DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INVENTORY OF EMISSIONS FROM RESIDENTIAL HEATING IN ISTANBUL

by
Tuba SABİT

February, 2012
İZMİR

INVENTORY OF EMISSIONS FROM RESIDENTIAL HEATING IN ISTANBUL

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by

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"INVENTORY OF EMISSIONS FROM RESIDENTIAL HEATING IN ISTANBUL"** completed by **TUBA SABİT** under supervision of **Assoc.Prof.Dr. TOLGA ELBİR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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INVENTORY OF EMISSION FROM RESIDENTIAL HEATING IN ISTANBUL

ABSTRACT

In this study, a local emission inventory for residental heating sources was prepared in the city of Istanbul. The emissions of main pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM10 and PM2.5), carbon monoxide (CO), nonmethane volatile organic compounds (NMVOCs), carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) were calculated by using emission factors for the winter (November-March) of 2009 - 2010. Spatial distribution maps of the emissions for all pollutants were plotted using a geographical information system (GIS) for a study area of 170 km by 85. Two different fossil fuel types; natural gas and lignite were used in emission calculations. In winter total seasonal consumptions for natural gas and lignite were 2,261,033,334 m3 and 1,228,653 tons, respectively. Total seasonal emissions for SO2, NOx, PM10, PM2.5, CO, VOC, CO2, N2O and CH4 were estimated as 21,429; 8,460; 11,046; 10,883; 127,671; 13,967; 7,130,209; 8,564 and 49 tons, respectively.

Keywords : Istanbul, residential heating, emission, emission inventory, geographical information system (GIS)

İSTANBUL'DA EVSEL ISINMADAN KAYNAKLANAN EMİSYON ENVANTERİ

ÖZ

Bu çalışmada, İstanbul'da evsel ısınmadan kaynaklanan hava kirletici emisyonlar için bir emisyon envanteri hazırlanmıştır. 2009-2010 yılı kış mevsimi (Kasım - Mart) için, kükürt dioksit (SO2), azot oksitler (NOx), havada asılı partikül maddeler (PM10 ve PM2.5), karbon monoksit (CO) ve metan harici uçucu organik bileşikler (NMVOCs), karbon dioksit (CO2), nitroz oksit (N2O) and metan (CH4) gibi ana kirleticilerin emisyonları emisyon faktörleri kullanılarak hesaplanmıştır. Tüm kirleticiler için emisyonların mekansal dağılım haritaları 85 km x 170 km'lik bir çalışma alanı için bir coğrafi bilgi sistemi yardımıyla çizilmiştir. Emisyon hesaplarında iki yakıt türü; doğal gaz ve linyit dikkate alınmıştır. Kış aylarına ait doğal gaz ve linyitin mevsimlik toplam tüketim miktarları sırasıyla, 2,261,033,334 m3 ve 1,228,653 ton olarak bulunmuştur. SO2, NOx, PM10, PM2.5, CO, VOC, CO2, N2O and CH4 için toplam kış mevsimi emisyonları sırasıyla, 21,429; 8,460; 11,046; 10,883; 127,671; 13,967; 7,130,209; 8,564 and 49 ton olarak hesaplanmıştır.

Anahtar Sözcükler: İstanbul, evsel ısınma, emisyon, emisyon envanteri, coğrafi bilgi sistemleri

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Atmosphere is the most important medium for human, animals and plants. It is polluted rapidly by growing of population, urbanization, heavy traffic and industrial facilities. These sources constitute PM_{10}, CO, NO_x, etc. emissions in air and cause air pollution. These emissions may be called as the physical transfer of material from one compartment of the world across a boundary into another compartment. These compartments frequently are human and environment (Winiwarter, Haberl & Simpson, 1999; Winiwarter & Schimak, 2005).

It is obvious that the composition of the atmosphere is affected by anthropogenic sources. Air pollutants are mainly consist of gases like SO_2, NO_x, O_3, atmospheric particles, dusts smaller than 10 microns in particle size, and hydrocarbons from different emission sources. Some of these effects can be regional but the majority of them are on global scale like the global warming due to the increase of greenhouse gases emissions, including CO_2, CH_4, N_2O and the halocarbons. These greenhouse gases (GHGs) are available with other trace gases such as SO_2, NO_x or VOC_s and aerosols in the atmosphere.

Monitoring and modeling of the air pollutants and preparation of emission inventories are commonly used for air quality management studies. Emission inventories are necessary for understanding the impact of human activity on air quality in the large urban areas. Emission inventory is important for developing emission control strategies, determining the applicability of permitting and control programs, ascertaining the effects of sources and appropriate mitigation strategies, and a number of other related applications by an array of users, including central and local agencies, technical consultants to several projects and industrial managers aiming at testing the compliance of their facilities (Elbir & Müezzinoğlu, 2004).

These inventories are fundamental and necessary tools for assessing the human and environmental risks that is from anthropogenic pollutant sources (Kim et al., 2009).

For estimation of the emissions from different sources like; point (industry), area (residential heating) and line (traffic), it is necessary to collect and store data. It is important to collect data from reliable sources. Depending on the substance investigated and source sector, different approaches which are the bottom-up and the top-down approach support determination of emissions. For the major part of emitters the emissions need to be calculated. For the inventory, emissions are calculated by multiplying the emission factor and activity (energy consumption, fuel types, traffic vehicle properties, production figure etc.). After preparing the emission inventory, it is easy to update inventory. Emission inventory is used for making projection future emissions, generating scenario for reducing emissions and preparation of data for dispersion models.

Air pollution in Turkey is one of the most important environmental problems of modern life due to rapid population growth, dense immigration, wrong place selection for industry, usage of poor quality fuel, usage of old combustion technologies in industry, lack of control technologies usage for stack gases, lack of information on traffic sources, etc. (Elbir et al., 2009). Air quality management is a difficult task in many Turkish cities and industrial facilities because of the scarcity of high quality local energy sources. Fossil fuels, mostly the lignite with high ash and sulfur contents as well as correspondingly low heating values are used as primary sources of energy. Petroleum and natural gas are also available for combustion in industries or larger units of combustion for heating although both are largely imported. Increasingly during the recent years, imported natural gas is replacing the traditional liquid and solid fuels in heating and industrial sectors especially around large cities where air quality has largely deteriorated. Altogether fossil fuels are the primary sources of energy in Turkish cities (Müezzinoğlu, Elbir & Bayram, 1998).

Istanbul is one of the world's biggest cities with approximately 13 million inhabitants in Turkey. Air pollution in Istanbul increases in particularly winter and it is the most important problems for environment and human. The major reasons of air pollution caused by heating during the winter are usage of poor quality lignite and old combustion technologies. Fuel consumption for residential heating is dependent to dimension of house, heating methods, isolation, size of family and economic reasons. The fuel types and consumptions in a region change by incomes of households or where they live. Meteorological parameters such as temperature, wind speed and direction, humidity affect to the rates of fuel consumptions in the city (Elbir et al., 2009).

The main objective of this study is to prepare an emission inventory for residential heating sources in the winter (November - March) of 2009-2010 in Istanbul. In this study, a local emission inventory was prepared for the airborne pollutants (SO_2, CO, PM, NO_x and VOC) as well as greenhouse gases (CO_2, CH_4 and N_2O) at the metropolitan area of 170 km by 85 km. The spatial distribution maps of calculated emissions were also plotted by a geographical information system (GIS).

CHAPTER TWO
LITERATURE REVIEW

Emission is the term used to describe the gases and particles put into the air by a variety of sources, including factories, power plants, motor vehicles, airplanes and natural sources such as trees and vegetation (EPA, 2007). Emission can be also called as the physical transfer of material from one compartment of the world across a boundary into another compartment (Winiwarter & Schimak, 2004). Emissions can pose health risks and contribute to air pollution, global warming and the destruction of the ozone layer (EPA, 2007).

The emission data are required for identification of main pollutant sources of, determination of objectives for pollution control, establishment of a basis for evaluation of optimal emission reduction strategies and creation of input data for models of transport and chemical transformation of air pollutants (Obermeir, Seier & Friedrich, 1992).

There are three different methods to estimating emissions; the source emission measurement method, mass balance method and usage of emission factors. In source measurement method, the process conditions and emission concentrations are reported as a result of direct measurements or monitoring service. In mass balance method, the emissions from activities are estimated; but to achieve this method, the inputs and outputs must be known for each point of the flow diagram of the process. In emission factors method, some coefficients which were created in different previous studies as a result of source test or mass balance methods done are used to estimate emissions. In previous studies, emission factors method were mostly used for estimating the emissions (Elbir, Müezzinoğlu, Bayram, Seyfioğlu & Demircioğlu, 2001; Odabas, 2009; Altug, Özden, Döğeroğlu & Kara, 2007; Kannari, 2007; Elbir & Muezzinoglu, 2004; Symeonidis, Ziomas & Proyou, 2004; Zeydan, 2008; El-Fadel & Bou-Zeid, 1999; Brulfert, Chollet, Jouve & Villard, 2005; Zhang, Wei, Tian & Yang, 2008; Dalvi et al., 2006; D'Angiola, Dawidowski, Gomez & Osses, 2010). Mass balance method was used, occasionally (Lane et al., 2007; Morino, 2010).

Sources of pollutants are mainly divided into three groups like point, line and area sources covering industrial, vehicular and domestic sources. The amounts of pollutant, emitted from these sources are estimated by using fuel consumption data and suitable emission factors. Some studies were estimated the emissions covering all three sources (Elbir et al., 2001; Altug et al., 2006; Elbir & Muezzinoglu, 2004; Zeydan, 2008). Some past studies estimated the only traffic emissions (D'Angiola et al., 2010; Symeonidis et al., 2004; El-Fadel & Bou-Zeid, 1999) while some of them studied about residential heating (Odabas, 2009; Cetin, 2006). In literature generally, European CORINAIR database (CITEPA,1992), US Environmental Protection Agency emission factors catalogue (USEPA, 1998) and Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006) are widely used for selection of emission factors (Elbir et al., 2001; Odabas, 2009; Altug et al., 2006; Kannari, 2007; Elbir & Muezzinoglu, 2004; Symeonidis et al., 2004; Zeydan, 2008; El-Fadel et al., 1999; Lin et al., 2005; Müezzinoğlu et al., 2000). Alternatively, there are different emission factor database used for preparation of inventories in literature (Dalvi et al., 2005; Brulfert et al., 2005; D'Angiola et al., 2010).

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per tons of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average) (EPA, 2011). The general equation for emissions estimation is given in Equation 1.

$$E = A \times EF \times (1 - ER/100) \qquad \textbf{(Equation 1)}$$

where:

E = emissions; kg/season

A = activity rate; m^3/season, ton/season

EF = emission factor; kg/ton, kg/m^3 and
ER = overall emission reduction efficiency; %

An emission inventory is a set of information on sources and emissions of air pollutants in a specified area. Commonly data are categorized in some detail by types of pollutant, source types and locations of sources. Emission estimations are prepared for a specific time periods. Air pollution emission inventory is a data collection and processing system which consist of information on anthropogenic or natural air pollution sources and their emissions. Generally, previous emission inventories were prepared for antropogenic sources, while there were some emission inventories were available for natural sources (Kannari, 2007; Brulfert et al., 2005).

There are mainly four steps which can be followed to prepare an emission inventory. The first step is the planing. In this step; the pollutants, emission sources, source categories, emission estimation methods, data management, reporting strategies and geographical boundaries of the inventory should be identified. The second step of preparation of an emission inventory is data collection. Questionnaries, meeting with the relevant institutions (e.g., industry and governmental institutions) and online measurements can be the ways of data collection. The third step is data analysis. In this step, the collected data should be arranged and evaluated to use in emission estimations. The fourth step of generating an emission inventory is data reporting. The results of emission inventory should be expressed clearly with the help of tables, graphics and maps. In this step, a geographical information system (GIS) is used as a tool that permits people to view and analyze spatial information at speeds. Most present studies used for urban air quality management are based on simple GIS applications. A GIS can not provide a map that could not be made by analogous means but preparation of maps using GIS is easier, faster, more flexible and cost effective and at the same time it produces high quality maps. In previous studies, GIS was commonly used for gridded maps of emissions (Zhang, et al., 2008; Symeonidis et al., 2004; Dalvi et al., 2005; Puliafito, Guevara & Puliafito, 2002).

However, none of the studies mentioned above provides comprehensive information on the emissions in Istanbul. The majority of the above mentioned studies is that they were compiled for one or more sources and pollutants. They presented emissions on national level, some of them gridded or temporally varied. In this study, residential heating emissions of the major pollutants including greenhouse gases were estimated in the city of Istanbul. CORINAIR and IPCC emission factors were used for estimating the emissions. The spatial distributions of emissions were plotted by a GIS.

CHAPTER THREE
STUDY AREA

3.1 Location and Topography

Istanbul is located in the Marmara region of Turkey, in the coordinates of 28^{o}10’ and 29^{o}40’ East longitudes and 40^{o}50’ and 41^{o}30’ North latitudes (Figure 3.1). Istanbul with a surface area of 5,313 km^{2} (TUIK, 2008) has two neighboring provinces; Kocaeli in the east and Tekirdag in the west. Marmara Sea at south and Black Sea at north surround the city besides these provinces. The Bosphorus, which connects the Black Sea with Marmara Sea, divides the city into two parts and also separates the European and Asian Continents. Two parts of Istanbul are connected with each other by two bridges (Fatih Sultan Mehmet and Bogazici).

The hilly structure is geographical feature of Istanbul created its quite unique urban landscape which greatly influenced and determined the existing urbanization and landuse patterns, transport systems, and eventually its urban structure, which is quite different and unique from other mega cities developed from huge flat plains or at the mouth of rivers or the straits.

The digital elevation map (Figure 3.2) indicates that in the eastern part, there are quartzite hills (Aydos - 537 m, Kayisdagi - 438 m, Alemdag - 442 m, Buyuk Camlica - 262 m and Yusa - 202 m) and higher areas, starting from the east of Gebze-Omerli Damn route and continuous rise (350 m) take place in the east of Istanbul Metropolitan area. In the western part, there is again a peneplain with wide based river valleys, apart from a couple of heights rising up to 200 m in some part in Bosphorus – Buyukcekmece – Karacakoy route.

The other prominent physical feature of Istanbul is its surface waters that run through its hills, ranging from the Bosporus Strait and the Golden Horn to various smaller rivers. The city’s uneven ground and hilly land created various lakes, which are the source of its rivers.

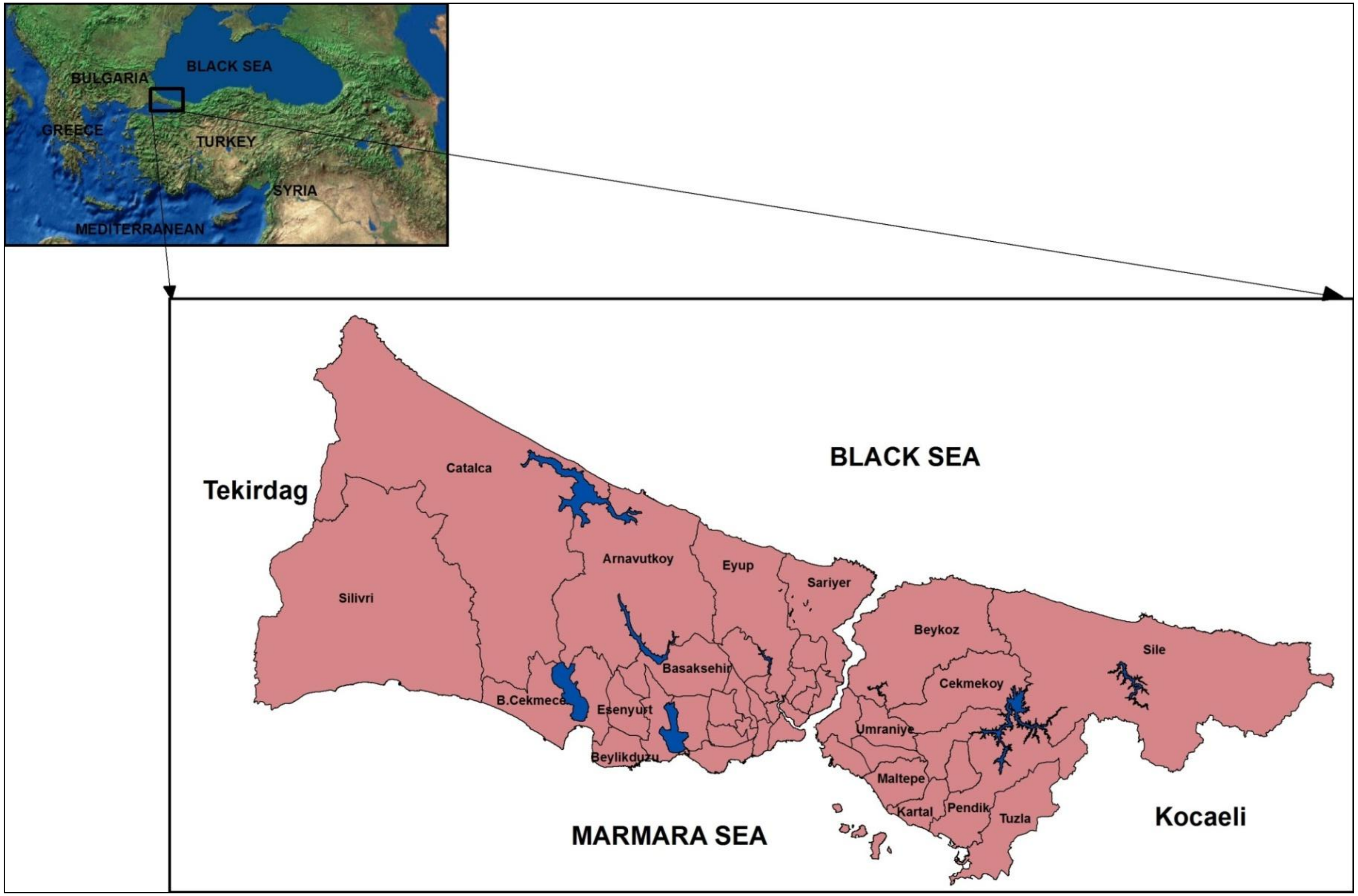

Figure 3.1 Location of the city

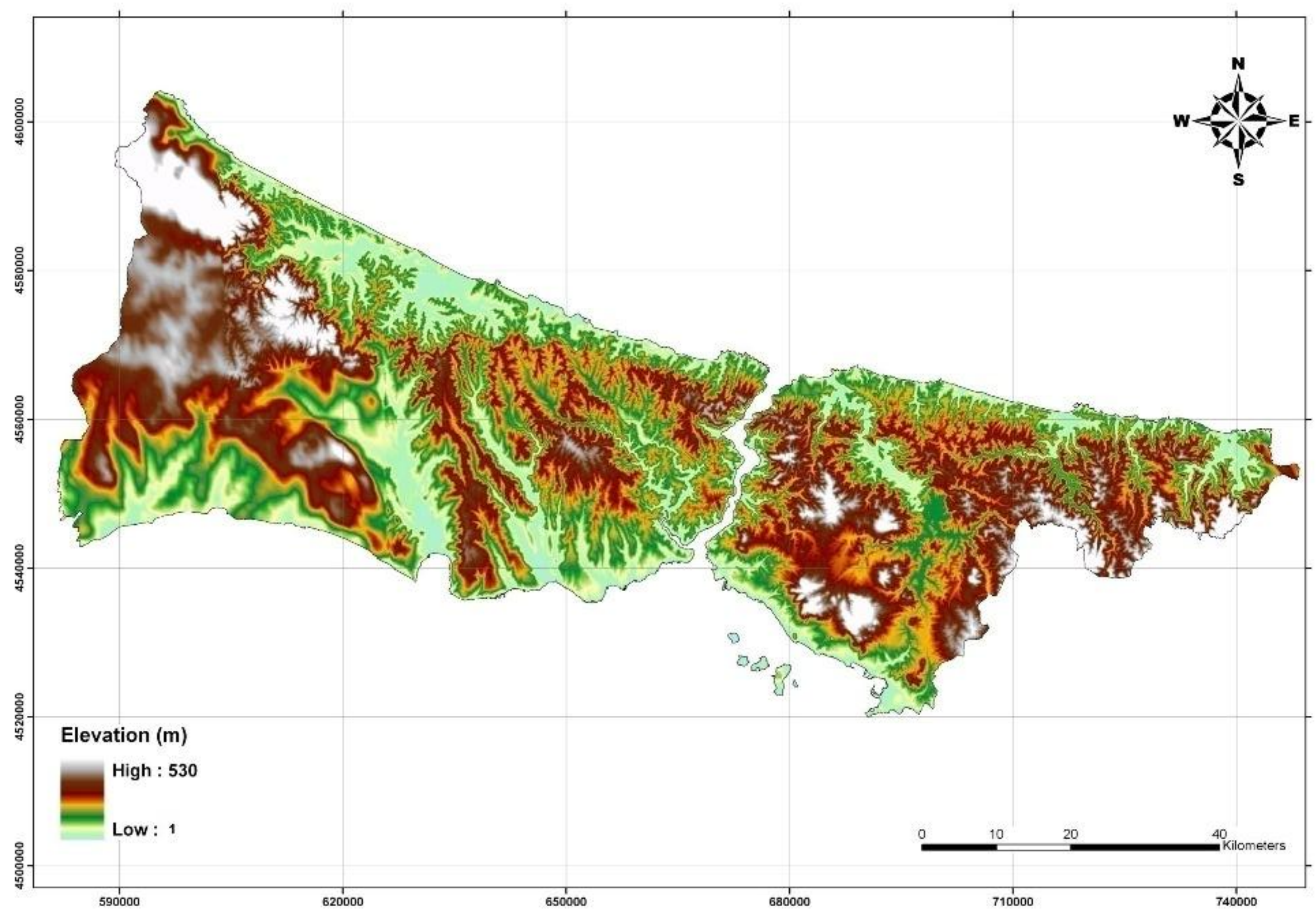

Figure 3.2 Topographic map of the city

3.2 Population and Demography

Istanbul had a population of 1,078,000 in 1945 (TUIK, 2007). After the development of industrialization, the city's population started to increase with a yearly average rate of 4% to 5% and reached to 7,309,000 in 1990 and 9,199,000 in 1997 (TUIK, 2007). According to the population census 2010, Istanbul had a population of over 13 million people. Figure 3.3 shows the population growth of the city since 1960.

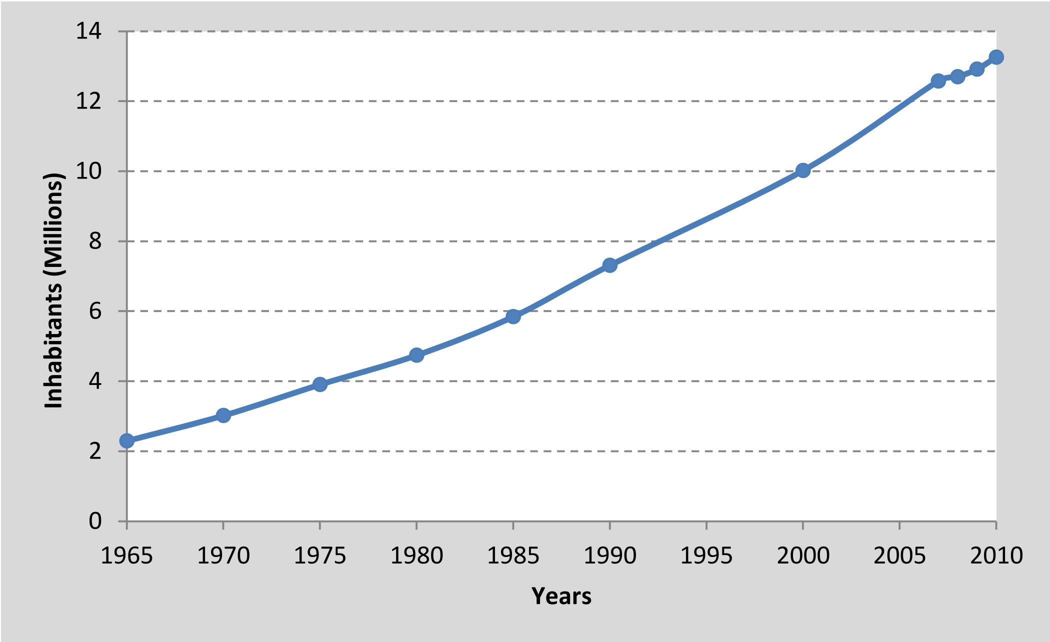

Figure 3.3 Population growths in Istanbul

According to official census data based on "Address Based Population Registration System", which was conducted by Turkish State Institute of Statistics (TUIK), shows that the internal migration to Istanbul still continues at a great speed and the population reached to 13,255,685 (TUIK, 2010). The population of 8,571,374 currently live in European side and the population of 4,684,311 live in Asian side of Istanbul (TUIK, 2010). Total female population of the city is 6,600,591 and total male population is 6,655,094 (TUIK, 2010). Table 3.1 shows the population in the districts (n=39) of the city in 2009. Figure 3.4 shows also the spatial distribution of population density in the city in the year 2009.

Table 3.1 Population in the districts of the city in 2009

European						Asian		
No	**County**	**Population**	**No**	**County**	**Population**	**No**	**County**	**Population**
1	Bakirkoy	220,387	**15**	Bayrampasa	269,425	**26**	Adalar	14,341
2	Besiktas	186,725	**16**	Avcilar	348,635	**27**	Beykoz	244,137
3	Beyoglu	247,965	**17**	Bagcilar	724,268	**28**	Cekmekoy	154,603
4	Catalca	63,277	**18**	Bahcelievler	576,799	**29**	Umraniye	574,914
5	Eyup	331,548	**19**	Gungoren	311,672	**30**	Uskudar	524,805
6	Fatih	444,473	**20**	Esenler	459,980	**31**	Kadikoy	529,191
7	Gaziosmanpasa	461,230	**21**	Arnavutkoy	177,352	**32**	Sultanbeyli	286,622
8	Sariyer	278,527	**22**	Basaksehir	226,387	**33**	Atasehir	361,615
9	Silivri	134,660	**23**	Beylikduzu	195,027	**34**	Maltepe	427,041
10	Sisli	321,685	**24**	Esenyurt	403,895	**35**	Kartal	426,680
11	Zeytinburnu	292,460	**25**	Sultangazi	452,563	**36**	Pendik	562,122
12	Buyukcekmece	175,738				**37**	Tuzla	181,648
13	Kagithane	413,797				**38**	Sancaktepe	241,233
14	Kucukcekmece	674,795				**39**	Sile	29,357
				TOTAL	**7,044,940**		**TOTAL**	**4,131,629**

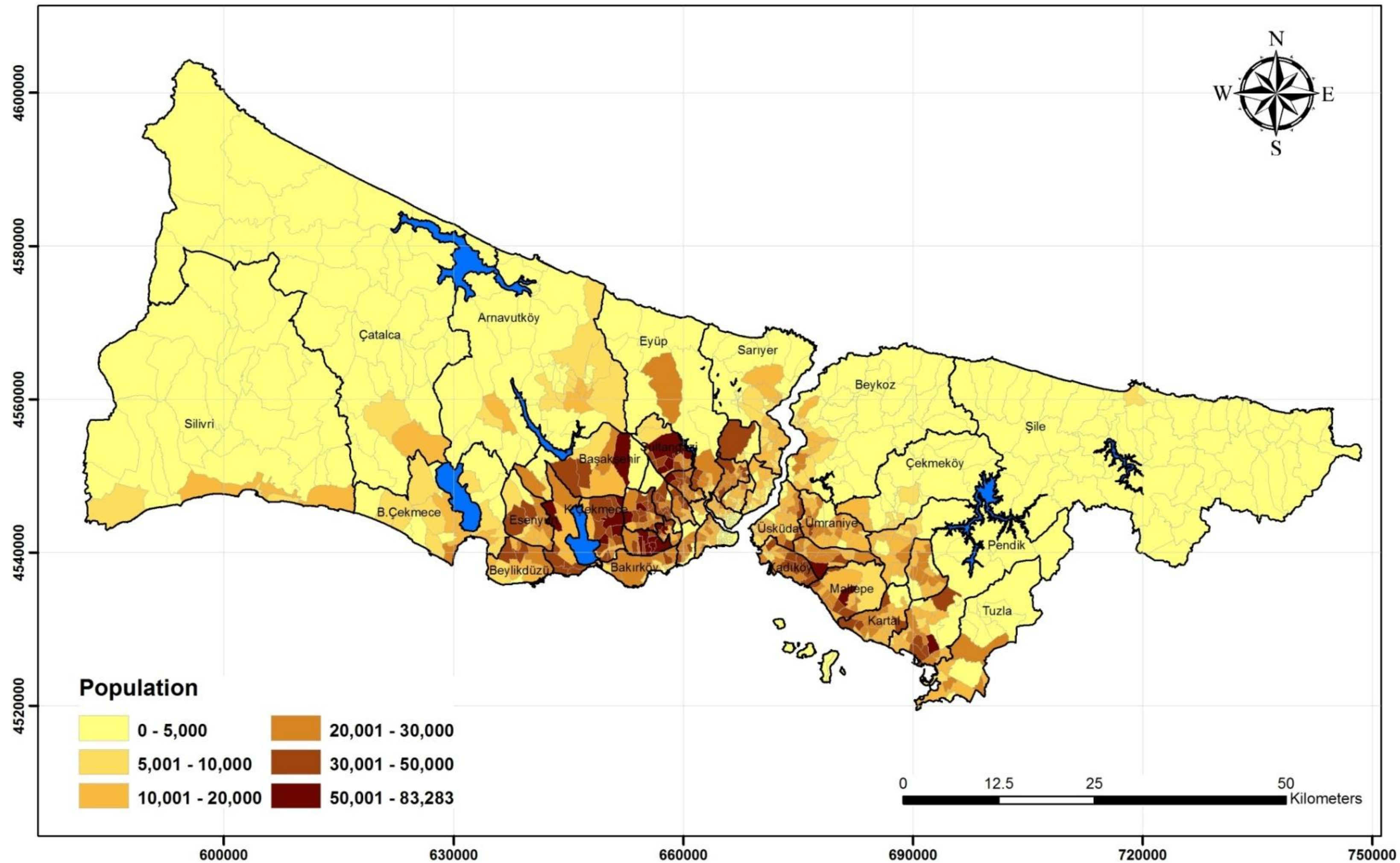

Figure 3.4 Spatial distribution of population density in the districts of the city in 2009

3.3 Economy

Istanbul has always been the center of the country's economic life because of its location as an international junction of land and sea trade routes. Today, the city generates 55% of Turkey's trade and 45% of the country's wholesale trade, and generates 21.2% of Turkey's gross national product (ITO, 2009). Istanbul contributes 40% of all taxes collected in Turkey and produces 27.5% of Turkey's national product (ITO, 2009). In 2005 the city of Istanbul had a Gross Domestic Product (GDP) of $133 billion (ITO, 2009). In 2005 companies based in Istanbul made exports worth $41.4 billion and imports worth $69.9 billion; which corresponded to 56.6% and 60.2% of Turkey's exports and imports, respectively, in that year (ITO, 2009).

Istanbul is also Turkey's largest industrial centers. It employs approximately 20% of Turkey's industrial labor and contributes 38% of Turkey's industrial workspace (ITO, 2009). Istanbul and its surrounding provinces produce cotton, fruit, olive oil, silk, and tobacco. Food processing, textile production, oil products, rubber, metal-ware, leather, chemicals, pharmaceuticals, electronics, glass, machinery, automotive, transport vehicles, paper and paper products, and alcoholic drinks are among the city's major industrial products.

Istanbul is one of the most important tourism center of Turkey. There are thousands of hotels and other tourist oriented industries in the city, catering to both vacationers and visiting professionals. In 2006 a total of 23,148,669 tourists visited Turkey, most of whom entered the country through the airports and seaports of Istanbul (ITO, 2009). Istanbul is also one of the world's major conference destinations and is an increasingly popular choice for the world's leading international associations.

3.4 Climate and Meteorology

Istanbul has a typical Mediterranean climate with hot summer and mild-rainy winter. In summer, the weather is hot and humid, the temperature between June and September averaging as 24 °C. Summers are relatively dry, but rain occurs all year round. The annual average rainfall is 718 mm for the past 50 years while highest annual rainfall was 943 mm in 1980. During winter the weather is cold, wet and occasionally snowy. Snowfalls tend to be heavy at times, but temperatures rarely drop below the freezing point. The maximum monthly average temperature in the city is 38.4 °C in June, while the minimum monthly temperature is -1.9 °C in February. Istanbul also tends to be a windy city.

The most important atmospheric parameters affecting the air pollution are pressure, wind speed and direction, humidity, temperature, stability, and mixing height. Most of these parameters are interrelated. Consequently, it is impossible to determine their contributions to air pollution separately. In a region, air quality during the episodes is also affected by geographical conditions.

Wind is one of the most important meteorological parameters affecting the air quality. Wind speed affects the dilution level while wind direction determines the areas that the pollutants will be transported. With the help of the wind data, it is possible to have better air quality by appropriately locating the pollutant sources such as industries before being established.

Wind direction and speed depend on the geographical features in a region. Annual wind roses were plotted for 24 stations in Istanbul and its surroundings using hourly wind data from each direction in 2007. By the help of these wind roses, the dominant wind directions in each station were determined. Figure 3.5 also shows these annual wind roses over the map. The annual mean wind speed is 3.5 m s^{-1} while the predominant wind directions are: NNE, 34.3%; NE, 24.0%; SSW, 11.1% and N, 10.8% for the year 2007 (Elbir et al., 2009).

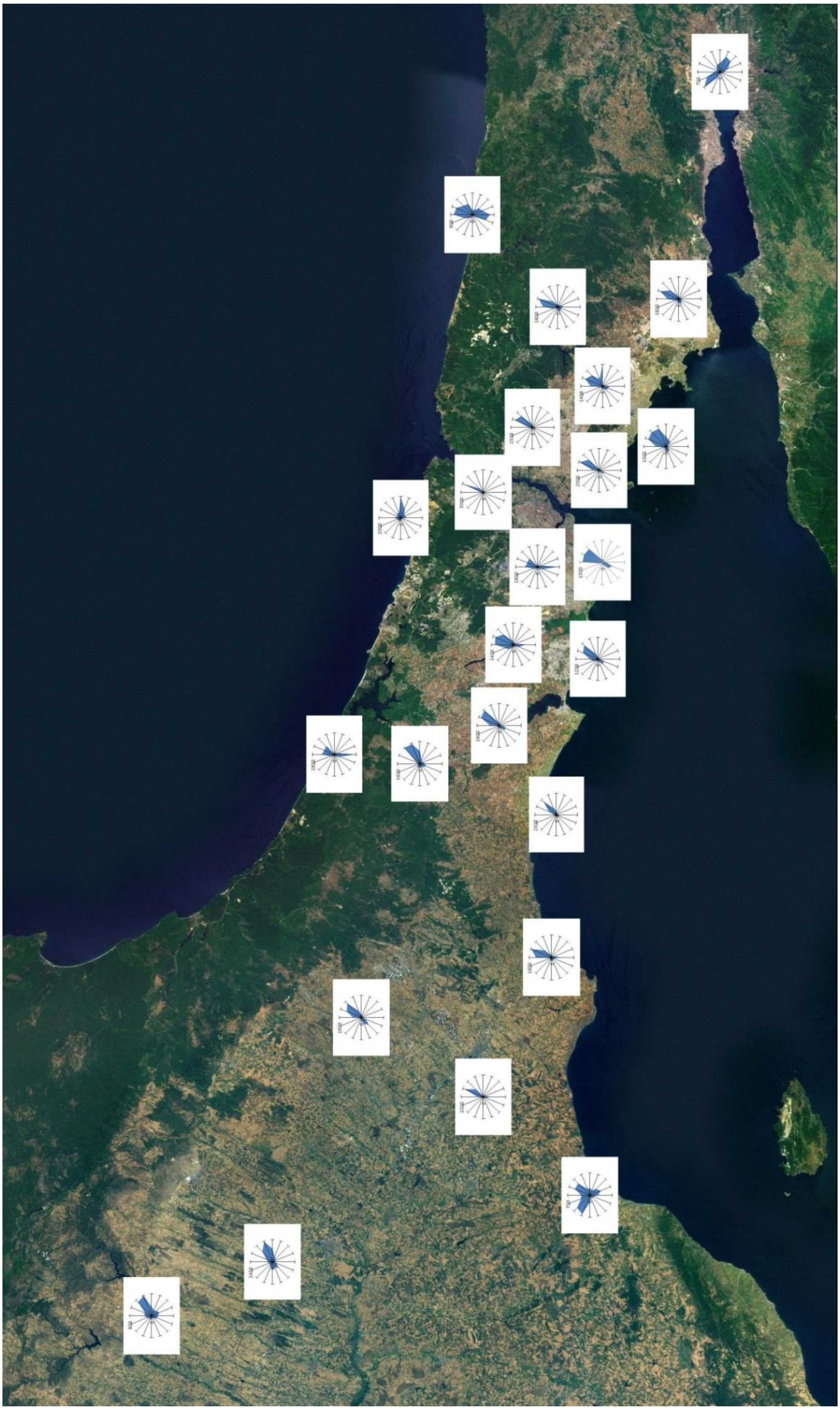

Figure 3.5 Annual wind roses in Istanbul

CHAPTER FOUR
MATERIALS AND METHODS

Emissions from sources, too small and difficult to be surveyed individually, were considered collectively as area sources. Therefore, residential heating constitute area sources. Residential heating sources were evaluated and allocated on the study area with respect to population density. For the calculation of residential heating emissions, the collected information included mainly number of inhabitants, number of residences, type of fuels used and fuel consumptions. The fuel use pattern in the city is generally controlled by population density and income level of the inhabitants. Population data was obtained from the statistics of the last population census held by TUIK in 2009.

In order to determine the air pollutant emissions from residential heating sources, a local emission inventory was prepared within an area of 170 km by 85 km centered at the metropolitan area of Istanbul. Nine major pollutants consisting of SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, NMVOCs, CO_2, CH_4 and N_2O emitted through residential heating sources were studied.

The emissions were calculated using fuel consumption data and appropriate emission factors. Emission factors were taken from two databases. European CORINAIR database for SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO and NMVOCs (EMEP/EEA, 2009) and the Intergovernmental Panel on Climate Change Guidelines (IPCC) for CO_2, CH_4 and N_2O (IPCC, 2006) were used. Table 4.1 shows original emission factors taken from these databases. Emission factors for small boilers indicating single household scale capacity with $\leq$ 50 KWth reported in CORINAIR were selected for natural gas. For lignite, the emission factors in CORINAIR were selected by assuming that the combustion technology used in residential areas is relatively old, manually fuelled and the penetration of new technologies is slow.

Table 4.1 Original emission factors and specifications of fossil fuels

Original Emission Factors (g/GJ)										Heating Value (kcal/kg, kcal/m^3)	Sulfur Content (%)
Fuel Types	**SO_2[(1)]**	**NO_2[(1)]**	**PM_{10}[(1)]**	**$PM_{2.5}$[(1)]**	**CO[(1)]**	**NMVOC[(1)]**	**CO_2[(2)]**	**CH_4[(2)]**	**N_2O[(2)]**		
Natural Gas	0.5	70	0.5	0.5	30	10	56100	5	0.1	8250	
Lignite (imported)	675	110	404	398	4600	484	101000	300	1.5	5800	0.9
Lignite (local)	1200	110	404	398	4600	484	101000	300	1.5	4000	1.6

(1):EMEP/EEA, 2009; (2): IPCC,2006

The units of original emission factors for natural gas, imported lignite and local lignite were converted into kg/tons or kg/m^3 by using their sulfur contents and heating values shown in Table 4.1. Table 4.2 shows the final emission factors that were used directly for emission calculations in this study.

Table 4.2 Final emissions factors used for emission calculations

Fuel Types	Final Emissions Factors									
	Unit	**SO_2**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**NMVOC**	**CO_2**	**CH_4**	**N_2O**
Natural Gas	**kg/m^3**	0.000017	0.002	0.000017	0.000017	0.001	0.0003	1.94	0.0002	0.000003
Lignite (imported)	**kg/ton**	16.38	2.67	9.80	9.66	111.63	11.75	2,451	7.28	0.036
Lignite (local)	**kg/ton**	20.08	1.84	6.76	6.66	76.99	8.1	1,690	5.02	0.025

Two different fuel types (lignite and natural gas) and electricity were mainly used as energy sources for residential heating in the winter (November – March) in Istanbul. In the study, lignite was categorized into two groups; imported lignite and local lignite according to their heating values and sulfur contents. Although more types of fuels such as LPG, motorine, biomass, etc. were also used for residential heating, the use of these fuels were neglected due to their low consumptions. The emissions from these fuels were not included in the emission inventory. Table 4.1 shows properties of fossil fuels which were used in Istanbul. Lignite properties were taken from a local report (Istanbul Governorship, 2010) and specifications of natural gas were taken from the natural gas company of the city (IGDAS - Istanbul Gas Distribution Industry and Trade Incorporated Company) (IGDAS, 2006).

Monthly natural gas consumption data as district and neighborhood basis were collected from IGDAS in Istanbul. The numbers of residences using natural gas for heating purposes were also taken from IGDAS. The residences of 3,710,973 used 2,261,033,334 m^3 of natural gas for the winter of 2009-2010 in Istanbul (IGDAS, 2010).

The numbers of residences using city water in Istanbul were also collected from Water and Sewage Management of Istanbul (ISKI) as 4,708,078 (ISKI, 2010). Table 4.3 shows ISKI and IGDAS residence numbers of districts. The numbers of residences in the districts were chosen from IGDAS or ISKI databases. The highest one was generally used as total number of residences in a neighborhood. Differences between the numbers of residences in IGDAS and ISKI databases were assumed as the residences using other energy sources like lignite and electricity for heating purposes. Figure 4.1 shows the contributions of energy sources to heating requirements in Istanbul. Figure 4.2 shows geographical distribution of residence numbers using natural gas in IGDAS database and the estimated residence numbers using the other energy sources in Istanbul.

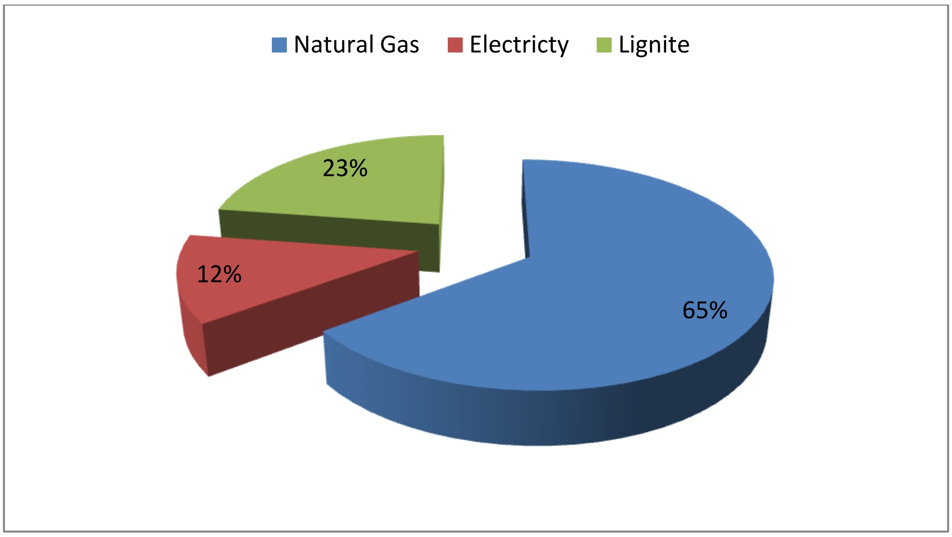

Figure 4.1 The contributions of energy sources to heating requirements in Istanbul

Table 4.3 The residence numbers of districts in Istanbul

Districts	**Total Residences (ISKI)**	**The Residences Using Natural Gas (IGDAS)**	**The Residences Using Other Energy Sources**
Adalar	10,524	3,933	2,457
Arnavutkoy	59,803	15,532	44,271
Atasehir	131,222	111,802	19,420
Avcilar	125,776	93,381	32,395
Bagcilar	217,538	166,135	51,403
Bahcelievler	199,734	168,899	30,835
Bakirkoy	115,215	115,215	0
Basaksehir	74,262	45,985	28,277
Bayrampasa	96,314	81,004	15,310
Besiktas	109,991	108,811	1,180
Beykoz	84,024	62,778	20,151
Beylikduzu	80,738	67,792	12,946
Beyoglu	94,298	70,026	24,272
Buyukcekmece	89,785	61,225	21,746
Catalca	27,278	0	27,278
Cekmekoy	56,004	47,250	8,754
Esenler	134,995	104,764	30,231
Esenyurt	139,736	89,997	49,739
Eyup	109,357	88,601	20,756
Fatih	176,532	146,090	30,442
Gaziosmanpasa	149,885	121,993	27,892
Gungoren	108,433	85,467	22,966
Kadikoy	218,507	203,875	14,632
Kagithane	143,708	106,535	37,173
Kartal	153,067	126,813	26,254
Kucukcekmece	226,074	176,919	49,155
Maltepe	157,275	129,192	28,083
Pendik	201,884	151,967	49,917
Sancaktepe	78,107	53,227	24,880
Sariyer	107,278	98,758	8,208
Silivri	69,619	36,101	33,518
Sultanbeyli	77,095	38,922	38,173
Sultangazi	138,185	108,019	30,166
Sile	21,595	6,967	9,941
Sisli	148,988	129,546	19,442
Tuzla	66,218	50,872	15,346
Umraniye	214,175	187,059	27,116
Uskudar	194,921	176,220	18,701
Zeytinburnu	99,938	73,301	26,637
TOTAL	**4,708,078**	**3,710,973**	**980,063**

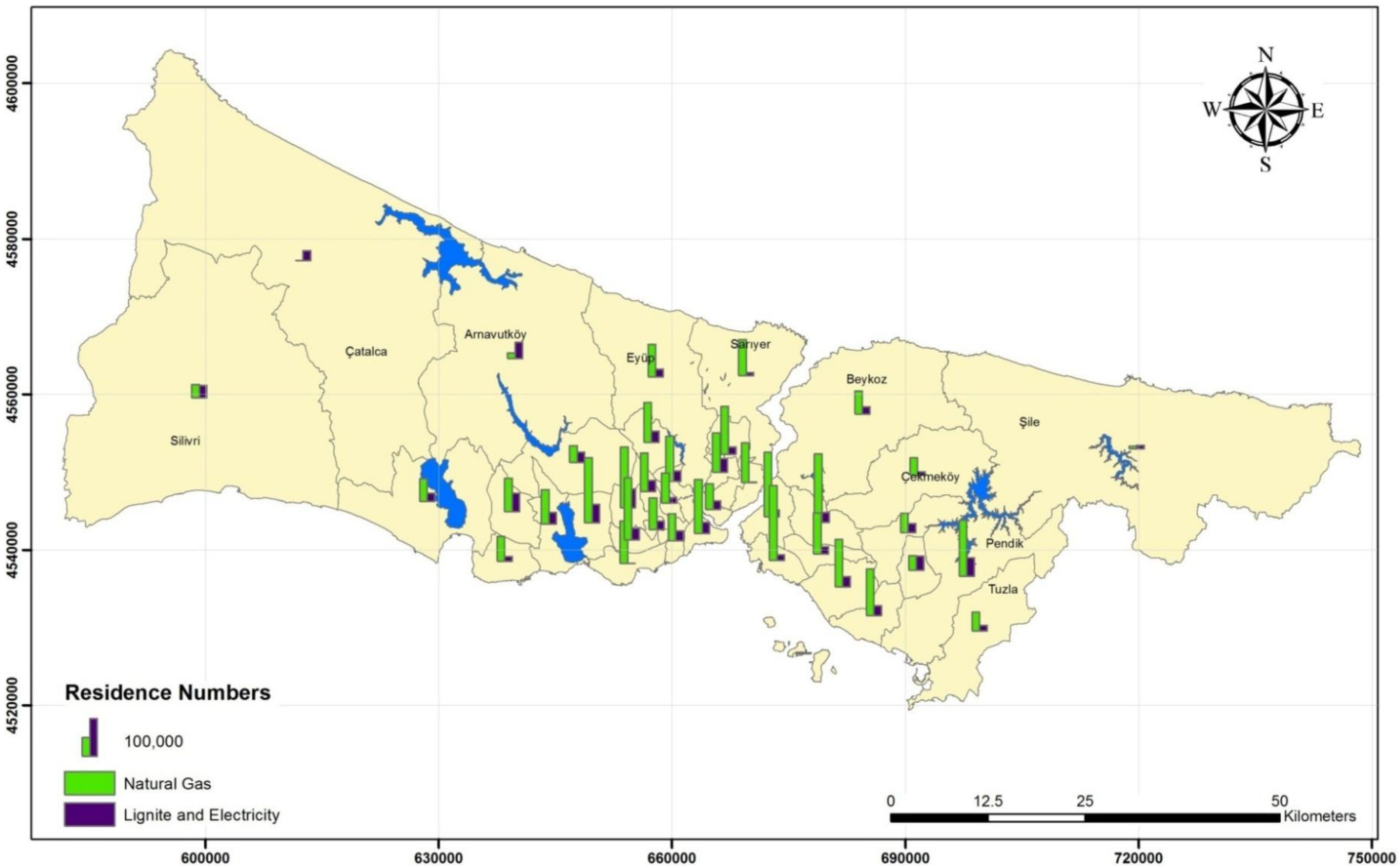

Figure 4.2 Spatial distribution of residence numbers using natural gas and other energy sources in Istanbul

Annual electricity consumption data in Istanbul were taken from Turkey's Statistical Yearbook for the year 2009 (TUIK, 2010). It was reported as 9,549,457,000 Kwh/year. Monthly electricity consumptions were also taken from a local report prepared by the Chamber of Electrical Engineers (EMO, 2006). Table 4.4 shows the monthly consumptions of electricity in the city.

Table 4.4 Monthly electricity consumption in the winter of 2006

	Mwh	**%**
January	738,367	19.3
February	722,997	18.9
March	758,868	19.8
November	774,025	20.2
December	831,772	21.7
TOTAL	**3,826,029**	**100.0**

For estimation of the lignite consumption in districts and neighborhoods; as first stage, monthly heating requirements for each district in the city were estimated. For this reason, a simple calculation method was used. For the city, calorific heating requirement for the unit volume of 1 m^3 in a standard residence was assumed as 45 kcal/hr (TSE, 1999). The height of roof for this standard residence was assumed as 2.7 m and total effective heating area was assumed as 40 m^2. Heating period was chosen as 240 hr in a month. Monthly heating requirement of 1 m^2 area was calculated as 29,160 kcal/m^2 month. Average heating requirement of a residence was calculated as 1,166,400 kcal/residence month. This average value was applied to all districts and neighborhoods in Istanbul. Finally, heating requirements of all districts and neighborhoods in the city were calculated for natural gas and electricity. The heating requirement differences between natural gas and electricity were assumed to be met by lignite.

Figure 4.3 shows the total fossil fuel consumptions in residential heating sector for the winter of 2009-2010. Figure shows that total natural gas consumption was 2,261,033,334 m^3 in Istanbul. Consumptions of imported lignite, local lignite and electricity were found 887,361 tons, 341,293 tons and 4,201,761,080 KWh, respectively. The total lignite consumption was calculated as 1,228,654 tons/season. The total lignite consumption was close the consumption which was taken from a local report of Istanbul Metropolitan Municipality (IMM), as 1,300,000 tons/season.

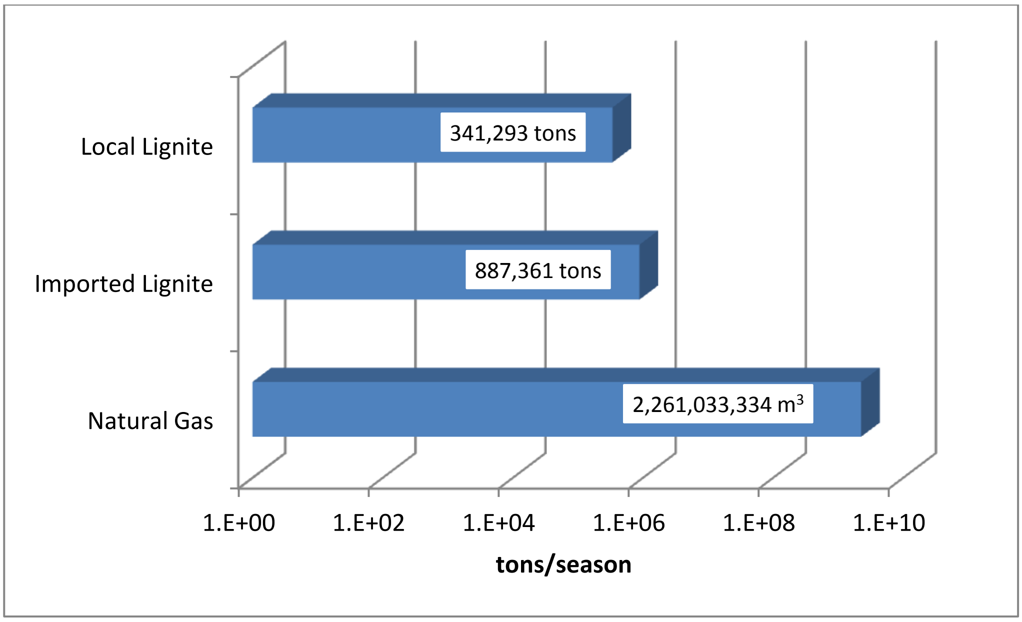

Figure 4.3 Seasonal fuel consumptions in residential heating sector for the winter of 2009-2010

After estimation of fuel consumption data, emissions for residential heating were calculated using Equation 2.

PE = EF x CF / 1000 (kg/tons) **(Equation 2)**

PE = pollutant emission (tons/season)
EF = emission factor (kg/m^3, kg/tons)
CF = consumption of fuel (tons/season, m^3/season)

At the end of the study, spatial distribution of all fuel consumptions and the estimated emissions were plotted by ESRI's ArcGIS 10 software. Figures 4.3 - 4.5 show fossil fuel and electricity consumptions in Istanbul for the winter of 2009-2010.

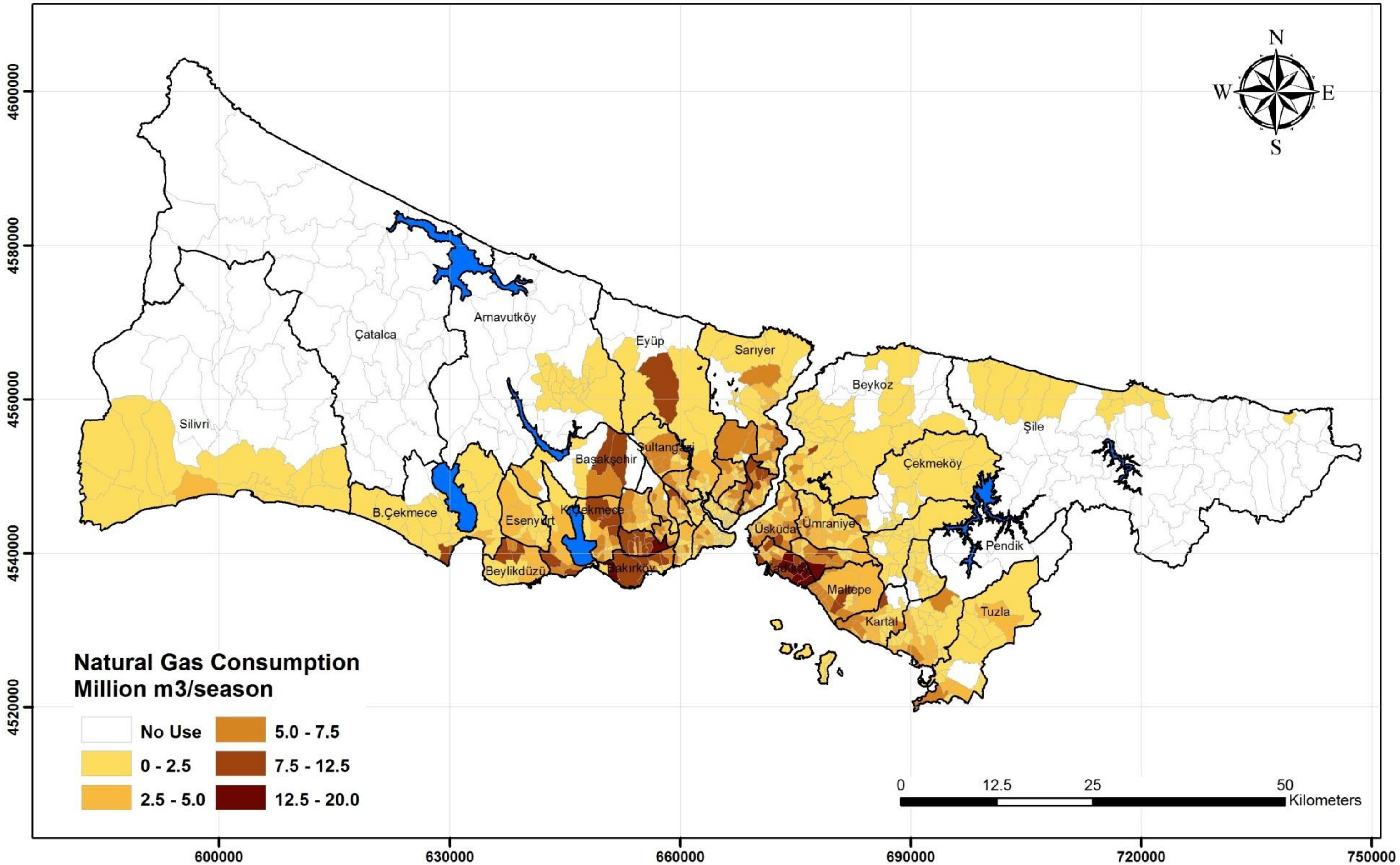

Figure 4.3 Spatial distribution of total natural gas consumption in residential areas for heating purposes in the city

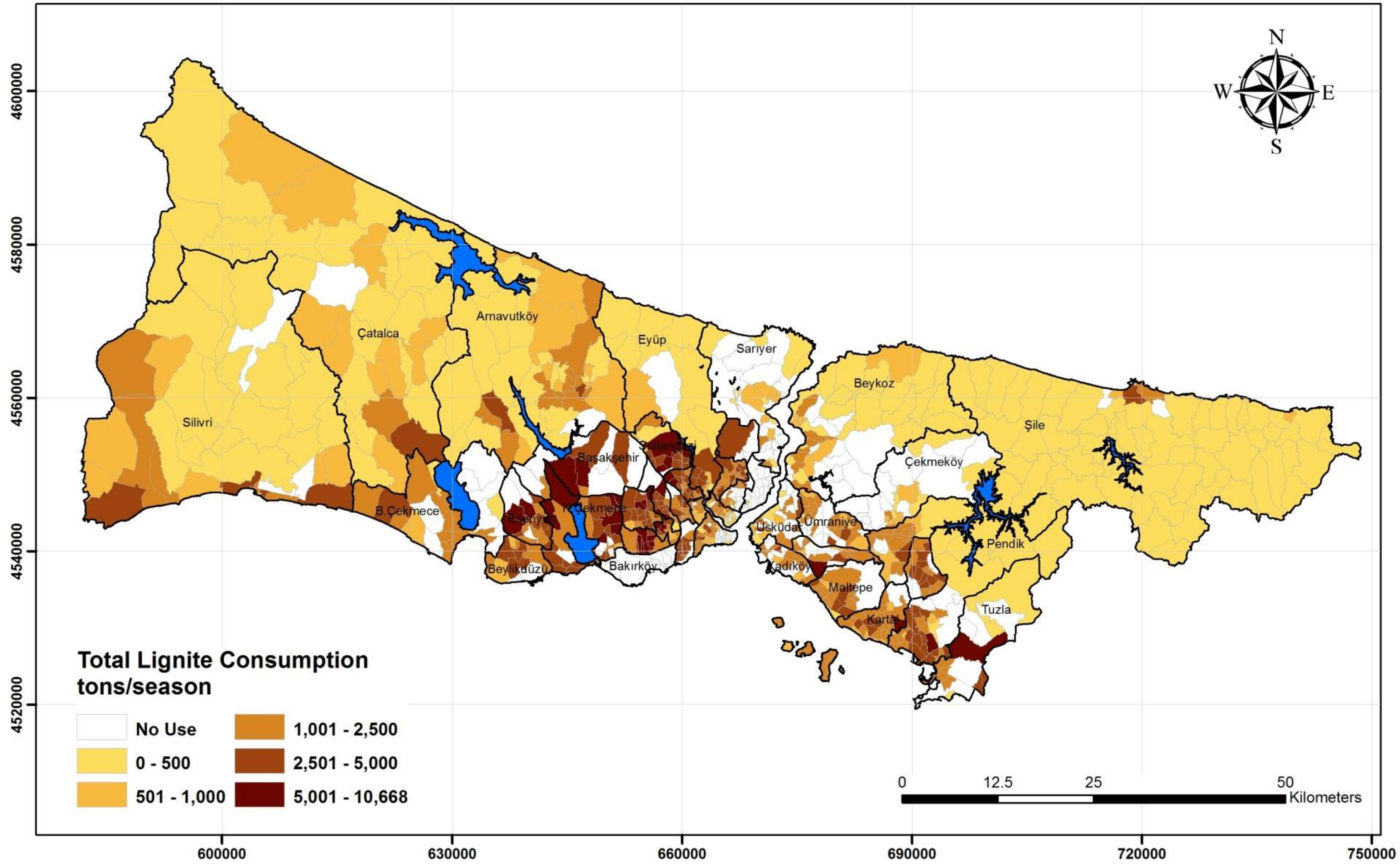

Figure 4.4 Spatial distribution of total lignite consumption in residential areas for heating purpose in the city

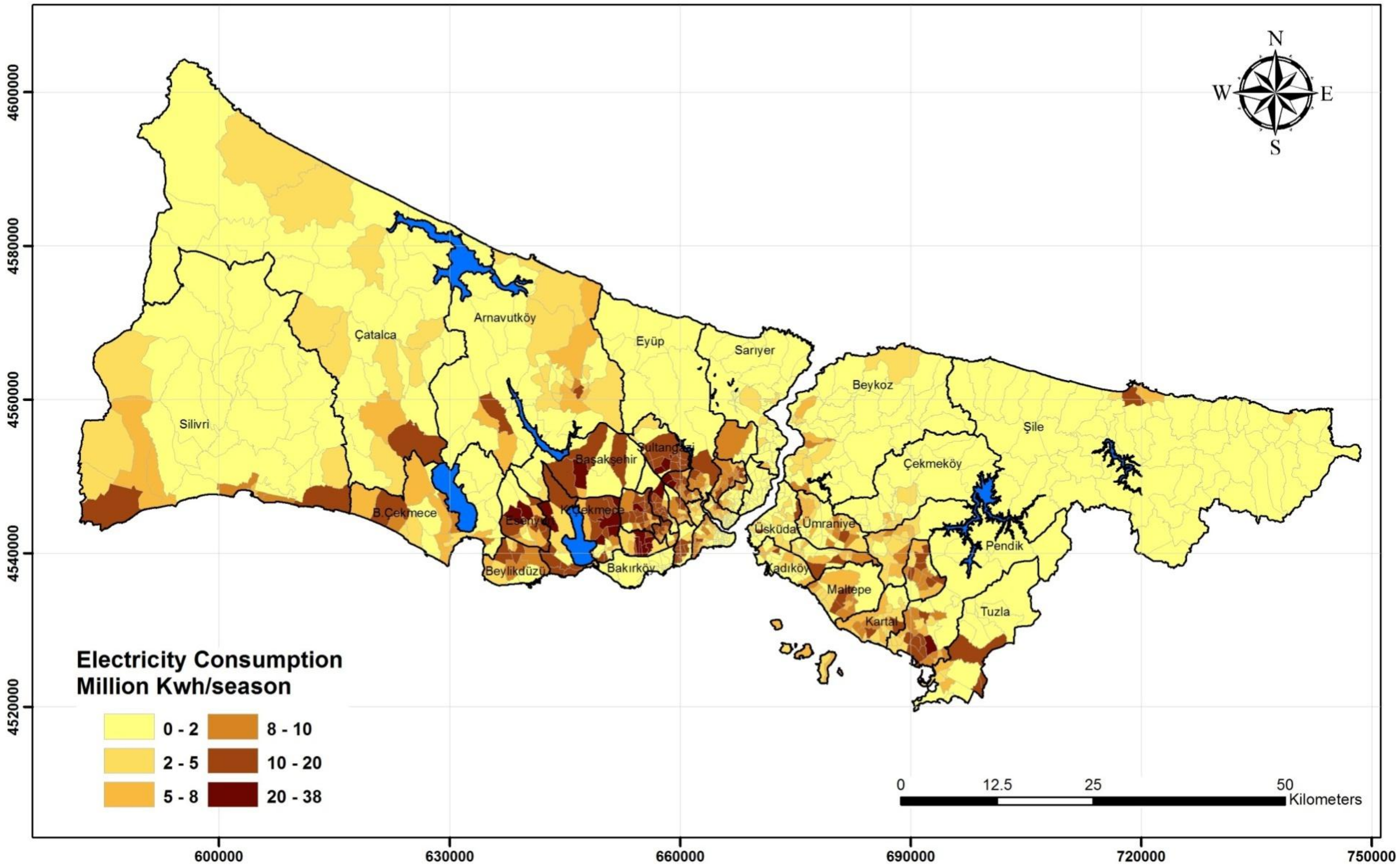

Figure 4.5 Spatial distribution of total electricity consumption in residential areas for heating purposes in the city

CHAPTER FIVE
RESULTS AND DISCUSSIONS

In this study, the emissions of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, NMVOCs, CO_2, CH_4 and N_2O emitted from residential heating sources were estimated using emission factors for between November 2009 and March 2010 in Istanbul.

During the winter of 2009-2010 11,046 tons of PM_{10} emissions were estimated to be released to the atmosphere from residential areas in Istanbul. PM_{10} emissions from residential heating were almost totally from lignite burning in uncontrolled burners. SO_2 emissions were also mainly coming from the use of fossil fuels with high sulfur content. Nearly 21,429 tons of SO_2 were estimated in the winter. The total emissions of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, NMVOCs, CO_2, CH_4 and N_2O were 21,429; 8,460; 11,046; 10,883; 127,671; 13,967; 7,130,209; 8,564 and 49 tons/season, respectively. Figure 5.1 shows the total estimated emissions from residential heating in Istanbul.

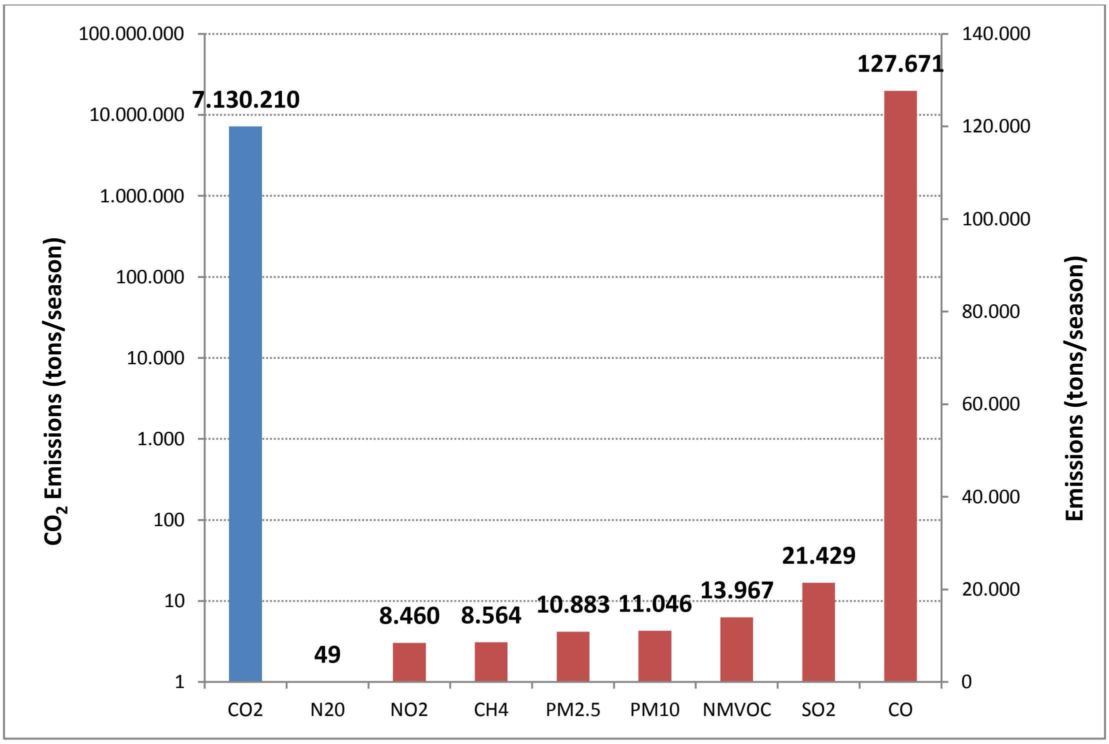

Figure 5.1 Total emissions from residential heating in the winter of 2009-2010

Figure 5.2 shows the contributions of fossil fuels to the total emissions. According to the figure, imported lignite was the major contributor for the emissions of SO_2, CO, PM_{10}, $PM_{2.5}$, NMVOCs, CH_4 and N_2O although natural gas was the main contributor for the emissions of NO_2 and CO_2. Table 5.1 shows the total emissions in the districts of Istanbul.

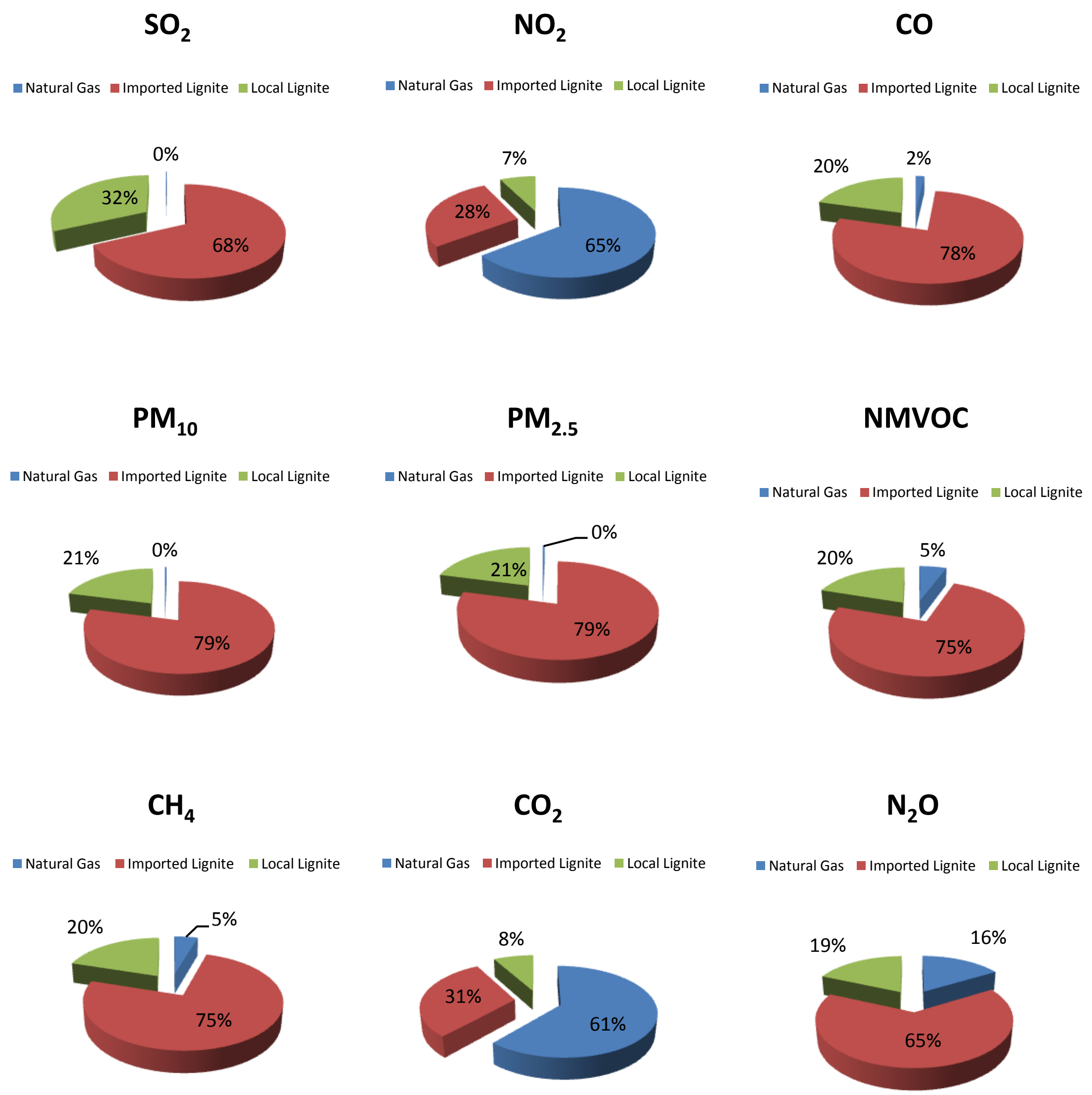

Figure 5.2 Contributions of fossil fuels to the total emissions

Table 5.1 The total estimated emissions in the districts, tons/season

Disctricts	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	NMVOC	CO_2	CH_4	N_2O
Adalar	120	18	62	61	704	74	16,334	46	0.2
Arnavutkoy	621	102	319	315	3,643	385	92,147	238	1.2
Atasehir	443	239	229	225	2,664	298	198,444	181	1.1
Avcilar	719	221	371	365	4,262	460	188,563	283	1.5
Bagcilar	1,318	379	679	669	7,796	839	325,030	517	2.8
Bahcelievler	982	374	506	499	5,848	638	315,491	392	2.2
Bakirkoy	2	217	2	2	93	31	173,819	15	0.3
Basaksehir	403	132	208	205	2,391	259	112,703	159	0.9
Bayrampasa	390	153	201	198	2,323	254	128,811	156	0.9
Besiktas	19	242	10	10	202	45	194,354	24	0.4
Beykoz	345	158	178	175	2,064	228	132,460	139	0.8
Beylikduzu	304	142	157	154	1,820	201	118,477	123	0.7
Beyoglu	454	176	234	230	2,701	295	148,810	181	1.0
Buyukcekmece	454	152	234	230	2,693	292	129,117	179	1.0
Catalca	332	46	171	168	1,943	204	42,670	127	0.6
Cekmekoy	155	84	80	79	933	104	70,155	64	0.4
Esenler	882	232	454	447	5,207	558	200,260	344	1.8
Esenyurt	1,005	234	518	510	5,926	633	204,171	391	2.1
Eyup	515	196	265	261	3,065	335	165,371	205	1.2
Fatih	716	309	369	364	4,278	471	259,333	288	1.7
Gaziosmanpasa	882	259	454	448	5,221	563	222,043	346	1.9
Gungoren	564	192	291	286	3,349	363	163,149	223	1.2
Kadikoy	331	545	172	170	2,134	273	442,414	161	1.3
Kagithane	796	250	410	404	4,716	510	213,543	314	1.7
Kartal	696	275	359	353	4,145	453	231,673	278	1.6
Kucukcekmece	1,056	367	544	536	6,271	681	311,092	419	2.3
Maltepe	559	282	288	284	3,352	373	235,401	227	1.4
Pendik	1,118	338	576	567	6,619	714	288,973	440	2.4
Sancaktepe	495	136	255	251	2,925	314	117,270	194	1.0
Sariyer	157	209	81	80	991	123	169,880	73	0.6
Silivri	521	113	268	264	3,066	327	99,260	202	1.0
Sultanbeyli	656	131	338	333	3,859	410	116,071	253	1.3
Sultangazi	847	237	436	430	5,007	538	203,653	332	1.8
Sile	241	36	124	122	1,411	149	32,956	92	0.5
Sisli	383	299	198	195	2,342	270	245,707	163	1.1
Tuzla	343	120	177	174	2,039	222	101,680	136	0.8
Umraniye	629	324	325	320	3,778	421	270,222	257	1.5
Uskudar	391	362	202	199	2,407	283	296,530	170	1.2
Zeytinburnu	588	178	303	299	3,483	376	152,173	231	1.3
TOTAL	**21,429**	**8,460**	**11,046**	**10,883**	**127,671**	**13,967**	**7,130,209**	**8,564**	**49.0**

Due to their dense population, and types of fuel, several regions in the metropolitan area such as Bagcilar, Kadikoy, Esenyurt, Bahcelievler, Pendik, Esenler, Gaziosmanpasa and Kucukcekmece have high residential heating emissions. Figures 5.3 – 5.11 show total emissions for all districts at the metropolitan area.

Bagcilar was the most polluted district for SO_2, PM_{10}, $PM_{2.5}$, CO, NMVOCs, N_2O and CH_4 with 1,318; 679; 669; 7,796; 839; 2.79 and 517 tons of emissions in the winter of 2009-2010, respectively. Bagcilar had the highest population density and residence numbers which use the other energy sources (lignite and electricity) as 724,268 and 51,403, respectively. Consumption of seasonal natural gas, imported lignite and local lignite were 80,391,522 m^3, 54,611 tons and 21,004 tons, respectively. Although natural gas consumption was higher than lignite in some districts, the emissions from lignite were higher than the emissions from natural gas. Bagcilar had the highest consumption of lignite in Istanbul. The estimated emissions were approximately 2 tons/season for SO_2, PM_{10}, $PM_{2.5}$, 93 tons/season for CO, 31 tons/season for NMVOC and 15 ton/season for CH_4 in Bakirkoy. Emissions of Bakirkoy were lower than the other districts due to the usage of natural gas in all residences. Natural gas consumption was calculated as 89,760,978 m^3/season in Bakirkoy.

Kadikoy had the highest emissions as 6% of total NO_2 emissions and 6% of total CO_2 emissions. Kadikoy had the sixth highest population density with 529,191 and consumption of natural gas, imported lignite and local lignite were 206,692,437 m^3, 13,596 tons and 5,229 tons in the winter, respectively. Kadikoy had the highest residence number. Adalar was the lowest polluted district with ratios of 0.2% for NO_2, 0.3% for CO_2 and 0.5 % for N_2O. Adalar had the lowest population density as 14,341 and consumption of natural gas and total lignite in this district were 463,395 m^3/season and 6,893 tons/season, respectively. Adalar is a summer place, therefore the number of residence was decreased in winter season. Figures 5.12 - 5.13 show the natural gas and total lignite consumptions.

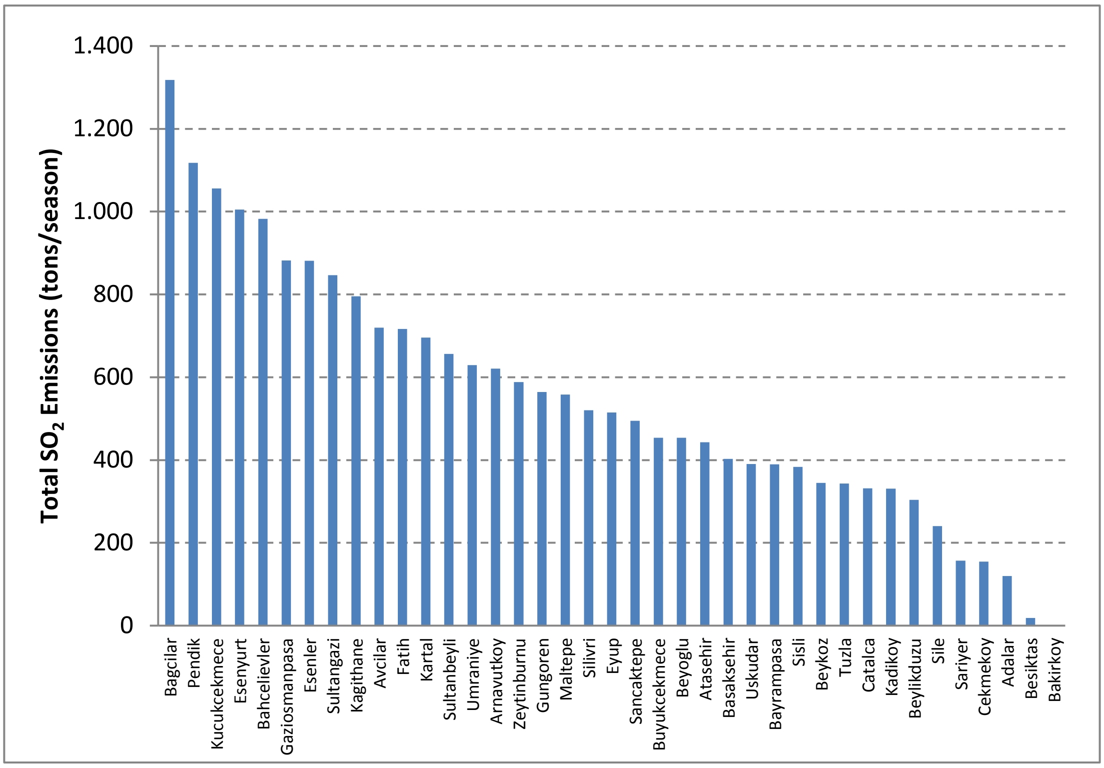

Figure 5.3 Total SO_2 emissions for all districts at the metropolitan area in winter

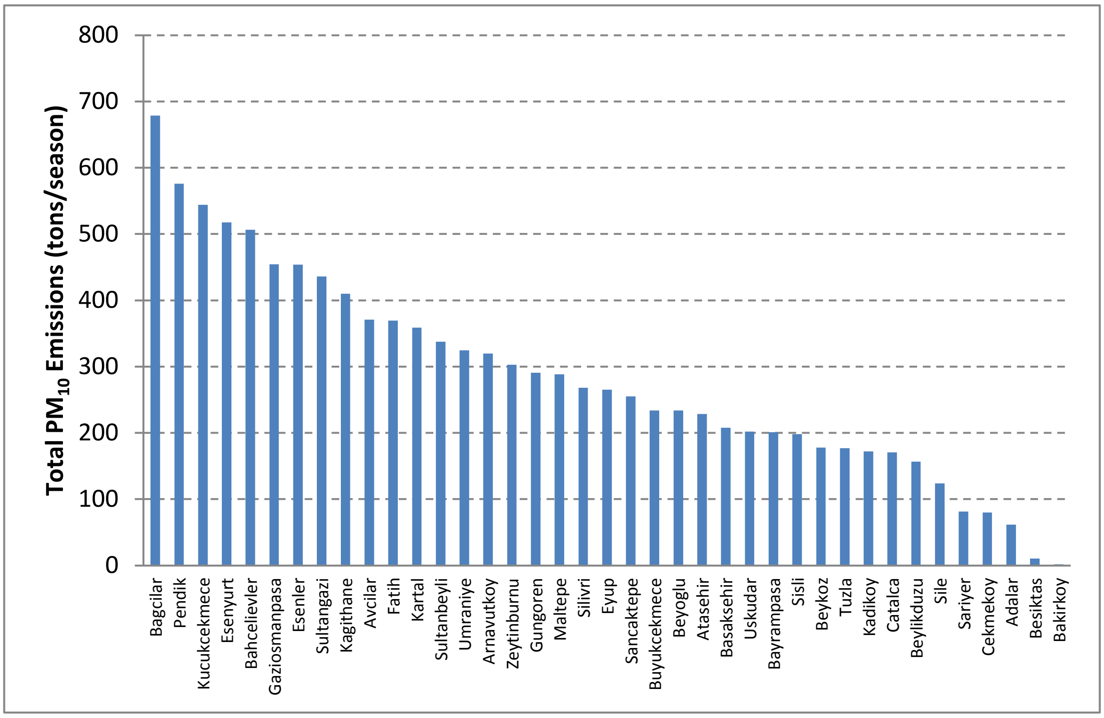

Figure 5.4 Total PM_{10} emissions for all districts at the metropolitan area in winter

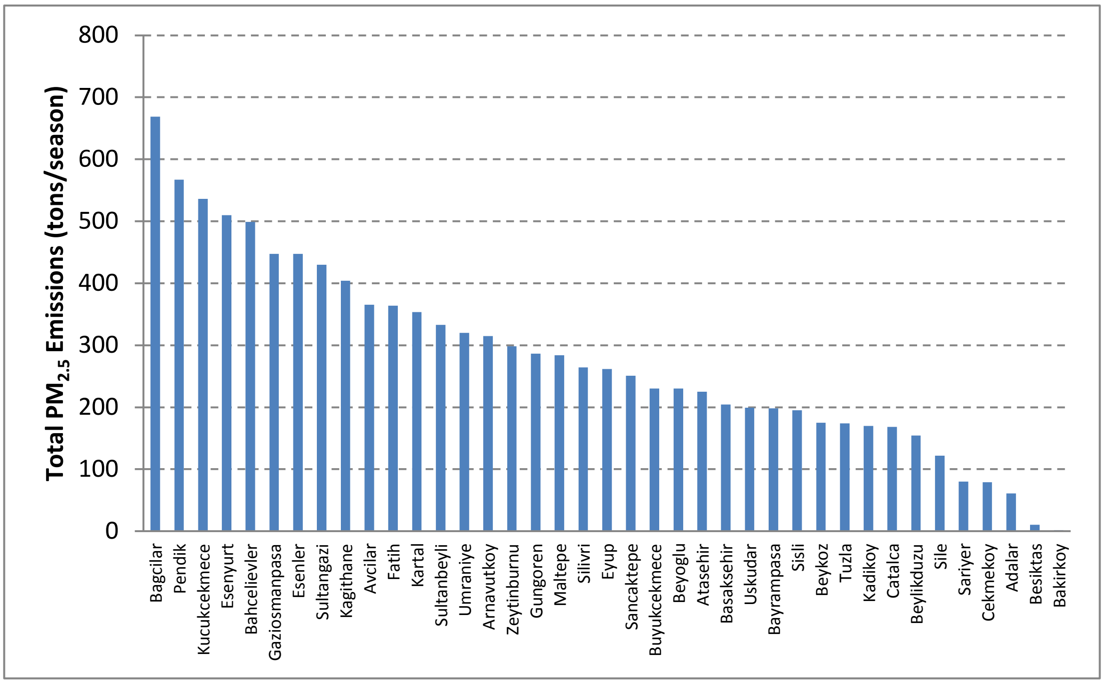

Figure 5.5 Total $PM_{2.5}$ emissions for all districts at the metropolitan area in winter

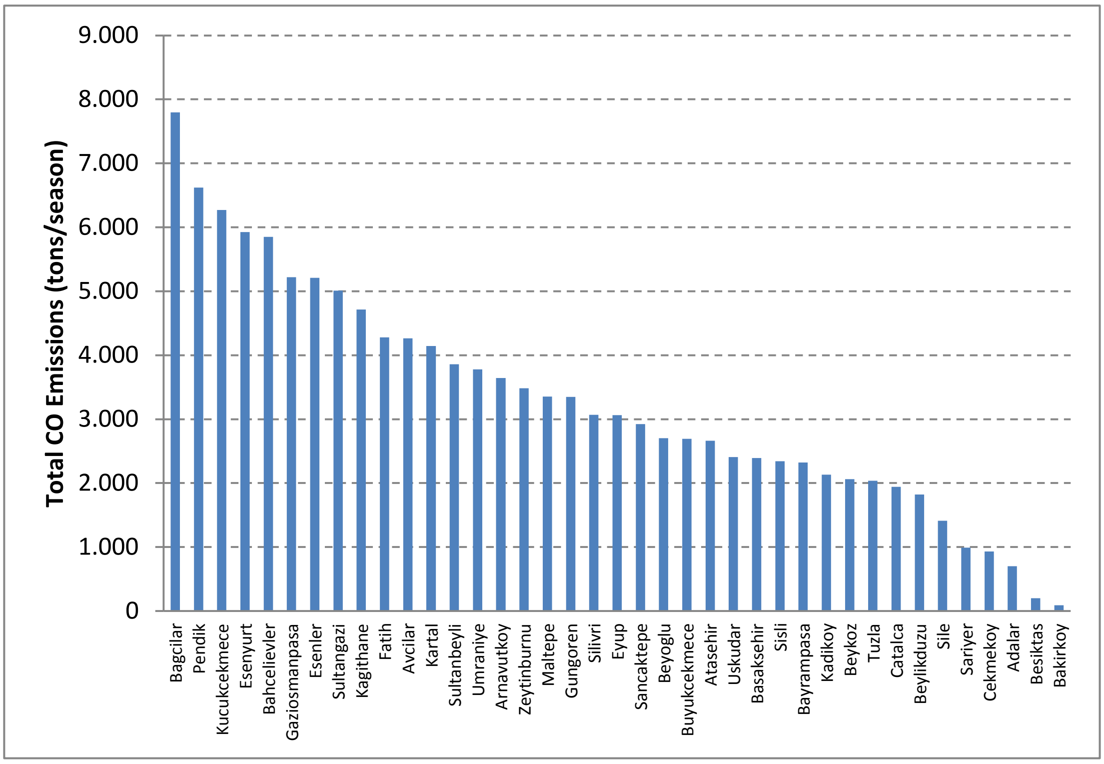

Figure 5.6 Total CO emissions for all districts at the metropolitan area in winter

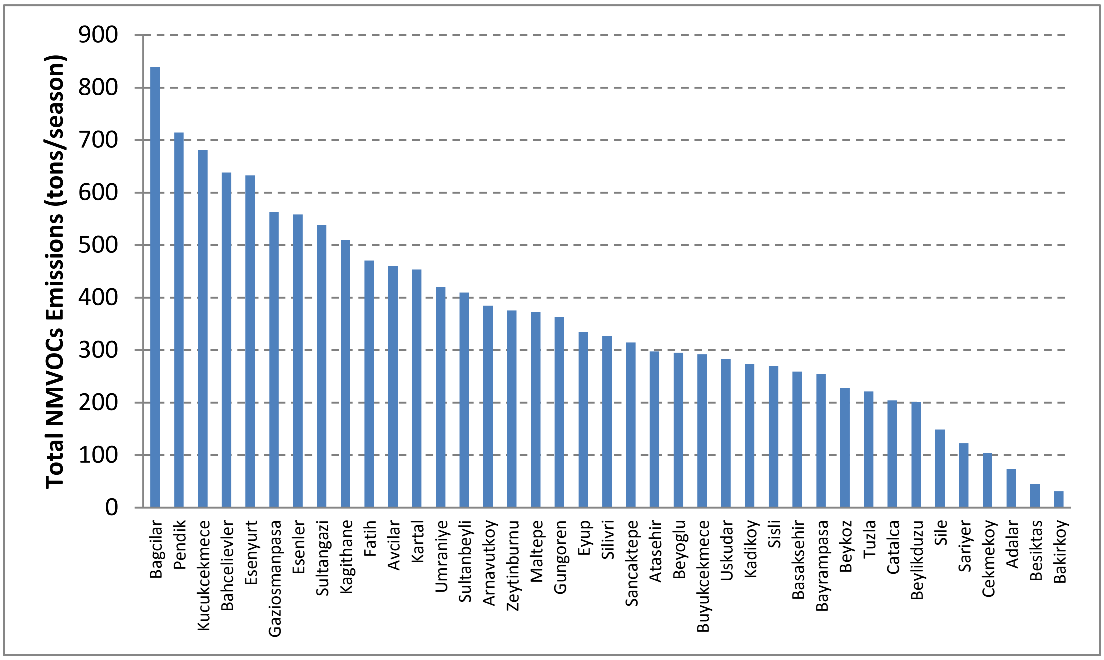

Figure 5.7 Total NMVOCs emissions for all districts at the metropolitan area in winter

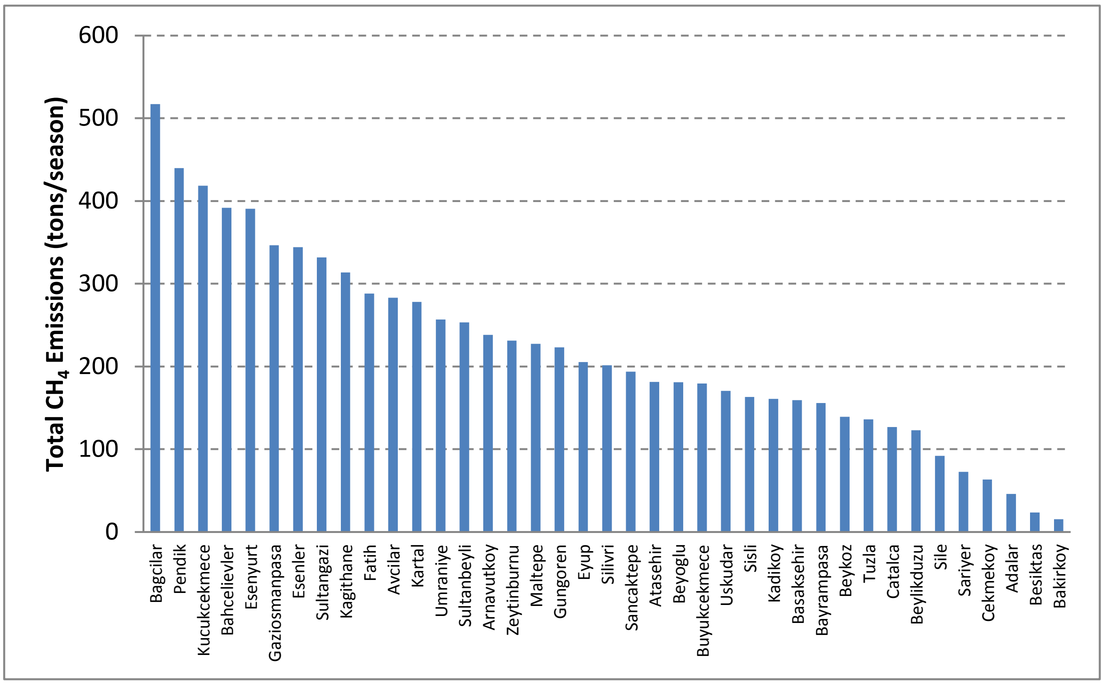

Figure 5.8 Total CH_4 emissions for all districts at the metropolitan area in winter

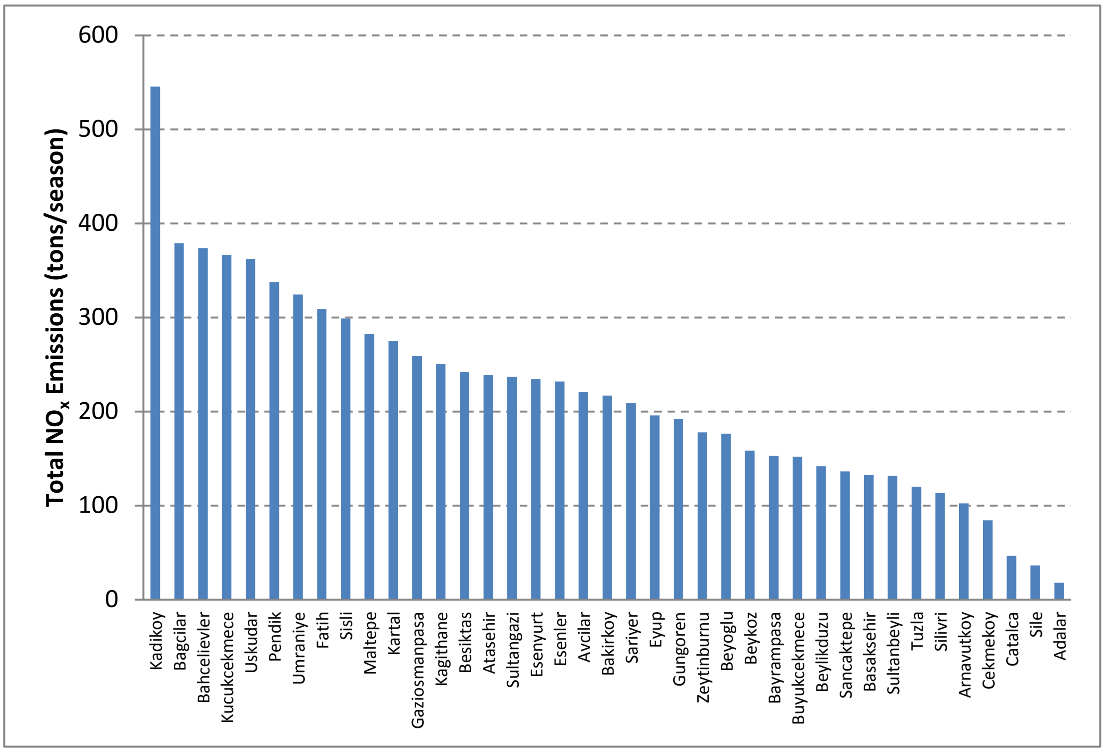

Figure 5.9 Total NO_x emissions for all districts at the metropolitan area in winter

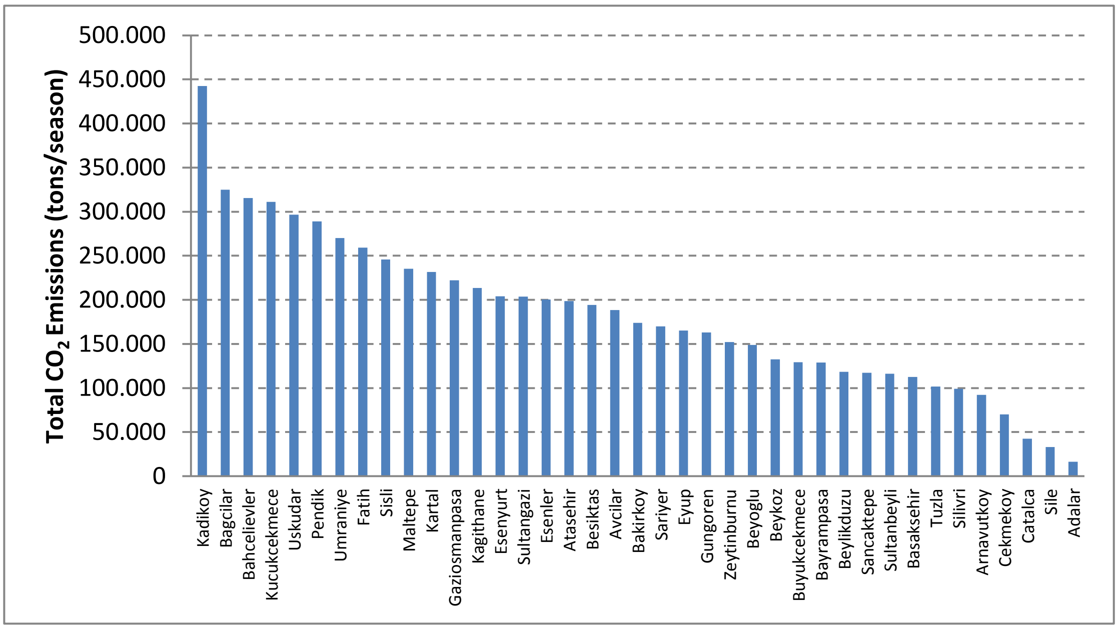

Figure 5.10 Total CO_2 emissions for all districts at the metropolitan area in winter

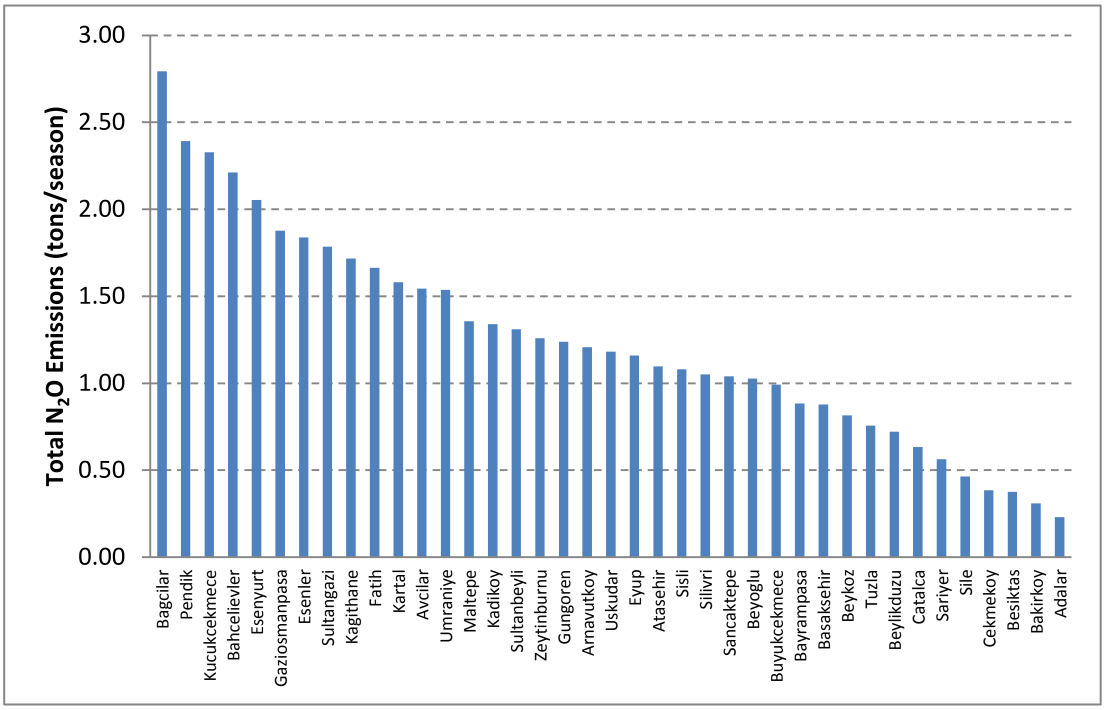

Figure 5.11 Total N_2O emissions for all districts at the metropolitan area in winter

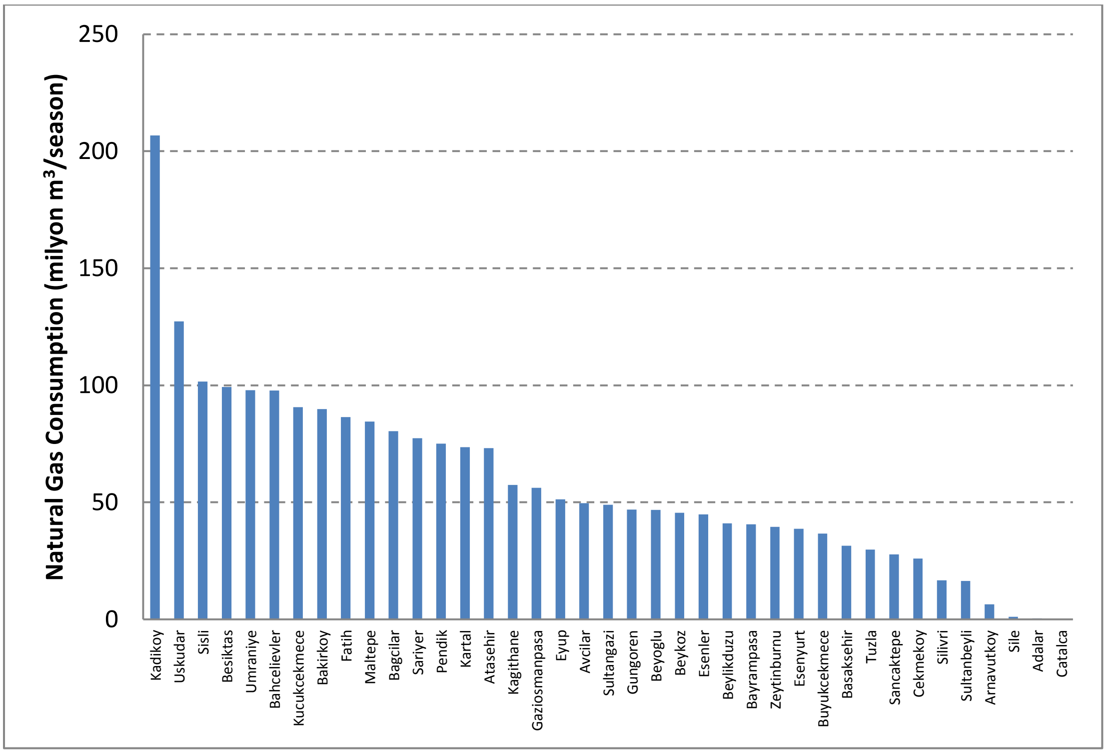

Figure 5.12 Natural gas consumptions for all districts at the metropolitan area in winter

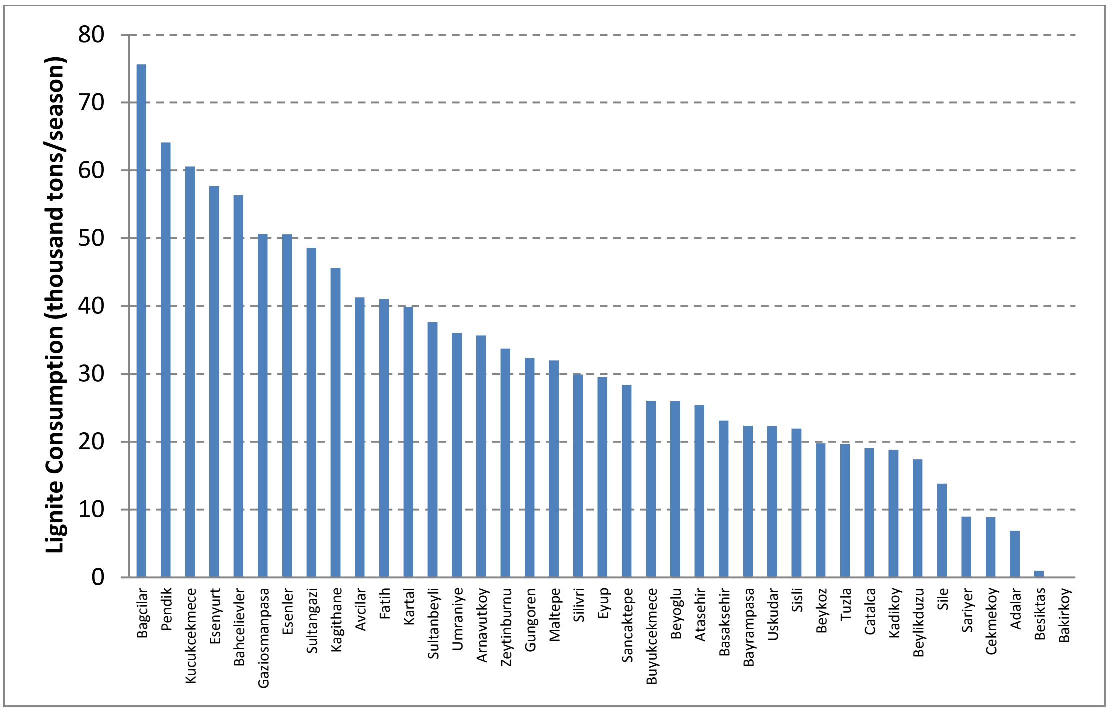

Figure 5.13 Lignite consumptions for all districts at the metropolitan area in winter

ArcGIS 10 was used to distribute emissions spatially in the city. Figures 5.14 – 5.22 show spatial distribution of total emissions from residential heating for nine pollutants at the metropolitan area.

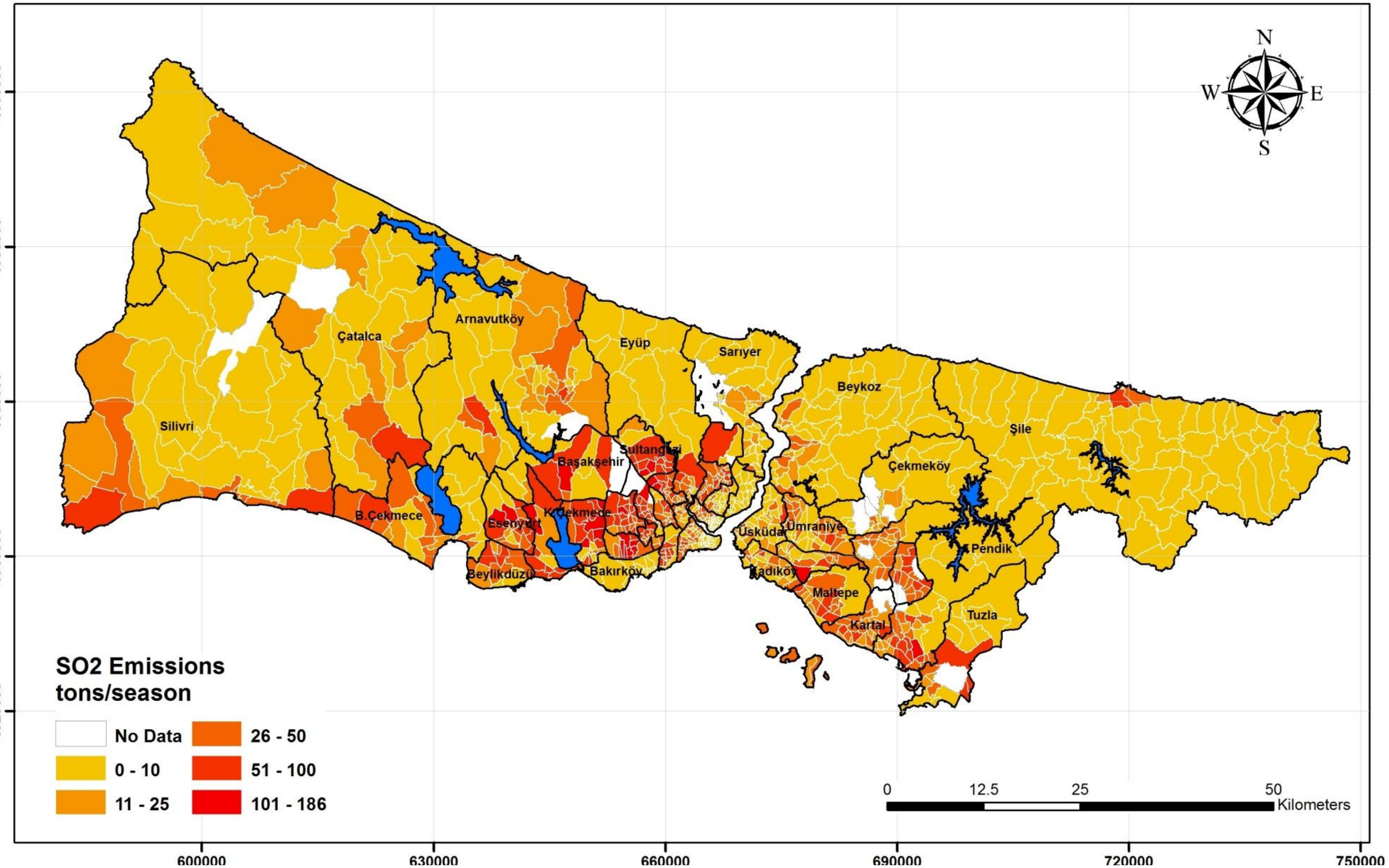

Figure 5.14 Spatial distribution of seasonal SO_2 emissions from residential heating

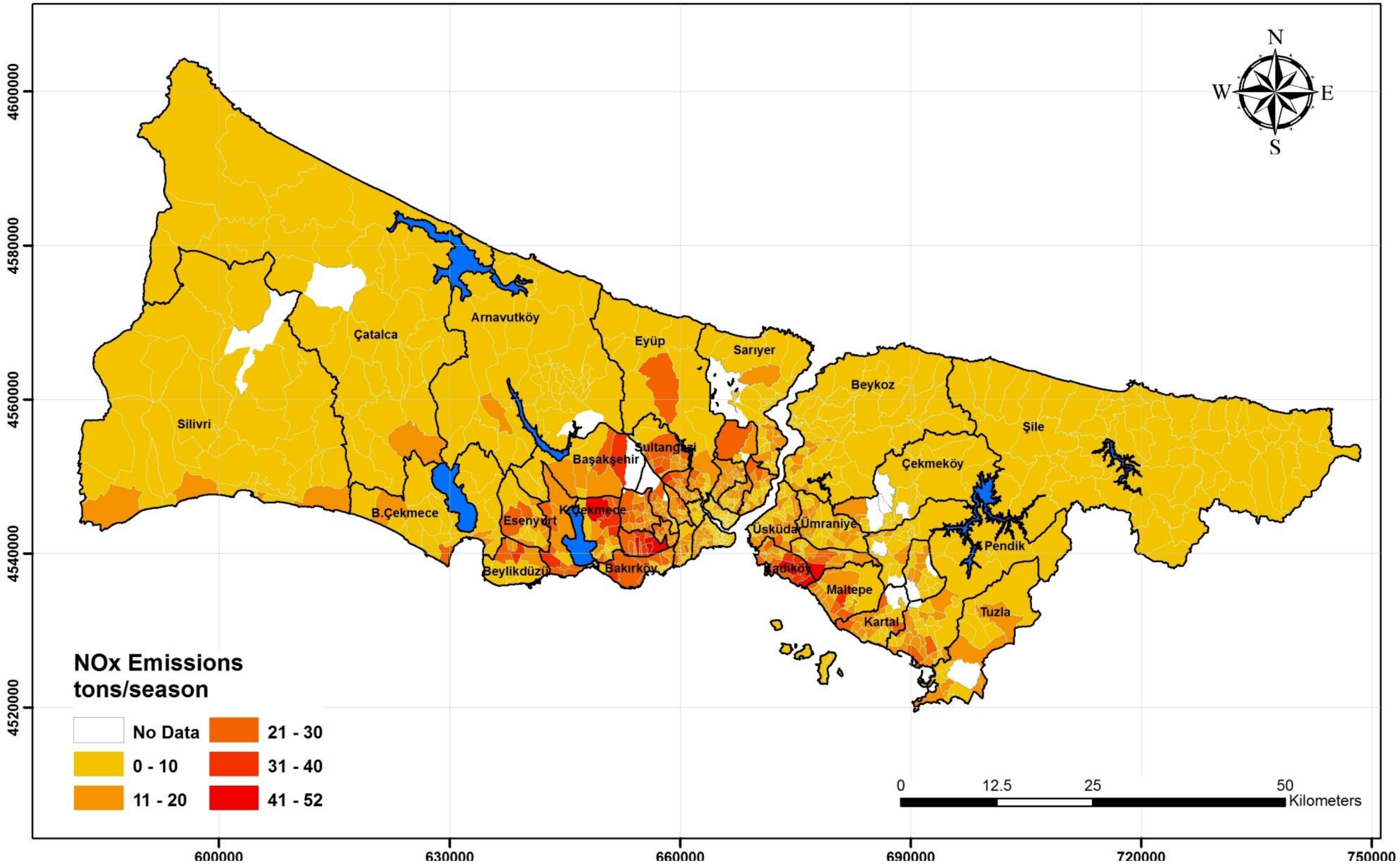

Figure 5.15 Spatial distribution of seasonal NO_x emissions from residential heating

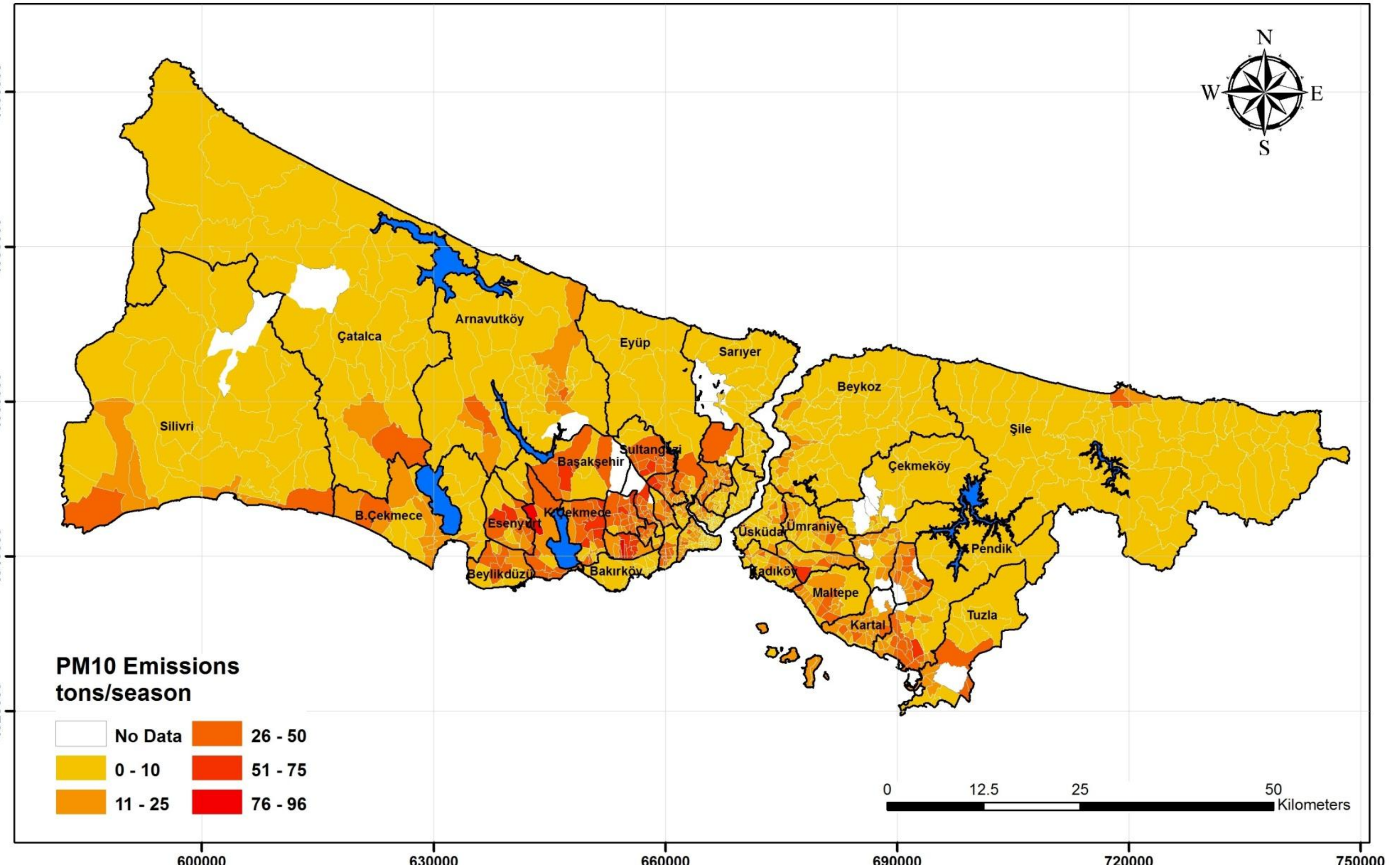

Figure 5.16 Spatial distribution of seasonal PM_{10} emissions from residential heating

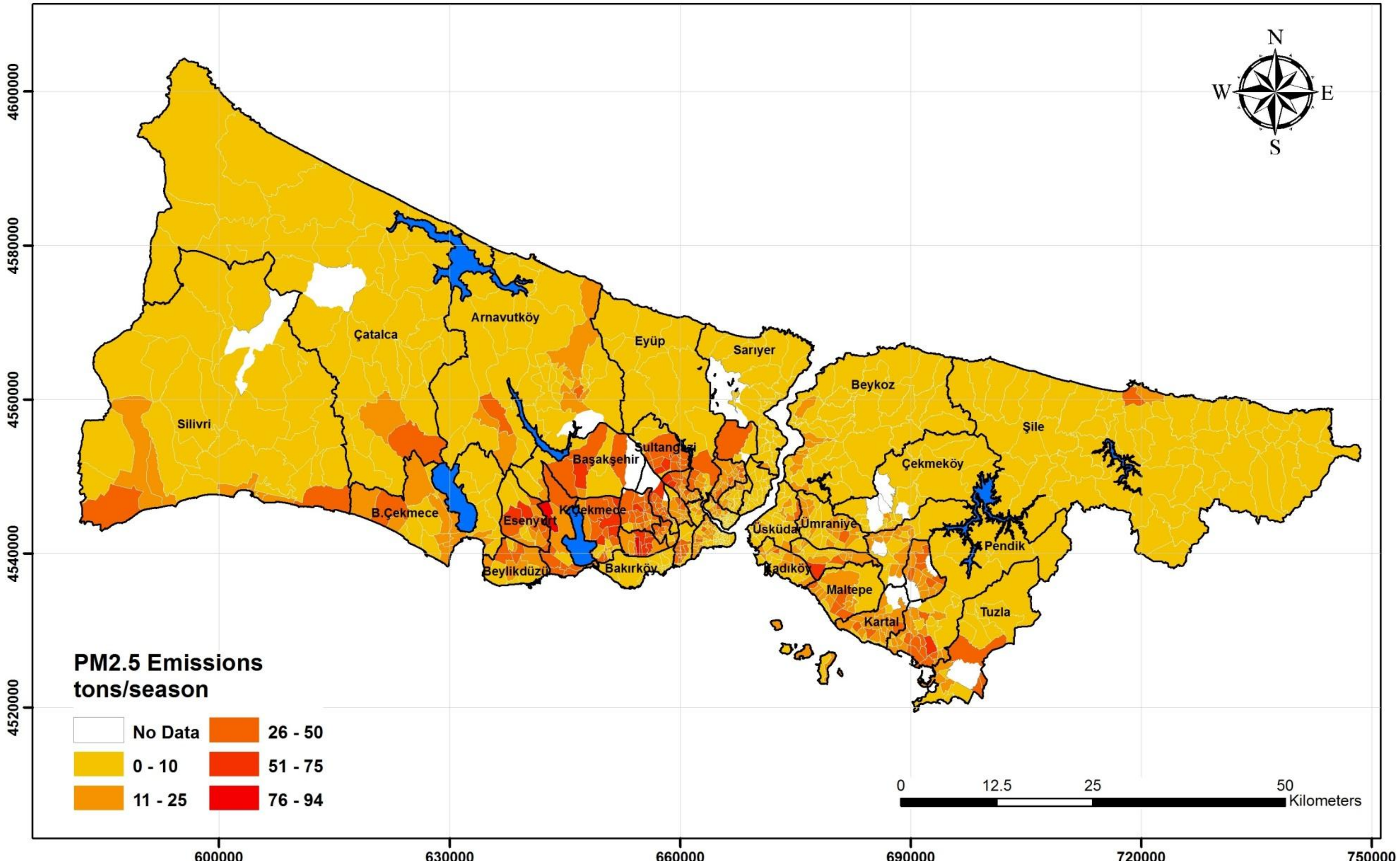

Figure 5.17 Spatial distribution of seasonal $PM_{2.5}$ emissions from residential heating

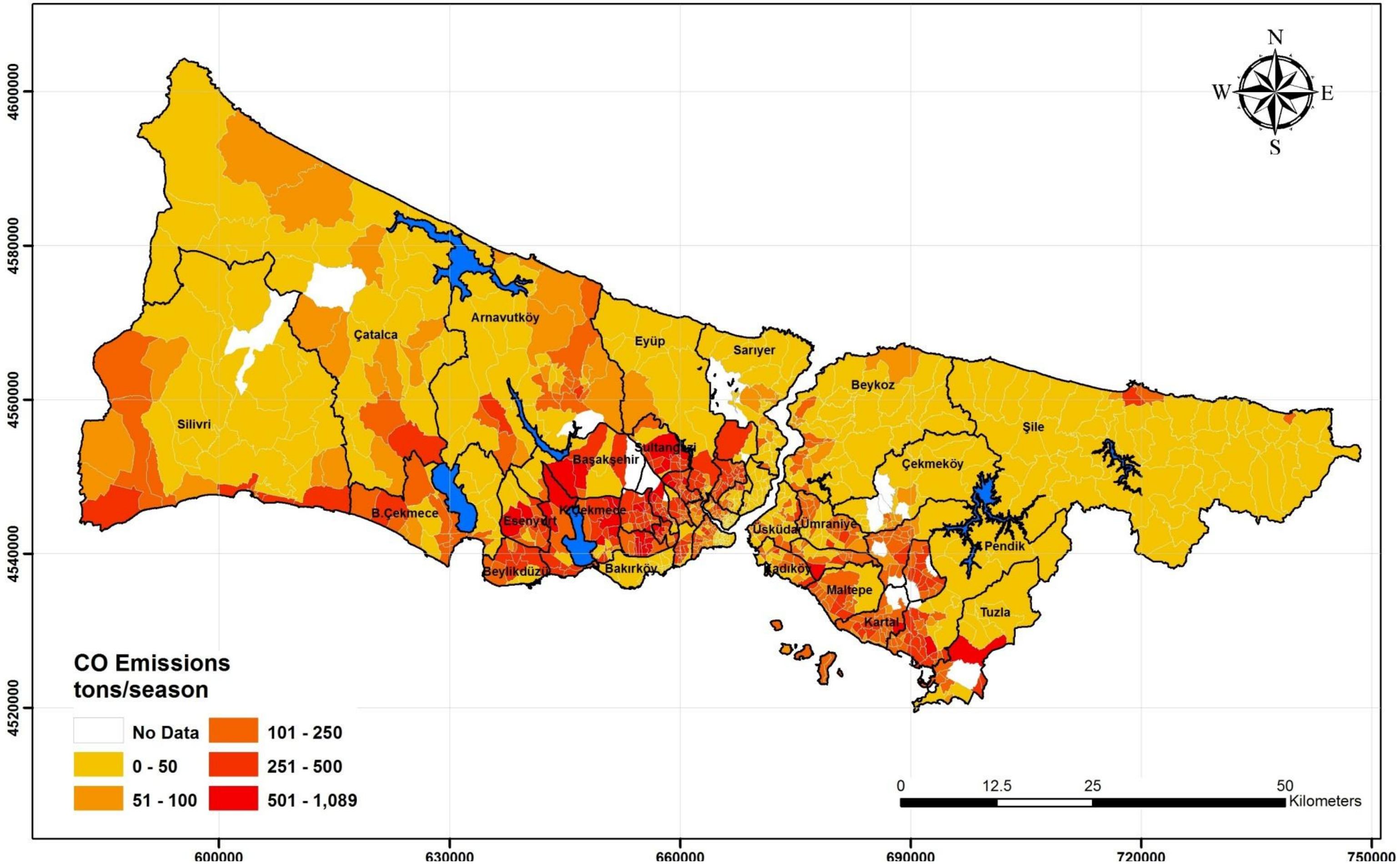

Figure 5.18 Spatial distribution of seasonal CO emissions from residential heating

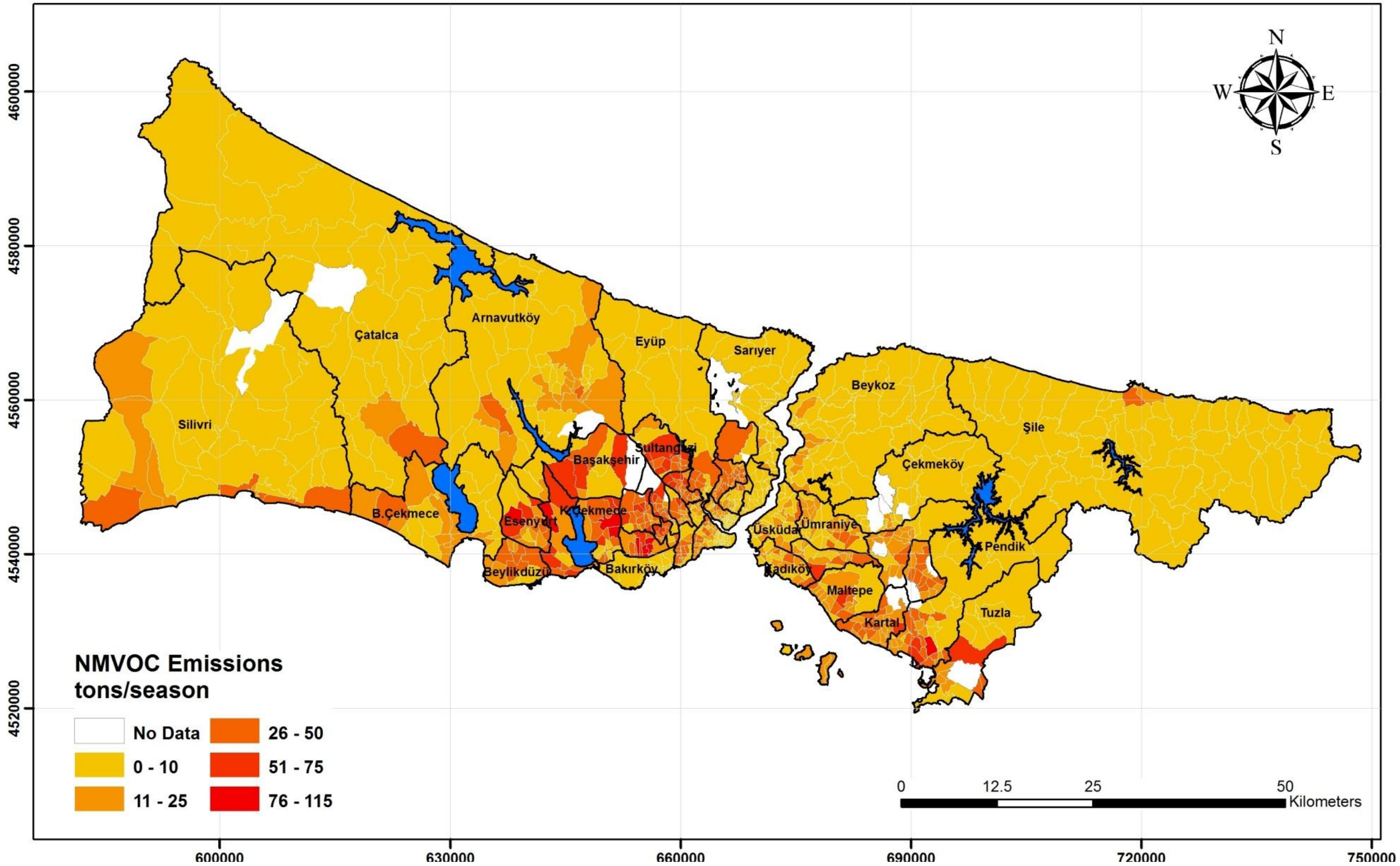

Figure 5.19 Spatial distribution of seasonal NMVOC emissions from residential heating

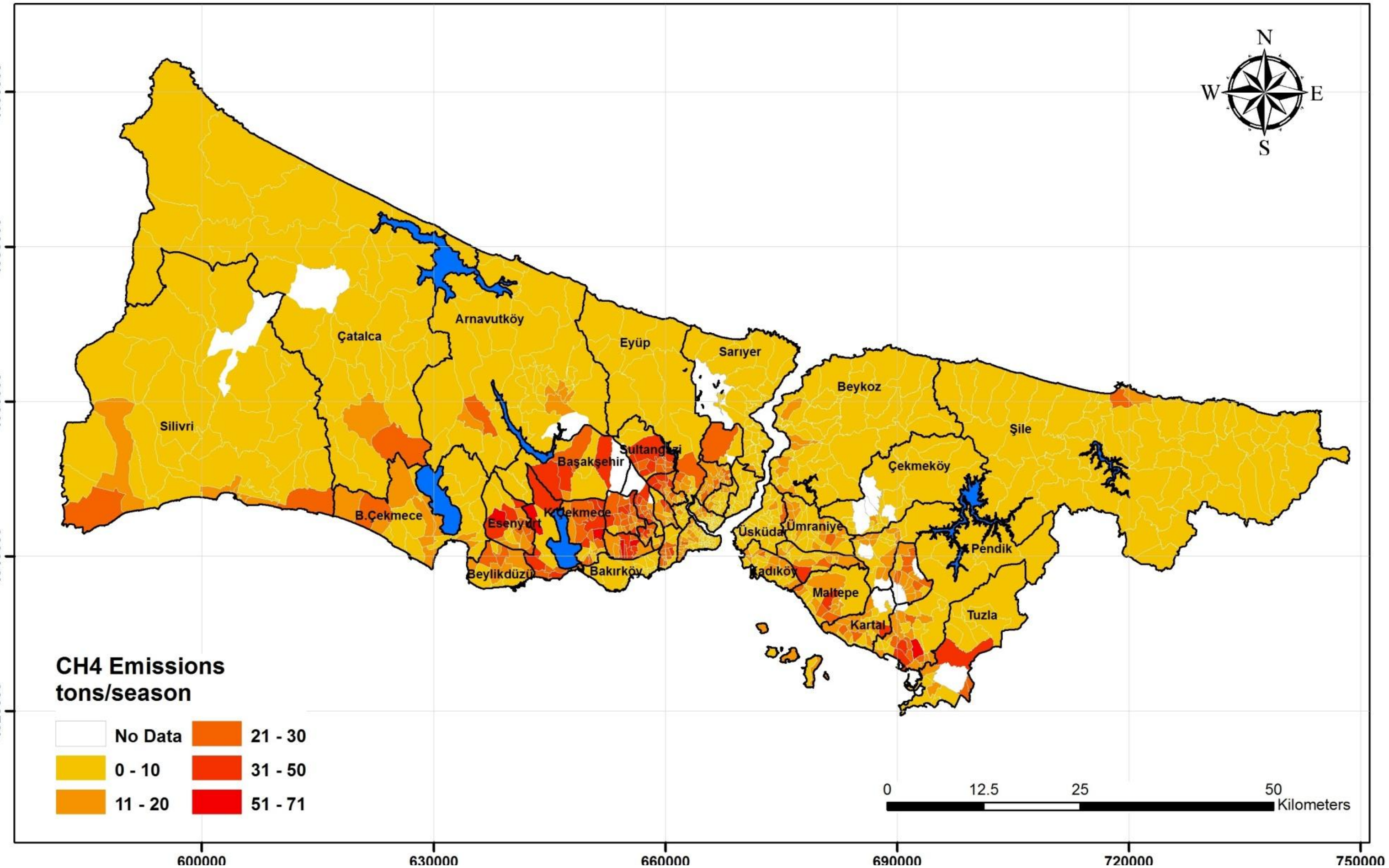

Figure 5.20 Spatial distribution of seasonal CH_4 emissions from residential heating

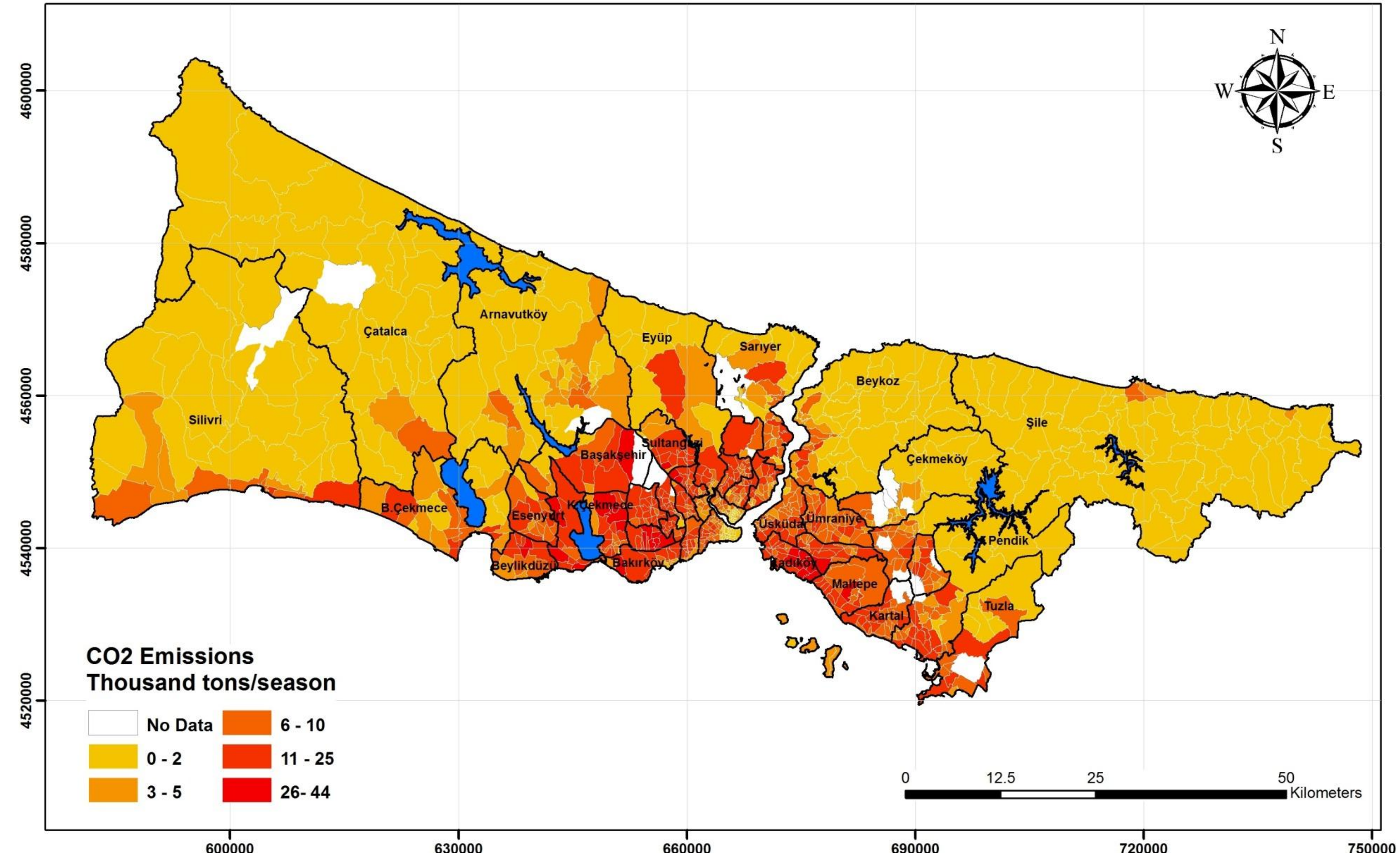

Figure 5.21 Spatial distribution of seasonal CO_2 emissions from residential heating

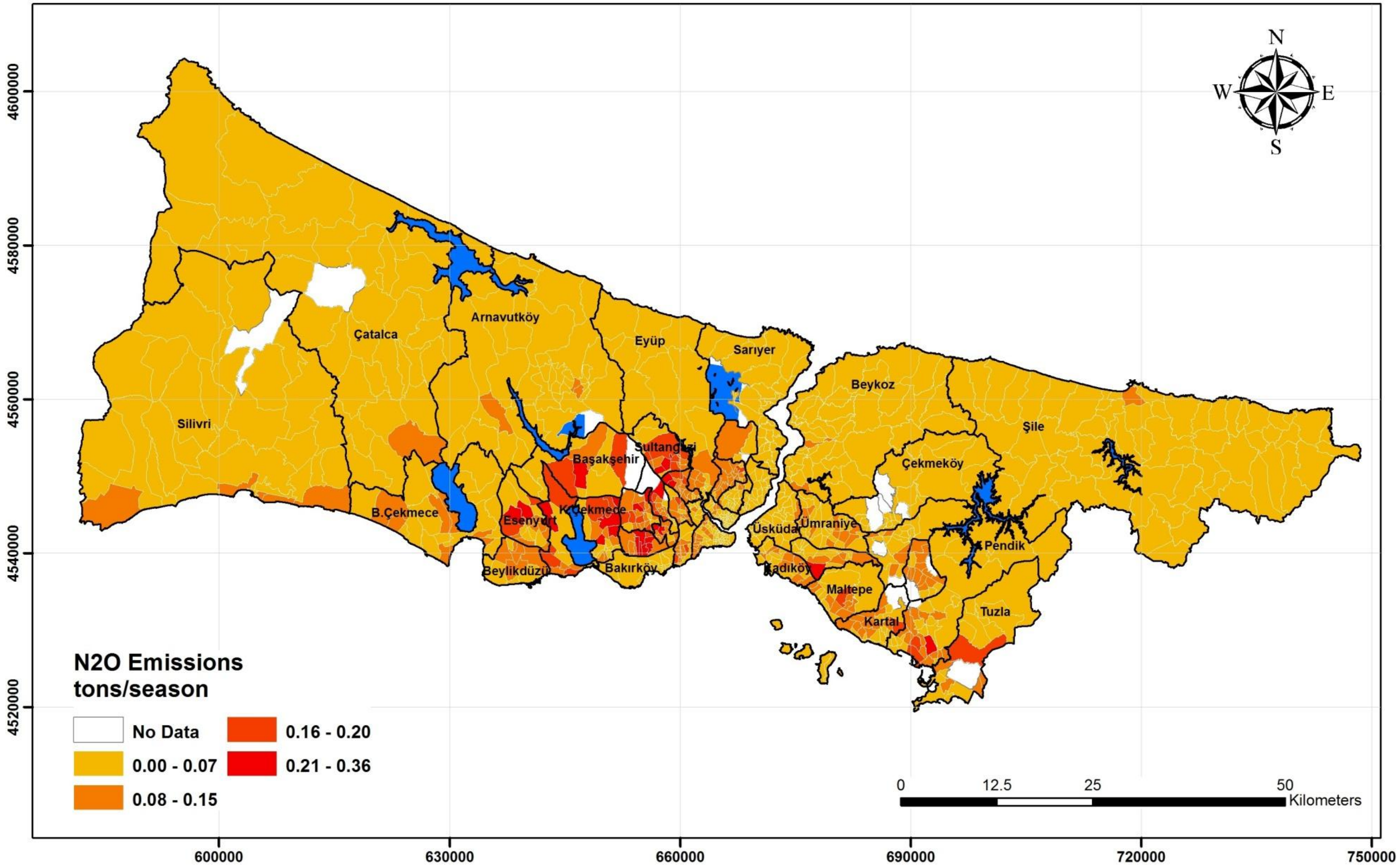

Figure 5.22 Spatial distribution of seasonal N_2O emissions from residential heating

Results of this study were compared with the results of a previous study (Elbir et al., 2009). Elbir and colleagues prepared an emission inventory in Istanbul for the year 2007 and estimated emissions as 10,893 tons/season for SO_2, 13,631 tons/season for PM_{10}, 7,014 tons/season for NO_2, 123,510 tons/season for CO and 18,351 tons/season for NMVOC (Elbir et al., 2009). The estimated emissions of all pollutants except PM_{10} and NMVOCs in this study are higher than the emissions from the previous study. Elbir selected four types of fossil fuels such as; natural gas, lignite, wood and fuel oil. Natural gas, lignite, wood and fuel oil consumptions were 2,481,530,566 m^3/season; 942,520; 1,040,517 and 73,250 tons/season, respectively. Natural gas, lignite consumption and residence numbers (ISKI and IGDAS) in 2007 were lower than natural gas, lignite consumption and residence numbers in 2010. In 2007, PM_{10} and NMVOC emissions were high, because there was usage of an additional fuel type (wood). In this study, emission factors for natural gas was also smaller than the previous study and just the opposite emission factors for lignite was bigger. Briefly, emission estimation method, fossil fuel types, fuel consumptions and emission factors used in these two studies were different.

For the city of Istanbul, Markakis et al. (2012) prepared an emission inventory covering all pollutant source categories (residential heating, traffic and industry) for the winter of 2007. USEPA emissions factors were used to estimate the emissions. The total annual emissions in this study were 13,369; 6,513; 4,286; 4,273; 47,399 and 2,011 tons/year for SO_x, NO_x, PM_{10}, $PM_{2.5}$, CO and NMVOC, respectively (Markakis, 2012). These emissions were lower than our estimated emissions due to different fossil fuel types, consumption of fuels, estimation method and different emission factors for the years of 2007 and 2010. In this previous study, the average consumption of lignite per capita in Istanbul was estimated as 0.1 tons/year and 386 m^3/year for natural gas. In 2010, the fossil fuel consumptions per capita consumed as approximately 0.42 tons/season for lignite and 203 m^3/season for natural gas.

Sari (2011) prepared an emission inventory for residential heating in Izmir, third biggest city of Turkey, for the winter of 2008-2009. Izmir had 3,276,815 population (TUIK,2007). This value was smaller than population of Istanbul (27%). USEPA emission factors were used for estimation of SO_2, NO_x, PM_{10}, CO and NMVOC. USEPA, CORINAIR and IPCC emission factors were used for estimation of greenhouse gasses. In this study, 74%, 6% and 20% of total residences used lignite, natural gas and the other energy sources (electricity, geothermal energy, etc.), respectively.

CHAPTER SIX
CONCLUSIONS

A local emission inventory of residential heating was carried out within an area of 170 km by 85 km centered at the metropolitan area of Istanbul. For calculation of emissions CORINAIR and IPCC emissions factors were mainly used. Nine major pollutants including greenhouse gases consisting of SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, VOCs, CO_2, N_2O and CH_4 emitted from residential heating sources were identified. Spatial distribution maps of emissions of these pollutants were also plotted by a GIS.

The inventory showed that the main energy source in the city for heating purposes is natural gas. The residences of 3,719,382 using natural gas were available in Istanbul, although the residences of 988,696 used lignite as energy source. The calculated fossil fuel consumptions indicated that each residence consumed approximately 1.25 tons/season. Two types of lignite were used in the city; imported lignite (79%) and local lignite (21%). It was calculated that each residence consumed approximately 609 m^3/season natural gas.

Istanbul was highly contributed to national emissions calculated in a previous study focusing national climate change in Turkey (CCNIR, 2007) . The results of our study show that about 17% of total SO_2 emission and 15% of total NO_x emission belong to the city of Istanbul.

As a suggestion, high quality lignite which has lower sulfur and ash content has to be used and usage of the natural gas must be grow up. This study should be also upgraded by higher quality data, when available Lignite consumption of districts and neighborhoods were not known exactly, so they were estimated in this study. Questionnaires must be applied to residences in different regions to have better data about lignite consumption. Some measures must be taken to reduce future emissions. These measures are mainly makinge heat insulation of buildings, use of central combustion systems and emission control systems.

Emission inventory prepared for the city of Istanbul should be updated and checked regularly for future projects. The results of the future emission inventories could be improved by having better quality data for fossil fuel consumptions in all districts.

Consequently, according to the results of this study, local administrations could prepare an action plan and emission models for air pollution abatement in residential areas. In addition all present outputs of this study such as the results and maps of emission inventory can be used to determine the locations and estimate the effects of the new residential areas that will be established in the city.

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