ISTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

QUANTIFICATION OF RESIDENTIAL HEATING EMISSIONS IN ISTANBUL VIA CMAQ AIR QUALITY MODEL

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ★AVRASYA YER BİLİMLERİ ENSTİTÜSÜ

İSTANBUL' DAKİ EVSEL ISINMA KAYNAKLI EMİSYONLARIN CMAQ HAVA KALİTESİ MODELİ KULLANILARAK İNCELENMESİ

YÜKSEK LİSANS TEZİ

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MAYIS 2016

Elvin ÖKSÜZ, a M.Sc. student of ITU Eurasia Institute of Earth Sciences 601121007 successfully defended the thesis entitled "QUANTIFICATION OF IMPACT OF RESIDENTIAL HEATING EMISSIONS IN ISTANBUL VIA CMAQ AIR QUALITY MODEL", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To all my family,

FOREWORD

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May 2016 Elvin ÖKSÜZ

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ABBREVIATIONS

APHEA : Air Pollution and Health: a European Approach
CMAQ :Community Multiscale Air Quality
CO : Carbon monoxide
EEA : European Environmental Agency
EF : Emission factor
EMEP : European Monitoring and Evaluation Programme
EPA : Environmental Protection Agency, USA
EPDK : Republic of Turkey Energy Market Regulatory Authority
EU : European Union
GAINS : The Greenhouse Gas and Air Pollution Interactions and Synergies
HEDDUs : High Electricity Demand Day Units
IIAS : International Institute for Applied Systems Analysis
IOA : Index of agreement
MACC : Monitoring and Atmospheric Composition and Climate
MB : Mean bias
NMB : Normalized mean bias
NMVOC : Nonmethane volatile organic compound
NO : Nitric oxide
NO_2 : Nitrogen dioxide
NO_x : Nitrogen oxides
NSPS : New Source Performance Standards
O_2 : Oxygen
PM : Particulate matter
PM_{10} : Particle matter less than or equal to 10 micrometers in diameter
$PM_{2.5}$: Particle matter less than or equal to 2.5 micrometers in diameter
r : Correlation coefficient
RMSE : Root mean square error
SNAP : Selection of Nomenclature for Air Pollutants Prototype
SO_2 : Sulphur dioxide
SO_x : Sulphur oxides
TKI : Turkey Coal/Lignite Enterprise
TMoEU : Turkish Ministry of Environment and Urbanization
TNO : Netherlands Organization for Applied Scientific Research
USA : United States of America
WRF : Weather Research & Forecasting Model

SYMBOLS

GJ	:	Gigajoule
$kcal$	:	Kilocalorie
kg	:	Kilogram
kW	:	Kilowatt
μm	:	Micrometer
mm	:	Milimeter
nm	:	Nanometer
ppm	:	Part per Million

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QUANTIFICATION OF RESIDENTIAL HEATING EMISSIONS IN ISTANBUL VIA CMAQ AIR QUALITY MODEL

SUMMARY

Istanbul is the most populated city of Turkey as well as Europe. The population is over than 14 million. The city is economical center of the country. Labour and social opportunities makes the city attractive to live and this situation causes inevitable increasing on urbanization of the province. According to authorities, it is expected that the population will be over 16 million in 2030. Due to high population, house holding is also increasing. Distribution of buildings is expending over the city. Residential heating is the main requirement of the people in cold, winter season. By the high population and urbanization, residential heating emissions significantly affects air pollution over the city. Results of many epidemiological studies proves that air pollution causes negative impact on cardiovascular and respiratory system, serious diseases such as cancer and hearth attack. Especially for sensitive people such as elders, children, babies or pregnant the effects may be higher and vitally important.

This study aims to examine residential heating impact over Istanbul city by atmospheric modelling. For this purpose WRF (Weather Research and Forecasting) meteorology model and CMAQ (Community Multiscale Air Quality) chemistry and transport model was applied. The first step was preparing emission inventory as input of the model. More complete and current emission inventory provides more trustable outputs. Residential heating emissions are generated with activity data and emission factor. The calculated emissions are also compared with TNO and EMEP emissions.

Another purpose of this study was developing region specific emission factors of residential heating for Istanbul. The main fuels which are commonly used in the city are determined and combustion system is analysed. Residential heating is commonly supplied from natural gas and solid fuels such as coals and wood. The coals are classified as domestic and import coal. The fuels were burned in conventional stoves that is commonly used individual combustion system in Istanbul and pollutant concentrations are measured. The measurements for solid fuels were continuous and the concentration values of each pollutants are reported minutely. For natural gas, individual combustion system was combi and concentrations were measured instantaneously. Combustion systems, burning efficiency and calorific values of the fuels are essential for burning regime and pollutant concentrations. Moreover, fuel consumption per unit time is a critical parameter for emission factor calculation. By considering all these parameters and concentrations emission factors are calculated for each fuels and pollutants. The main pollutants of this source are SO_x, NO_x, CO, PM_{10}. Moreover, uncertainties of region specific emission factors that are calculated with continuous measurements are evaluated for solid fuels. Statistical methods are used in order to quantify the factors. Both parametric and non-parametric bootstrapping

techniques applied and many distribution fitting models and related diagnostics were applied in the study.

The emissions via using calculated region specific emission factors and WRF meteorological model outputs were used as input of CMAQ. The study episode was three months that is from December 1, 2009 to February 30, 2010. As reference case CMAQ model is applied with TNO inventory and then the model is run for the same episode with new emission inventory that is updated with calculated residential emissions. The difference of concentrations between two model outputs provide to understand contribution of the revised residential emissions over the city. The days and hours that have maximum concentration differences are determined as giving the highest response to the new inventory.

İSTANBUL' DAKİ EVSEL ISINMA KAYNAKLI EMİSYONLARIN CMAQ HAVA KALİTESİ MODELİ KULLANILARAK İNCELENMESİ

ÖZET

İstanbul Türkiye'nin ve Avrupa'nın en kalabalık şehridir.14 milyonu aşkın nüfusu ile ülkenin ekonomi başkentidir. İş ve sosyal yaşam imkanları şehri cazip kılarak önlenemez bir nüfus artışına sebep olmaktadır. Otoritelere göre 2030 yılında şehrin nüfusunun 16 milyonu aşması beklenmektedir. Populasyonun artmasıyla kentleşme ve konut sayısı da artmaktadır. Şehirdeki bina sayısı artmakta ve binaların dağılımı şehir içinde genişlemektedir. Populasyondaki ve dolayısıyla kentleşmedeki hızlı artış hava kirliliğinde de artışa neden olmaktadır. Özellikle kış aylarında hissedilen ve en temel gereksinimlerden olan ısınma ihtiyacı, artan konutlaşma ile birlikte hava kalitesini oldukça etkilemektedir.Epidemiyolojik çalışmalar hava kirliliğinin kardiyovasküler sistem ve solunum yolu üzerinde negatif etkileri olduğunu, kirliliğin kanser ve kalp krizi gibi ciddi hastalıklara sebep olduğunu kanıtlamıştır. Özellikle yaşlı, çocuk, bebek ya da hamile gibi duyarlılığı fazla olan hassas kişilerde kirliliğin sağlık etkisi daha fazladır.

Hava kirliliğinin ciddi ve negatif etkilerinden ötürü, hava kalitesinin yaşanılabilir seviyede olmasını sağlamak önemlidir. Nefes alınabilir bir atmosferde soluyabilmek için bölge, şehir ya da ülke bazlı hava kalitesi yönetiminin sağlanması gerekmektedir. Hava kalitesinin yönetimini sağlamak için ilk adım gözlem istasyonlarıdır. Bu istasyonlarda belli noktalarda ölçülen anlık kirletici konsantrasyonları elde edilebilir. Bu veriler seçilen istasyonda ölçülen atmosferdeki kirletici konsantrasyonlarının hava kalitesi için belirlenmiş kirletici limit değerlerinin altında ya da üstünde olduğu ile ilgili bilgi sağlayabilir. Fakat farklı meteorolojik ya da atmosferik şartlarda konsantrasyon değerlerinin nasıl değişeceğini belirlemek için ölçüm istasyonu değerleri yeterli olamamaktadır. Farkli senaryo analizleri ya da kaynak bazlı emisyonların seçilen bölge ve episod üzerindeki etkilerin incelenebilmesi için hava kalitesi modeline ihtiyaç vardır. Model sonuçları kullanılarak bölge üzerindeki hava kalitesi incelenebilir, etkili kaynaklar belirlenebilir ve karar vericiler bu sonuçları değerlendirerek emisyonları azaltıcı yaptırımlar uygulayabilirler.

Bu çalışma, evsel ısınmanın İstanbul ili üzerindeki etkisini atmosferik modelleme ile açıklamayı amaçlamaktadır. Bu yüzden, WRF (Weather Research and Forecasting) meteoroloji modeli ve CMAQ (Community Multiscale Air Quality) kimyasal taşınım modeli kullanıldı. Çalışmada ilk adım, modele girdi olarak verilen emisyon envanterini hazırlamaktı. Çünkü tamamlanmış ve güncel veriler ile hazırlanmış emisyon envanteri modele verildiğinde daha güvenilir model sonuçlarının elde edilmesi sağlanır. Emisyon envanteri noktasal, alansal, hareketli ve doğal kaynaklar olarak sınıflandırılır. Bu tezde alansal kaynaklar kategorisinde olan evsel ısınma kaynaklı emisyonları üzerinde çalışıldı.İlk olarak İstanbul için 10 farklı sektördeki emisyon kaynaklarını içeren TNO envanteri referans alınarak modele verildi. Bu envanter

SNAP kodları ile sınıflandırılmış enerji, evsel ısınma, endüstri, fosil yakıtların çıkarımı ve dağıtımı, ürün kullanımı, ulaşım, iş makinaları, atık, tarım emisyonlarını içeren kaynakları kapsamaktadır. Çalışmamızda, evsel ısınma emisyonlarını içeren SNAP2 sektörü emisyonları, İstanbul için sağlanan güncel aktivite verileri ve geliştirilen emisyon faktörleri ile hesaplanarak güncellendi. Bu tez çalışması Ulusal Hava Kİrliliği Emisyon Yönetim Sisteminin Geliştirilmesi Projesi (KAMAG) 'nin bir parçası olduğundan güncel verilerin sağlanması ve emisyon faktörü hesaplamak amacıyla çok sayıda ölçüm yapılması proje kapsamında gerçekleştirilmiştir.Daha sonra, TNO emisyon envanterinde İstanbuldaki sadece bu sektöre ait emisyonlar değiştirilerek, kaynağın şehirdeki etkisi incelendi. Ayrıca hesaplanan emisyonlar TNO ve EMEP emisyonları ile karşılaştırıldı, herbir kirletici için farklı envanterlerdeki farklar incelendi.

Bu çalışmanın diğer bir amacı da bölgeye özel emisyon faktörü belirlemektir. Bu amaçla İstanbul'da evsel ısınma amaçlı kullanılan temel yakıtlar ve yakma sistemleri belirlendi. Şehirde evsel ısınmada yaygın olarak doğalgaz ve kömür, odun gibi katı yakıtların kullanıldığı görüldü ve analizler bu yakıtlar üzerine yapıldı. Kömür yakıtlar yerli (yardımlaşma kömürü) ve ithal kömür olarak sınıflandırıldı. Katı yakıtlar için yakma sistemi genellikle bireysel konveksiyonel sobalar olduğundan, bu yakıtlar için ölçüm yapılırken bu sobalar kullanılmış ve kirletici konsantrasyonlarının değerleri ölçüldü. Katı yakıtlar için emisyon faktörleri birçok sebepten belirsizlik içerdiğinden bu yakıtlar için sürekli ölçüm uygulandı ve konsantrasyon değerleri dakikalık olarak kaydedildi. Doğalgaz için ise şehirde en yaygın olarak, bireysel kullanılan kombi sistemleri tercih edildi ve ölçüm sonuçları anlık olarak kaydedildi. Yakma sistemleri, yanma verimliliği ve yakıtların kalorifik değerleri yanma rejimi ve dolayısıyla kirletici konsantrasyonlarını önemli ölçüde etkilemektedir. Ayrıca birim zamanda yakılan yakıt miktarı da emisyon faktörü hesaplanmasından kritik bir parametredir. Bütün bu parametreleri ve ölçülen kirletici konsantrasyonlarını göz önüne alarak her bir yakıt ve en temel kirleticiler olan SO_x, NO_x, CO ve PM_{10} için emisyon faktörleri hesaplandı. Böylece evsel ısınma kaynaklı emisyonlar çalışılan alan olan İstanbul şehrine en uygun faktörler ile hesaplandı.

Ayrıca evsel ısınma için kullanılan küçük kapasiteli soba gibi sistemlerde yanma rejimi, verimliliği ve dolayısıyla baca gazı konsantrasyonları büyük endüstrilerdeki yanma sistemleri gibi az değişen yapıda değildir. Ölçüm sırasında kullanılan yakıt kalitesi, ortam koşulları, yanma sıcaklığı gibi birçok sebep oluşan anlık konsantrasyon değerlerini ve dolayısıyla hesaplanacak emisyon faktörlerinin değişkenliğini etkilemektedir. Bu sebeple, sürekli konsantrasyon ölçümleriyle hesaplanan emisyon faktörlerinin belirsizliğini anlayabilmek için, katı yakıtlara ait emisyon faktörleri üzerinde istatistiksel analizler yapıldı. Çalışmada hesaplanan emisyon faktörleri için birçok parametrik ve parametrik olmayan testler uygulanarak faktörlerin en uygun dağılım modelleri incelendi.

Bölgeye özel geliştirilen emisyon faktörleri kullanılarak hesaplanan yeni emisyon envanteri ve WRF meteoroloji modeli kullanılarak CMAQ kimyasal tanışım modeli çalıştırıldı. Çalışmada, kış aylarında evsel ısınmanın etkisinin görülebilmesi için episod Aralık 2009, Ocak ve Şubat 2010 olarak belirlendi. Referans olarak değerlendirmek için öncelikle TNO emisyon envanteri kullanılarak model çalıştırıldı ve sonrasında bizim evsel ısınma emisyonlarında değişiklik yaparak hazırladığımız emisyon envanteri kullanılarak aynı episod için model tekrar çalıştırıldı. Aradaki

konsantrasyon farkına bakıldı ve böylece envanterdeki değişimin etkisinin en yüksek olduğu günler ve saatler belirlendi.

1. INTRODUCTION

Rapid economic development and urbanization makes air pollution one of the most challenging environmental problems for public health. People migrate from rural areas to urban zones in order to get better economical and living conditions. However, human activities in urban areas such as transport, households, power plants, agriculture, waste treatment and industrial growth makes living conditions unbearable with increased levels of atmospheric pollution (Mayer, 1999).

Atmospheric pollution causes harmful effects and significant nuisances on the atmosphere, human and animal health or plant life. Although clean air is identified as one of the basic requirements of human well-being(WHO, 2006), air pollution remains to be one of the major health risks, even in developed countries.

There is now substantial scientific evidence that link air pollution and health problems. Epidemiological studies showed a strong correlation between particulate and sulfur dioxide concentrations in the atmosphere and potential risks of death, irritation, cancer and acute respiratory diseases. Especially in studies focusing on the impact of particulate air pollution on public health; findings reveal that increase in particulate matter concentrations triggers rise in the number of deaths from cardiovascular and respiratory disease among older people (Seaton, MacNee, Donaldson, & Godden, 1995; PopeIII, Bates, & Raizenne, 1995; Donaldson, Mills, MacNee, Robinson, & Newby, 2005). A $10\mu g/m^3$ increase in long-term average $PM_{2.5}$ concentrations causes approximately a 4 percent, 6 percent, and 8 percent increasing risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively (PopeIII et al., 2002). In a study conducted by (Silva et al., 2001) it has been found that globally and annually, 470,000 premature respiratory deaths occur due to anthropogenic ozone pollution.Same study also found that 2.1 million deaths are linked to anthropogenic $PM_{2.5}$ related cardiopulmonary diseases and lung cancer .

One of the critical epidemiological studies is APHEA-2 (Air Pollution and Health: a European Approach) (Atkinson et al., 1995), which was conducted in 29 European cities, covering over 43 million people for more than 5 years in the 1990s with an objective of identifying the impact of increased particulate matter (PM) levels on daily mortality and hospital admissions for asthma and chronic obstructive pulmonary disease (COPD). The results showed that all-cause daily mortality increased by 0.6 percent for $10\mu g/m^3$ increase in PM_{10}. APHEA-2 hospital admission study was conducted in 8 European cities, covering 38 million people. Hospital admissions for asthma and COPD were observed to be increased by 1 percent per $10\mu g/m^3$ increase in PM_{10} among older people (65+) (Katsouyanni et al., 2001). In other studies, the range for increase in all-cause daily mortality is between 0.6 and 1.2 percent per $10\mu g/m^3$ increase in PM. (Pope & Dockery, 2006).

Although long-term effect studies are not as numerous as the short-term effect studies, there are over 30 publications on this subject. As summarized by (Pope & Dockery, 2006), the range for all-cause mortality rates is between 1 and 17 percent per $10\mu g/m^3$ increase in $PM_{2.5}$. For cardiopulmonary mortality rates this range is between 5 and 42 percent and for lung cancer it is between 0.8 and 81 percent.

In other studies, relation between air pollutants and reduced growth in children were analyzed. (Guaderman et al., 2000) found that fourth graders who are exposed to PM, NO_2 and inorganic acid vapors, showed significant reduction in growth of lung function. Deficits were found to be higher for children spending more time outdoors. In a study conducted by (Avol et al., 2001), children who relocated to areas of lower PM_{10} showed increased growth in lung function whereas children who live in areas with high PM_{10} show decreased growth in lung function. The authors concluded that changes in air pollution exposure during growth years have a significant impact on lung function growth and performance.In another study, (Perera et al., 2009), monitored children from birth till 5 years of age and showed that children in high exposure group had full-scale and verbal IQ scores that were 4.31 and 4.67 points lower, respectively, than those of less-exposed children.

Regulatory agencies setup air quality standards in order to protect public health. Air quality standards are limits on the quantity of pollutants in the atmosphere that are not to be exceeded during a given time period in a defined area. Although the threshold

Table 1.1 : European and Turkish Limit values. (* Date of EU Values will be valid for Turkey)

Pollutant	**Time**	**Limit Value of Turkey 2015**	**Limit Value of EU**	*
SO_2	Hourly	470	350	1.1.2019
	Daily	225	125	
	Warning Limit (3 consequence hours)	500	500	
	Hourly exceeding time	-	24	
	Daily exceeding time	-	3	
	Annually (ecosystem)	20	20	1.1.2014
PM_{10}	Daily	90	50	1.1.2019
	Annually	56	40	
	Daily exceeding time	-	35	
NO_2	Hourly	290	200	1.1.2024
	Annually	56	40	
	Warning Limit (3 consequence hours)	400	400	
	Hourly exceeding time	-	18	
NO_x	Hourly	30	30	1.1.2014
CO	8 hours average	14	10	1.1.2017
O_3	8 hours average	120	120	1.1.2002
	Hourly information limit	-	180	
	Hourly warning limit	-	240	

level varies in different countries, the main purpose of the standards stays the same. Table 1 shows the European Union (EU) and Turkish Ministry of Environment and Urbanization (TMoEU) authorized limit values for the considered pollutants both in long and short-term periods. As seen in Table 1, in general the standards for TMoEU follow the EU standards with a time lag. For example, the 24 hour average standard value for PM_{10} in EU is $50 \mu g/m^3$ where as the current TMoEU standard is $90 \mu g/m^3$ and the date to implement the EU standard is 1/1/2019.

1.1 Air Quality Management (AQM)

As indicated by European Environment Agency (EEA), 97.2 percent of the urban population in Turkey is exposed to unhealthy levels of PM_{10} that is higher than $50 \mu g/m^3$ in 2012 (European Environment Agency (EEA), 2014). Air quality management systems and regulations are setup in order to decrease the high concentrations of

pollutants and achieve cleaner air quality levels. The steps of an AQM system can be summarized as given in Figure 1.1.

Figure 1.1 : Air quality management pyramid.

The first step in AQM is air quality monitoring. One has to measure ambient pollutant concentrations and observe whether pollution levels violate air quality standards or not. In Turkey, TMoEU has an air quality monitoring network of 195 stationary and 4 mobile stations. Mobile stations are used in determined time as integrated with the observation systems for regions where have air quality problem temporarily to report the pollution (shown in Figure 1.2).

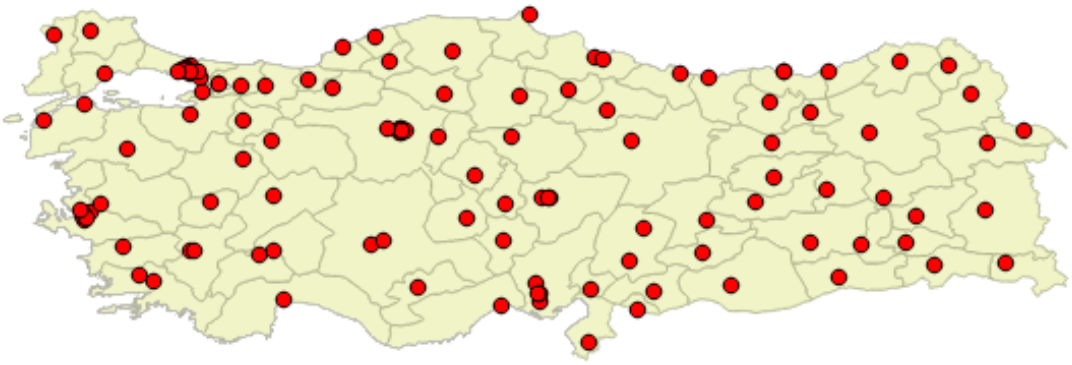

Figure 1.2 : Air quality observation stations network in Turkey.

While most cities generally have only one station, cities with high population such as Istanbul, Ankara, Izmir have more than one station (i.e., 26, 8, 8 stations respectively). These stations are being used to monitor air quality for different pollutants. At every station PM_{10} and SO_2 are measured while some stations have NO, NO_2, NO_x, CO and O_3 monitoring (Ministry of Environmental and Urbanization, 2015). As an

example, daily average PM_{10} measurements between 01.01.2009 and 4.30.2015 are presented in Figure 1.3. As seen in figure, the PM_{10} measurements range between 23.5 and 175$\mu g/m^3$ with an overall average of 63.03$\mu g/m^3$ and standard deviation of 23.67$\mu g/m^3$. Overall there is a decreasing trend in PM_{10} concentrations, having much higher observations during 2009 and 2010 as compared to 2014 and 2015. It should be noted that significantly high PM_{10} concentrations occur during winter months. The winter months has an overall average of 79.45$\mu g/m^3$ whereas the average value for the fall, spring and summer is 65.54, 56.47, 49.98$\mu g/m^3$ respectively. Although these seasonal average values are below Turkish standards, they are high as compared to the EU standard of 50$\mu g/m^3$ (Figure 1.3). This finding suggests that significant mitigation efforts are needed to lower PM_{10} concentrations in Turkey.

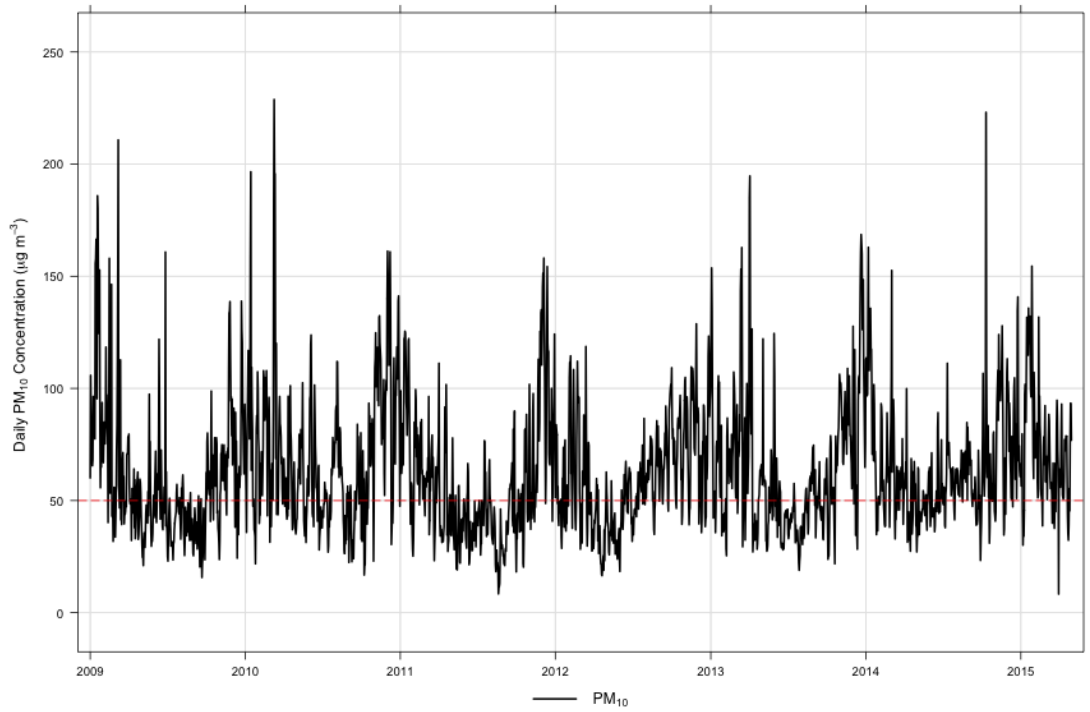

Figure 1.3 : Daily Average PM_{10} measurements for Turkey between 01/01/2009 and 4/30/2015.

A critical step in finding the right mitigation measure is to develop an extensive inventory of emission sources. An emissions inventory is a summary of emissions discharged to atmosphere by a group of sources in a specified area and time period. It provides quantitative understanding of actual emissions and the contribution of particular sectors. The major source groups that cause high contribution to air pollution can be identified leading to policies to reduce their impact.

Table 1.2 : Sectors of TNO inventory.

Codes	Sectors
S1	Combustion in energy and transformation industries
S2	Non-industrial combustion plants
S3	Combustion in manufacturing industry
S4	Production processes
S5	Extraction and distribution of fossil fuels and geothermal energy
S6	Solvent and other product use
S7	Road transport
S8	Other mobile sources and machinery
S9	Waste treatment and disposal
S10	Agriculture

Man made (i.e.anthropogenic) emissions originate from either stationary or non-stationary sources which are classified as point, area, mobile. Point sources are single sources of origin that have individually high impact on air pollutant discharge. Major stationary industrial facilities, power plants are included among point emission sources. Area source emissions are spread over an area. In addition, they represent emissions that are comprised by many small point sources located together, which have individually ignorable but cumulatively has significant effect on air pollution. Emissions originated from mobile sources are non-stationary such as on-road vehicles, aircraft, locomotives etc.

There are global efforts to develop regional emission inventories. TNO (Netherlands Organization for Applied Scientific Research) emission database is one of these efforts. TNO emission inventory which is developed to support EU FP7 Monitoring and Atmospheric Composition and Climate (MACC) project, is prepared according to snap sectors. The database is based on official country reported data (from EMEP database), IIASA GAINS model outputs and expert estimates for the years between 2003 and 2007. The emissions data from TNO database for Turkey is provided in Figure 1.4 below. Pollutants are emitted from different sectors. As is it seen in Figure 1.4, according to TNO inventory, the main source of NOx and NMVOC is road transport. CO is a pollutant, which is known as a product of incomplete combustion. In the figure, the major source of CO seems as non-industrial combustion plants and road transport, NH_3 is mainly emitted from agricultural activities. According to TNO inventory, SO_2 is mainly caused from combustion in energy and transformation industries. In Turkey

since solid fuel combustion is the main source for residential heating, emissions from non- industrial combustion sector is expected high, however this sector (S2) does not play a great part in the figure as source of SO_2. As different from developed European countries and USA, residential heating emissions have significant effect on SO_2 and particulate matter emissions because of extensive usage of poor quality and environmentally hazardous fuels. Quantification of spatial impact of a source is possible with air quality modeling.

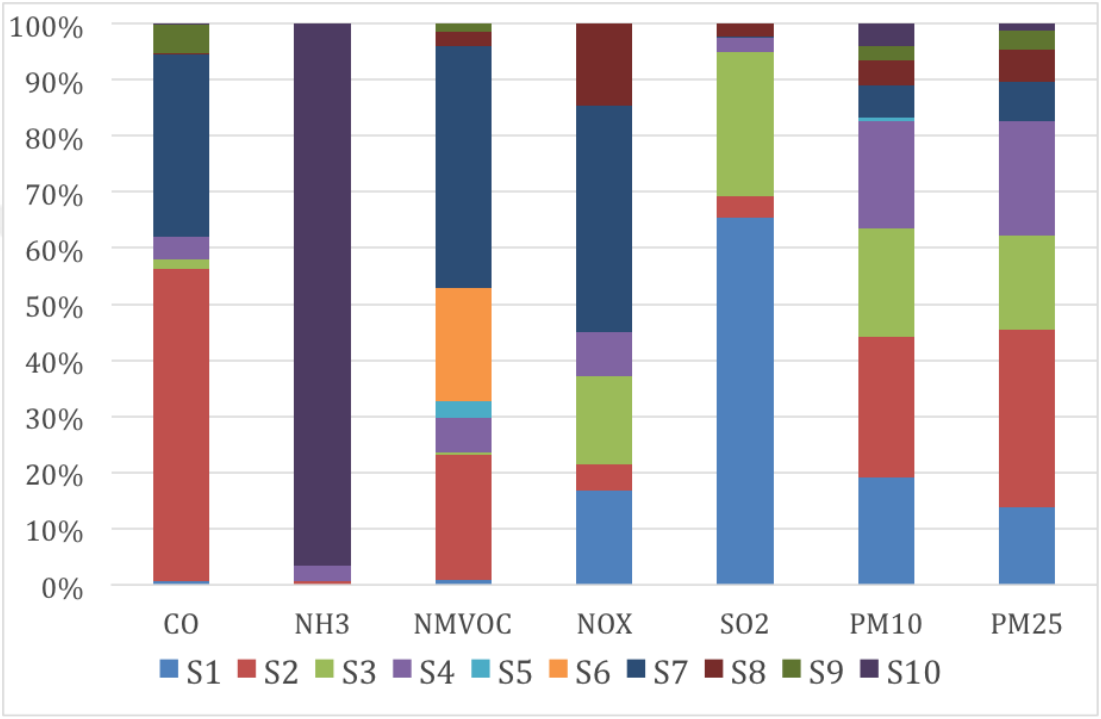

Figure 1.4 : Sectorial distribution of pollutants in TNO inventory.

The third step of air quality management is air quality modeling. Air quality models are mathematical representations of atmospheric phenomenon (such as advection, diffusion, etc.). Eulerian air quality models require emissions data along with meteorological data over a gridded domain. These models were first developed in the early 1970s and have been improved since that time. The developments are summarized by (Tesche, 1983; Seinfeld & Pandis, 1998).Community Multiscale Air Quality (CMAQ) model is one of the most widely used air quality models. CMAQ model is used by USEPA to understand the sources of air pollution in USA and test the effect of mitigation measures. For example, having lower emission standards for High Electricity Demand Day Units (HEDDUs) was tested by the State of New Jersey using CMAQ modeling system (Unal, 2003).

Emission inventories are used in conjunction with meteorological data to assess priorities for air quality as air quality model inputs. Meteorological data that is used in meteorological model solves equations to managing fluid dynamics of the atmosphere and radioactive transfer. Outputs of the meteorological models are used in air quality model as an input. Many scientific studies have shown that inputs of air quality models have significant effect on model outputs and preparing high quality inputs are important for the obtain better results (Russell & Dennis, 2000; Hanna et al., 2001).

In Figure 1.5, schematic explanation of monitoring air quality system is shown. In order to reach air quality goals, there is a need a systematic air quality management. For this purpose, better understanding spatial distribution of pollutants via an air quality model and identify role of each emission sources are fundamental.

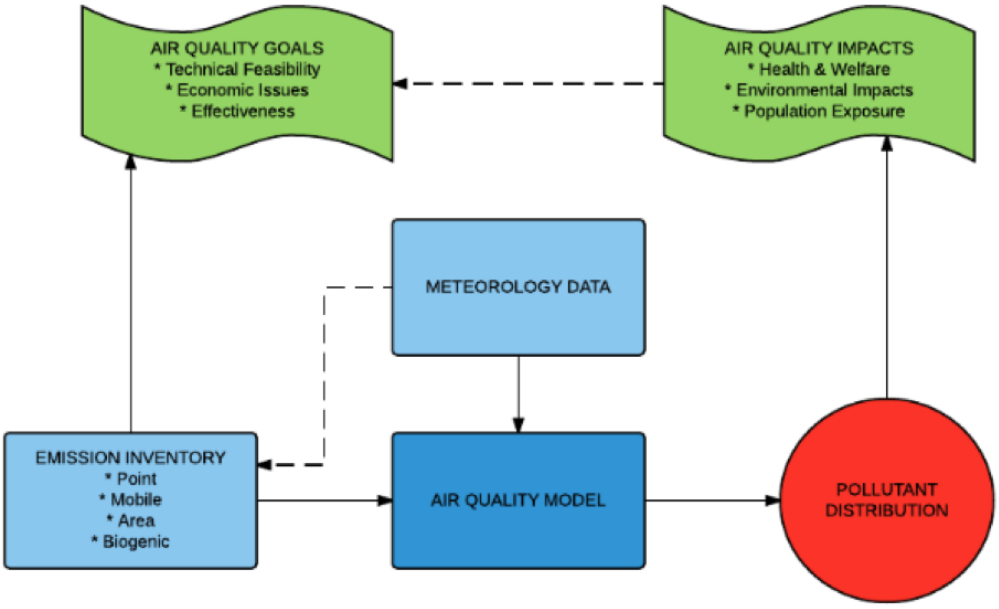

Figure 1.5 : Air quality management system.

1.2 Area Emissions

Area sources are stationary emission sources that are not identified individually as different from point sources. Area sources individually do not emit significant amount of pollutants but they are groups of numerous small sources and collectively make appreciable contribution to the emission inventory (Claire, Dinh, Fanai, Nguyen, & Schultz, 2010).According to US Environmental Protection Agency (EPA), area sources emit less than 10 tons per year of a single hazardous air pollutant, or less than 25 tons

per year of a combination of hazardous air pollutants. The impact of the small-scale emissions is perceived particularly in heavily populated areas where large numbers of sources exist.

Area sources include but are not limited to:

- Stationary small scale fuel combustion; (e.g. residential heating by coal, wood, natural gas, biomass combustion)
- Solvent use (e.g. small surface coating operations)
- Product storage and transport distribution (e.g. gasoline)
- Agriculture (e.g. feedlots, crop burning, tilling)
- Waste management (e.g. landfills)
- Miscellaneous area sources (e.g. forest fires, wind erosion, unpaved roads)
- Excavation area
- Mining
- Industrial fuel combustion in Organized Industrial Zone

Emissions from residential heating have a significant impact on air quality for Marmara region of Turkey due to high population and rapid growth. Measurement results show that during winter seasons there is a prominently increasement in air pollution concentration that is mostly attributed to the burning of solid fuels such as coal, wood and biomass for residential heating.

Air quality guidelines and standards for especially particulate matter less than 10 microns (PM_{10}) are exceeded at this time of the year, as a consequence of increased emission loads and the presence of temperature inversions.(Im et al., 2010)

Although home heating is basic requirement for people, it contributes significantly to particulate matter emissions, and volatile organic compound (VOC) emissions, which are precursors to the ground-level ozone (Atkinson & Arey, 2003).Most of residential heating sourced emissions derive from poor combustion of fuels or low quality fuel usage. Economical condition is the most dominant reason of inadequate access to clean fuels and high technologies on combustion system. Especially in developing countries solid fuel consumption is commonly used for home heating instead of clean fuels and this consumption causes highly negative effects to the atmosphere. In Turkey solid fuels are the main fuel for primary heating, while more than 80 percent of the

housing stock is connected to the natural gas network (TurSEFF, 2014). Poland and Turkey are the countries that are using highest amount of solid fuels for household energy consumption. In these countries, 30 percent of household energy consumption provided by solid fuels (Raudjärv & Kuskova, 2013) .

Some studies prove the significant impacts of the fuel usage on emissions and correspondingly public health.The ban on marketing, sale, and distribution of bituminous coals burning in Dublin (Ireland) in the 1990s effected pollutant concentrations substantially. The ban resulted in reduction of average black smoke concentrations by 71 percent and sulfur dioxide by 34 percent in Dublin. Moreover, mortality rate that is related with cardiovascular and respiratory system diseases is decreased by 7 percent and 13 percent, respectively in the city (Clancy, Goodman, Sinclair, & Dockery, 2002).

As conclusion of literature review, there are not many detailed study found in Turkey about impact of residential emissions over a region. "Inventory of emissions from residential heating in Istanbul" is MSc. thesis of (Sabit, 2012). In the study, residential heating sourced SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, NMVOCs, CO_2, N_2O and CH_4 emissions in Istanbul are calculated by emission factors for the period of 2009-2010 winter season. Geographical Information System (GIS) is used to spatial distribution of the emissions over the region. Another recent study is MSc. thesis of (Durukan, 2014), which is titled as "Spatial Distribution Of Emissions From Industrial And Residential Heating Systems Using Geographic Information System For Turkey". In the study, emissions emitted from industrial, residential heating and power plants were considered and GIS is used for spatial distribution of the emissions over Turkey. Although both in these studies residential heating emissions were calculated, air quality model was not applied to quantify impact of the emissions in based on pollutants.

This study aims to develop region specific emissions factors that are generated by fuel burning for residential heating in Istanbul as well as EPA and EMEP factors. By using the developing factors, more representative residential heating emissions were calculated for the city and the emissions were used as input of Community

Multi-Scale Air Quality (CMAQ) Modeling System in order to identify impact of residential heating emissions with region-specific factors over the Istanbul city.

2. DATA & METHODOLOGY

2.1 Study Area

Istanbul which is the most populated city in Turkey is selected as study area for this study. It is also the most densely populated city in Europe and the 15th most populated city in the world with a population more than 14 million in 2014. The Average annual rate of population change of Istanbul is 2.2 percent between 2010 and 2015. According to United Nations expected population of the city will be 16,694,000 in 2030. (United Nations, 2014)

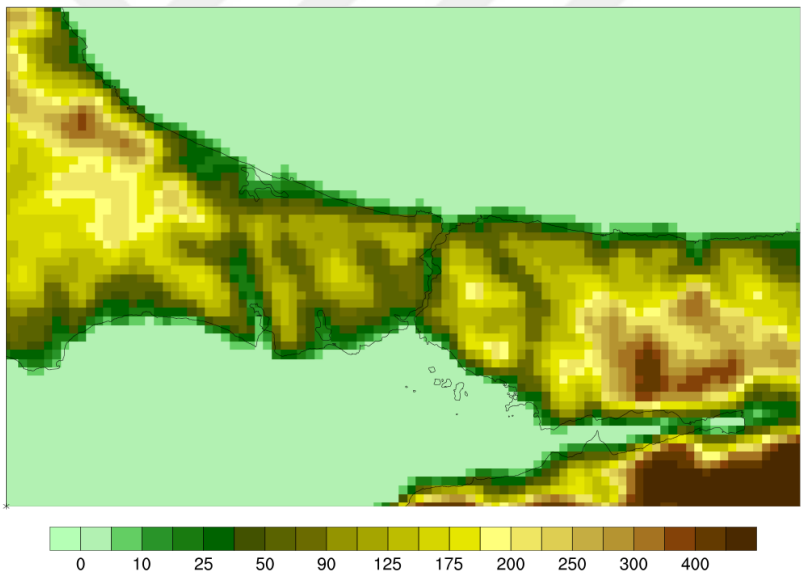

Figure 2.1 : Topographic map of Istanbul.

Istanbul is an intercontinental city and has a unique location which is at confluence of Europe and Asia. A narrow and deep strait, Bosphorus, links the Sea of Marmara with the Black Sea. The western part of Istanbul lies in Europe, while the eastern portion is part of Asia. Both European and Asian side of Istanbul has total area of 5313 square kilometers and 3,699,930 households. Population density of the city is 2759 square kilometers (Turkish Statistical Institute , 2013; Nufusu, 2015).

Istanbul is economic capital of Turkey with 40 percent of contribution to capital budget (İstanbul Metropolitan Municipality , 2010). The geographic location and economical

reasons make the city more attractive to work and live. All this conditions cause migration and increasing on population.The city suffers from environmental problems due to its rapid socio-economic development.

Figure 2.2 : Comparison of the growth of Istanbul between 1975 and 2011 (NASA Earth Observatory, 2012).

Figure 2.2 reveals comparison of urbanization of Istanbul in 1975 and 2011. Both two images were taken from the Landsat series of satellites by NASA. The images are in false color. Grey lands show buildings while red areas show the plant covered land of the city. Lightly vegetated land or bare earth is tan, and water is black. In the figure, building areas are expended especially through the west side of the city in 2011 according to year 1975 .The growth of the city is happening as people move to Istanbul because of its social and economical opportunities.

2.2 Residential Combustion and Emission Factors

Residential combustion is a required and essential energy source for people. In purpose of supplying this requirement, there are some residential fuel types that are using by different combustion technologies. Although cleaner fuels such as electricity or natural gas are being used in the world, solid fuels have significant portion as main residential fuel type in many countries like Turkey. Use of these kind of fuels for residential heating cause significant effects on air quality.

Residential heating is critical for air pollution in Istanbul because of its high population and household number. According to (TUIK), the city has 3700000 households in 2011 and this number increases year by year with increasing population and spatial extension of the city. Therefore, there is a need for a more accurate emission inventory to estimate the impact residential heating on air quality in Istanbul. In this study, common used fuels which are coal (domestic and imported), wood and natural gas are taken under investigation as residential fuels in order to determine the emissions from this sector. Methods of European and U.S. authorities are examined for this sector in order to develop appropriate emission inventory for air quality model.

According to European Monitoring and Evaluation Programme (EMEP) non-industrial combustion sector includes residential combustion and small consumers that has thermal capacity less than 50 MW and do not count as point source because of low fuel using capacity (European Environment Agency, 2013). It is characterized by a great variety of combustion techniques. Variability of emission factor in residential heating sector depends on several issues. Normally, older combustion installations release more emissions than modern combustion installations. Furthermore, using stoves in different technologies, firebox sizes, air inlet and control systems directly effects combustion efficiency especially for solid fuels. In addition to many different stove types, used fuel characteristics vary from home to home. Moisture contain of the fuel, burning rate, burning duration, damper setting, kindling approach are also important points for combustion condition and emissions (Houck et.al Epa conference paper, n.d.). Especially for solid fuels, emissions from incomplete combustion are many times greater in residential combustion because of its small capacity with respect to industrial combustion (European Environment Agency, 2013).

Emission factors are representative values that provide a measure of pollutant discharge for a specific type of activity and fuel consumption. They give information about emitted pollutant mass per burned fuel amount or obtained energy. The factors are generally expressed as kilograms of a specific pollutant emitted per tons of fuel burned. Selection of emission factor is important to calculate emissions accurately. The factors from non industrial combustion sector should be selected based on fuel types, heating unit sizes and combustion technologies. European and U.S. emission factors are examined to select more proper factors for our region. Although in many cases it was not possible to find completely available factors, wherever possible, the most recent releases of Environmental Protection Agency, USA (EPA-AP42) and EMEP factors were selected. For individual and boiler type residential heating systems, most closely matched residential combustion technologies were selected from EMEP and EPA.

In Turkey, residential heating is a major source because of widely usage of poor quality solid fuels and low technology burning systems. Individual stoves and boilers are still among the mainly used combustion techniques for home heating. Low technology causes insufficient combustion and ineffective usage of the fuel. High amount of solid fuel usage without emission control cause high amount of pollutant emissions correspondingly. Especially NO_x, SO_x, CO and particulate matter are major pollutants from residential emissions.

The of emission calculation depends on the activity rate, efficiency of emission control techniques and emission factors. The general algorithm for emissions estimation as follows:

$$E_{\text{pollutant}} = AR_{\text{fuel consumption}} x EF_{\text{pollutant}} \quad \textbf{(2.1)}$$

where:

- $E_{pollutant}$ = Emissions of the specific pollutant,
- $AR_{fuel\ consumption}$ = Activity rate for fuel consumption,
- $EF_{pollutant}$ = Emission factor for this pollutant.

E is calculated annual emission amount of pollutant. For each fuel and pollutant type, emission factors changes. The activity rate (AR) should refer to the fuel consumption as mass (kg or ton) or energy (GJ) unit according to unit of activity data.

As it is seen from the equation, activity rate and emission factors are both inputs of emission calculations. Although emission factors are essential for accurate emission calculation, activity data is also important.

2.2.1 Wood: EMEP and EPA

Emission factors for residential wood combustion has high variability by depend on construction, combustion and emission characteristics of stoves. In the Table 2.1, there are emission factors belong to five different types wood burning stoves: The conventional wood stove, the non-catalytic wood stove, the catalytic wood stove, the pellet stove, and the masonry heater. The factors according to each stove are determined and presented by EPA.

Conventional stoves generally have old type design properties and do not have catalyst and any emission reduction technology. These stoves comprise different stoves that designed with different airflow types such as updraft, downdraft, cross draft and S-flow. Because of including various kinds of stoves, emissions of conventional stoves can be highly uncertain as depend on their burning system.

Non-catalytic wood stoves also do not have catalyst but as different from conventional stoves, they have emission reduction technology such as baffles and secondary combustion chamber.

Catalytic stoves include catalyst material that allows combustion gases to burn at lower temperatures, thereby cleaning the exhaust gas while generating more heat.. This system increases combustion efficiency and provides reduction in especially CO and VOC emissions. Furthermore, catalytic stoves greatly reduce the amount of needed fuel to produce the desired heat and increases burning time per unit fuel load.

Pellet stoves burn compacted pellets usually made of wood, but they can also be derived from other organic materials. Some models can burn nutshells, corn kernels, and small wood chips. Some pellet stove systems that are certified by the EPA according to 1988 New Source Performance Standards (NSPS) are likely to be in the 70 % to 83 % efficiency range, while others are exempt due to a high air-to-fuel ratio (i. e., greater than 35-to-1).

Table 2.1 : Emission factors for wood burning in different stove types in unit kg/ton (EPA AP42)

	Wood Stove Type Emission Factor			**Pellet Stove Type**		**Masonry Heater**
	Conventional	Noncatalytic	Catalytic	Certified	Exempt	Exempt
PM_{10}	15.30	9.8	10.2	2.1	4.4	2.8
CO	115.4	70.4	52.2	19.7	26.1	74.5
NOx	1.4	-	1	6.9	-	-
SOx	0.2	0.2	0.2	0.2	-	-
CO_2	-	-	-	1476	1835.5	1924.5
TOC	41.5	14	13.3	-	-	-
Methane	15	8	0.8	-	-	-
NMVOC	26.5	6	7.5	-	-	-

Table 2.2 : Emission factors for wood burning in different stove types in unit kg/ton (EMEP Guidebook 2013)

	Open fire-places	**Conventional Stoves**	**Conventional boilers < 50 kWth**	**Energy efficient stoves**	**Advanced / ecolabelled stoves and boilers**	**Pellet stoves and boilers**
PM_{10}	15.96	14.44	9.12	7.22	1.81	0.55
$PM_{2.5}$	15.58	14.06	8.93	7.03	1.77	0.55
TSP	16.72	15.20	9.50	7.60	1.90	0.59
CO	76.00	76.00	76.00	76.00	38.00	5.70
NO_x	0.95	0.95	1.52	1.52	1.77	1.52
SO_2	0.21	0.21	0.21	0.21	0.21	0.21
NH_3	1.41	1.33	1.41	0.70	0.70	0.23
NMVOC	11.40	11.40	6.65	6.65	4.75	0.19

Masonry heaters are large combustion system that is available to burn a large charge of wood without overheating. The heat is stored in the masonry thermal mass, and then slowly radiates into your house for the next 18 to 24 hours. Masonry heaters are exempt from the 1988 NSPS due to their weight (i. e., greater than 1764 lb)

There are also Europe based emission factors, which are determined by EMEP. In Table 2.2 emission factors belong to seven different burning devices that are commonly used in Europe are presented. The burning systems are open fireplaces, conventional stoves, conventional boilers that have energy capacity less than 50 kWth, energy efficient stoves, advanced/ ecolabelled stoves and boilers, pellet stoves and boilers and residential biomass burning.

Open fireplaces have generally basic design with their large opening to the fire bed and dampers above the combustion area to prevent heat lose. They have very low combustion efficiency and that situation causes insufficient combustion of fuels. Thus, as product of open fireplaces high TSP, CO and NMVOC emissions are expected.

Energy efficient stoves are improved form of conventional stoves. They have secondary air in the combustion chamber, more efficiency in combustion (between 55 % and 75 %) and low emissions as combustion product.

Advenced/ ecolabelled stoves have new technology with multiple air inlets and pre-heating system of secondary combustion air by heat exchange with hot flue gases. The advanced technology provides more efficiency in combustion (near 70 % at full load) and low emissions. Especially less TSP, CO and NMVOC emissions are expected with respect to old designed conventional stoves.

2.2.2 Coal: EMEP

Coals consists of various types combinations of organic matters and inorganic mineral matters formed as result of different vegetation, layer, temperature and pressure in where the coal originated, as well as the length of time the coal has been forming in the deposit. This complex combination structure causes classification rank according to ingredients and alteration of coal. The classification does not depend on only a single parameter. Coals contain carbon, hydrogen, oxygen, nitrogen and varying amounts of sulphur. Generally, high-rank coals have high carbon and heat value, but low hydrogen, oxygen and moisture content. Low-rank coals have low carbon but high hydrogen oxygen and moisture content. Anthracite has the highest carbon content, followed by bituminous, sub-bituminous and lignite coal, which has the lowest carbon.

Coal contents and combustion efficiency affect its, contributions on air quality. Emissions from coal combustion depend on composition of fuel, technology of the stove, firing conditions, control technologies and burning efficiency (Mitchella et al., 2016). The major pollutants of coal burning is particulate matter, sulfur dioxides (SO_x) and nitrogen dioxides (NO_x). Incomplete combustion of coal results in emissions of high carbon monoxide and other toxic contaminants even under proper operating

Table 2.3 : Emission factors for residential domestic coal burning in unit kg/ton (EMEP Guidebook 2013)

	Hard Coal and Brown Coal	**Solid Fuel (not biomass)**	**Advanced coal combustion techniques <1MWth- Advanced stove**
PM_{10}	8.12	6.63	4.82
$PM_{2.5}$	8.00	6.63	4.42
TSP	8.92	7.03	5.02
CO	1499.21	100.48	40.19
NO_x	2.21	1.21	3.01
SO_x	18.09	10.05	9.04
NH_3	0.01	0.10	-
NMVOC	29.82	12.06	6.03

Table 2.4 : Emission factors for residential import coal burning in unit kg/ton (EMEP Guidebook 2013)

	Hard Coal and Brown Coal	**Solid Fuel (not biomass)**	**Advanced coal combustion techniques <1MWth- Advanced stove**
PM_{10}	8.00	8.84	6.43
$PM_{2.5}$	10.66	8.84	5.90
TSP	11.90	9.38	6.70
CO	1998.95	133.98	53.59
NO_x	2.95	1.61	4.02
SO_x	24.12	13.40	12.06
NH_3	0.01	0.13	-
NMVOC	39.76	16.08	8.04

Table 2.5 : Emission factors for residential natural gas burning in unit kg/10^6m^3 (EPA AP42)

	Uncontrolled	**Controlled- Low NO_x burners**	**Controlled- Low NO_x burners / Flue gas recirculation**
PM_{total}	121.6	121.6	121.6
$PM_{condensable}$	91.2	91.2	91.2
$PM_{filterable}$	30.4	30.4	30.4
CO	1344	1344	1344
NO_x	1600	800	512
SO_2	9.6	9.6	9.6

conditions. Particulate matter is another important pollutant of coal combustion (EPA AP-42, Volume 1, Fifth Edition).

In the United States, coal usage for purpose of residential heating is not commonly used. According to Residential Energy Consumption Survey of U.S. Energy Information Administration, natural gas or electricity has 85 percentage in the residential fuel consumption while the remain other share is dominantly belong to propane and oil (EIA, 2009). Because of that, EPA emission factors for residential solid fuels are not applicable to use for estimating the emissions in our country.

2.2.3 Natural Gas: EMEP and EPA

Natural gas is one of the the most affordable forms of energy and main fuel for residential heating in Istanbul. The fuel is environmentally friendly and cleaner than solid fuels. Natural gas infrastructure for residential usage is widespread in the city when compared other cities of Turkey. It is preferable due to its ease of use. Natural gas is used in households not only for heating, but also for different purposes such as cooking and getting hot water.

For residential heating, natural gas combustion is used in individual stoves or boilers that has capacity of less than 50 kW. Efficiency of the combustion mechanism effects fuel usage and proportionally amounts of pollutants that comes from natural gas.

NO_x is the main pollutant of natural gas combustion. The emission levels depends on different parameters such as volume of the combustor and physical conditions of

Table 2.6 : Emission factors for residential natural gas burning in unit g/GJ (EMEP Guidebook 2013)

	Stoves, Fireplaces, Saunas and Outdoor Heaters	**Small (single household scale, capacity <= 50 kWth) boilers**
PM_{10}	2.2	0.2
$PM_{2.5}$	2.2	0.2
TSP	2.2	0.2
CO	30	22
NO_x	60	42
SO_x	0.3	0.3
NMVOC	2.0	1.8

Table 2.7 : Emission factors for residential natural gas burning in unit kg/10^6m^3 (EMEP Guidebook 2013)

	Stoves, Fireplaces, Saunas and Outdoor Heaters	**Small (single household scale, capacity <= 50 kWth) boilers**
PM_{10}	74.6	6.8
$PM_{2.5}$	74.6	6.8
TSP	74.6	6.8
CO	1017.4	746.1
NO_x	2034.8	1424.3
SO_x	10.2	10.2
NMVOC	67.8	61.0

operating system. Oxygen concentrations and temperature during the combustion are essential parameters that has impact on NO_x formation. By increasing of oxygen concentration, peak temperature and time of exposure at peak, NO_x emissions increases.

In USA, natural gas is highly rife fuel for residential usage. For this commonly used fuel, emission factors which are determined by EPA for uncontrolled and controlled combustion conditions are presented in Table 2.5. Control technologies for natural gas combustion are determined as based on the main pollutant, NO_x. While emission factor of uncontrolled burning for NO_x is 1600 kg/10^6m^3, the factors decreases dramatically with control technologies to 800 and 512 kg/10^6m^3.

2.3 Combustion Experiments and Emission Factor Calculations

The contribution of emissions from residential combustion to the total emissions varies and depends on type, quality and quantity of using fuels over the region. In order to generate region specific and more realistic emission factors for residential heating, concentration measurements were done. The measurements are applied for individual type residential heating systems measurements for import and domestic coals, wood and natural gas which are the most common used fuels in Turkey for residential heating. While the combustion system is conventional stoves for solid fuels, natural gas combustion is occurred in combies which is specific individual burning system for this fuel. Because of that, solid fuel concentration measurements are done in conventional stoves and natural gas concentration measurements are done in combies. As natural gas concentrations were done instantaneously, solid fuels concentrations measured continuously because of high variability on combustion of these fuels. Figure 2.3 shows the conventional stove during the continuous measurements.Concentration values from the continuous measurements used for obtaining minutely emission factor by assuming uniform fuel consumption is occurred during the burning regime and analysed uncertainty of the factors with statistical methods.

The first step of the measurement process was calibration. Assuring the quality of a measurement is crucial to achieve reliable values from the instrument. Besides routine calibration of the instruments, additional calibration was also applied by using NO, CO and SO_2 control tubes which have already known concentrations. While

Table 2.8 : Fuel consumption amount per time.

Fuel Type	Fuel Amount	Time	Fuel Consumption
Wood	1320 g	41 min	1.93 $^{kg}/_{h}$
Import coal	2700 g	151 min	1.07 $^{kg}/_{h}$
Domestic coal	1015 g	75 min	0.81 $^{kg}/_{h}$
Natural gas	0.61 m^3	80 min	0.46 $^{m^3}/_{h}$

the known tube has 286 ppm SO_2 concentration, the instrument measured 297 ppm which is in acceptable range ($\pm$ 5.72 %). CO tube that has 100 ppm concentration is measured as 100-102 ppm by the instrument. For NO pollutant similar correction is done. The known NO tube with 500 ppm concentration is measured as 499 ppm by the instrument. That value is almost same with the exact NO concentration and in acceptable range ($\pm$ 10 %). After being sure that the instruments give the trustable concentration values, they used for measurements.

During the solid fuel concentrations measurement process two different types equipment were used at the same time. First one is Cev - Tek measurement instrument, which gives instantaneous concentration with electrochemical working principle. The other instrument, which was used at the same time, is Horriba PG-350, which gives continuous concentration results with paramagnetic working principle. Even they have different measurement methods; obtaining similar concentrations from two different type instruments proofs accuracy of the measured concentration values.Continuous measurements gave concentrations per minute in ppm unit. By minutely concentrations, burning regime of the fuels was also examined.

Both two instrument measurements gave the similar concentration values. Continuous concentrations are used because of affluence of its data. The data includes minutely concentrations of the NO, SO_2, CO gases in unit of ppm. Firstly, the concentrations converted to mg/m^3 unit. Then emissions of all the pollutants are calculated, in kg/ hr unit, by multiplying flow rate of the gases. Also particulate matter concentrations are measured by gravimetric method. Mass of clean filter is measured and than it is extracted from mass of filter with dust after 30 minutes. The difference gave the total particulate matter amount in half hour. Emissions of particulate matter is calculated by multiplying flow rate of the particulate matter.

Figure 2.3 : Measurement with conventional heater commonly used in residential heating

After this step, emissions were calculated by multiplying the measured concentrations and flow rates. By using emission values emission factors are calculated. Fuel consumption in unit time (Table 2.8) is also essential for this calculation. The emission factors of pollutants (NO, SO_2, CO and PM) for each fuels (wood, import and domestic coal) are determined by dividing emissions to hourly fuel consumptions. Combustion order was selected as starting with the cleanest fuel in order to avoid contamination. All the fuels were burned in the same stoves. In these measurements, considering fuel consumption in unit time is also critical to determine emission factor. Firstly wood was weighted in at 1320 g and burned until it burned completely. The combustion lasted 41 minutes. Then 2700 import coal was weighted and burned in the stove 151 minutes. Finally domestic fuel was weighted in at 1015 g and burned 75 minutes (Table 2.8). Continuous and instantaneous concentrations, flow rates of the stack gases and temperatures are recorded both in the two instruments.

Continuous and online measurements were made in order to obtain a representative emission factor values for each pollutant types and each fuel types. Pollutant concentrations and used fuel consumption per a combustion time period was taken into

Table 2.9 : Emission factors of EMEP and OUR for domestic coal (kg/ton)

POLLUTANTS	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	2.21	92.44	9.73	18.09	0.01	8.12
This Study	0.34	7.18	-	0.12	-	30.29

Table 2.10 : Emission factors of EMEP and OUR for import coal (kg/ton)

POLLUTANTS	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	2.95	123.26	12.97	24.12	0.01	10.83
This Study	0.93	11.25	-	0.76	-	23.86

Table 2.11 : Emission factors of EMEP and OUR for natural gas (g/m^3)

POLLUTANTS	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	1.42	0.75	0.06	0.01	-	0.01
This Study	1.89	3.74	-	-	-	-

account in the emission factor calculations. The factors were determined in terms of kilograms for each pollutants emitted per ton of fuel burned. The obtained factors were compared with EMEP emission factors in Table 2.9, 2.10 and 2.11. The calculated region specific emission factors were generally lower than the EMEP factors except PM for domestic and import coal. For natural gas, NO_x and CO concentrations which are the main pollutnats for this fuel were measured and only for these two pollutants emission factors were determined. The calculated factors for natural gas fuel were much more similar to EMEP factors with respect to coal fuels. These compared values showed that variability in widely used combustion technologies in the regions and burning efficiency during the measurements may cause highly differences in emission factors. Especially solid fuel combustion conditions effects emission factor values essentially.

2.3.1 Uncertainty of Emission Factors

Emission factors are representative values in order to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant (Pouliot, Wisner, Mobley, & Hunt, 2012). Estimation of emission factors are crucial for the characterization and the assessment of emission sources of air pollution at

regional or national scales. Emission factors are essentially the averages from available source tests. However, most of the cases, the available source tests are from a very small sample set. Since it is almost impractical if not impossible to have numerous tests from a variety of sources to estimate an emission factor, the limited numbers of available tests leads to uncertainty in the emission factors. Uncertainty in the emission factor usually contributes largely to the overall uncertainty in the emission inventory.

Quantitative characterization of emission factor uncertainty provides the ability to determine the analysis of the data being used for both scientific and policy decisions more accurately. For example, the quantitative measure of uncertainty associated with air quality modeling studies and development of emission inventories give decision makers a guidance.

Air pollution from domestic coal and wood burning has always been an important contributor to poor ambient air quality in developing countries or less developed areas of Asia and especially the rural areas. The recent trends show that Scandinavian part of Europe is not the only region that use wood burning as residential heating. Across the European Union, the use of biomass (including wood) in heating set to rise by 57–111 % between 2010 and 2020, as the 27 member states are committed to obtain 20 % of their energy requirements from renewable sources, including biomass, as part of a draft of proposals to reduce CO_2 emissions (Wagner et al., 2010). To illustrate, wood combustion is estimated to comprise 60 % of residential energy use in Portugal, but accounts for almost 99 % of domestic PM_{10} emissions (Borrego et al., 2010). In Denmark, (Glasius et al., 2006) found that increasing fossil fuel costs contributed to doubling of wood stoves and boilers over a ten year period.

Emission estimations from the combustion of fossil fuel and bio fuel/biomass in residential heating is a challenging task thus indicates considerable uncertainties. Disparities mainly arise from difficulties in representative sampling due to numerous field measurements from a variety of solid fuels types, preprocessing of some solid fuels (e.g., coal washing), burning styles (from small stoves to heating boilers) and experimental measurement errors. In many studies (Y. Zhao, Nielsen, & McElroy, 2011, 2012a, 2012b; Z. J. Zhao Y. & Nielsen, 2013), the results of the emission uncertainty analyses show that among sectors, the uncertainties associated with

residential sector is among the largest. This is mainly due to poor understanding of emission factors and activity levels for combustion of solid fuels.

Although residential emissions are dominated by the combustion of solid fuels, studies on emission factors among different solid fuels burned in residential stoves are limited (S. Shen G.F.and Wei et al., 2012; G. Shen et al., 2010, 2014). In this study, emission factors of NO_x, SO_2, and CO for solid fuels burned in the residential heating are locally measured and compared. In this study the solid fuels that are investigated are domestic coal, import coal and wood (briquette). Repeated field measurements are done by using a Horriba PG-350 instrument that can be considered as CEMS—Continuous Emission Monitoring Systems, a method for continuously monitoring emissions and collecting data averaged over intervals of a few minutes.

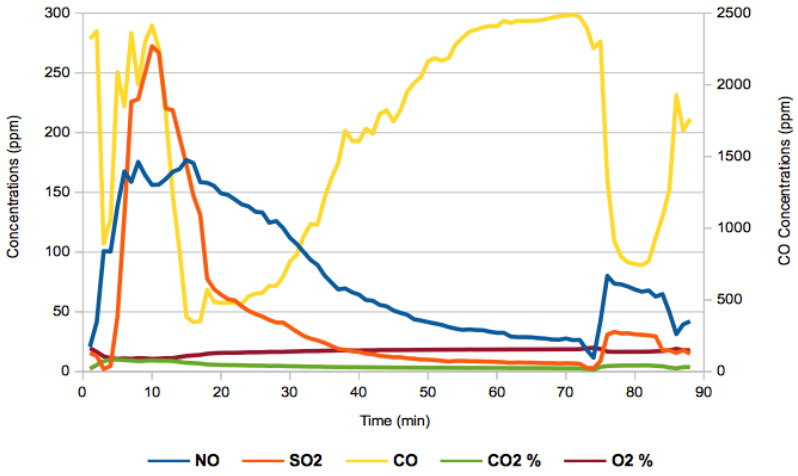

Figure 2.4 : Continuous import coal burning measurement concentrations (ppm)

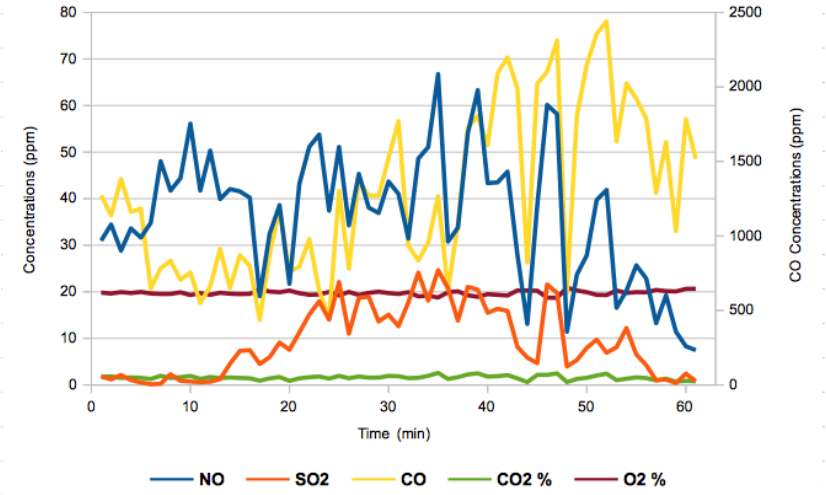

Figure 2.5 : Continuous domestic coal burning measurement concentrations (ppm)

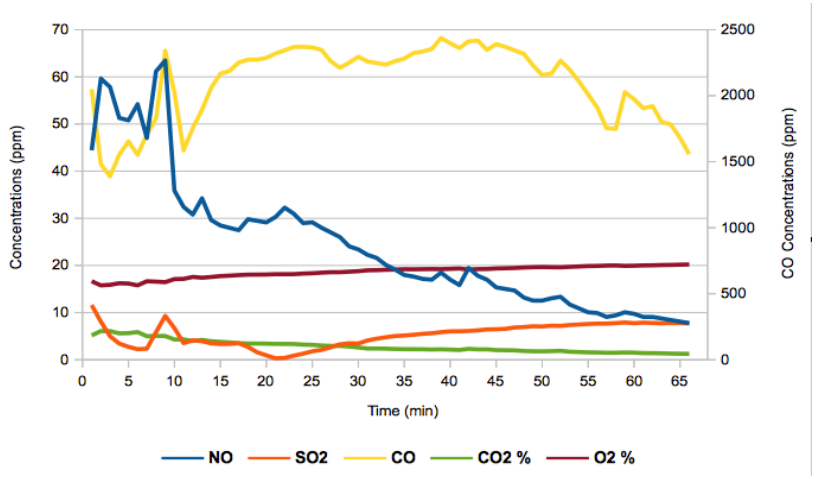

Figure 2.6 : Continuous wood burning measurement concentrations (ppm)

Results from our domestic field measurements and investigations show that there is considerable uncertainty concerning the likely magnitude of the change in air pollution concentration arising from coal and wood burning. The impact will depend not only on the type of solid fuels but also on the type of stoves applied, the preprocess that the coal type was subjected, and the instrumentation/experimental errors. The lower concentrations and emissions factors (EFs) of SO_2 thus might imply that some local practices of coal sellers, such as coal washing.

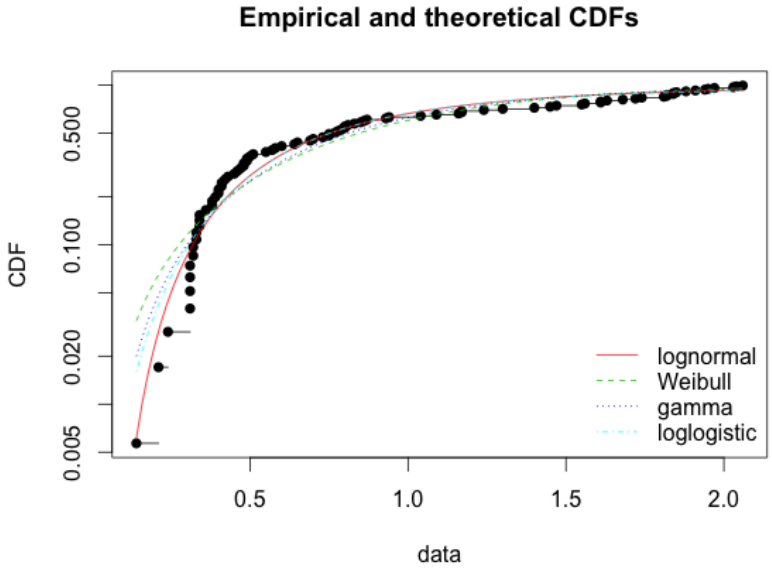

Figure 2.7 : CDF for NO_x from import coal burning measurements.

In this study, we have utilized statistical methods to quantify uncertainty in residential heating emissions. Variability and uncertainty in emissions factors were quantified using both parametric and non-parametric bootstrapping techniques. Several

Table 2.12 : Goodness-of-fit statistics for NO_x from import coal burning measurements

	gamma	**weibull**	**lognormal**	**llogis**
Kolmogorov-Smirnov statistic	0.08211	0.09763	0.05768	0.0621
Cramer-von Mises statistic	0.1477	0.2373	0.0688	0.0829
Anderson-Darling statistic	1.1128	1.6900	0.5724	0.6628
Goodness-of-fit criteria	**gamma**	**weibull**	**lognormal**	**llogis**
Aikake's Information Criterion	877.2451	884.4234	873.2932	877.4406
Bayesian Information Criterion	882.2447	889.4230	878.2928	882.4403

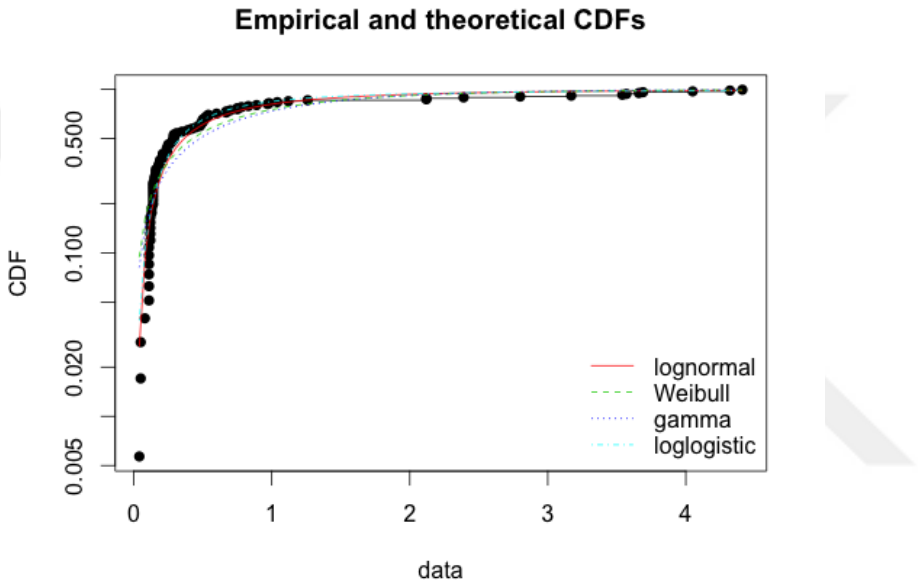

Figure 2.8 : CDF for SO_2 from import coal burning measurements.

Table 2.13 : Goodness-of-fit statistics for SO_2 from import coal burning measurements

	gamma	**weibull**	**lognormal**	**llogis**
Kolmogorov-Smirnov statistic	0.1079140	0.1118548	0.08921712	0.09049264
Cramer-von Mises statistic	0.2356855	0.2416007	0.15586095	0.17853599
Anderson-Darling statistic	1.4387798	1.5635851	0.99124985	1.17054402
Goodness-of-fit criteria	**gamma**	**weibull**	**lognormal**	**llogis**
Aikake's Information Criterion	716.8754	721.5798	711.4152	717.1489
Bayesian Information Criterion	721.8750	726.5794	716.4148	722.1485

distribution-fitting (e.g. lognormal, loglogistic, weibull, burr) and related diagnostics were applied to quantify uncertainties of region-specific emission factors for each pollutant. Preliminary analysis suggested that both NO_x and SO_2 emissions follow

a lognormal distribution. Bootstrapped means and the 95 percent confidence intervals for lognormal distribution for NO_x are 0.632, (0.56 – 0.70) and for SO2 0.276 and (0.24 and 0.32) respectively.

These values suggest that NO_x emissions from residential heating with domestic and import coal can be as high as 520628 tons per year while minimum and average are less than 13 and 2 times of maximum emissions, respectively. Using a point value for emission estimation can cause high uncertainties in emission inventories. This study summarizes the findings on emission estimates as well as its possible impact on air quality via using air quality models.

2.4 Activity Data

Data collection period, which is in responsibility of the regularity agency, is troublesome and that situation also makes residential emissions highly uncertain in Turkey. In order to improve the data collection and better estimate the emissions, Development of National Emissions Inventory Management System for Turkey (KAMAG) Project was studied. By this project, all the activity data from determined sectors were collected and emissions of the sectors can be calculated systematically. In the project, a national system was developed for emission inventory preparation and Marmara region is selected as pilot region. The project was generated for point, area and mobile emission calculations by the developed system. Area emissions were a part of the KAMAG Project. Residential heating was the major source of area emissions. For this purpose, region specific emission factor development for residential heating, calculating emissions with these factors and identifying impacts of the pollutants from this sector in Istanbul via air quality modeling were the main objectives of this study.

High quality data collection was a tedious and time-consuming process. Fuel amounts for home heating purpose were collected from different sources. Domestic coal is only used as social solidarity aimed and distributed people who are in need by Ministry of Environmental and Urbanization (MoEU) in Turkey. Annual distributed domestic coal amount was obtained from the MoEU. General Directorate of Forestry provided wood amount that was using for residential combustion. Data for annual residential natural gas usage amount was obtained from Istanbul Greater Municipality.

However determining import coal amount that is using for residential heating was not available because of wide and uncontrolled sales network. Theoretical import coal amount is calculated by using unit energy consumption of a household. For this calculation, first stage was identifying the natural gas usage amount only for heating purpose in the households. The steps of this calculation are summarized as follow:

- Monthly natural gas consumption data for 2010, which is in neighborhood level, obtained by Istanbul Greater Municipality.
- The consumption amount represents residential natural gas usage but not only for heating and also for other purposes such as cooking and obtaining hot water.
- While heating is a need only for cold seasons, other domestic consumption is necessary in all seasons. Thus, natural gas amount in summer season is assumed as only for domestic purpose, not for heating.
- In order to determine natural gas amount for residential heating in Istanbul, average natural gas consumption in summer season (July and August) is extracted from the other monthly usage. By this methodology, only heating purposed natural gas is diverged from total domestic natural gas usage for Istanbul. The calculations proved that, 76 percent of residential natural gas consumed for heating and 24 percent of the consumed for other domestic purposes such as hot water or cooking in Istanbul city.

In the method, average natural gas consumption in July and August is assumed as only for domestic purpose. Because in this summer period, average temperature achieves the highest values in the Istanbul and the gas usage is minimum of the year.

The main purpose of the identifying of the natural gas amounts for only heating is using this value in calculating theoretical import coal usage in households by considering fuels the calorific values. In order to calculate the used import coal, energy based methodology is used. The steps of the methodology to determine an approximate value for residential import coal consumption are as follows:

- People who do not use natural gas assumed as use domestic and import coal for residential heating. The all required energy for residential heating is supplied from natural gas or domestic and import coal.
- Total household number was available for 2011 and the number is projected to 2013 according to household size by TUIK. Natural gas subscripter number obtained

from EPDK Report (2013) and extracted from total household number to determine number of houses that use domestic and import coal instead of natural gas.

- Annual natural gas consumption for residential heating in Istanbul is available as unit of m^3. This value is converted into energy unit, kcal by multiplying calorific value of natural gas.
- By dividing the energy comes from natural gas to natural gas subscriber number, required energy per household is obtained.
- The calculated required energy per household for heating purpose is multiplied with the number of houses that use domestic and import coal. Thus, total energy comes from domestic and import coal is determined in unit of kcal.
- Annual domestic coal amount is obtained from Ministry of Environmental and Urbanization in Turkey as social solidarity aimed. The energy comes from this fuel is calculated by multiplying its caloric value.
- While all required energy comes from coal (domestic and import) is available, the energy provided by domestic coal is extracted from the total. Thus, the energy from only domestic coal is determined in unit of kcal.
- The energy in kcal unit is multiplied to calorific value and amount of the annual domestic fuel consumption is calculated in ton.

All from these activity data collection period, residential fuel consumptions for Istanbul city is determined. Annual fuel consumption amounts of Istanbul for residential domestic coal, import coal and natural gas are 72506 tons, 11905 tons and 346805 m^3 in 2013, respectively.

2.5 Air Quality Modelling

The emissions have complex relation structure in the atmosphere and it is not possible to solve this complicity manually.Air quality modelling is a tool to understand chemical and physical behaviour of the pollutants in the atmosphere. Air quality models represents atmospheric processes numerically. The models attempt to simulate chemical reactions of the pollutants, atmospheric transport and deposition. It is possible to understand the dynamics of air pollution through high-resolution modelling and evaluate impact of the emissions in the real world condition for a specific region and time period.

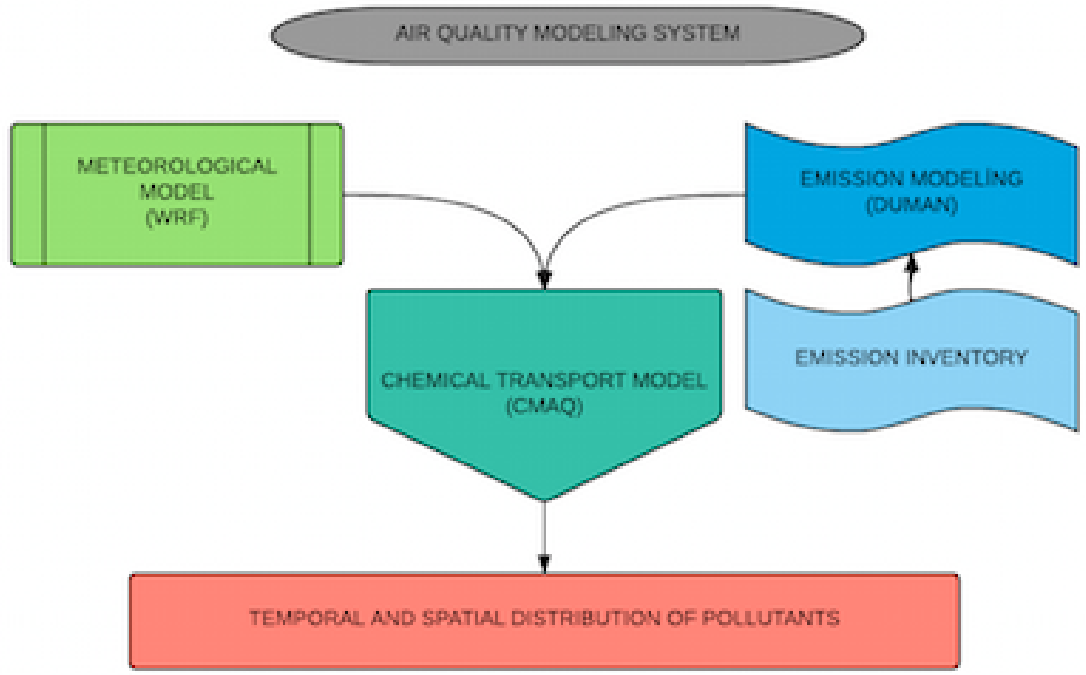

Figure 2.9 : Air Quality Modeling System

Although air quality monitoring is a method to measure pollutant concentrations, the values from stations belong to certain time and point locations. They can not give any opinion for different places, time or meteorological conditions. In order to estimate further scenarios for a selected region and episode, air quality modelling is necessary.

Air quality modeling requires three main processes which are meteorological, emission and finally chemical transport modelling.Outputs of each models are used as input for the next step. Chemical transport model uses meteorological data from meteorological model and emission from emission model to determine temporal and spatial distribution of pollutant concentrations for a certain domain and episode.

In this study, Weather Research Forecasting Model (WRF) is used as meteorological model and The Community Multiscale Air Quality (CMAQ) Model as chemical transport model. The emissions are prepared for CMAQ model by DUMAN module. DUMAN is generated by using country based profiles by Istanbul Technical University.

In this study, Advanced Research WRF (Weather Research and Forecasting) Model is used as meteorological model. Version 3.1 of the model is developed based on the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) (Grell, Dudhia, Stauffer, 1994). For meteorological modeling system 2 nested domains which are

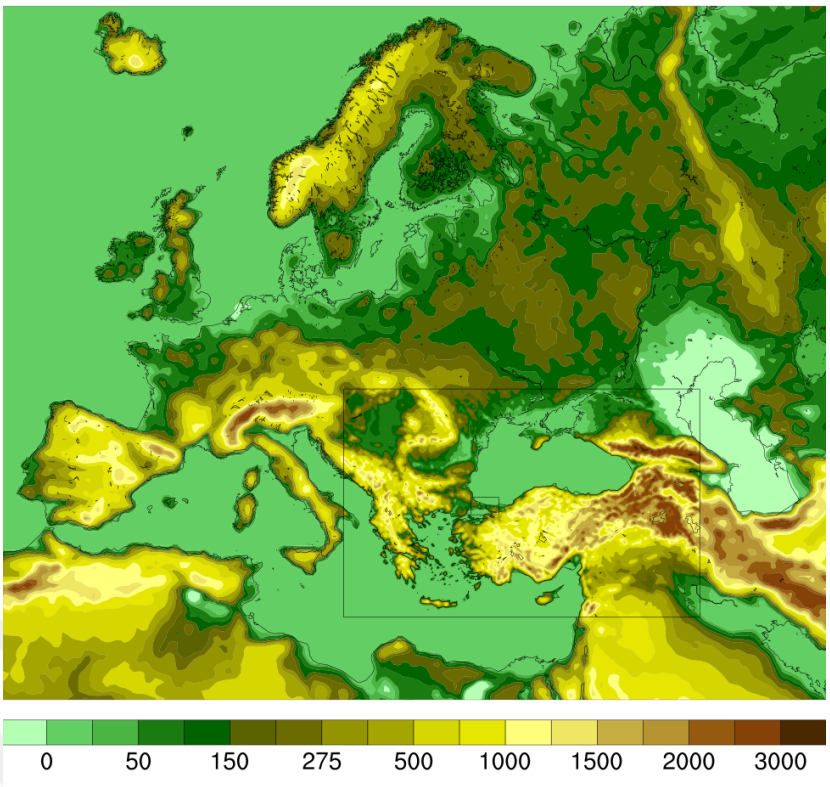

Figure 2.10 : WRF Model Domains

showed in Figure 2.10 are set up. The first and main domain has 30 km spatial resolution. The largest domain covers Europe of 191 by 159 grid cells. The second domain has 10 km spatial resolution and covers all Turkey of 154 by 241 grid cells. The vertical structure is set up with 35 layers.

CMAQ modelling system is an computational tool that is able to simulate multiple air quality issues such as tropospheric ozone, fine particles, toxics, acid deposition, and visibility degradation simultaneously. The 3 dimensional Eularian model is developed by USEPA as Models-3 project. As different from the other models, CMAQ analyzes atmospheric air quality by its state-of-the-science capabilities for modeling multiple air quality issues and multi-scale capabilities for urban and regional scale.(Ching Byun, 1999). Due to its multi-scale structure it, CMAQ model is not required separate models for urban and regional air quality modelling.c

The CMAQ modeling system consists of several processors and the chemical-transport model:

- Meteorology-chemistry interface processor (MCIP)
- Photolysis rate processor (JPROC)
- Initial conditions processor (ICON)

- Boundary conditions processor (BCON)
- CMAQ chemical-transport model (CCTM)

Meteorology-chemistry interface processor (MCIP) prepares all meteorological fields with 24 layers that are required from DUMAN and CCTM. The processor converts meteorological model outputs into proper format to CMAQ model. It uses WRF model output files and create netcdf formatted input meteorology data for DUMAN module that is the emission processor to compute emissions for CMAQ. Photolysis Rate Processor (JPROC) calculates clear sky photolysis rates and outputs from JPROC are used to calculate gas phase chemical transformations and pollutant calculations. Initial Condition (ICON) generates a gridded binary netCDF file of the chemical conditions in the modeling domain for the beginning of the simulation and Boundary conditions processor (BCON) also generates a gridded binary netCDF file of the chemical conditions along the horizontal boundaries of the modeling domain. In this study, Initial and Boundary Concentrations was obtained from global simulations of MACC project (2012, 200x200 km with 60 vertical levels from the surface to 0.1 hPa). After all these processes, CMAQ chemical-transport model (CCTM) integrates the output from the preprocessing programs and DUMAN and simulate continuous atmospheric chemical conditions in order to calculate chemical, transport and deposition processes over the domain (CMAS, 2014).

3. RESULTS & DISCUSSION

3.1 Emissions

In this study, region specific emission factors for residential wood, natural gas, domestic and import coal combustion were calculated. For the wood and coal measurements, conventional stoves were used. The stoves are the most commonly used individual residential combustion systems for solid fuel. For natural gas combustion, the most common combustion system was combi. Measurements for this fuel was applied on combies. While for the solid fuels pollutant concentrations were measured continuously and the values were recorded secondly, natural gas was measured instantaneously. By using pollutant concentrations, flow rate and unit fuel consumption per unit time, emission factors of each pollutants for each fuels were determined.

Emission factors of EMEP were obtained by (European Environment Agency, 2013), small combustion sector which has 1.A.4.b.i NFR code. The emission factors belong to residential plants without an advanced technology and similar to conventional stove combustion type were selected as comparable with our calculated emission factors. The factors were reported as energy unit (g/GJ) in the EMEP Guidebook. In order to convert units, calorific values of the fuels are used. The values were 4800 kcal/kg, 6400 kcal/kg and 8100 kcal/ m^3 for domestic coal, import coal and natural gas, respectively. In Table 3.1, 3.2 and 3.3 calculated emissions with our emission factors and EMEP emission factors were presented. Although for coal fuels our emissions for each pollutants seems lower, emissions from natural gas with our emission factors are higher than emissions with EMEP factors.This difference could be caused by calorific values which were used in unit conversion EMEP factors from g/GJ to kg/ton.

The emission factors that are obtained by measurements were used in emission calculations for each pollutants of natural gas, import and domestic coal. For NH_3 and NMVOC pollutants, concentrations were not measured and because of that reason

Table 3.1 : Emissions of Istanbul with EMEP and OUR emission factors for domestic coal (ton/year)

	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	160	6702	705	1311	0.44	588
OUR	24	521	-	9	-	2196

Table 3.2 : Emissions of Istanbul with EMEP and OUR emission factors for import coal (ton/year)

	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	1321	55235	5812	10807	4	4851
OUR	418	5043	-	339	-	10692

Table 3.3 : Emissions of Istanbul with EMEP and OUR emission factors for natural gas (ton/year)

	NO_x	CO	NMVOC	SO_x	NH_3	PM
EMEP	4940	2587	212	35	-	24
OUR	6542	12980	-	-	-	-

EMEP emission factors were used with our activity data in order to complete our residential emission inventory. In Istanbul, natural gas combustion was 3,468,049,153 m^3 per year, domestic and import coal combustion were 72,506 and 448,122 ton per year, respectively. These fuel amounts were took into the calculations as activity data in this study.

The calculated and determined emission factors were used in emission calculations and residential emissions of TNO emission inventory was revised with these current emissions. Emissions are one of the most uncertain, but one of the most important inputs into air quality models. Currency in activity data and emission factors are essential for this calculation. More accurate emissions provides better model outputs in order to evaluate impact of the specific source over the study area.

TNO inventory was used as base inventory in this study. The obtained 10x10 gridded emissions of TNO was revised with our calculated residential emissions for our Istanbul domain. In Figure 3.1 calculated residential emissions were compared with other prepared inventories. The emission inventory was developed according to snap

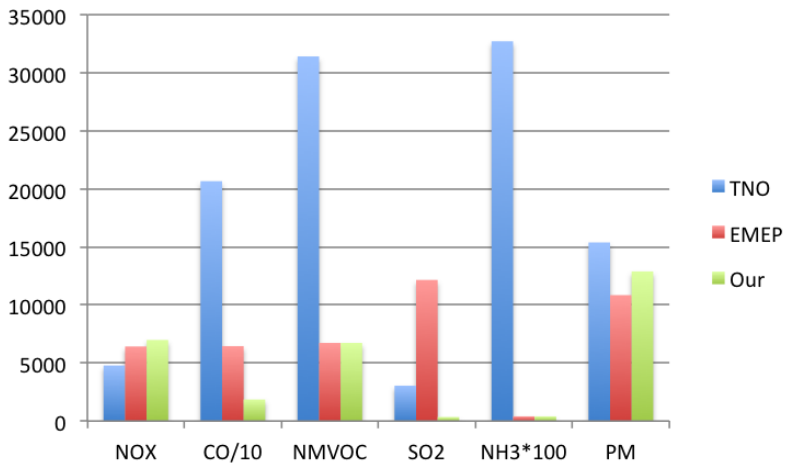

Figure 3.1 : Distribution of residential pollutant emissions for different inventories

sectors by TNO and non industrial combustion sector (SNAP 2) represents residential combustion. EMEP emissions in Figure 3.1 were calculated by using our activity data and EMEP based residential heating emission factors (European Environment Agency, 2013). Our emissions were calculated by using collected activity data and generated region specific emission factors as result of measurements. For our emission inventory preparation, because of absence of NMVOC and NH_3 concentrations in our measurements, EMEP emission factors were used for these two pollutants instead of calculated factors. As it is presented by Figure 3.1, emissions in TNO inventory are generally higher than our calculated emissions. Especially for CO, NMVOC and NH_3, TNO inventory has significantly high emission values. The difference between the inventories can be caused by uncertainty of activity data and emission factors. The emission inventory preparation processes of TNO were not reported. The activity data collection period and used emission factors which was applied by TNO do not known clearly. Because of that reason, in the TNO inventory preparation, obtained activity data belong to fuel consumptions and methods for emission factors and emission calculations have high obscurity. Although data collecting system has some deficiency and still in developing in Turkey, the activity data that was used in this study is relatively trustable and the region specific emission factors which were generated by considering using fuel types and emission technologies in the study area are more proper for Istanbul city.

Sectoral distributions of emissions in Istanbul according to TNO and our inventory is presented in Figure 3.2 and 3.3. The difference of amounts and distribution of

pollutants can be seen in the figures. Although the ranges of emission amounts are generally higher in TNO inventory, SO_2 and PM has greater portion in our inventory.

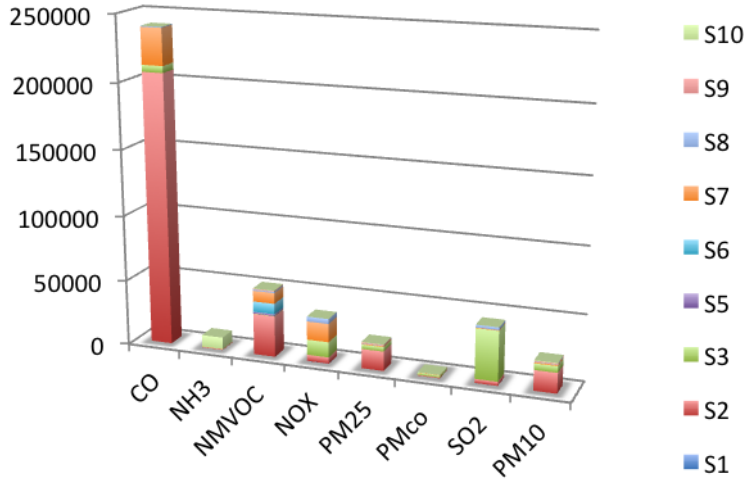

Figure 3.2 : Sectoral distribution of emissions in Istanbul according to TNO inventory (ton/yr)

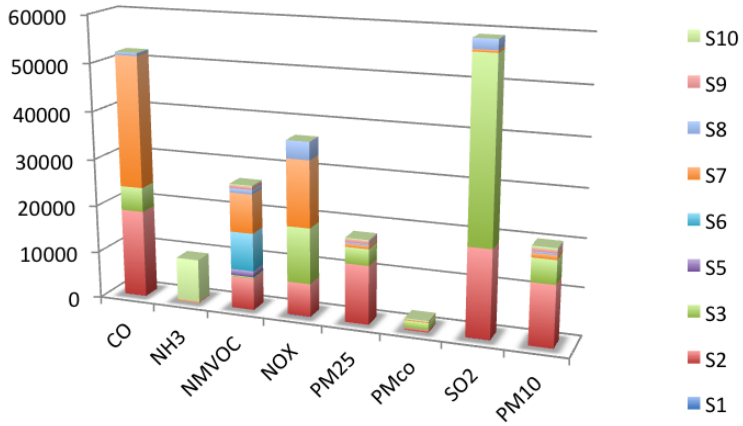

Figure 3.3 : Sectoral distributions of emissions in Istanbul according to Our inventory (ton/yr)

TNO inventory was taken as base inventory in this study and Figure 3.4 presents difference of TNO and our calculated residential emission inventories for Istanbul city. For all pollutants except NO_x, TNO emissions are higher than ours. NO_x emissions according to TNO inventory was 4783 ton/year,but in our calculations the emission value for this pollutant was higher, 6984 ton/year. While TNO emissions were 11 and 8 times higher than our emissions for CO and SO_2 respectively, PM values were quite close to each other. According to TNO inventory PM_{10} emissions were obtained

as 15383 ton/year and the emissions from our calculations for this pollutant was 19 times higher (12888 ton/year). NMVOC and NH_3 are not very dominant pollutants in residential heating sector and for emission calculations of NMVOC and NH_3, EMEP based emission factors were used with our activity data.

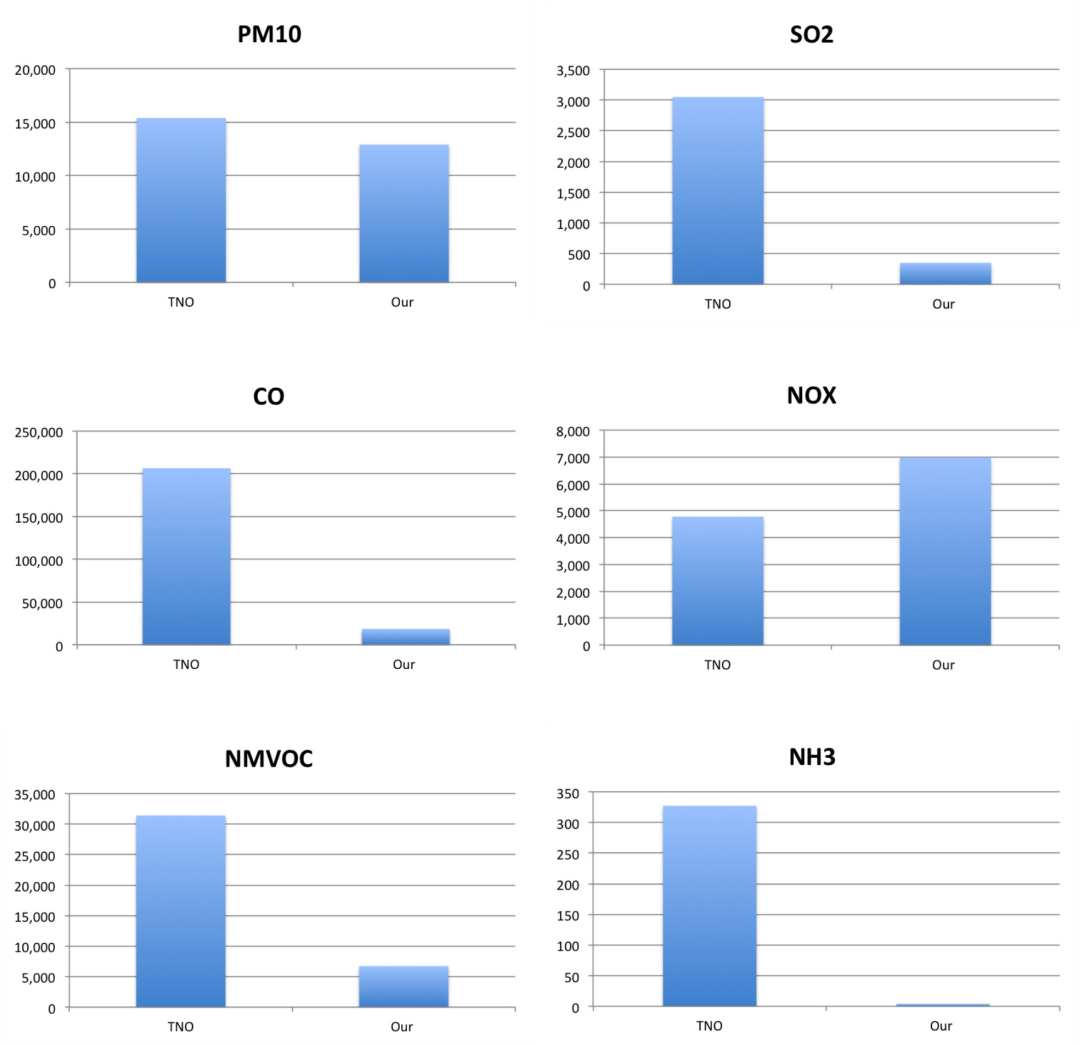

Figure 3.4 : TNO vs Our calculated residential heating emissions of Istanbul (ton/year)

Figure 3.5, Figure 3.6 and Figure 3.7 present spatial distribution of PM, CO and SO_2 emissions for TNO and our inventory in December 2009, January 2010, February 2010, respectively. As it is seen from the figures, the monthly average emission distribution during the all period are similar over Istanbul city.

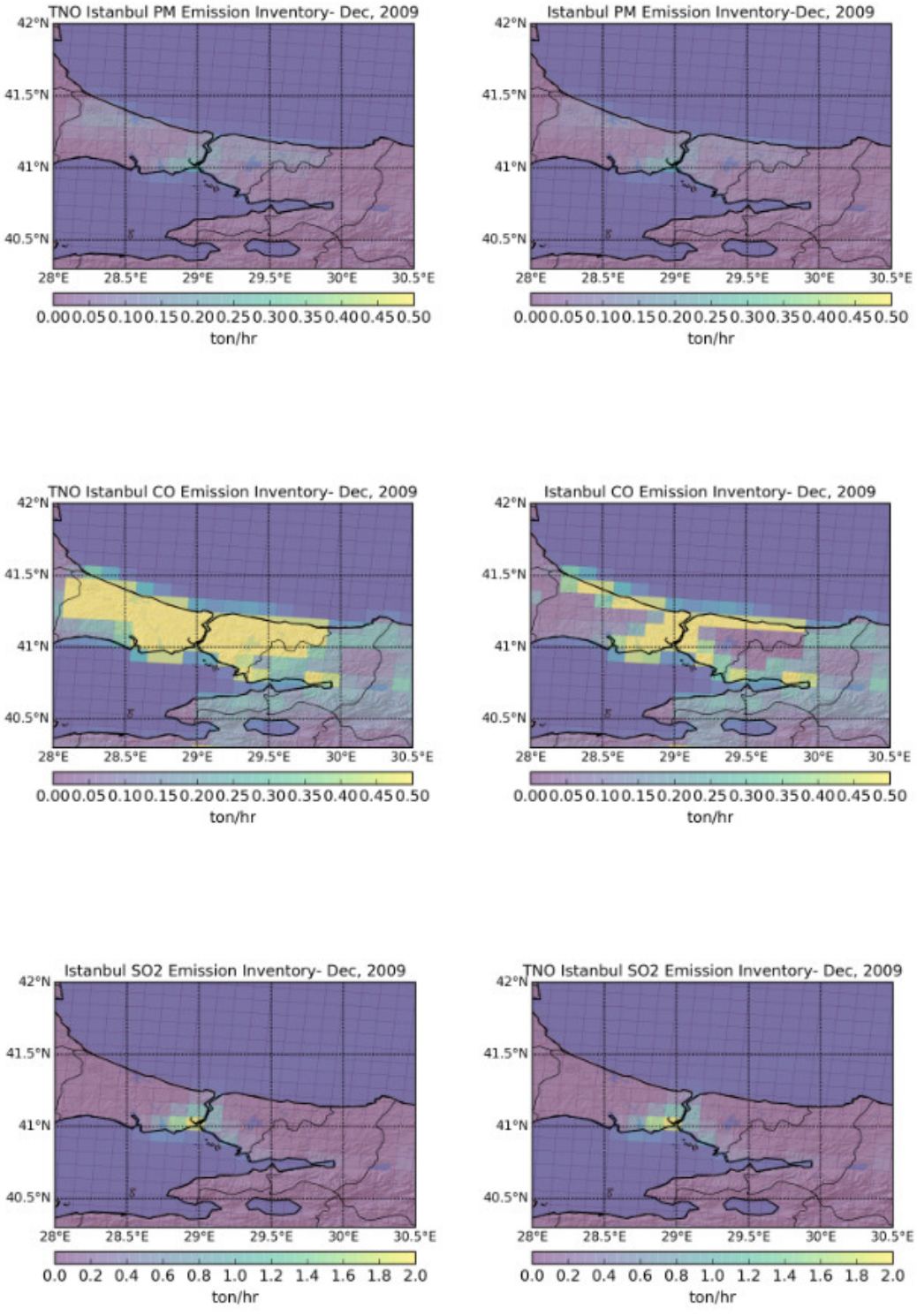

Figure 3.5 : December, 2009 average TNO vs Our PM_{10} , CO and SO_2 emissions (ton/hr).

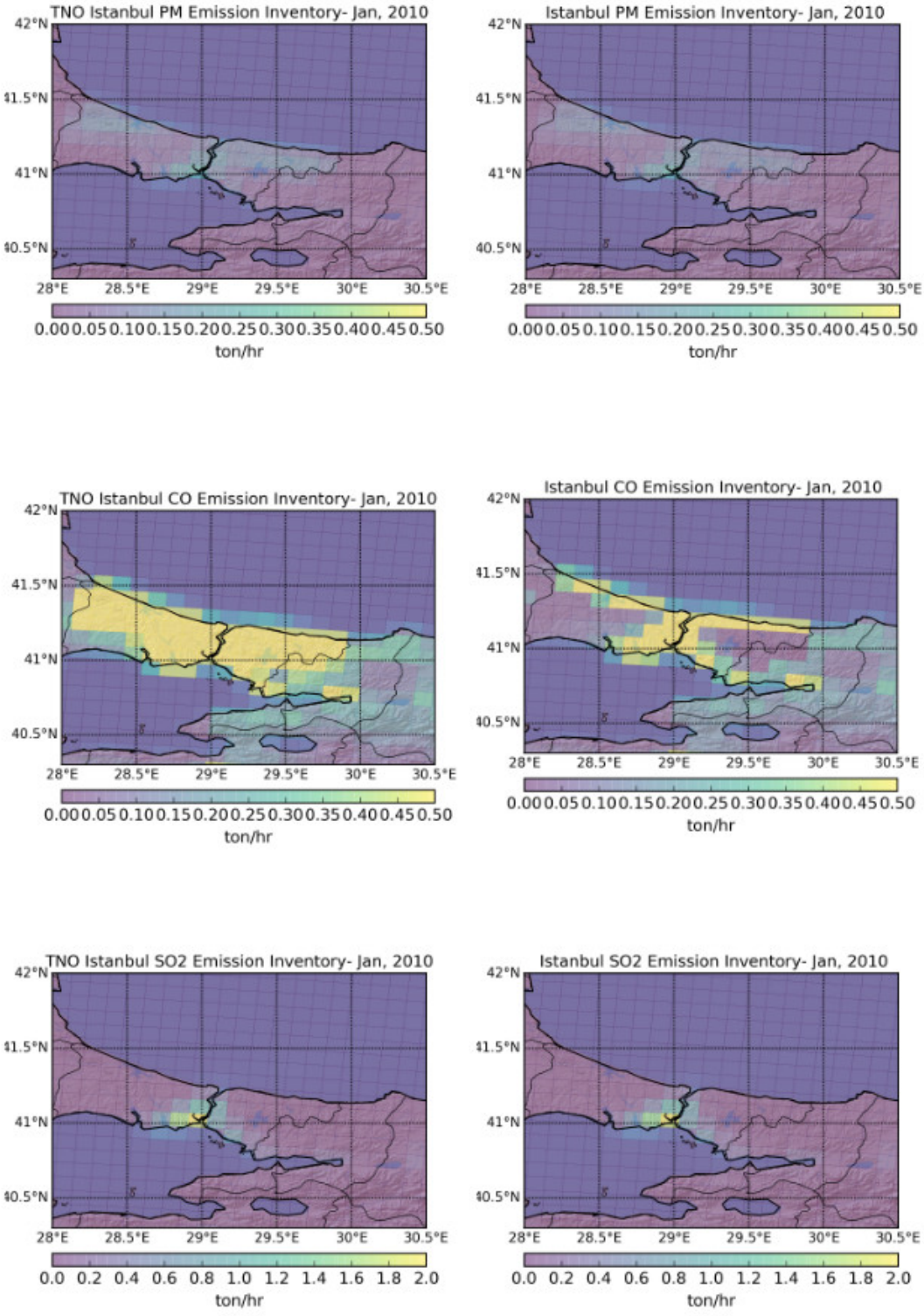

Figure 3.6 : January, 2010 average TNO vs Our PM_{10} , CO and SO_2 emissions (ton/hr).

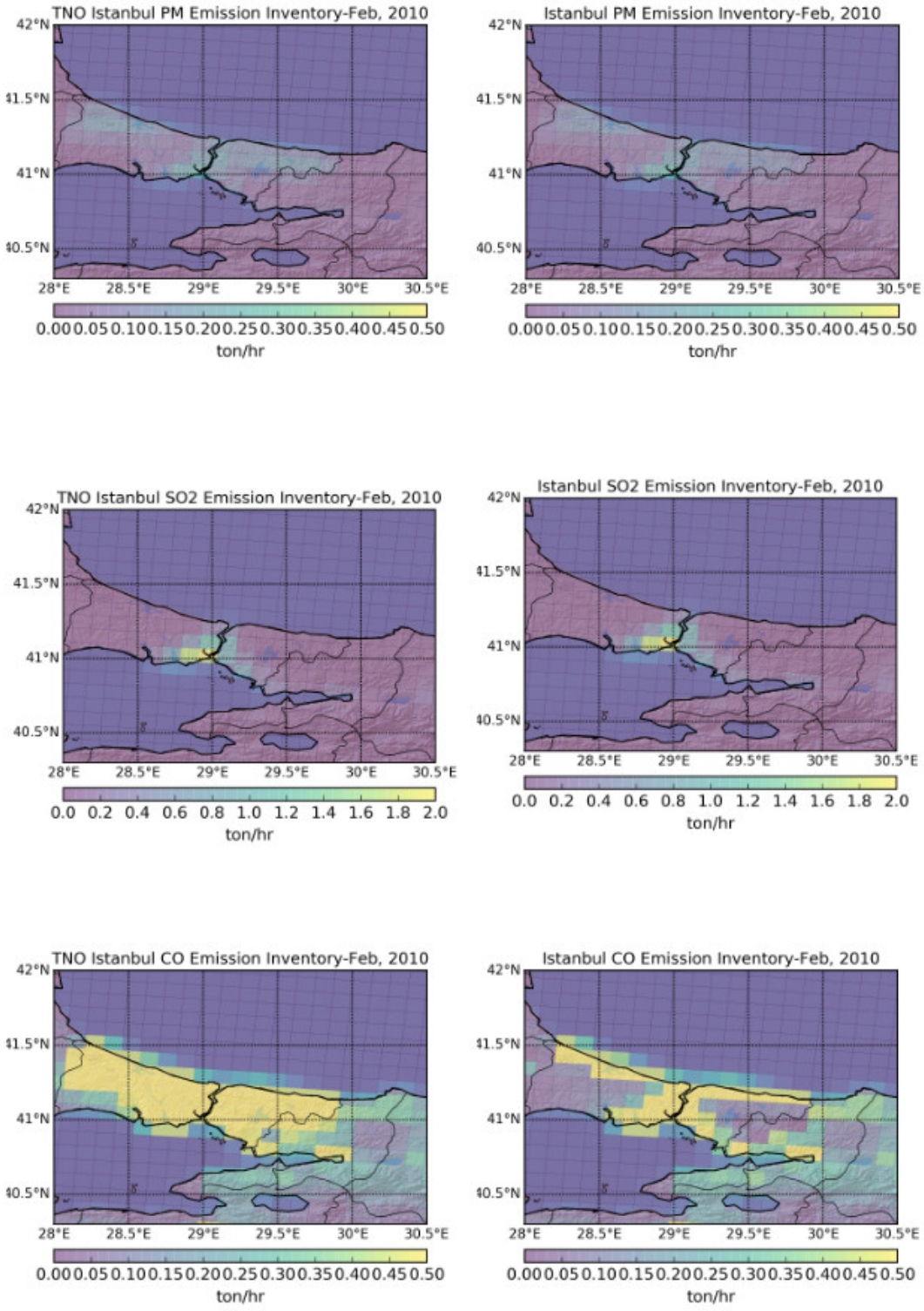

Figure 3.7 : February, 2010 average TNO vs Our PM_{10} , CO and SO_2 emissions (ton/hr).

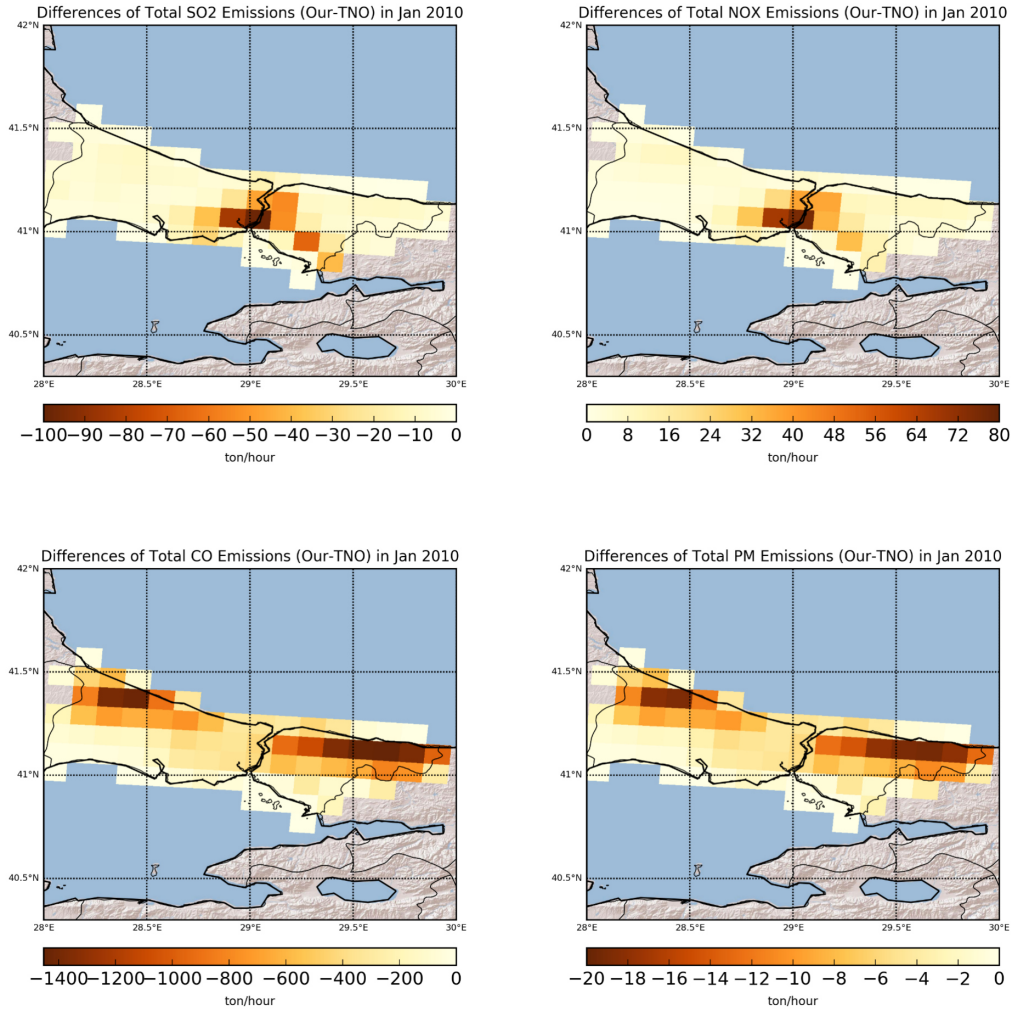

Figure 3.8 : Monthly total emission differences (Our-TNO) of January, 2010 (ton/hr).

The pollutants in the Figures 3.5, Figure 3.6 and Figure 3.7 are the main pollutants of residential heating source for winter seasons. In order to examine impact of the residential heating source December 2009, January 2010 and February 2010 selected as study period. The average residential emission values were generally similar in these 3 winter months. Although each pollutants in different range as magnitude, high residential emissions of each pollutants distributed over the city center that has dense population. While PM and SO_2 have generally similar magnitude and distributed similar in TNO and our inventories, distribution of CO and PM emissions are slightly different between two inventories. This distribution could be caused by spatial distribution of TNO gridded inventory data.

Figure 3.8 presents differences of Our and TNO total monthly emissions (Our-TNO) in January, 2010 in unit of ton/year. Although each pollutants have different magnitudes, the dense of the emission differences spatially distributed over similar area in Istanbul. The highest emission differences between Our and TNO inventory observed in regions that have dense emission sources. The differences observed generally in negative for each pollutants due to decreasing in Our emission inventory except NO_x. NO_x emissions were increased with the revised inventory.

3.2 WRF Model Performance

WRF meteorological model performance is evaluated by comparison with daily station observations of national air quality monitoring network of Istanbul. Ataturk Airport observation station (40.9 N and 28.8 E) was selected and the WRF model grid cell that cover this station was examined. WRF and station 2 m level temperature and wind speed results compared with each other in order to understand how they are similar to each other. Figure 3.9 presents daily average temperature comparison for three month episode (December 2009, January 2010 and February 2010). The figure shows although difference was observed in some days, trends are generally similar with model and observation results.The average temperature is around 8.7 C°for three month period.

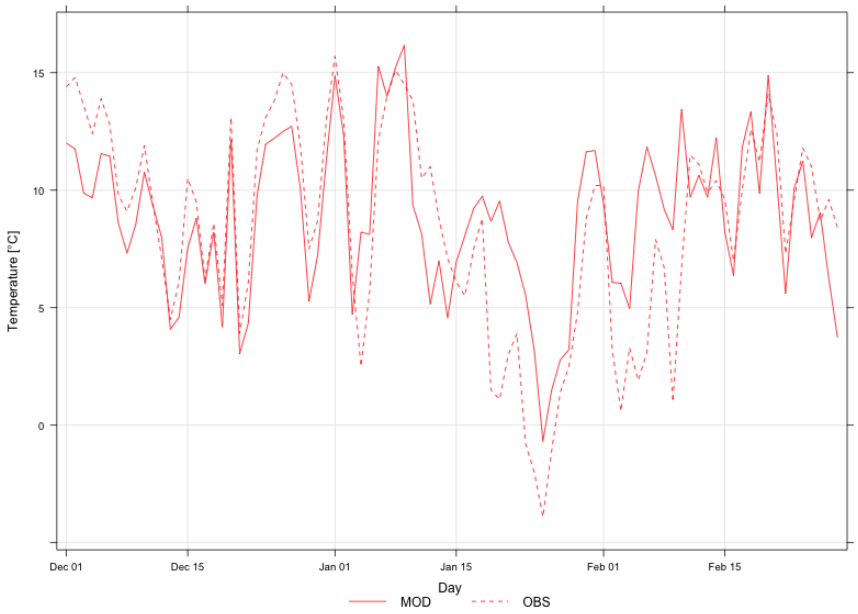

Figure 3.9 : Modelled and observed temperature values in Ataturk Airport Station.

In order to understand wind speed performance of WRF model, similar analysis was applied for this parameter. Daily WRF model wind speed values were compared with Ataturk station observation result values. Figure 3.10 presents timeseries of the values in study period. The performance analysis shows that model is in similar trend with the observations however wind speed values are under the station values. WRF model underestimated wind speed with respect to observation results.

Table 3.4 : Statistical relation between simulated WRF model outputs and observation station values for temperature and wind speed.

	MB	**NMB**	**RMSE**	**r**	**IOA**
Temperature	0.37	0.04	3.11	0.73	0.68
Wind Speed	-15.22	-0.80	17.48	0.06	-0.12

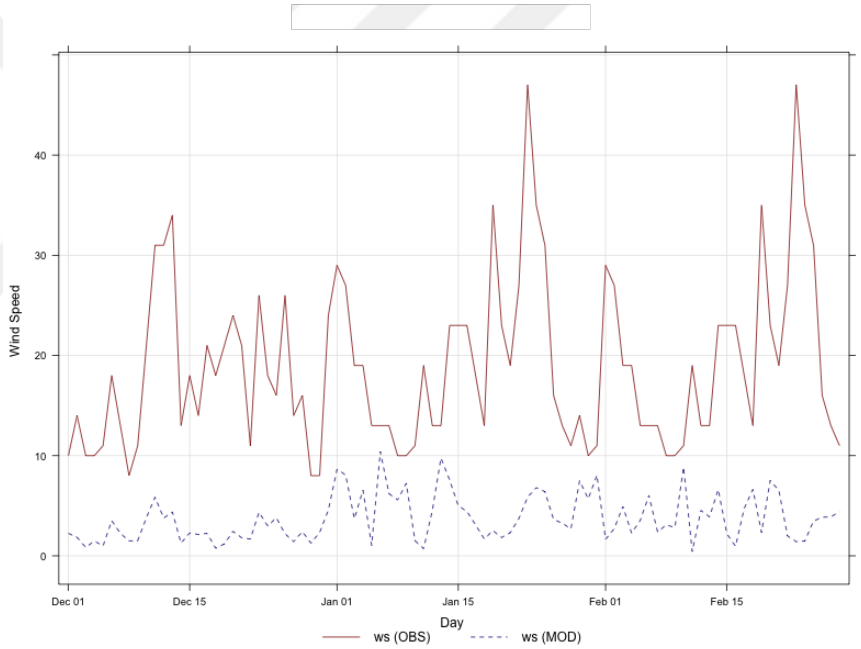

Figure 3.10 : Modelled and observed wind speed values in Ataturk Airport Station.

In order to express the difference between observation station measurements and Our simulated WRF model outputs, statistical analysis was performed. Statistical relation between simulated model and Ataturk Airport observation station for temperature and wind speed values were examined in Table 3.4. For this analysis mean bias (MB), normalized mean bias (NMB), root mean square error (RMSE), r value that is the correlation coefficient and index of agreement (IOA) value were considered. The MB provides a good indication of the mean over or under estimate of predictions. Positive values of mean bias represent over-prediction of model and negative values represent

under-prediction. The NMB is useful for comparing pollutants that cover different concentration scales and the mean bias is normalised by dividing by the observed concentration. The RMSE value is square root of the variance of the residuals and provides a good overall measure of how close the observed data points are to the model's predicted values. RMSE can be in range from 0 to and lower values represent better fit in model performance. Another statistical parameter for interpreting relation of meteorological values is correlation coefficient, r. The value of r is always between +1 and –1. While O means no linear relation between variables, -1 represent perfect linear relationship with negative slope and +1 represent perfect linear relationship with positive slope between two variables. IOA value that is index of agreement, spans between 1 and +1 with values. +1 value represents better fit and 0.5 value indicates that the sum of the error magnitudes is one half of the sum of the observed-deviation magnitudes. When IOA is 0.0, it signifies that the sum of the magnitudes of the errors and the sum of the observed-deviation magnitudes are equivalent. When 0.5 indicates that the sum of the error-magnitudes is twice the sum of the perfect model-deviation and observed-deviation magnitudes.

As it is presented in Table 3.4, for 2 meter temperature values are slightly positively biased and r value, which is expected to be 1 for proper simulation is 0.73. For wind speed, MB is negative and values are negatively biased. Simulated WRF model underestimated with respect to observation values. r and IOA values which are expected to be -1 or +1 for the proper fit for this parameter are not perfect. The reason of the differences between the measurement and the simulated model results is that model gives only one value for 10x10 km^2 area, but observations represent one value at specific point. Low resolution models give average values, thus errors from these approximations are also averaged.

3.3 CMAQ Model Performance and Evaluation

The CMAQ chemistry and transport model has run for the European domain of 30 km resolution on 191 and 159 grids at x and y directions, respectively. The inner domain has 10 km spatial distribution and covers all Turkey with 154 by 241 grid cells. Calculated daily PM_{10} concentrations were compared with observed PM_{10} concentrations of Istanbul Ataturk Airport Station. For this purpose, the grid cell

that include the selected station coordinates (40.9 N and 28.8 E) was determined and the concentration values from the observation station and model grid cell were compared. Figure 3.11 presents comparison of daily modelled and observed PM_{10} concentrations. The timeseries shows the daily concentration values for three months study period. Although both model and observation values have similar trend, variability of observation concentration values are higher. In some days such as 11th December and 16th February observation stations measured PM_{10} concentrations over 170 ug/m^3. Although there is an increasing trend in model for these days the calculated concentrations were underestimated in these days according to observations.

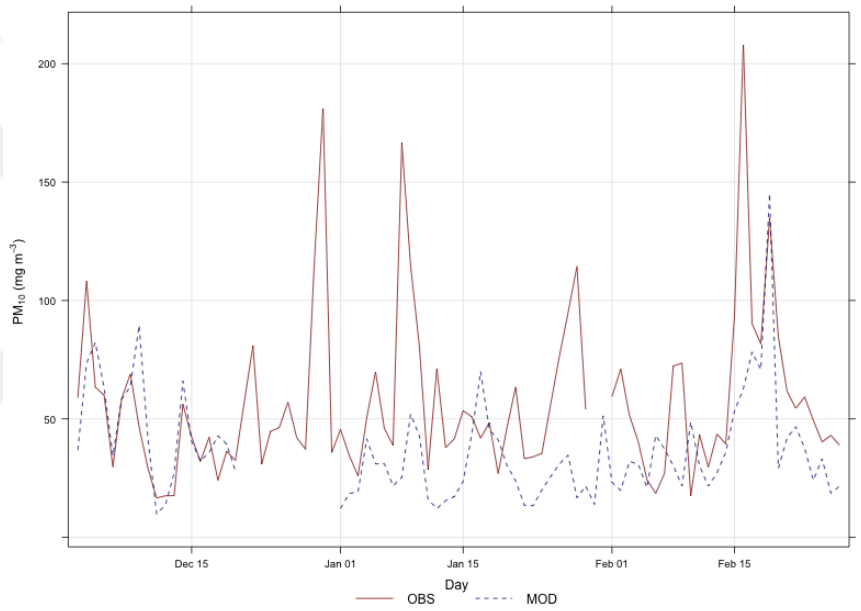

Figure 3.11 : Modelled and Observed PM_{10} concentrations in Ataturk Airport Station (ug/m^3).

In Figure 3.12 daily PM_{10} concentrations of average Istanbul observation stations and CMAQ outputs that were calculated by Our and TNO emission inventories were presented. Figure 3.12 shows that while CMAQ outputs of TNO and Our were almost same with each other. Daily average PM_{10} observation station concentrations were higher than the model outputs although all three of them has similar trend.

In order to make comparisons between simulated CMAQ model and observation station results, physically meaningful and simple statistical parameters such as MB, NMB, RMSE, r and IOA values were considered. The statistical relation between model outputs and observation values for PM_{10} was presented in Table 3.5. For

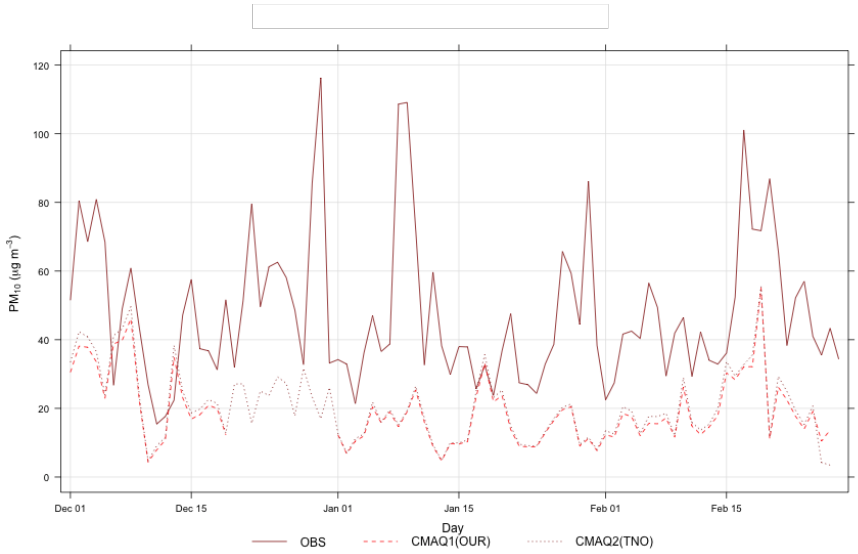

Figure 3.12 : Comparison of daily PM_{10} concentrations of average Istanbul observation stations, OUR and TNO CMAQ Outputs (ug/m^3) .

Table 3.5 : Statistical relation between simulated CMAQ model outputs and observation station values for PM_{10} concentrations

	MB	**NMB**	**RMSE**	**r**	**IOA**
TNO	-27.17	-0.57	34.33	0.27	0.15
OUR	-27.06	-0.59	33.20	0.34	0.11

both model results of TNO and OUR concentrations MB values are negative and that indicate the values are negatively biased, model is under-predicted. r and IOA values which are expected to be -1 or +1 for the proper fit for this parameter are not perfect. The reason of the differences between the measurement and the simulated model results is that model gives only one value for 10x10 km^2 area, but observations represent one value at specific point. Low resolution models give average values, thus errors from these approximations are also averaged. Moreover air quality model also covers some errors that come from meteorological model outputs and inital-boundary conditions.

Pollutant concentrations for PM_{10}, SO_2, NO_x and CO were obtained from national air quality monitoring network of Istanbul. The values in the Table 3.6 are average concentrations from the all stations of Istanbul for three months study period (from December, 2009 to February, 2010). Average concentrations generally do not have high differences over all the three months. PM_{10} monthly average concentrations are around 44 - 51 ug/m^3 with standard deviation around 23 - 27. SO_2 monthly average

Table 3.6 : Monthly average observation stations concentrations and standard deviations of Istanbul (ug/m^3)

	PM_{10}		SO_2		NO_x		CO	
	AVE	**STD**	**AVE**	**STD**	**AVE**	**STD**	**AVE**	**STD**
DECEMBER	51.42	27.33	10.85	7.01	134.80	71.52	810.93	403.14
JANUARY	44.00	24.81	8.80	5.66	128.17	44.00	718.14	133.42
FEBRUARY	47.22	23.21	9.67	4.54	137.00	50.93	812.50	342.63

concentrations are around 8-10 ug/m^3. Standard deviation that represent variability of the SO_2 concentrations are low (between 4 -7) and that means the concentrations do not include very extreme values and concentrated around the mean in the period. NO_x monthly average concentrations are around 128 -137 ug/m^3 and standard deviation is between 44 and 71. CO concentrations are observed between 718 - 812 ug/m^3 with high standard deviation values (between 133 - 342). The high standard deviation represents high variability in the concentration values for this pollutant in the episode. While the minimum CO concentration is 251 ug/m^3, the maximum concentration is observed as 1926 ug/m^3 in the episode.

In this study CMAQ model was run with TNO inventory as base case. Then residential heating emissions (SNAP 2) for the grids that cover Istanbul city was revised and the model was run again with the new inventory. In order to estimate the impact of the emission changes over the city, the concentration values from the model outputs were visualized in Figure 3.13. Spatial distribution of simuated CMAQ model with TNO and Our emissions for main pollutants were presented in Figure 3.13.

Monthly average concentration differences (Our-TNO) were visualized and presented in Figure 3.14 for CO, SO_2, NO_2 and PM_{10} concentrations. The distributions were similar with emission distributions, highest concentration differences were obtained in city center where is highly populated and urbanized.

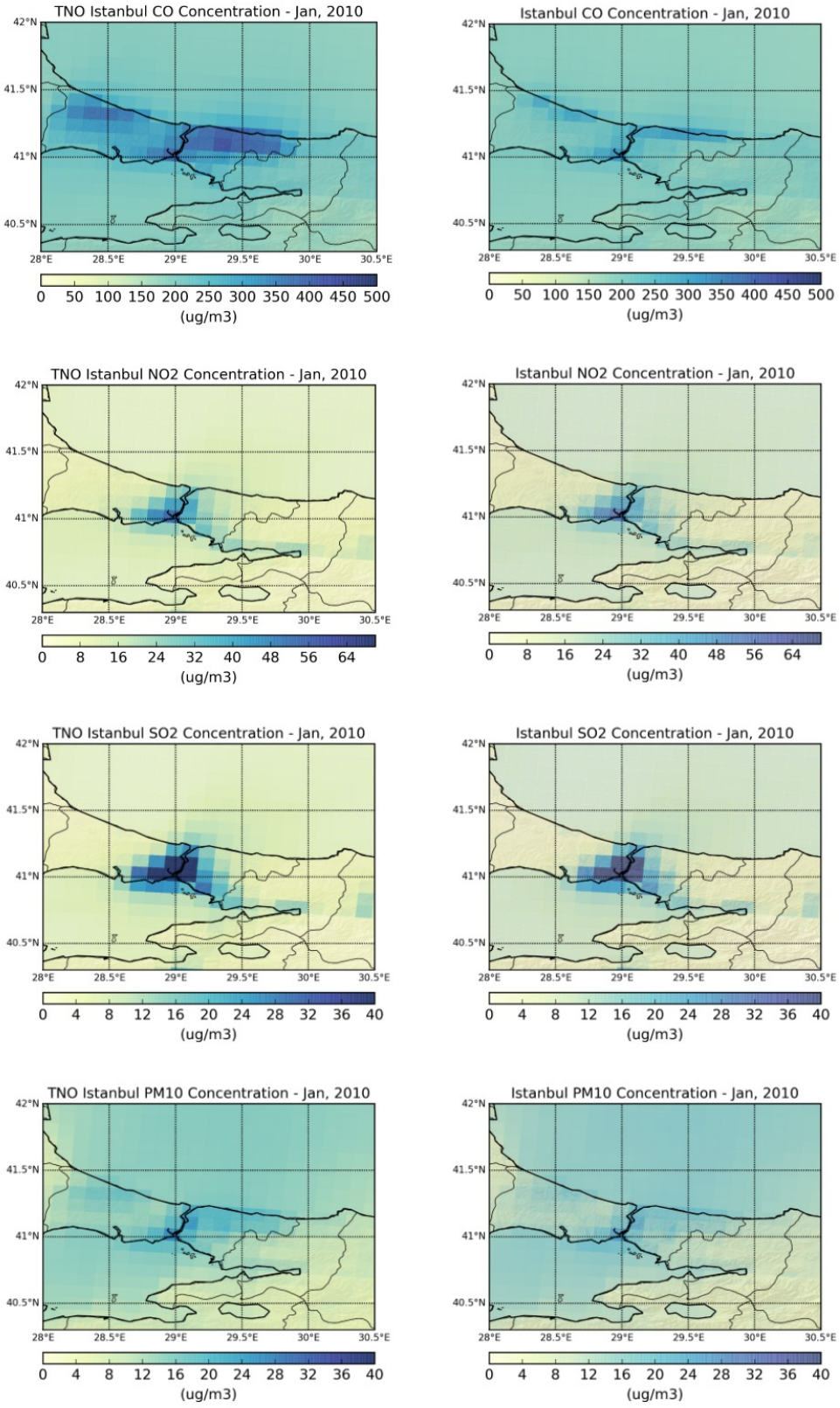

Figure 3.13 : Monthly Average CO and NO_2, SO_2 and PM_{10} concentrations of TNO vs Our January, 2010 (ug/m^3).

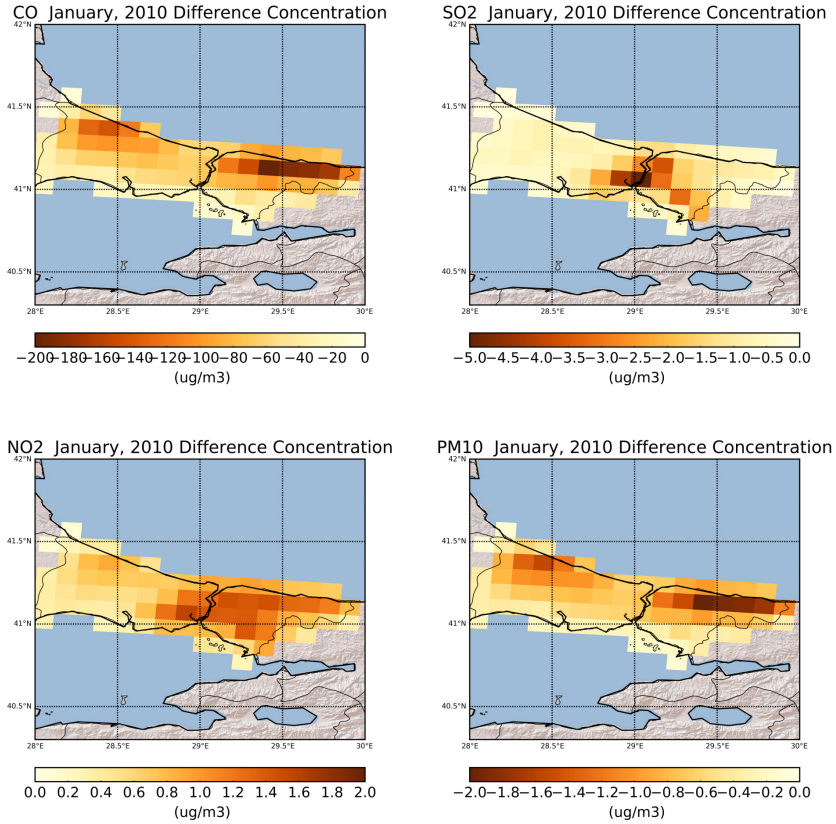

Figure 3.14 : Monthly average concentration differences (Our-TNO) of January, 2010 (ug/m^3).

In order to determine the days that gave maximum response to changes in the inventory, differences of daily PM_{10} concentrations were examined. Figure 3.15 presents timeseries maximum, minimum and average differences on daily PM_{10} concentrations for December 2009, January 2010 and February 2010. From the figures highest differences were observed in 2th and 7th December with 12 - 11 ug/m^3 , 20th January with 8 ug/m^3 and 19th February with 10 ug/m^3. The differences (Our-TNO) are generally negative because of decreasing in our new emission inventory. In addition, maximum, minimum and average hourly differences of PM_{10} concentrations in each months were also presented in Figure 3.15 in order to understand the time that gave the maximum response in the episode months.As it is seen from the figure, the highest responses were obtained in similar times because of the temporal distribution.

After all these analysis the days and times that include maximum differences of PM_{10} concentrations were examined from CMAQ outputs (Our - TNO). The visualization of the PM_{10} concentration differences were presented in Figure 3.16 . In December 2009, maximum PM_{10} difference was observed on 7th December with 11 ug/m^3 and on at

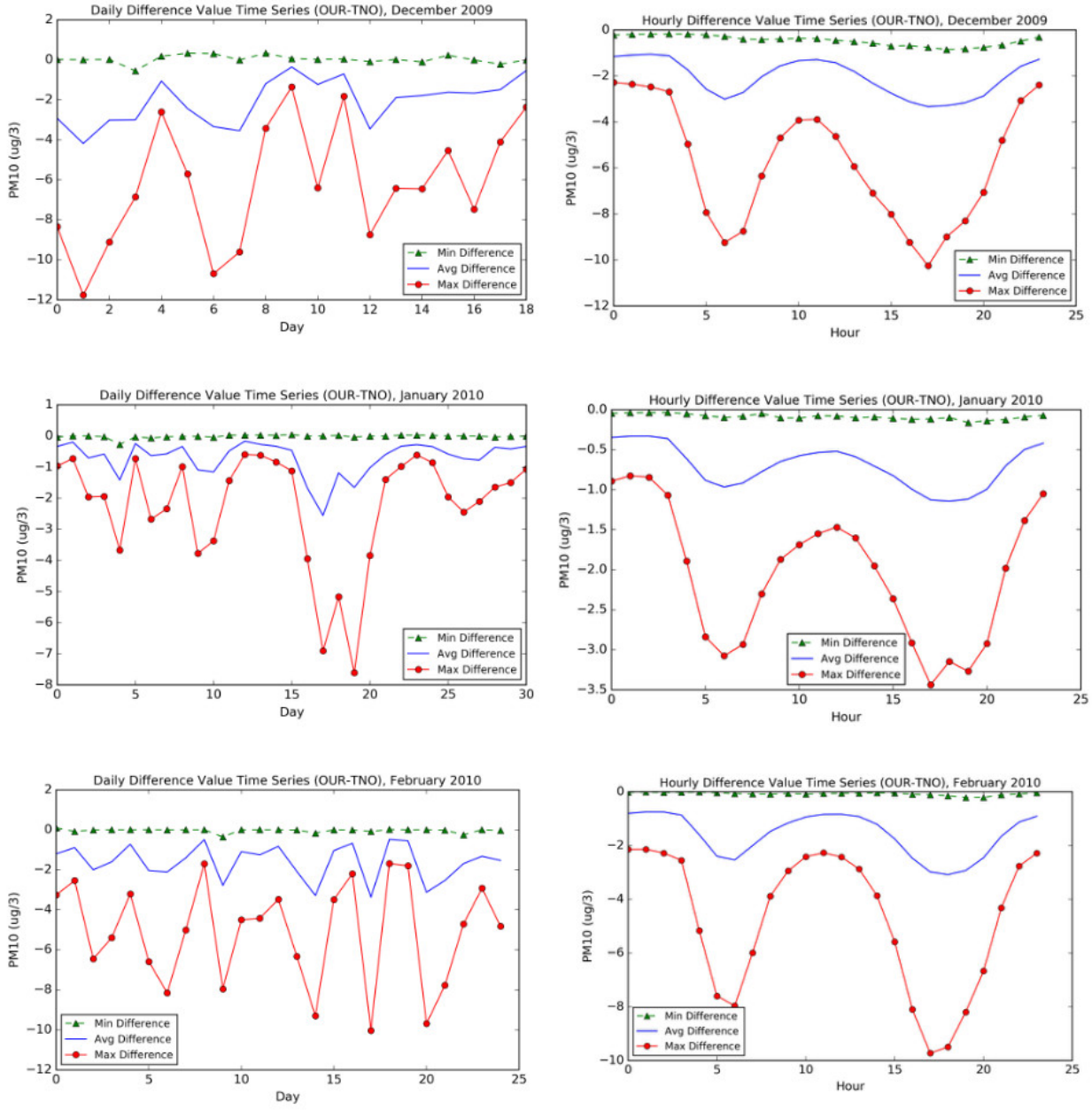

Figure 3.15 : Maximum, minimum and average differences of daily and hourly PM_{10} concentrations (OUR-TNO) in December 2009, January 2010 and February 2010 (ug/m^3).

17:00, in January 2010, on 20th day with 8 ug/m^3 at 17:00 and in February 2010, on 19th day with 10 ug/m^3 at 17:00.

Beside these detailed PM_{10} analysis, similar analyses were done for other main pollutants. Figure 1, 3 and 5 in Appendices part represent maximum, average and minimum concentration differences in December 2009, January 2010 and February 2010 for SO_2, CO and NO_2, respectively.

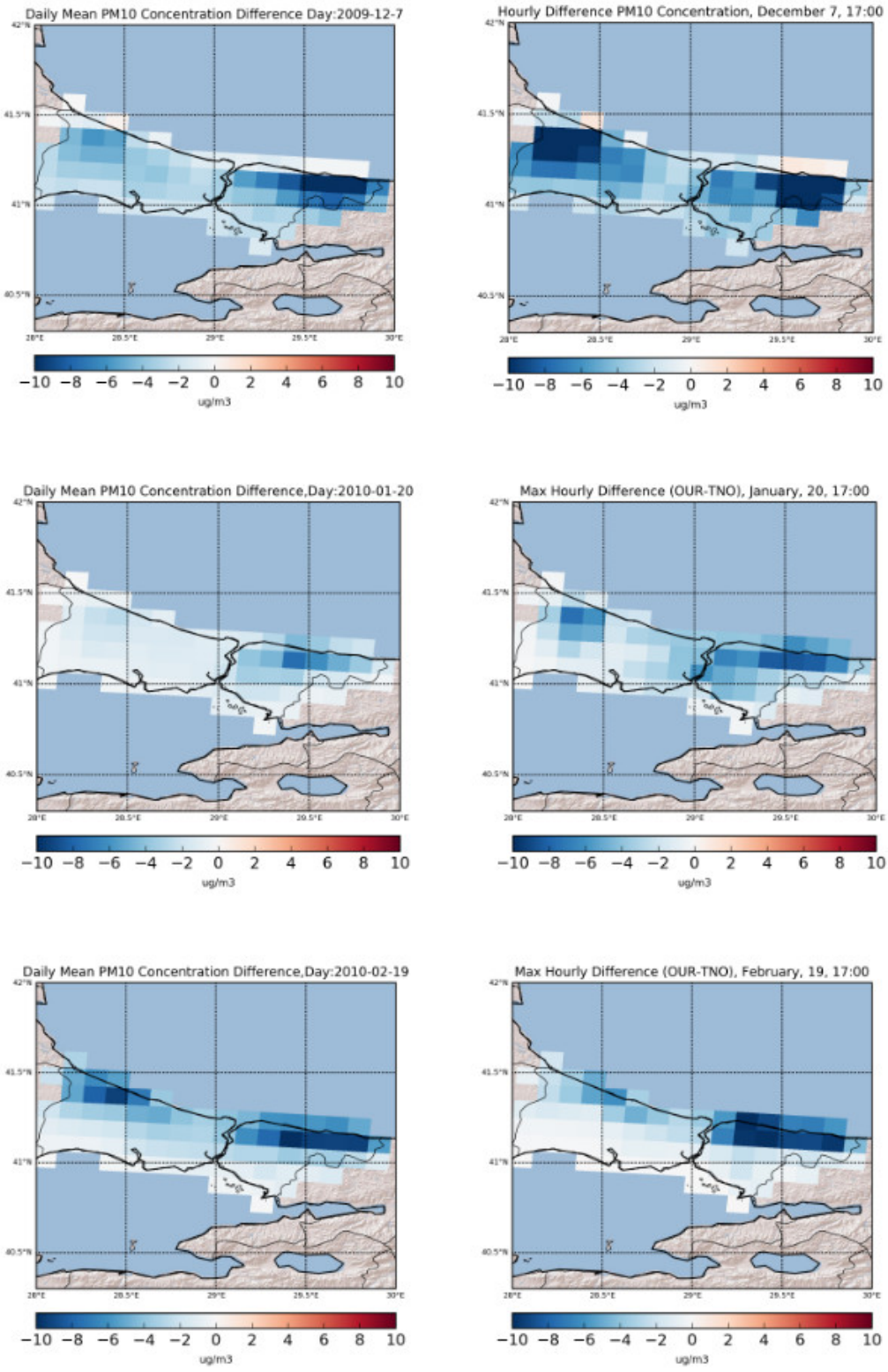

Figure 3.16 : Maximum difference of daily and hourly PM_{10} Concentrations (OUR-TNO) in 7th December, 2009 at 17:00, in 20th January at 17:00 and in 19th February at 17:00 (ug/m^3).

As result of modification on emission inventory, maximum response of SO_2 concentration was observed on 7th day of December 2009, 18th day of January 2010 and 15th day of February 2010 with 27 ug/m^3, 13 ug/m^3 and 20 ug/m^3, respectively. For CO pollutant, range of concentrations were in higher range with respect to other pollutants. Because of that obtained average and maximum response of CO concentrations were also higher. Maximum concentration difference was observed on 7th December with 720 ug/m^3, 20th January with 800 ug/m^3 and 21th February with 600 ug/m^3. Although for PM_{10}, SO_2 and CO pollutants differences were generally negative due to decreasing of emissions, only for NO_x concentration differences were positive because of increasing of emissions for this pollutant. Maximum difference of NO_x concentrations were observed on 7th December 2009, 18th January 2010 and 15th February 2010 with 8 ug/m^3, 4.5 ug/m^3 and 11 ug/m^3, respectively.

4. CONCLUSION

In this study, the aim was generating a more accurate emission inventory for residential heating emissions. Residential heating is a problem for air quality in Istanbul although it is not very important source for developed countries. Because in Turkey as well as Istanbul, solid fuels and natural gas are the most common fuels for home heating. In Istanbul, 72506 ton/year import coal, 448122 ton/year domestic coal and 3468049 m^3/year natural gas are used to provide residential heating energy for the year 2013. The fuel usage amounts and emissions come from residential heating are expected to be higher in the future years as the population increases.

In order to prepare emission inventory, the first step was generating region specific emission factors for Istanbul. For this purpose, several measurements were done and the factors for natural gas, import and domestic coal were calculated by considering combustion parameters such as flow rate of the gas stack and fuel consumption in unit time. The factors for PM_{10}, NO_x, SO_2 and CO were calculated. Concentrations of NH_3 and NMVOC were not measured and the emission factors for these pollutants were obtained by EMEP factors. After determining the emission factors for each fuels and pollutants, emissions calculated by multiplying the factors with activity data.

This study is a part of Development of National Emissions Inventory Management System for Turkey (KAMAG) Project.The activity data collection period was completed by providing data from Environment and Urbanization Ministry, General Directorate of Forestry, Istanbul Greater Municipality and EPDK sector reports.

The new residential heating emissions are generated by region specific emission factors and more accurate activity data. SNAP 2 sector TNO emissions are revised with the prepared emissions and new inventory used as input of CMAQ model in order to understand its impact over the Istanbul city in study episode.The study episode is selected as winter season (from December 1, 2009 to February 30, 2010), three months, in order to evaluate residential heating emissions. The base inventory is taken

as TNO 2009 emission inventory. TNO was not reported about which activity data and emission factors were used in preparations process of the inventory. Because of that our inventory is open for improvement according to TNO even it has still uncertainties.

The TNO residential emissions were generally decreased in new emission inventory. While CO and SO_x emissions were decreased dramatically (around 90 percent), PM_{10} emissions decreased 16 percent and NO_x emissions were increased 32 percent. As result of this improvement on emission inventory, concentration values from CMAQ model outputs were analysed in order to cover its impact over the Istanbul city. For this purpose, firstly monthly average effects and spatial distributions of concentrations were analysed. For particulate matter concentrations, the days which have maximum concentration differences investigated to examine better for each months. Finally the the concentration differences of specific days were examined hourly in order to determine maximum response in hour level. As result of changes on emission inventory, PM_{10}, SO_x and CO concentrations averagely decreased 4.3, 7.6 and 37.2 percent respectively. Changes of NO_x concentrations were in positive way with averagely 8.3 percent.

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APPENDICES

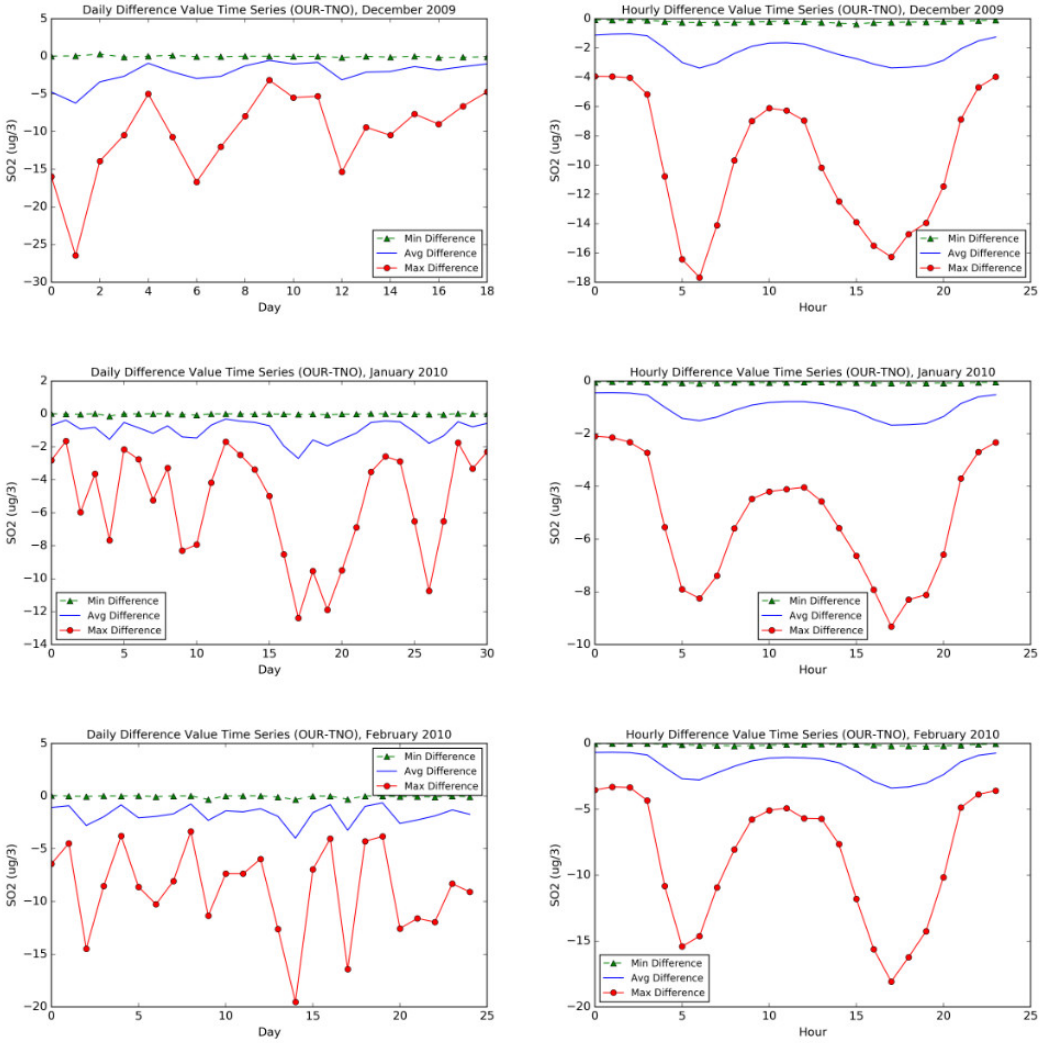

Figure 1 : Maximum, minimum and average differences of daily and hourly SO_2 concentrations (OUR-TNO) in December 2009, January 2010 and February 2010 (ug/m^3).

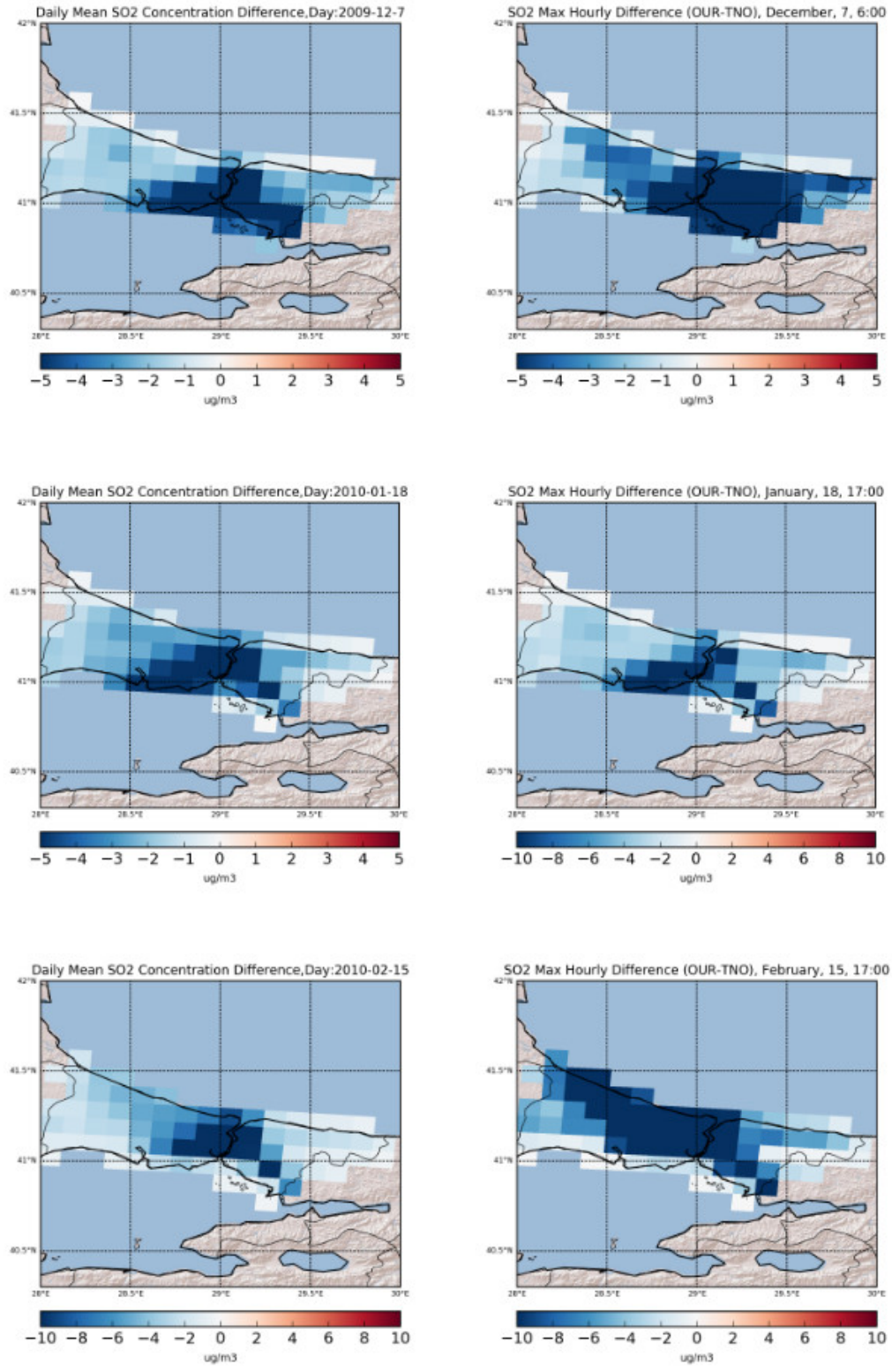

Figure 2 : Maximum Difference of daily and hourly SO_2 concentrations (OUR-TNO) in 7th December, 2009 at 6:00, in 18th January at 20:00 and in 15th February at 19:00 (ug/m^3).

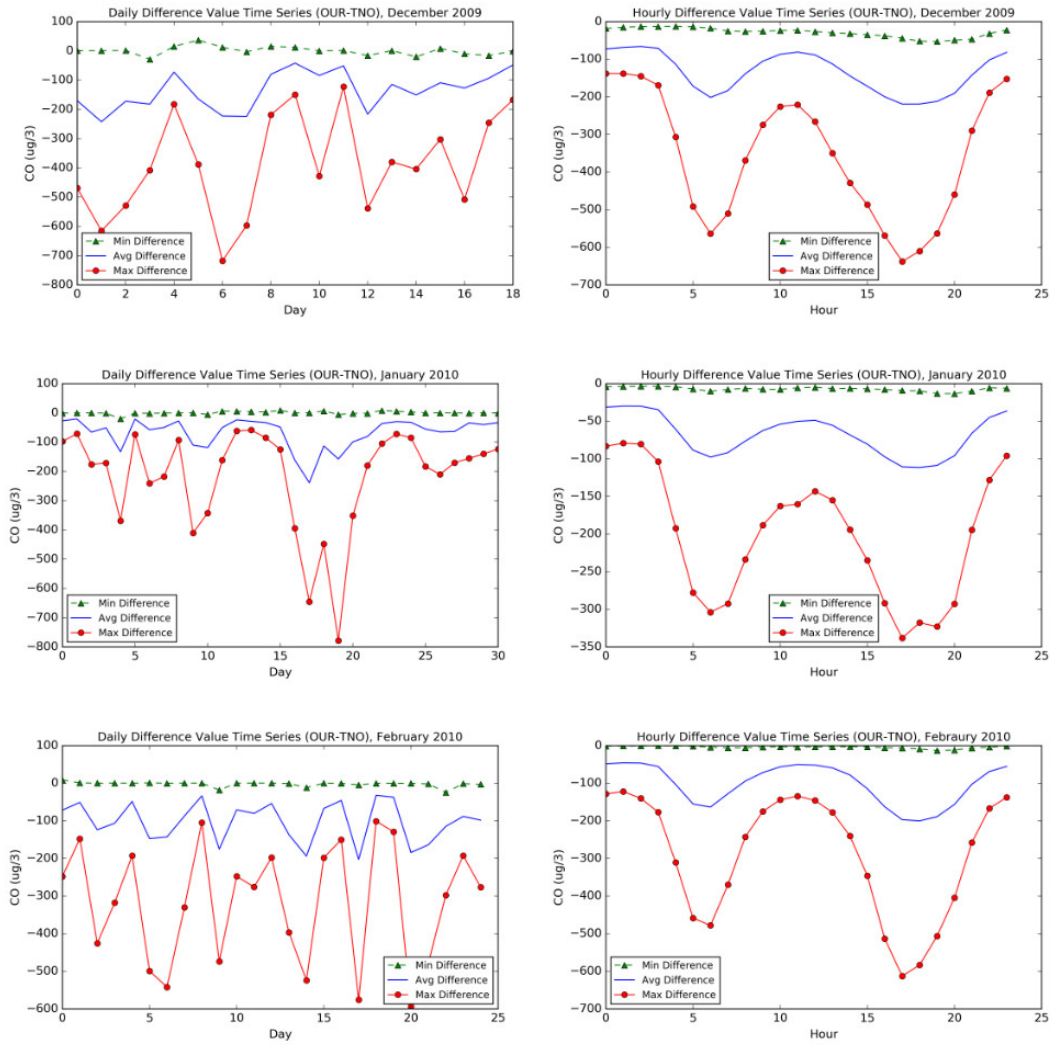

Figure 3 : Maximum, minimum and average differences of daily and hourly CO concentrations (OUR-TNO) in December 2009, January 2010 and February 2010 (ug/m^3).

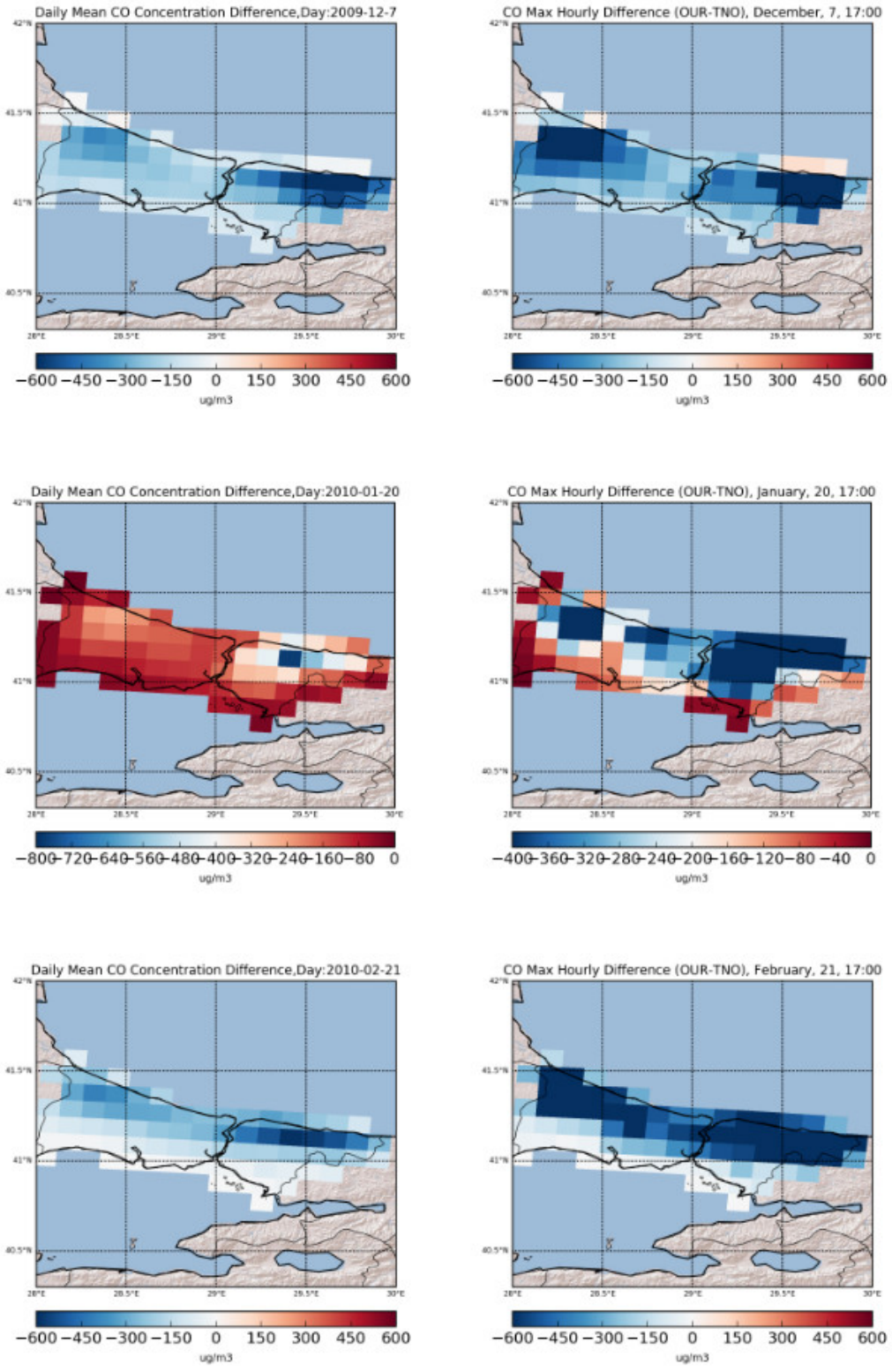

Figure 4 : Maximum Difference of daily and hourly CO concentrations (OUR-TNO) in 7th December, 2009 at 17:00, in 20th January at 17:00 and in 21th February at 17:00 (ug/m^3).

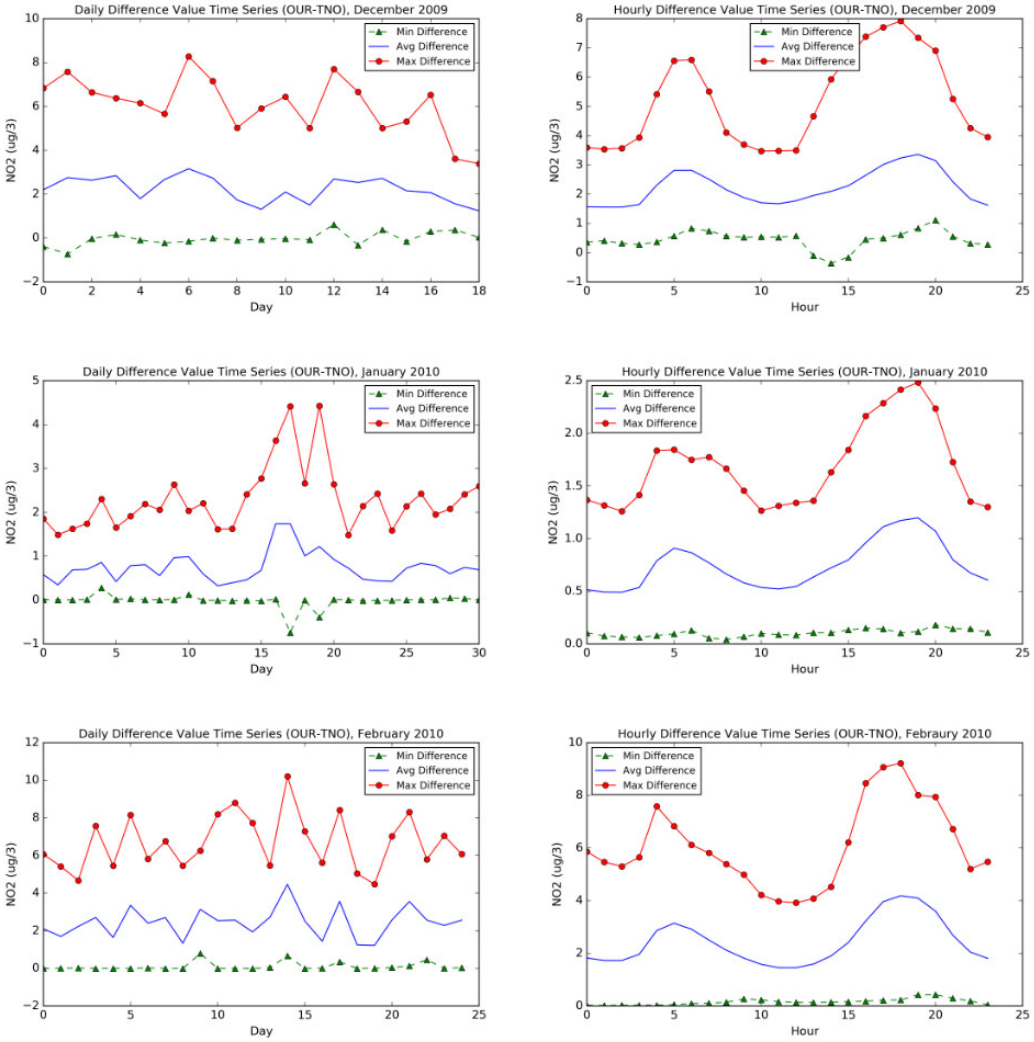

Figure 5 : Maximum, minimum and average differences of daily and hourly NO_2 concentrations (OUR-TNO) in December 2009, January 2010 and February 2010 (ug/m^3).

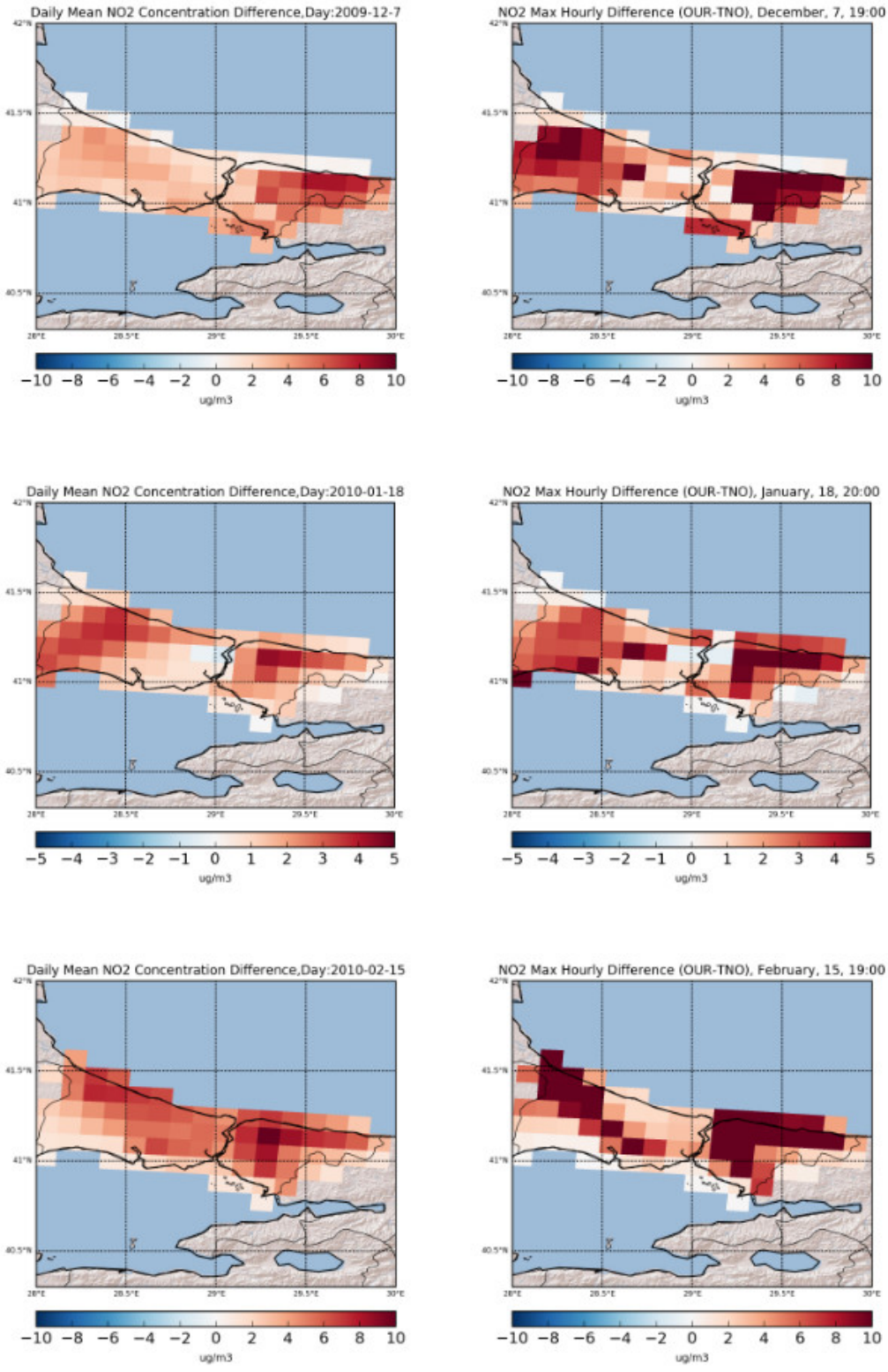

Figure 6 : Maximum Difference of daily and hourly NO_2 concentrations (OUR-TNO) in 7th December, 2009 at 19:00, in 18th January at 20:00 and in 15th February at 19:00 (ug/m^3).

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