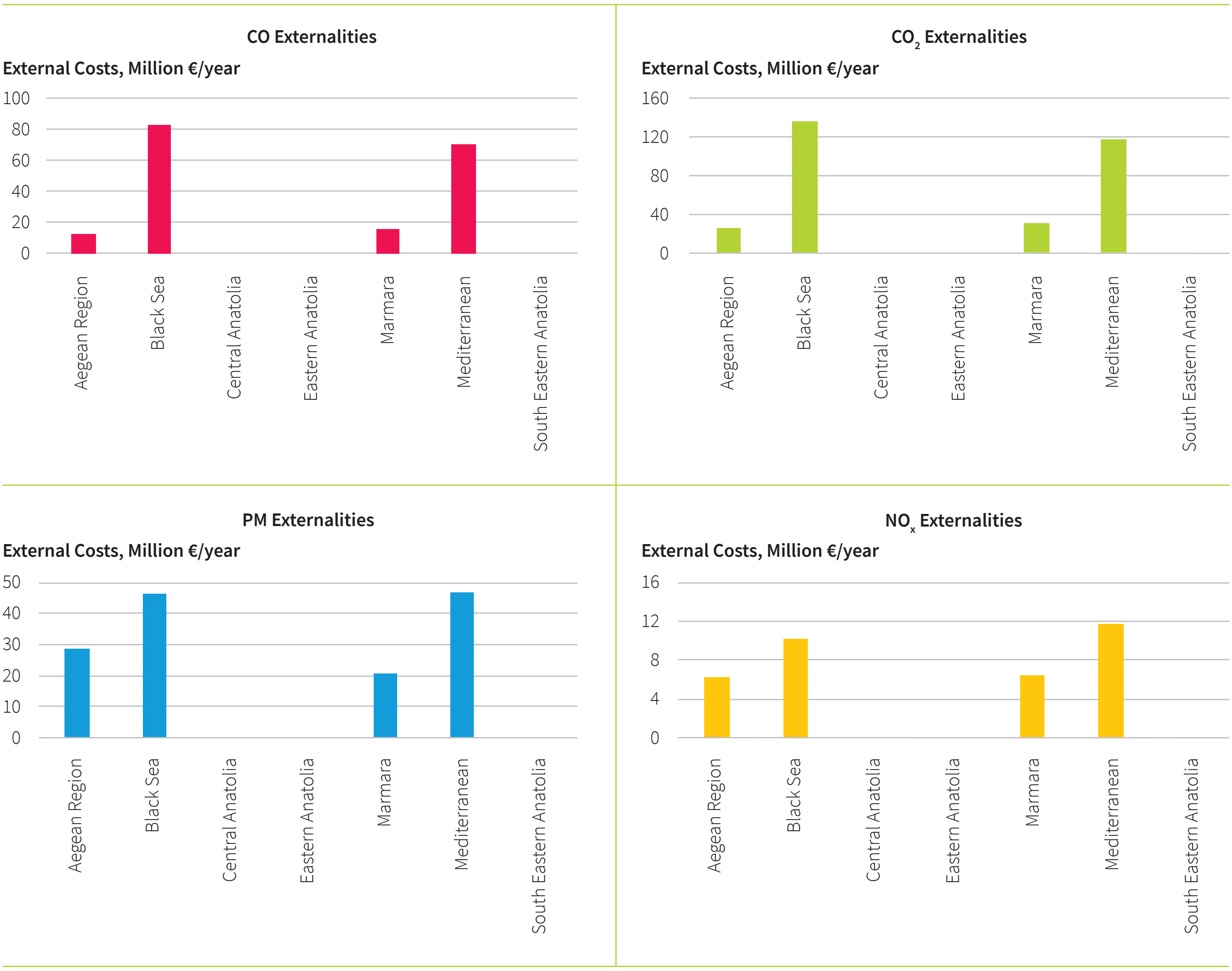
Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
CO	12.28	83.04	0.00	0.00	15.33	70.22	0.00	180.87
CO_2	6.80	110.71	0.00	0.00	18.70	92.92	0.00	229.13
N_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_x	1.85	4.23	0.00	0.00	3.63	5.56	0.00	15.27
NO_x Via Ozone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	22.24	37.36	0.00	0.00	16.59	37.61	0.00	113.80
PM_{10}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM_{25}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_x	0.65	2.03	0.00	0.00	0.62	1.87	0.00	5.16
TSP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VOC	0.00	0.00	0.00	0.00	5.08	3.66	0.00	8.74
TOTAL	43.82	237.36	0.00	0.00	59.97	211.85	0.00	552.99

Table 36: *Overall iron and steel industry external costs (combustion + processes), million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0	0	0	0	0	0	0	0
CO	13	83	0	0	15	71	0	182
CO_2	25	136	0	0	30	118	0	309
N_2O	0	0	0	0	0	0	0	0
NO_x	6	10	0	0	6	12	0	35
NO_x Via Ozone	0	0	0	0	0	0	0	0
NMVOC	0	0	0	0	0	0	0	0
PM	29	46	0	0	21	47	0	143
PM_{10}	2	3	0	0	1	3	0	8
PM_{25}	1	2	0	0	1	2	0	6
SO_2	0	0	0	0	0	0	0	0
SO_x	4	7	0	0	3	7	0	21
TSP	0	0	0	0	0	0	0	0
VOC	0	0	0	0	5	4	0	9
TOTAL	79	287	0	0	83	262	0	712

The regional distribution of major pollutants and CO_2 externalities from iron & steel industry is depicted in Figure 35. As expected, more than 80% of the externalities are from Black Sea and Mediterranean regions because of the production activities of integrated plants.

Figure 35: *Regional distributions of major pollutants and CO_2 externalities from iron & steel industry.*



Almost 80% of the external costs from combustion in iron & steel production arise from hard coal use and the majority of the remaining external costs arise from natural gas use.

The external costs by fuel types of the iron & steel industry is presented in Table 37. Almost 80% of the external costs from combustion arise from hard coal use and the majority of the remaining external costs arise from natural gas use. If processes were to be included, the share of hard coal in total external cost would be over 90%.

Table 37: *External costs of combustion in the iron and steel industry by fuel types, million Euro/year*

Pollutant	Hard Coal	Natural Gas	Liquid Fuel	Total
CH_4	0.00	0.00	0.00	0.01
CO	0.33	0.70	0.00	1.03
CO_2	51.68	27.94	0.23	79.85
N_2O	0.06	0.00	0.00	0.06
NO_x	15.47	3.71	0.07	19.25
PM	28.79	0.02	0.00	28.81
PM_{10}	8.50	0.00	0.00	8.50
$PM_{2.5}$	5.52	0.00	0.00	5.52
SO_x	15.89	0.00	0.03	15.92
TOTAL	126.25	32.38	0.33	158.95

2.2.5.3. Ceramics Industry

External costs of fossil fuel emissions from ceramics production are calculated based on the detailed emissions estimates presented in section 3.7 of the Methodology Document, following Section 2 of the same document. Lignite and natural gas are the main fuels for ceramic production plants in Turkey and thus the externalities due to CO_2, NO_x, and PM emissions from this sector have higher shares. The externalities due to the combustion of fossil fuels in this industry are presented in Table 38.

Table 38: *Ceramics industry external costs due to fossil fuel combustion, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.09	0.04	0.10	0.00	0.32	0.00	0.00	0.55
CO_2	4.44	1.87	5.04	0.00	16.03	0.00	0.00	27.38
N_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
NO_x	0.88	0.37	1.00	0.00	3.19	0.00	0.00	5.44
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	0.84	0.35	0.95	0.00	3.02	0.00	0.00	5.17
PM_{10}	0.26	0.11	0.29	0.00	0.93	0.00	0.00	1.59
PM_{25}	0.06	0.02	0.06	0.00	0.20	0.00	0.00	0.34
SO_x	0.35	0.15	0.40	0.00	1.26	0.00	0.00	2.15
TOTAL	6.92	2.91	7.85	0.00	24.99	0.00	0.00	42.68

Process based emissions of ceramics sector is only estimated for VOC emissions due to the availability of the external costs for this pollutant, and the external cost estimates are presented in Table 39.

Table 39: *Ceramics external costs due to processes, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
VOC	0.07	0.03	0.08	0.00	0.25	0.00	0.00	0.42
TOTAL	0.07	0.03	0.08	0.00	0.25	0.00	0.00	0.42

The total of process and combustion based external costs are presented in Table 40.

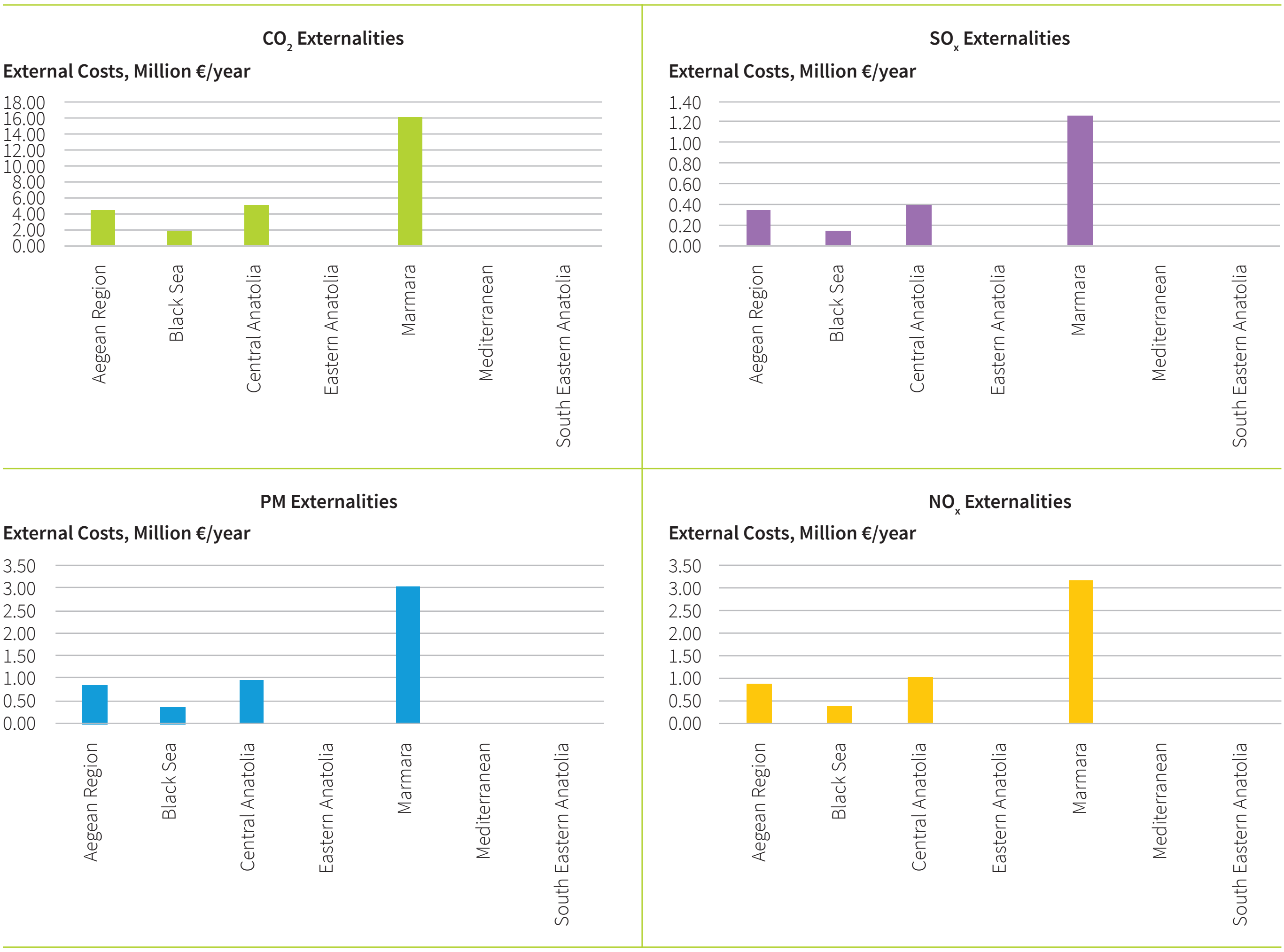
Table 40: *Ceramics external costs due to combustion and processes, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.09	0.04	0.10	0.00	0.32	0.00	0.00	0.55
CO_2	4.44	1.87	5.04	0.00	16.03	0.00	0.00	27.38
N_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
NO_x	0.88	0.37	1.00	0.00	3.19	0.00	0.00	5.44
PM	0.84	0.35	0.95	0.00	3.02	0.00	0.00	5.17
PM_{10}	0.26	0.11	0.29	0.00	0.93	0.00	0.00	1.59
PM_{25}	0.06	0.02	0.06	0.00	0.20	0.00	0.00	0.34
SO_x	0.35	0.15	0.40	0.00	1.26	0.00	0.00	2.15
VOC	0.07	0.03	0.08	0.00	0.25	0.00	0.00	0.42
TOTAL	6.99	2.94	7.93	0.00	25.24	0.00	0.00	43.10

Almost 60% of the externalities in ceramics production are in the Marmara Region where the majority of the plants are located.

The regional distribution of the externalities of the major pollutants and CO_2 is presented in Figure 36. Almost 60% of the externalities are in the Marmara Region where the majority of the plants are located.

Figure 36: *Regional major pollutant and CO_2 externalities from ceramics sector*



Natural gas, the predominant fuel in consumption, constitutes 60% of the external costs in the ceramics industry.

The external costs by fuel types from the ceramics industry are presented in Table 41. Almost 60% of the external costs stem from natural gas use and the majority of the remaining external costs stem from lignite use.

Table 41: *External costs of the ceramics industry by fuel types, million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Total
CH_4	0.00	0.00	0.00	0.00
CO	0.01	0.02	0.53	0.55
CO_2	0.98	5.29	21.11	27.38
N_2O	0.00	0.01	0.00	0.01
NO_x	0.29	2.34	2.81	5.44
PM	0.54	4.61	0.01	5.17
PM_{10}	0.16	1.43	0.00	1.59
$PM_{2.5}$	0.10	0.24	0.00	0.34
SO_x	0.30	1.85	0.00	2.15
TOTAL	2.39	15.82	24.47	42.68

2.2.5.4. Textile and Leather Industry

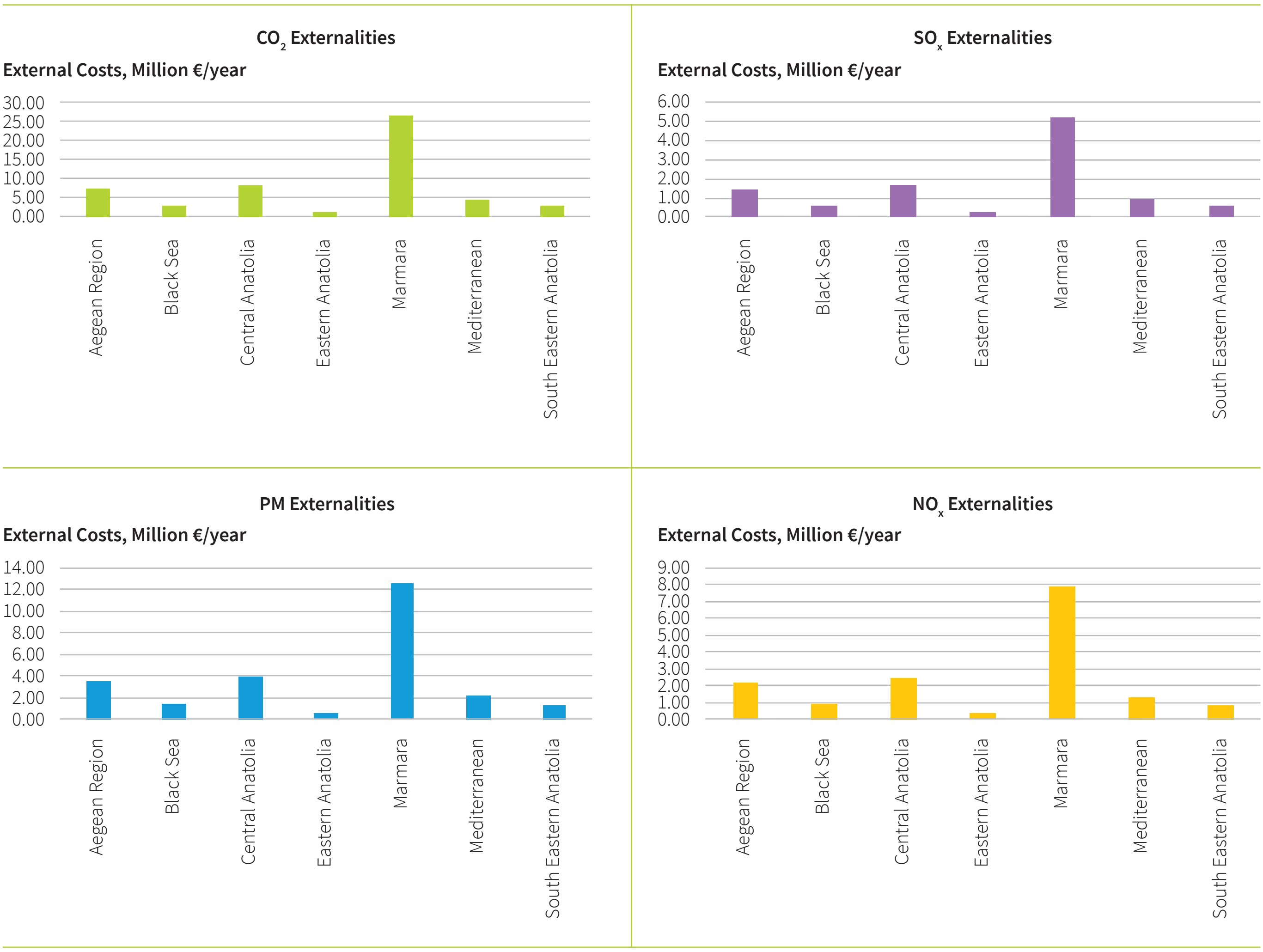
External costs of fossil fuel emissions from textile and leather production are calculated based on the detailed emissions estimates presented in section 3.8 of the Methodology Document, following Section 2 of the same document. Within the textile and leather industry, odour is considered as one of the major problems, and emissions are in higher quantities to water rather than air. As only fossil fuel-based emissions are included in this study, only combustion related external costs are considered as presented in Table 42.

Table 42: *Textile external costs, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.003
CO	0.09	0.04	0.11	0.02	0.33	0.06	0.03	0.68
CO_2	7.32	3.08	8.31	1.23	26.44	4.49	2.74	53.61
N_2O	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.04
NO_x	2.18	0.92	2.47	0.37	7.87	1.34	0.82	15.97
PM	3.48	1.46	3.94	0.58	12.55	2.13	1.30	25.46
PM_{10}	1.06	0.45	1.20	0.18	3.82	0.65	0.40	7.75
PM_{25}	0.24	0.10	0.27	0.04	0.86	0.15	0.09	1.74
SO_x	1.45	0.61	1.64	0.24	5.23	0.89	0.54	10.61
TOTAL	15.83	6.66	17.95	2.66	57.13	9.70	5.92	115.86

The regional distribution of major pollutants and CO_2 externalities from textile industry is depicted in Figure 37. As expected, almost half of the externalities are from the Marmara Region due to high production activity in this region.

Figure 37: *Regional distribution of major pollutants and CO_2 externalities from textile sector*



In textiles, lignite use, constituting two-thirds of external costs, has the highest share.

The external costs by fuel types from the textile and leather industry are presented in Table 43. Lignite use, constituting two-thirds of external costs, has the highest share, followed by natural gas.

Table 43: *External costs of the textile and leather industry by fuel types, million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Liquid Fuel	Total
CH_4	0.00	0.00	0.00	0.00	0.00
CO	0.04	0.08	0.56	0.00	0.68
CO_2	5.51	25.41	22.35	0.34	53.61
N_2O	0.01	0.03	0.00	0.00	0.04
NO_x	1.65	11.25	2.97	0.10	15.97
PM	3.07	22.37	0.01	0.00	25.46
PM_{10}	0.91	6.85	0.00	0.00	7.75
$PM_{2.5}$	0.59	1.15	0.00	0.00	1.74
SO_x	1.69	8.87	0.00	0.04	10.61
TOTAL	13.45	76.02	25.90	0.48	115.86

2.2.5.5. Food Industry

External costs of fossil fuel emissions from the food industry are calculated based on the detailed emissions estimates presented in section 3.9 of the Methodology Document, following Section 2 of the same document. External costs of fossil fuel use in the food industry are assessed only for the emissions from combustion, due to the low amount of chemical processes involved. As expected, CO_2 is the main contributor of total damage and PM and NOx come the second and third, respectively (see Table 44).

Table 44: *Food industry external costs, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.004
CO	0.11	0.04	0.12	0.02	0.38	0.06	0.04	0.77
CO_2	6.97	2.93	7.90	1.17	25.15	4.27	2.61	51.00
N_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03
NO_x	1.78	0.75	2.02	0.30	6.43	1.09	0.67	13.04
PM	2.51	1.06	2.84	0.42	9.05	1.54	0.94	18.36
PM_{10}	0.76	0.32	0.86	0.13	2.74	0.47	0.28	5.56
PM_{25}	0.23	0.10	0.26	0.04	0.82	0.14	0.08	1.66
SO_x	1.11	0.47	1.26	0.19	4.00	0.68	0.41	8.12
TOTAL	13.46	5.67	15.26	2.26	48.59	8.25	5.04	98.53

The regional distribution of the externalities of the major pollutants and CO_2 is presented in Figure 38. Almost half of the externalities are from the Marmara Region where majority of the plants are located.

Figure 38: *Regional distribution of major pollutants and CO_2 externalities from food sector*

Nearly half the external costs in the food industry is due to lignite combustion.

The external costs by fuel type from the food industry are presented in Table 45. Almost half of the external costs are based on lignite combustion, followed by natural gas combustion based external costs.

Table 45: *External costs of the food industry by fuel types, million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Liquid Fuel	Total
CH_4	0.00	0.00	0.00	0.00	0.00
CO	0.06	0.05	0.66	0.00	0.77
CO_2	9.08	15.09	26.40	0.43	51.00
N_2O	0.01	0.02	0.00	0.00	0.03
NO_x	2.72	6.68	3.51	0.13	13.04
PM	5.06	13.28	0.02	0.00	18.36
PM_{10}	1.49	4.07	0.00	0.00	5.56
$PM_{2.5}$	0.97	0.69	0.00	0.00	1.66
SO_x	2.79	5.27	0.00	0.05	8.12
TOTAL	22.19	45.14	30.60	0.61	98.53

2.2.6. Total Externalities

The combustion based, process based, and total externalities from power, transportation, buildings, petroleum refining, cement, iron & steel, ceramics, textile, and food industries are summed and presented in Tables 46, 47, and 48 and Figure 39.

Table 46: *Sectoral distribution of fossil fuel combustion based total externalities, million Euro/year*

Pollutant/ GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Building	Food	Petro Refining	Cement	Steel and Iron	Textile	Ceramics	TOTAL
CH_4	0.02	0.03	0.03	0.24	1.27	0.00	0.01	0.07	0.01	0.00	0.00	1.69
CO	1.78	2.16	8.97	126.07	137.60	0.77	0.74	2.72	1.03	0.68	0.55	283.08
CO_2	532.13	595.59	356.22	797.62	423.07	51.00	59.90	244.72	79.85	53.61	27.38	3,221.09
N_2O	0.52	0.67	0.05	1.83	0.53	0.03	0.07	0.26	0.06	0.04	0.01	4.06
NO_x	274.41	133.12	47.43	1,429.54	201.63	13.04	15.95	49.70	19.25	15.97	5.44	2,205.48
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	319.28	129.32	11.75	59.94	187.16	18.36	0.12	62.90	28.81	25.46	5.22	848.33
PM_{10}	139.16	38.39	0.00	128.89	220.41	5.56	0.00	18.63	8.50	7.75	1.59	568.88
$PM_{2.5}$	23.46	31.89	0.00	118.43	244.34	1.66	0.00	9.55	5.52	1.74	0.34	436.94
SO_x	200.11	43.06	0.68	33.55	181.93	8.12	7.14	31.80	15.92	10.61	2.15	535.07
VOC	0.00	0.00	0.00	17.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.43
TOTAL	1,490.88	974.24	425.13	2,713.55	1,597.93	98.53	83.94	420.37	158.95	115.86	42.68	8,122.04

Table 47: *Sectoral distribution of process based total externalities, million Euro/year*

Pollutant/ GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Building	Food	Petro Refining	Cement	Steel and Iron	Textile	Ceramics	TOTAL
CH_4								0.00	0.02		0.00	0.02
CO								69.55	180.87		0.00	250.42
CO_2								324.54	229.13		0.00	553.68
N_2O								0.00	0.00		0.00	0.00
NO_x								218.06	15.27		0.00	233.33
NMVOC								0.00	0.00		0.00	0.00
PM								81.88	113.80		0.00	195.68
PM_{10}								104.12	0.00		0.00	104.12
$PM_{2.5}$								64.76	0.00		0.00	64.76
SO_x								80.86	5.16		0.00	86.02
VOC								1.76	8.74		0.42	10.93
TOTAL								945.54	552.99	0.00	0.42	1,498.96

Table 48: *Sectoral distribution of total externalities, million Euro/year*

Pollutant/ GHG	Lignite PP	Hard Coal PP	Natural Gas PP	Transportation	Building	Food	Petro Refining	Cement	Steel and Iron	Textile	Ceramics	TOTAL
CH_4	0.02	0.03	0.03	0.24	1.27	0.00	0.01	0.07	0.03	0.00	0.00	1.71
CO	1.78	2.16	8.97	126.07	137.60	0.77	0.74	72.27	181.90	0.68	0.55	533.50
CO_2	532.13	595.59	356.22	797.62	423.07	51.00	59.90	569.26	308.98	53.61	27.38	3,774.77
N_2O	0.52	0.67	0.05	1.83	0.53	0.03	0.07	0.26	0.06	0.04	0.01	4.06
NO_x	274.41	133.12	47.43	1,429.54	201.63	13.04	15.95	267.76	34.51	15.97	5.44	2,438.81
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	319.28	129.32	11.75	59.94	187.16	18.36	0.12	144.79	142.61	25.46	5.22	1,044.01
PM_{10}	139.16	38.39	0.00	128.89	220.41	5.56	0.00	122.75	8.50	7.75	1.59	672.99
$PM_{2.5}$	23.46	31.89	0.00	118.43	244.34	1.66	0.00	74.32	5.52	1.74	0.34	501.71
SO_x	200.11	43.06	0.68	33.55	181.93	8.12	7.14	112.66	21.09	10.61	2.15	621.09
VOC	0.00	0.00	0.00	17.43	0.00	0.00	0.00	1.76	8.74	0.00	0.42	28.35
TOTAL	1,490.88	974.24	425.13	2,713.55	1,597.93	98.53	83.94	1,365.91	711.95	115.86	43.10	9,621.00

Figure 39: *Sectoral distribution of externalities of some major pollutants and CO_2 due to fossil fuel combustion, million Euro/year*

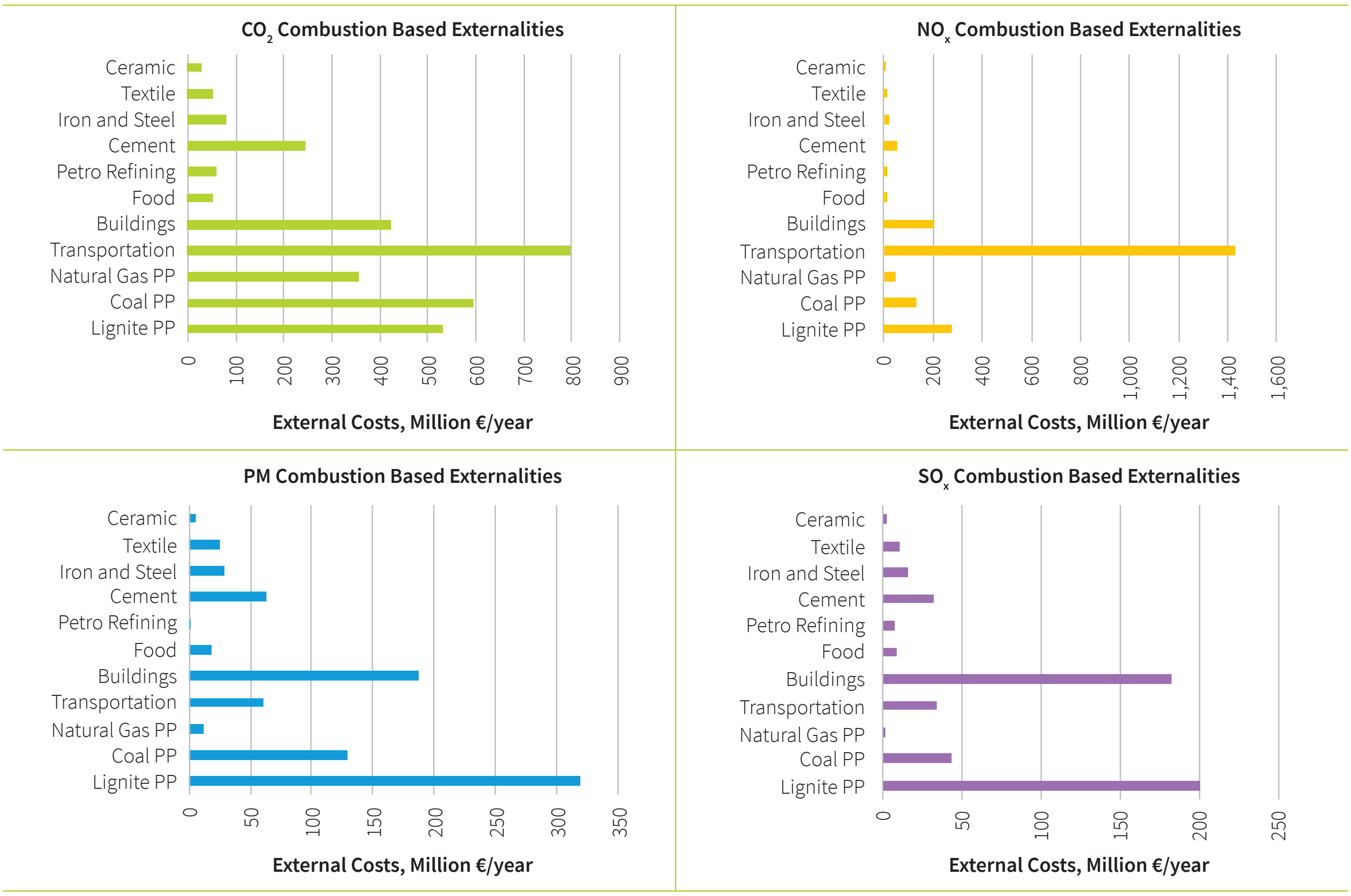


Figure 40: *Sectoral distribution of externalities of some major pollutants and CO_2 due to processes, million Euro/year*

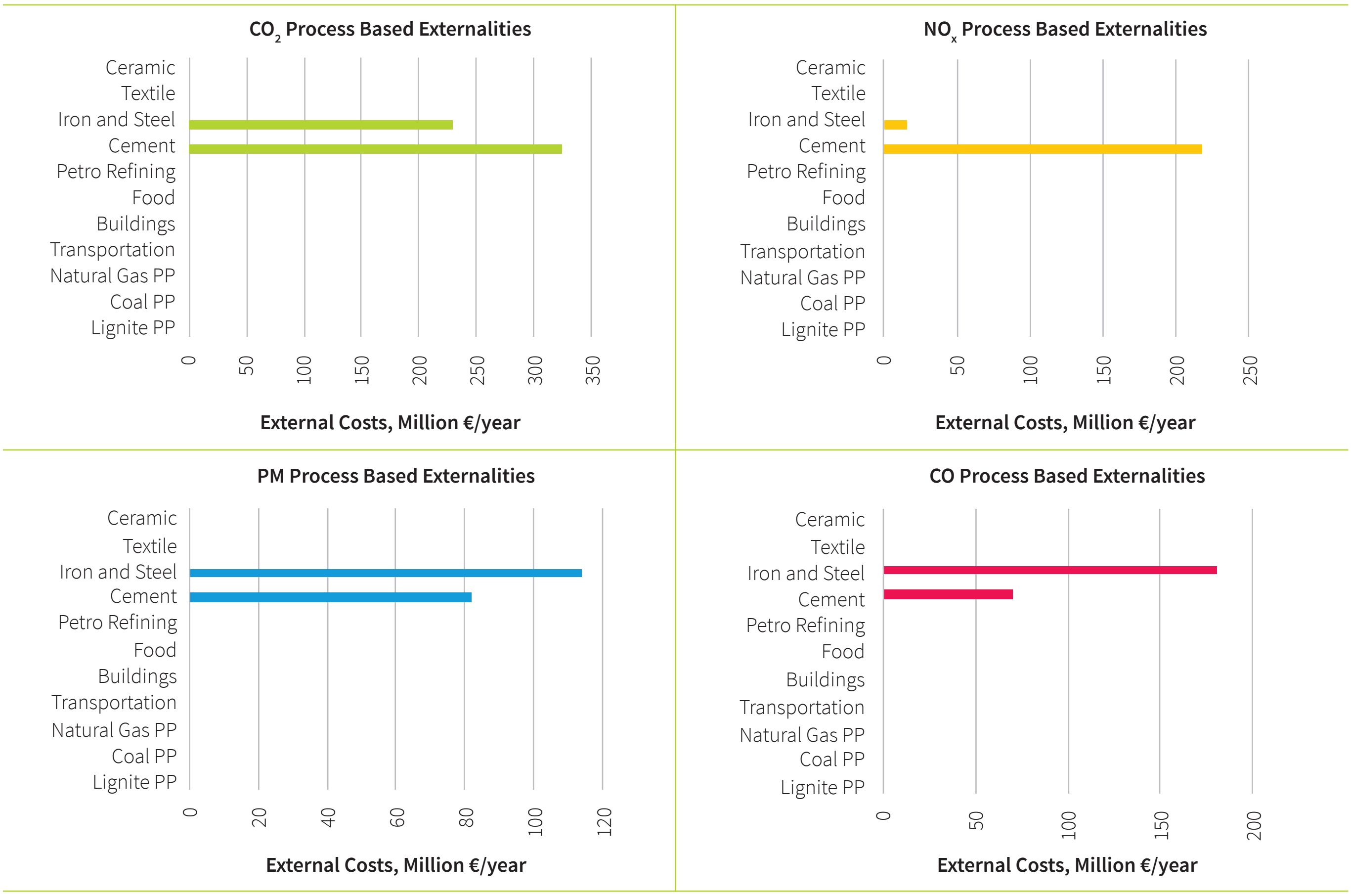
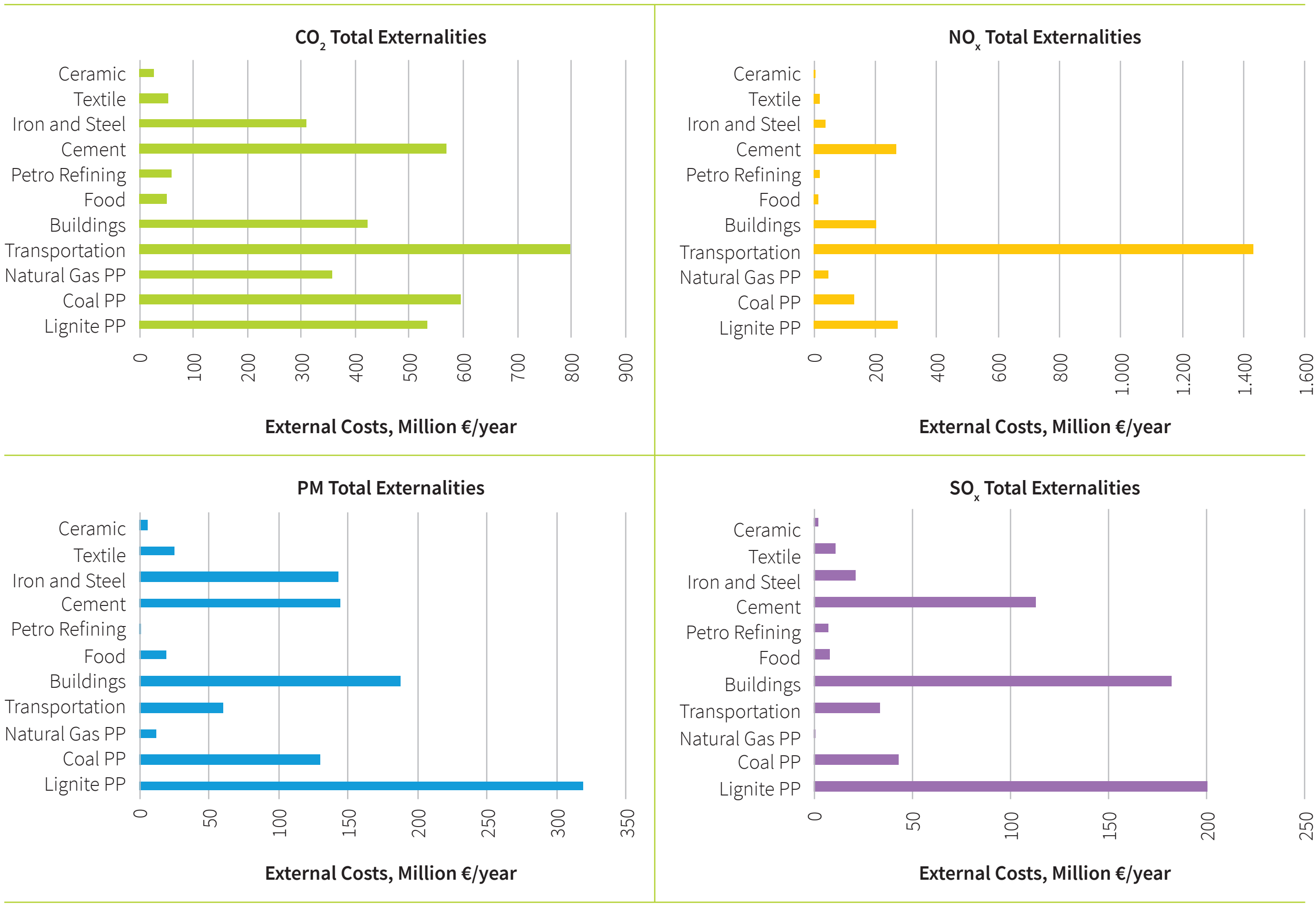


Figure 41: *Sectoral distribution of total externalities of some major pollutants and CO_2, million Euro/year*



The sectoral distributions of total externalities due to fossil fuel combustion and processes exhibit, as expected, trends similar to the emissions discussed in Section 3.1.6. Due to high NO_x emissions from the transport sector, the external cost of NO_x emissions from this sector is also the highest, with a share of about 60%. Similarly, due to high SOx and PM emissions from buildings and lignite fired power plants, the external costs of SO_x and NO_x emissions from these sectors account for almost half of the total SO_x and NO_x externalities. The process based CO externalities from iron & steel and cement industries are responsible for almost half of the CO externalities. The PM externalities of the lignite fired power plants alone account for almost one third of the total PM externalities. When the sectoral shares of total external costs are analysed, transportation, building, and lignite fired power plants account for almost 60% of the total externalities, with shares of 28%, 17%, and 16%, respectively.

Transportation, buildings, and lignite fired power plants account for almost 60% of the total externalities.

The regional distributions of externalities due to the fossil fuel combustion, processes, and total emissions of power, transportation, buildings, petroleum refining, cement, iron & steel, ceramics, textile, and food industries are presented in Table 49 / Figure 42, Table 50 / Figure 43, and Table 51 / Figure 44, respectively.

Table 49: *Regional distribution of externalities due to fossil fuel combustion, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.22	0.16	0.27	0.11	0.55	0.22	0.16	1.69
CO	37.27	27.02	44.76	19.47	90.18	36.07	28.31	283.08
CO_2	585.91	356.09	415.28	100.61	1,058.31	540.84	164.06	3,221.09
N_2O	0.66	0.46	0.55	0.18	1.27	0.66	0.28	4.06
NMVOC	401.07	219.10	335.77	119.54	642.07	315.00	172.93	2,205.48
NO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	238.23	79.48	116.47	24.40	186.99	159.87	42.88	848.33
PM_{10}	122.88	51.12	82.48	27.61	143.45	99.05	42.28	568.88
PM_{25}	62.26	46.67	63.69	27.63	129.26	65.84	41.59	436.94
SO_x	141.36	45.44	87.71	18.90	112.07	92.54	37.04	535.07
VOC	2.24	1.68	2.78	1.29	5.35	2.22	1.87	17.43
TOTAL	1,592.11	827.23	1,149.76	339.73	2,369.51	1,312.29	531.41	8,122.04

Table 50: *Regional distribution of externalities due to processes, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
CO	18.07	16.55	11.48	4.72	106.75	88.48	4.38	250.42
CO_2	32.02	43.69	55.40	26.62	208.16	165.34	22.45	553.68
N_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_x	19.98	24.65	35.99	14.80	61.38	62.81	13.72	233.33
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	28.60	26.28	13.98	6.72	58.56	55.88	5.66	195.68
PM_{10}	8.09	12.39	17.77	8.54	26.88	23.23	7.20	104.12
PM_{25}	5.03	7.71	11.06	5.31	16.72	14.45	4.48	64.76
SO_x	7.37	9.11	13.35	5.49	22.52	23.10	5.09	86.02
VOC	0.21	0.22	0.37	0.12	5.77	4.13	0.11	10.93
TOTAL	119.37	140.60	159.39	72.32	506.75	437.43	63.09	1,498.96

Table 51: *Regional distribution of total externalities, million Euro/year*

Pollutant/ GHG	Aegean	Black Sea	Central Anatolia	Eastern Anatolia	Marmara	Mediterranean	South Eastern Anatolia	TOTAL
CH_4	0.22	0.16	0.27	0.11	0.56	0.23	0.16	1.71
CO	55.34	43.57	56.24	24.19	196.93	124.55	32.69	533.50
CO_2	617.93	399.78	470.68	127.23	1,266.46	706.18	186.51	3,774.77
N_2O	0.66	0.46	0.55	0.18	1.27	0.66	0.28	4.06
NO_x	421.04	243.75	371.76	134.34	703.45	377.81	186.66	2,438.81
NMVOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	266.83	105.76	130.45	31.12	245.56	215.75	48.54	1,044.01
PM_{10}	130.97	63.52	100.26	36.15	170.33	122.28	49.49	672.99
PM_{25}	67.29	54.38	74.74	32.94	145.99	80.29	46.07	501.71
SO_x	148.74	54.55	101.06	24.39	134.59	115.64	42.13	621.09
VOC	2.45	1.90	3.15	1.41	11.12	6.35	1.98	28.35
TOTAL	1,711.48	967.83	1,309.16	412.05	2,876.26	1,749.73	594.50	9,621.00

Figure 42: *Regional distribution of externalities of some major pollutants and CO_2 due to fossil fuel combustion*

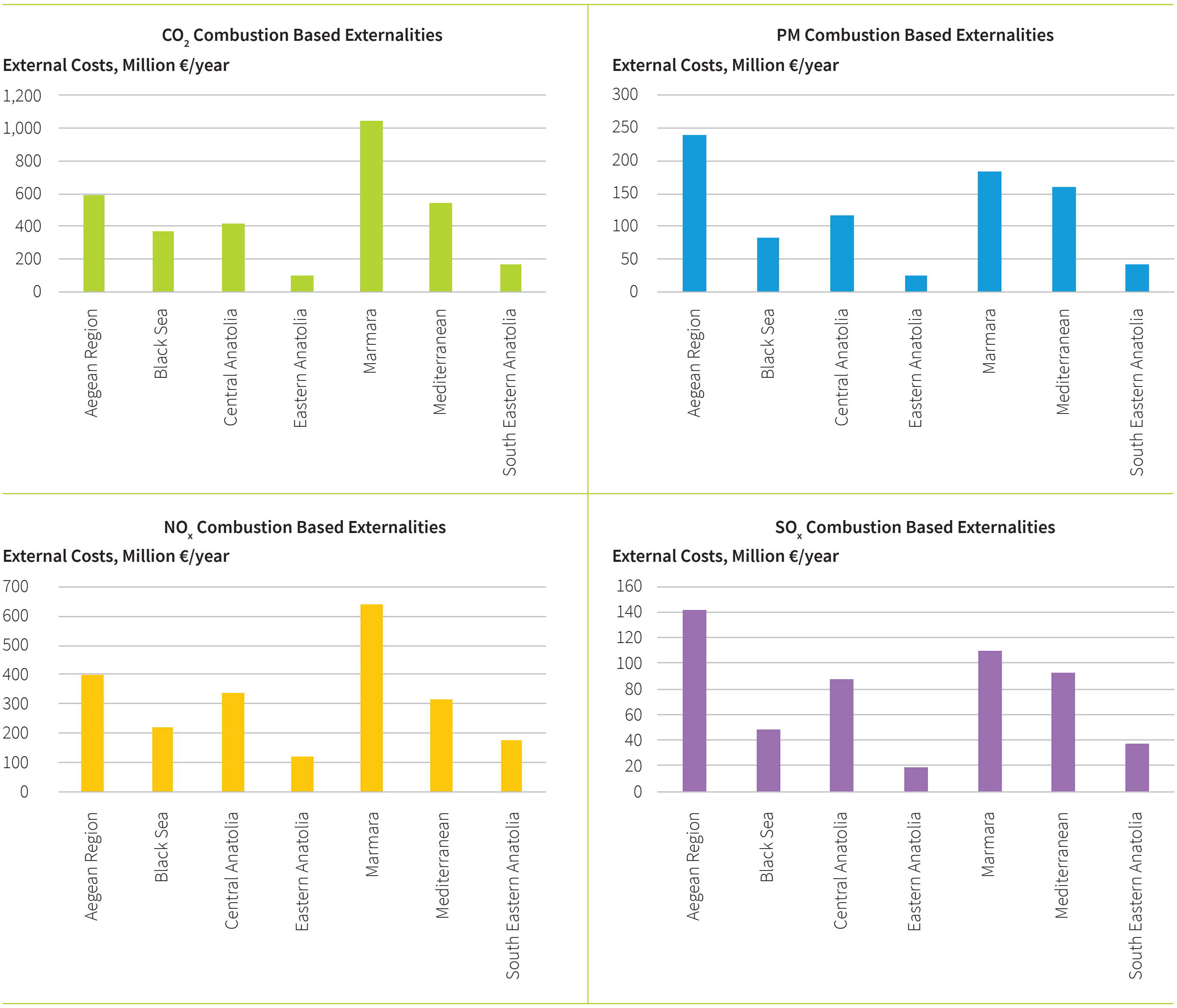
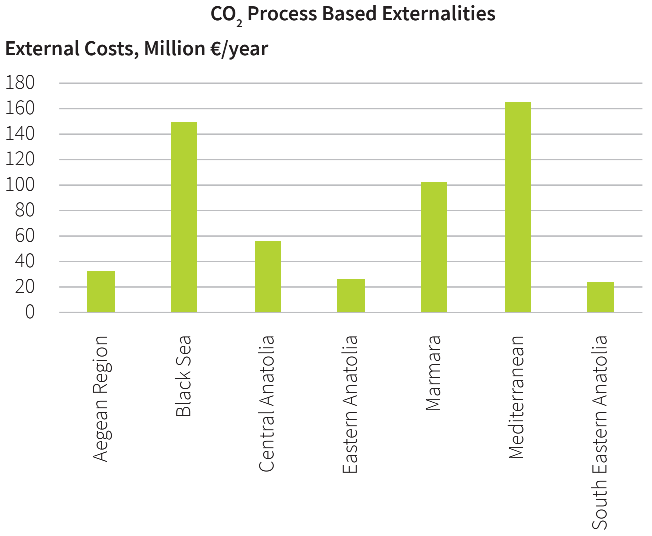
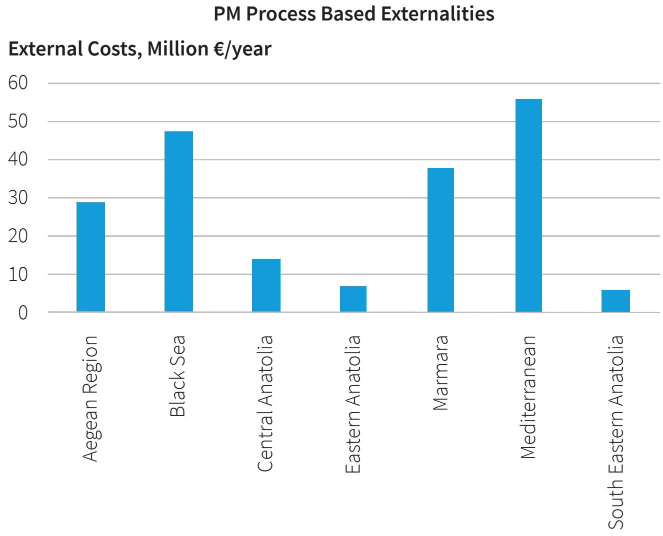
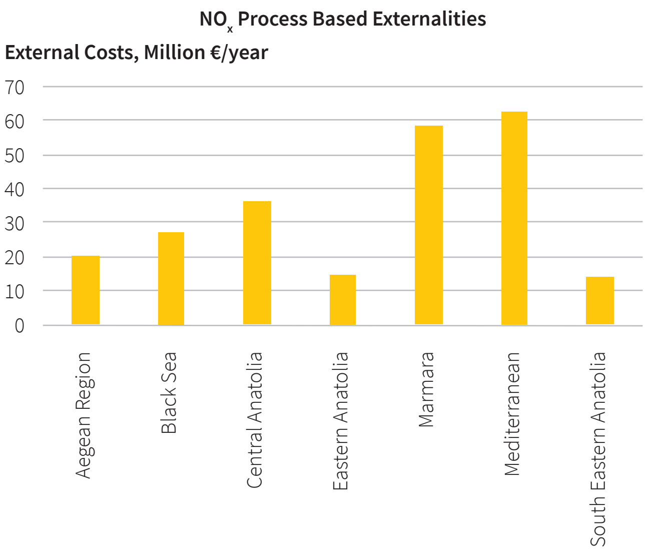


Figure 43: *Regional distribution of externalities of some major pollutants and CO_2 due to processes*







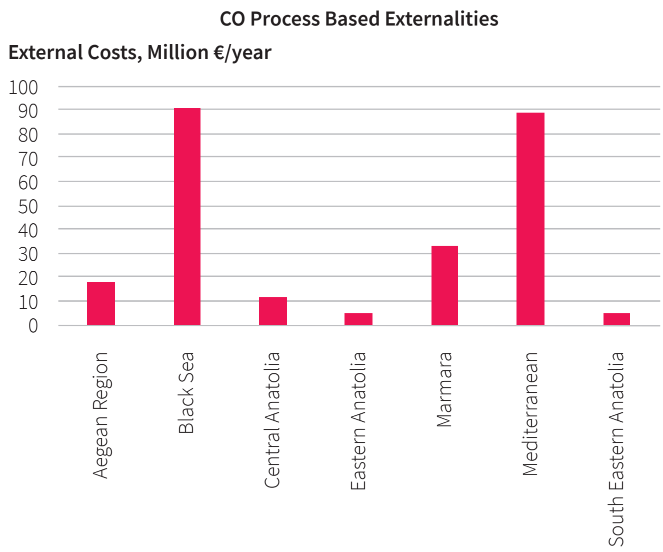
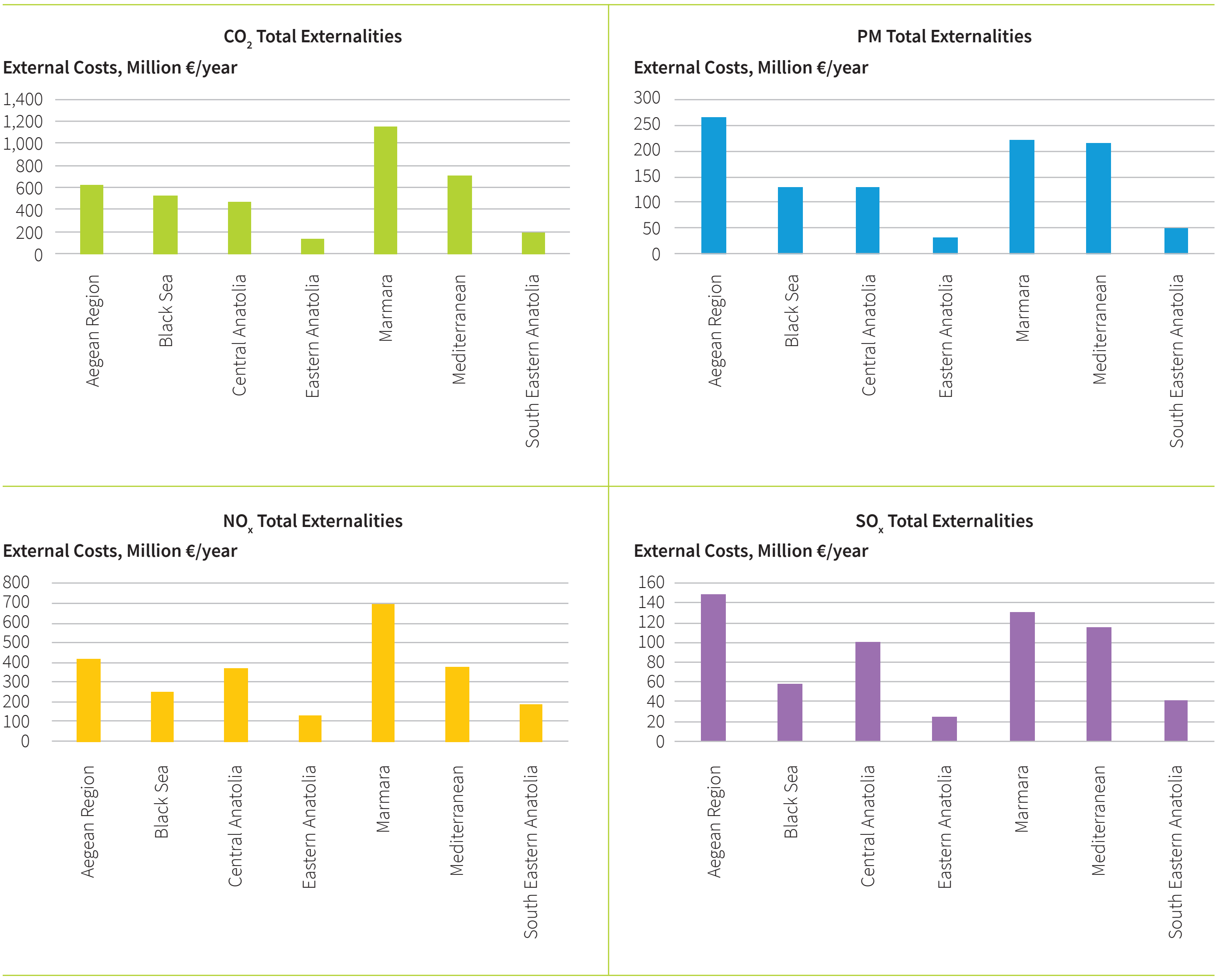


Figure 44: *Regional distribution of total externalities of some major pollutants and CO_2*



The Marmara region constitutes 28% of the total external costs due to emissions from fossil fuel consumption.

Similar to the sectoral distribution, the regional distribution of the externalities due to fossil fuel consumption follow the same trends seen for the emissions, as expected. Marmara region has the highest share of costs for all the pollutants except SO_x and PM, which have high costs for Aegean Region due to high number of lignite fuelled power plants in this region. The Marmara region constitutes 28% of the total external costs due to emissions from fossil fuel consumption. The costs of the CO_2 emissions are the largest amongst other nine pollutants and GHGs, followed by the cost of NO_x emissions.

The total externalities from fossil fuel combustion and processes add up to 9.6 billion €.

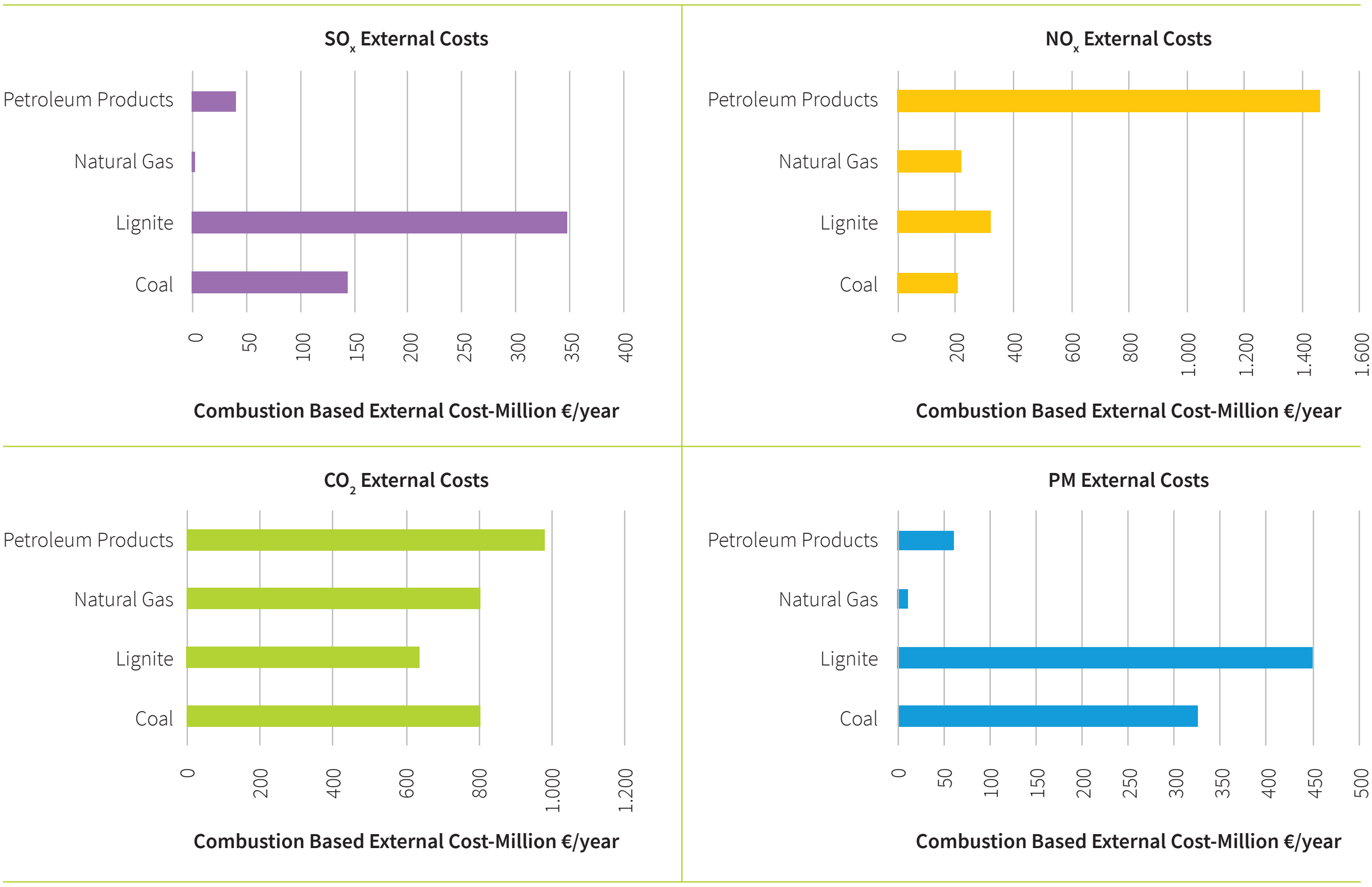
The total externalities from fossil fuel combustion and processes add up to 9.6 billion € for Turkey for 2018. The total externality is about 32% of the national health expenditures of 165.2 billion TL (approximately 30.4 billion €) in 2018, (TÜİK, 2018). The total externality is also about 1.4% of the total GDP of Turkey in 2018 (TÜİK, 2019). The total cost of the fossil fuel combustion based emissions in Turkey is estimated as 8.1 billion €. The process based externalities (1.5 billion €) cover 16% of the total externalities. Almost two thirds of the externalities are due to the emissions from Marmara and Mediterranean Regions. The process based externalities exhibit a trend similar to emissions.

The external costs of some major pollutants and GHGs due to fossil fuel combustion in power, transport, buildings, petroleum refining, cement, iron & steel, ceramics, textile, and food industries are presented in Table 52 and Figure 43. As can be seen below, more than half of the PM and SO_x external costs are from lignite combustion. About two thirds of the NO_x external costs are from petroleum products, which is the primary fuel of transportation sector.

Table 52: *External costs of major pollutants and GHGs based on the combustion of coal, lignite, natural gas, and petroleum million Euro/year*

Pollutant	Hard Coal	Lignite	Natural Gas	Petroleum Products	Total
CH_4	0.73	0.46	0.18	0.32	1.69
CO	82.62	53.53	18.52	128.41	283.08
CO_2	803.03	634.31	803.42	980.33	3,221.09
N_2O	0.90	0.62	0.49	2.04	4.06
NO_x	206.44	323.65	216.67	1,458.71	2,205.48
PM	325.86	450.18	11.82	60.47	848.33
PM_{10}	196.98	243.00	0.00	128.89	568.88
$PM_{2.5}$	196.40	122.11	0.00	118.43	436.94
SO_x	144.53	347.93	1.80	40.81	535.07
VOC	0.00	0.00	0.00	17.43	17.43
TOTAL	1,957.50	2,175.79	1,052.91	2,935.85	8,122.04

Figure 45: *External costs of SO_x, CO_2, NO_x, and PM based on the combustion of hard coal, lignite, natural gas, and petroleum products*



2.3. Comparison with Similar Studies

The external costs of fossil fuel use calculated in this study, 9.6 billion €, is nearly three times the value of subsidies provided to fossil fuels.

This study of the external costs of fossil fuel use in Turkey is unique as a first-time attempt at quantification of the unpriced costs resulting from combustion and processes using fossil fuels specifically for Turkey. Previous studies for Turkey have focused on the magnitude and effect of fossil fuel subsidies, but do not cover unpriced (external) costs of fossil fuels in terms of their impact on human health and the environment (Acar&Yeldan, 2016; Acar, et.al., 2018; Taranto, et.al., 2019). According to the most recent study on energy sector subsidies performed by SHURA (Taranto, et.al., 2019), the total magnitude of non-market flows, including special energy taxes, in 2018 was 8 billion US$, of which 3.8 billion US$ (about 3.3 billion €) flowed to the production and consumption of fossil fuels. By comparison, the external costs of fossil fuel use calculated in this study, 9.6 billion €, is nearly three times the value of subsidies provided to fossil fuels.

This study covers the external costs of emissions from fossil fuels used for combustion and processes in power generation, industry, transport and buildings. The effects taken into account are mainly air pollution and greenhouse effects caused by emissions. The impact of coal mining and fossil fuel consumption for agriculture and impacts on water resources and soil are beyond the scope of this study and would be a worthwhile effort for future studies.

Based on energy balance tables for 2018, made available by the Ministry of Energy and Natural Resources of Turkey, the sectors included in the report (buildings, road transport, iron & steel, cement, ceramics, textiles and food) cover 85% of the fossil fuel consumption other than conversion (power generation and petroleum refineries) and non-energy use. Coverage is around 90% for hard coal, lignite, and petroleum products, over 95% for coke and 76% for natural gas. Fossil fuel consumption coverage for power generation and refineries is close to 100%.

The methodology used in this study is comparable to international studies conducted for similar purposes. Estimation of emissions follows accepted international standards and the valuation of externalities related to the impact of pollutants was adopted for Turkey from international databases designed specifically for such valuation.

The methodology used in this study is comparable to international studies conducted for similar purposes. Estimation of emissions follows accepted international standards (see Methodology Document for details) and the valuation of externalities related to the impact of pollutants was adopted for Turkey from international databases designed specifically for such valuation. Nevertheless, as detailed in the relevant sections of this report and the Methodology Document, there is a degree of uncertainty in the values.

The most recent study published by Greenpeace, entitled Toxic Air: The Price of Fossil Fuels (Greenpeace, 2020), estimates that the average global cost of health and economic impacts of air pollution caused by fossil fuels in 2018 is 2.5 trillion US$, ranging from 1.8 trillion US$ to 3.4 trillion US$. The study focuses on health effects of major pollutants and takes into account secondary effects such as Type 2 diabetes. The estimated external cost of fossil fuels reported in the study for Turkey is an average of 21 billion US$, ranging from 14 billion US$ to 30 billion US$, which is higher than the average 9.6 billion Euro (11.3 billion US$) calculated in this study. The methodology and assumptions for the estimates for Turkey in the Greenpeace study are not discussed explicitly; however, it can be inferred that the difference results partly from the inclusion of secondary and indirect effects in the Greenpeace study, and the fact that the analysis undertaken in this study points to a lower end of a wide range of external costs in Turkey, considering assumptions and the uncertainties in reference values. A study by IRENA, using a similar methodology and assumption set shows a variation in external costs between 1 and 3.5 times when such uncertainties are accounted for (IRENA, 2016).

In all comparisons, including the Greenpeace study, estimates of emissions and the basic assumptions need to be comparable. Assumptions related to abatement measures (controlled emissions) are important. Most industrial and power generation plants use abatement measures that reduce the emission of pollutants; however, the actual extent to which the measures are applied are not always known with certainty and therefore various assumptions need to be made. This study has made maximum use of locally available information on the operation of large industrial and power generation plants on an individual basis and reported controlled emissions with as many cross checks as possible.

One of the most widely accepted databases of emissions for the European area is the Emissions Data for Global Atmospheric Research (EDGAR) of the European Commission Joint Research Centre (European Commission Joint Research Center, 2015). For pollutants, the database provides data for all countries for the period 1970-2015 while for CO_2 data is available through the OECD database for the period 1970-2018. The database covers emissions from fossil fuels by type of pollutant by country and sector, thereby enabling a limited comparison with the results of our study. A detailed methodology document and a paper by the authors of the study are available to test the limitations of the comparison (Crippa et al., 2016; European Commission Joint Research Center, 2015). The table below showing a comparison of the emissions from fossil fuels by sectors for Turkey reveals the wide range of variation depending on the assumptions made for calculating the emissions.

Table 53: *Comparison of Emissions by Types of Pollutant and Sectors for Turkey*

Pollutant	Central Power & Heat Production	Petroleum Refining & Other Energy	Manufacturing & Construction	Road Transport	Residential & Other Sectors	TOTAL
CO (ton)						
EDGAR 2015	70.33	7.06	571.37	336.58	1386.78	2372.11
SHURA 2018	35.17	2.01	697.88	343.44	374.83	1453.34
NO_x (ton)						
EDGAR 2015	316.77	6.42	139.78	281.24	80.54	824.75
SHURA 2018	97.66	3.42	72.28	306.84	43.28	523.48
SO_x (ton)						
EDGAR 2015	928.94	6.80	249.54	24.72	191.46	1401.47
SHURA 2018	62.78	1.84	39.81	8.64	46.84	159.91
PM_{10} (ton)						
EDGAR 2015	16.91	0.11	46.37	14.97	170.62	248.98
SHURA 2018	25.88	0	21.30	18.79	32.12	98.08
$PM_{2.5}$ (ton)						
EDGAR 2015	10.10	0.09	47.25	11.55	125.00	193.98
SHURA 2018	7.13	0	10.77	15.26	31.49	64.65
CO_2 (Mton)						
OECD 2018	145.99	not reported separately	66.19	81.01	66.56	359.75
SHURA 2018	146.05	5.90	44.93	78.50	41.64	317.02

The total emissions for the specified sectors reported by the international databases are 1.6 times higher for CO and NO_x emissions, 8.8 times higher for SO_x emissions, 2.5 times higher for PM_{10} emissions, 3 times higher for $PM_{2.5}$ emissions, and 1.1 times higher for CO_2 emissions. A small part of the difference between the studies result from coverage of sectors while a greater part arises from the difference in assumptions, especially assumptions related to how much of the emissions for each type of pollutant are mitigated by pollution control technologies applied in each sector[3]. Based on communications with the authors of the EDGAR study, below are the reasons for some of the main differences between the SHURA study and the databases compared.

[3] Mitigation is only possible for pollutants other than CO2; therefore, a wider range of variation exists for other pollutants.

Power generation: In terms of coverage, the SHURA study is more realistic than the EDGAR database as the database assumes generation parallel to installed capacity of existing plants while the SHURA study uses actual generation of all major power plants for 2018. As actual generation in many of the fossil fuel plants is below capacity, generation and emissions in the EDGAR database are likely to be overstated. In terms of assumptions regarding mitigation, there are some significant differences between the two studies. The assumptions used by the EDGAR database and the SHURA study are summarized in the table below.

Table 54: *Comparison of Mitigation Assumptions in the EDGAR and SHURA Studies*

Pollutant	EDGAR Assumption Range	SHURA Study Assumption
NO_x	30%-90%	75%
SO_x	50%-90%	95%
PM_{10}	90%-99.95%	98%
$PM_{2.5}$	0%-99.60%	98%

The specific assumptions used for Turkey by the EDGAR database are not available; however, the main approach used is adjusting specific data on fuel characteristics and removal technologies available as of 2005 with recent plant capacity and state of the art technology. The SHURA study uses an approach similar to the EDGAR study in that, energy balance tables are used for total fuel consumption of power plants and cross checked with plant-level generation technology and actual generation data. Data for plant-level emission removal technologies and actual usage are unavailable; however, assumptions were made in the SHURA study based on experiences and field evidence from existing plants. Turkey has a dual structure; while some of the oldest plants have no NOx removal units, middle aged plants tend to have either emission reduction technologies at combustion units or removal technologies at the chimneys or hoods and many use a combination of both. Newer plants, especially natural gas plants use state of the art removal technologies such as SCR/SNCR. Therefore, average figures based on field experience and available international and local studies were used. More detail on the assumptions can be found in the Methodology Document attached to this study. Nevertheless, a substantial uncertainty continues to exist.

Industry and other sectors: In terms of coverage, while the SHURA study includes most fossil fuel use in the most energy-intensive sectors, the EDGAR database may generally have more coverage including sectors such as agriculture and construction which are not covered by the SHURA study. Uncertainty increases as we move from more centralized sectors such as power generation and large industry to buildings and smaller, more diffused heat generation units. While energy intensive industries such as iron & steel, ceramics and cement are closely monitored and are required to use abatement measures, no such measures exist for buildings and none were assumed in the SHURA study. Nevertheless, EDGAR database assumptions for pollutants such as CO may be overstated in the residential sector where natural gas has rapidly replaced coal-based heaters in recent years.

The external costs of fossil fuel use based on the emissions estimates in this study may be deemed conservative with substantial upward potential.

An overall assessment puts in a question mark especially for SO_x and NO_x emissions in the power generation and industrial sectors and PM emissions in the buildings sector. As they stand, the emissions reported in the EDGAR database may represent an upper bound for emissions from fossil fuel use in power generation, industry, road transport and buildings in Turkey, given that they are mostly based on older data prior to the recent developments in fuel use and abatement technologies. On the other hand, the external costs of fossil fuel use calculated based on the emissions in this study may be deemed conservative with substantial upward potential. In other words, if emissions were assumed at the level reported in the EDGAR database, the external costs would have been about twice the level calculated in this study, approaching to 20 billion Euros.

3. Conclusions

This report presents the external costs of major pollutants and GHGs originated due to fossil fuel consumption from power, transportation, buildings, petroleum refining, cement, iron & steel, ceramics, textile, and food industries, and also process based pollutant and GHG emissions from cement, iron & steel, and ceramics industries. The estimation results show that the transport, building, and lignite fuelled power plants are the main sources of combustion based emissions such as SO_x, NO_x, CO, PM, and CO_2. The transport sector is concluded to be responsible for about 65% of the combustion based NO_x and 25% of the CO_2 emissions. The major emitters of combustion based SO_x and PM emissions are lignite fuelled power plants and the building sector.

Due to the location of the lignite fuelled power plants, the PM emissions from the Aegean Region is found to be the highest among all regions. Most of pollutant and GHG emissions from the Marmara and Mediterranean Regions are higher than other regions since most of the power plants and industry are in these regions. The CO_2 emissions are distributed almost evenly among the major fossil fuels, namely hard coal, lignite, natural gas, and petroleum products. Combustion of petroleum products result in the majority of the CO and NO_x emissions, whereas more than half of the PM emissions are from the combustion of lignite.

The sectoral and regional distributions of the fossil fuel combustion-based and process-based external costs exhibit similar trends to those for the estimated emissions. The NO_x and CO_2 externalities from the transport sector are found to be the highest among all sectors, due to the high share of diesel vehicles in Turkey. The buildings sector has the highest SO_x externalities due to high use of lignite in buildings, followed by the lignite fuelled power plants. Similar to the sectoral distributions, the regional distributions of the externalities due to fossil fuel consumption follow the same trends as for the emissions, as expected. The Marmara region has the highest share of costs for all the pollutants, except SO_x and PM, whose costs are higher in the Aegean Region. In total, the costs of fossil fuel consumption emissions for the Marmara Region is almost one-third of the total cost nationally. The CO_2 external costs are evenly distributed among petroleum products, hard coal, lignite, and natural gas; and they account for about 40% of the total external costs estimated. The lignite and hard coal combustion accounts for more than half of the SO_x and PM external costs. The combustion of petroleum products account for about two thirds of the NOx external costs. The estimated external costs are based on the emissions which are estimated using average emission factors. Thus, a major uncertainty of these external cost estimates is due to using average emission figures. The external costs are expected to lie in a wide range due to uncertainties. For example, the lignite fuelled power plants' CO_2 external costs are expected to differ by about 26% between minimum and maximum values depending on the emission figure used.

The total external costs for 2018 is about 32% of the national health expenditures in the same year and about 1.4% of the total GDP of Turkey.

The total cost of fossil fuel combustion-based emissions in Turkey is estimated as 8.1 billion €. The process-based externalities (1.5 billion €) cover 13% of the total externalities. The total externalities from fossil fuel combustion and processes are estimated to be 9.6 billion € for Turkey in 2018 based on the emissions from power, transportation, buildings, petroleum refining, cement, iron & steel, ceramics, textile, and food industries. The total external costs for 2018 is about 32% of the national health expenditures in the same year and about 1.4% of the total GDP of Turkey.

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Istanbul Policy Center (IPC) is a global policy research institution that specializes in key social and political issues ranging from democratization to climate change, transatlantic relations to conflict resolution and mediation. IPC organizes and conducts its research under three main clusters: The Istanbul Policy Center–Sabancı University–Stiftung Mercator Initiative, Democratization and Institutional Reform, and Conflict Resolution and Mediation. Since 2001, IPC has provided decision makers, opinion leaders, and other major stakeholders with objective analyses and innovative policy recommendations.

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Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests, but rather to its commitment to confronting climate change.

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