ISTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

LOW EMISSION ZONE STUDY IN ISTANBUL BY USING MODELS-3 /CMAQ FRAMEWORK

M.Sc. THESIS

Merve GÖKGÖZ ERGÜL

Climate and Marine Sciences

Earth System Sciences

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Thesis Advisor: Prof. Dr. Alper ÜNAL

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İSTANBUL'DA MODELS-3 / CMAQ MODEL SİSTEMİ KULLANARAK DÜŞÜK EMİSYON BÖLGESİ ÇALIŞMASI

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May the force be with this thesis,

FOREWORD

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Dec 2015 Merve GÖKGÖZ ERGÜL

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ABBREVIATIONS

ABSE : Absolute error
ACM : An aerosol module
AERO : An aerosol module
AFWA : Air Force Weather Agency
AQM : Air Quality Model
BCON : Boundary Condition
BVOC : Biogenic volatile organic compound
CCTM : Chemical Transport Model
CMAQ : Community Multiscale Air Quality
CNG : Compressed Natural Gas
CO : Carbon monoxide
COPERT : Computer Programme to calculate Emissions from Road Transport
DUMAN : An emission-chemistry interface module
EBI : Euler backward approximation
ECMWF : European Centre for Medium-Range Weather Forecast
EEA : European Environmental Agency
EU : European Union
FAA : Federal Aviation Administration
GDAS : Global Data Assimilation System
HC : Hydrocarbon
ICON : Initial Condition
IOA : Intex of Agreement
IPCC : Intergovernmental Panel on Climate Change
JPROC : Photolysis Rate Processor
LEZ : Low Emission Zone
MB : Mean Bias
MCIP : Meteorology – Chemistry Interface Processor
MEGAN : Model of Emissions of Gases and Aerosols from Nature
NCAR : National Center for Atmospheric Research
NCEP : National Centers for Environmental Prediction
NEMO : A Natural Emission Model
NMB : Normalized Mean Bias
NMVOC : Non methane volatile organic compound
NO : Nitric oxide
NO_2 : Nitrogen dioxide
NO_x : Nitrogen oxides
O_3 : Ozone
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
RMSE : Root Mean Square Error

TNO : Netherlands Organization for Applied Scientific Research
TÜVTÜRK : Vehicle Inspection Station
TÜIK : Turkish Statistical Institute
USEPA : United States Environmental Protection Agency
USGS : United States Geological Survey
SO_2 : Sulphur dioxide
WRF : Weather Research & Forecasting Model
WRF-ARW : Advanced Research Weather Research & Forecasting Model
WRF-NMM : Non-hydrostatic Mesoscale Weather Research & Forecasting Model
VOC : Volatile organic compound

SYMBOLS

mb : milibar
μg : microgram
km : Kilometer
hPa : Hectopascal
$^\circ C$: Celcius Degree
€ : Official currency sign of Euro
$\%$: Percentage

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LOW EMISSION ZONE STUDY IN ISTANBUL
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SUMMARY

Istanbul is the most populated city of Turkey as well as one of the mega cities of the world. Due to growing population and economy, city has been experiencing the problems of air pollution. There are many studies about air pollution effects on human health in the literature. Road transport emissions are released in areas where people live intensively, therefore these emissions are important for public health. This thesis aims to identify and quantify the measures to be taken to prevent traffic-related air pollution by using WRF meteorology model and CMAQ chemistry and transport model. This study presents the first Low Emission Zone study in Istanbul by using modeling and highlights the requirements of Low Emission Zone establishment.

Istanbul-specific inventory includes main anthropogenic sources on 2 km horizontal and hourly temporal resolution. Road transport emissions were obtained from COPERT emission model. Emission model results reveal that on-road traffic emissions are the main source for most of the pollutants such as CO, NMVOC and NO$_x$, industrial combustion is responsible for high amount of SO$_2$ emissions and solvent use and traffic are the main participants for NMVOC emissions. The spatial distribution of air pollutants has proved that the highest concentrations occur at the places where emission sources are located. But uncertainties may be occur due to the activity data, emission factors and temporal profiles used in this thesis.

WRF model was run for a 11-day period, includes PM concentrations are mostly higher than EU limit value (50$\mu g/m^3$), from November 2 to November 12, 2010. Model run results from the WRF simulation were compared with observations from Ataturk Airport and Goztepe air quality stations. According to statistical and time plot results WRF has captured surface temperature successfully. But this performance can be further improved by changing physical parameters of WRF.

The results from the CMAQ model were compared with Aksaray air quality station based on PM$_{10}$ concentrations. The statistical performance of model shows low correlation with the observations. Differences between model with measurement results can arise from many causes such as; uncertainty in the meteorological model and COPERT model, improper boundary conditions and temporal profiles and measurement errors.

In order to limit traffic related air pollutants, methods and regions which have high density of population and work places were determined. Based on these criteria Historical Peninsula, Kadikoy and Maslak were selected as candidates. When transport sector emissions were reduced by 30% and given to DUMAN model, Historical Peninsula has demonstrated most significant response which is 10$\mu g/m^3$ reduction in

PM_{10} hourly concentration. Then, effect of each method on PM levels was examined by using literature studies and COPERT model. The most effective method was found as EURO 3 standard causes 85% reduction in PM_{10} emissions. In the case of only EURO 3, EURO 4, EUR0 5 and EURO 6 vehicles can enter the zone, hourly PM concentration differences between base situation and low emission case has reached up $35 \mu g/m^3$. Overall, a low emission zone will be announced on the Historical Peninsula, will provide a significant improvement in regional air quality.

İSTANBUL’DA MODELS-3 / CMAQ MODEL SİSTEMİ KULLANARAK DÜŞÜK EMİSYON BÖLGESİ ÇALIŞMASI

ÖZET

İstanbul, Türkiye’deki en büyük şehir olmasının yanı sıra 14 milyonu aşan nüfusuyla dünyadaki mega şehirlerden biridir. Bu şehir, artan nüfusu ve gelişen endüstrisi sebebiyle sıklıkla hava kirliliği problemi yaşamaktadır. Hava kirliliğinin, insan sağlığı üzerindeki etkileri literatürdeki bir çok çalışma tarafından kanıtlanmıştır. Kirleticilere maruz kalmanın, akciğer ve solunum yolu rahatsızlıkları, kardiyovasküler hastalıklar, astım şikayetlerinde artış, erken doğum ve ölüme varan sonuçları görülmektedir. Ulaşım kaynaklı emisyonlar, toplumun yoğun yaşadığı şehirleşmiş bölgelerde yoğunlaştığı için insan sağlığı açısından diğer emisyon kaynaklarına göre daha önemli bir yere sahiptir. Ayrıca bu emisyonların yer seviyesinde salınıyor olması da hava kirliliğine maruziyeti arttıran sebeplerden biridir. Bu tez çalışmasında trafik kaynaklı emisyonları sınırlandırmak ve azaltmak için alınacak önlemleri belirlemek ve etkilerini hesaplayabilmek için WRF meteroloji modeli, COPERT trafik kaynaklı emisyon hesaplama modeli ve CMAQ kimyasal taşınım modeli kullanılmıştır. Literatürdeki emisyon azaltım yöntemleri bu çalışmada teknolojik, davranışsal ve yönetimsel olarak gruplandırılmıştır. Bu önlemler arasında dizel partikül filtre kullanımı, EURO standartlarına göre araç girişlerinin sınırlandırılması, elektrikli otobüslerle toplu ulaşımın sağlanması, düşük emisyon bölgesi içindeki park ücretlerinin arttırılması, bölgeye giriş yapacak araçların trafik sıkışıklığı ücreti ödeyerek bölgeye giriş yapması, sinyalizasyonda yapılacak iyileştirmeler ve geliştirilmiş toplu ulaşım sistemleri sayesinde özel otomobil kullanımının azaltılması bulunmaktadır. Düşük Emisyon Bölgesi çalışması bu önlemlerin tek başına ya da topluca uygulanabildiği bir yöntemdir. Dünyada uygulama alanı gittikçe genişleyen bu metod 8 ülke ve 70 şehirde kurulmuş durumdadır. Bu tez çalışmasında İstanbul için aday bölgeler belirlenerek Düşük Emisyon Bölgesi çalışması ilk defa modellenmiştir.

Meteoroloji ve kimyasal taşınım modelleri, 3 domain için koşturulmuştur. Ana domain tüm Avrupa’yı, Kuzey Afrika’yı ve Doğu Asya’nın bir kısmını, ikinci domain tüm Türkiye’yi, üçüncü domain İstanbul’u kapsamaktadır ve çözünürlükleri sırasıyla 30 km, 10 km, ve 2 km’dir. 30 km ve 10 km’lik domainlerde TNO’nun hazırlamış olduğu emisyon envanteri kullanılmıştır. Im’in İstanbul için hazırlamış olduğu emisyon envanteri 2 km mekansal çözünürlükte ve saatlik olarak başlıca antropojenik kaynakları içermektedir. Bu kaynakların içerisinde evsel ısınma, endüstri, atık yönetimi, solvent kullanımı, enerji üretimi, yakıt işleme ve ulaşım yer almaktadır. Bu çalışmada, COPERT modeli ile trafik kaynaklı emisyonlar hesaplanarak İstanbul’ a ait envanterin ulaşım sektörü kısmında kullanılmıştır. Biyojenik emisyonlar için MEGAN modeli kullanarak doğal emisyonlar da hesaba katılmıştır. Emisyonların dağılımına bakıldığında ulaşım sektörü CO, NMVOC ve NO_x kirleticilerinin ana kaynağı olarak görülmektedir. Endüstri ise SO_2 emisyonlarının, çözücü kullanımı

ve trafik ise NMVOC emisyonlarının ana kaynağıdır. İstanbul envanterindeki trafik sektörü, insan sağlığı açısından en önemli kirleticilerden biri olan PM için ana kaynak iken, COPERT'e ait emisyonların ulaşım sektörü için kullanılması durumunda PM için ana kaynak, üretim endüstrisi olmaktadır.

İstanbul'da 26 adet hava kalitesi ölçüm istasyonu bulunmaktadır. Bu istasyonların hepsinde SO_2 ve PM_{10} ölçümü yapılmakta olup bazılarındaysa bunlara ek olarak sıcaklık, rüzgar, azotoksit (NO, NO_2, NO_x), CO ve O_3 ölçümleri yapılmaktadır. Bu çalışma esnasında bu istasyonlardan elde edilen konsantrasyon değerleriyle model sonuçları karşılaştırılmıştır. WRF modeli, 2-12 Kasım 2010 tarihleri arasında koşturulmuştur. Modelin sonuçları Atatürk Havaalanı ve Göztepe'deki hava kalitesi istasyonlarından elde edilen ölçüm sonuçlarıyla karşılaştırılmıştır. Zaman serisi ve istatistiksel analizler, WRF'un yüzey sıcaklığını yakalamada başarılı olduğunu göstermektedir. Modelin performansını arttırmak için modelin fiziksel parametreleri üzerinde değişiklikler yapılarak en uygun seçenek belirlenebilir.

CMAQ modelinin çıktılarına göre hesaplanan saatlik PM_{10} konsantrasyonları, Aksaray hava kalitesi istasyonundan elde edilen PM_{10} ölçüm sonuçları ile tüm domainler için karşılaştırılmıştır. 30 km ve 10 km'lik domainler, 2 km'lik domaine göre model performansı açısından daha başarılıdır. İstanbul simülasyonu için, modelin ölçüm sonuçlarına göre daha yüksek konsantrasyonlar sergilediği görülmüştür. İstatistiksel analizler yapıldığında ölçüm sonuçları ve simüle edilmiş sonuçlar arasında düşük bir korelasyon görülmüştür. Bu zayıf performansın sebebi saatlik ölçümlerin karşılaştırılması, tek bir noktaya ait ölçüm sonuçlarının baz alınması, meteorolojik modeldeki ve COPERT modelindeki belirsizlikler, çalışma alanına uygun olmayan model sınır koşulları, zamansal profillerin uygun olmaması ve ölçüm hataları olabilir.

Trafik kaynaklı hava kirliliğini azaltmak için uygun olan bölge ve yöntemler belirlenmiştir. Bölgeler belirlenirken yüksek gündüz nüfusuna sahip olmaları ve iş yerleri açısından merkez niteliğinde olmaları göz önünde bulundurulmuştur. Aday bölgeler Kadıköy, Maslak ve Tarihi Yarımada olarak seçilmiştir. Bu bölgeler trafik çekme özellikleriyle de düşük emisyon bölgesi uygulaması açısından uygundurlar. Trafik kaynaklı emisyonların 30% azaltılarak DUMAN emisyon işleme modeline verilmesi sonucunda, Tarihi Yarımada'da saatlik PM_{10} konsantrasyonlarında $10{\mu g}/{m^3}$ 'a varan düşüş görülmüştür. Kadıköy bölgesi için maksimum fark $7{\mu g}/{m^3}$, Maslak bölgesi için maksimum fark $3{\mu g}/{m^3}$ olarak simule edilmiştir. Hem gündüz nüfusunun en fazla olduğu hem de emisyonlardaki azaltıma konsantrasyon değişimi olarak en çok yanıt veren bölge Tarihi Yarımadadır. Düşük Emisyon Bölgesi için seçilen Tarihi Yarımada'da uygulanacak yöntemlerin her birisi için PM_{10} emisyonlarında ne kadar düşüşe neden olduğu literatürdeki çalışmalar ve COPERT modelinin çıktıları kullanılarak hesaplanmıştır. Belirlenen metodların arasında, bölgeye sadece EURO 3 ve üzeri araçların girişine izin verilmesi uygulaması PM_{10} emisyonlarında 85% azaltım sağlamaktadır. Emisyondaki bu azaltım, referans durum ile Düşük Emisyon Bölgesi ilan edilen durum arasında saatlik bazda $35{\mu g}/{m^3}$ ' e varan farka sebep olmaktadır. PM için günlük ortalamalarda fark $15{\mu g}/{m^3}$' e varmaktadır. Bu önemli farkın sebebi EURO 3 standardından düşük olan araçların hem sayıca fazla olması hem de diğer yeni araçlara göre daha fazla kirletici yaymalarıdır. Bölgeye yalnızca yeni teknolojili ve az sayıda araç girişine izin verildiği takdirde hava kalitesinde önemli ölçüde iyileşmeler görülecektir.

Bu çalışma, Istanbul'u daha fazla temsil eden sınır koşulları kullanılarak ve daha ayrıntılı emisyon envanteri hazırlanarak geliştirilebilir. Şu anda devam etmekte olan Ulusal Hava Kirliliği Emisyon Yönetim Sisteminin Geliştirilmesi projesi (KAMAG) ve COPERT'in araç dağılımı ve özellikleri kısımlarının güncellenmesi sayesinde model performansı yükseltilebilir.

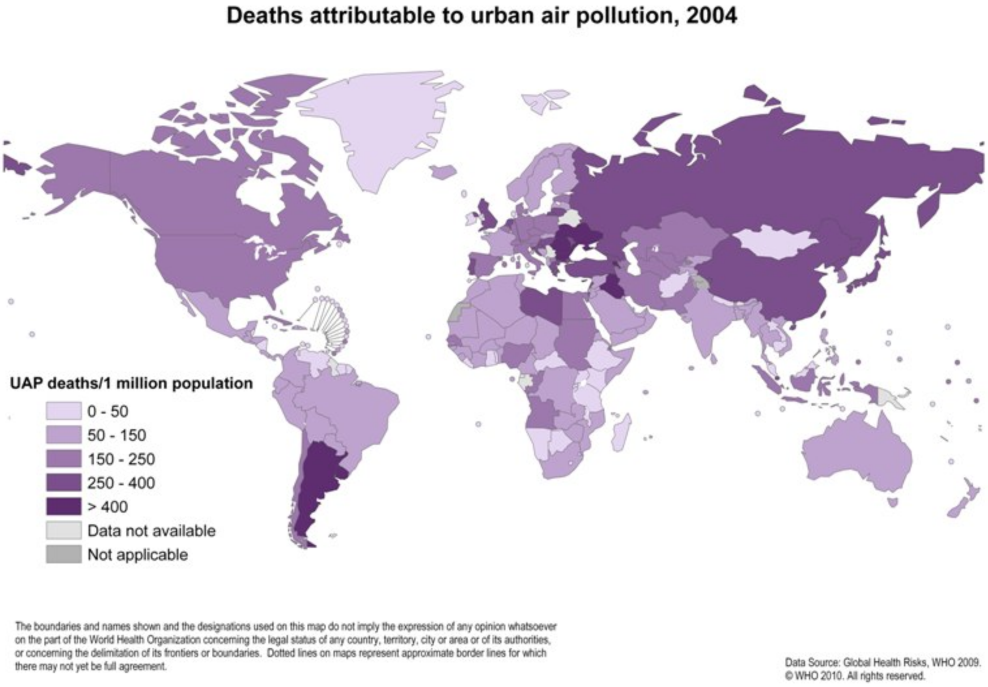
1. INTRODUCTION

Clean air is the most basic need of people to maintain their lives (WHO, 2006). However, today, air pollutants (e.g., carbon monoxide, ozone, nitrogen oxides, sulfur dioxide, particulate matter and lead) are the important factors that threaten human health. In literature there are many studies that link air pollution to adverse effects to public health. Exposure to pollutants during pregnancy is known to be cause of health problems and premature births (Maisonet, Correa, Misra, & Jaakkola, 2004). Cardiovascular and neurobehavioral effects are seen when exposed to low concentrations of carbon monoxide (CO). Exposure to high concentrations of CO may result in unconsciousness and death (Raub, Mathieu-Nolf, Hampson, & Thom, 2000).

Ground-level ozone is formed in the presence of nitrogen oxides (NO_x) and Volatile Organic Compounds (VOCs) (EPA, 2015a). Ozone is a kind of irritant that causes adverse health effects such as decreased lung function and mortality. As indicated by Bell, McDermott, Zeger, Samet, and Dominici, a 10-ppb increase in the concentration of ozone was associated with a 0.52% increase in daily mortality. Irreversible loss of lung function was observed in case of long term exposure to ozone in a study (Mudway & Kelly, 2000). The nitrogen dioxide and sulphur dioxide (SO_2) is harmful to the respiratory system of healthy humans and is known as the reason of increased number of complaints about asthma (Studnicka et al., 1997).Particulate matter is one of the most important out of these pollutants (Valavanidis, Fiotakis, & Vlachogiani, 2008). Concentration, exposure time and size of the particle are the most important factors indicating the effects of particulate matter on human health.For example; the particles less than 10 micrometers (PM_{10}) and particles less than 2.5 micrometers ($PM_{2.5}$) in diameter can reach to human lung and to even blood stream (EPA, 2015b). According to Pope III and Dockery (2006), chronic pulmonic diseases and cardiovascular mortality may occur in case of long-term exposure to particulate matter and hospital admissions and stroke mortality are reported in case of short term exposure. A $10 \mu g/m^3$ of increase in PM_{10} causes 0.6% increase in general mortality

(Atkinson et al., 2008). A $10\mu g/m^3$ of increase in $PM_{2.5}$ causes $1-17\,\%$ increase in general mortality, $5-42\,\%$ increase in cardiovascular related deaths and $1-17\,\%$ increase in lung cancer related deaths (Pope III & Dockery, 2006).

Mortality due to urban air pollution-related as estimated by World Health Organization is shown in Figure 1.1. These values are calculated by considering the population that were exposed to air pollution. Generally low and middle income countries have more deaths linked to outdoor air pollution. Turkey has a high mortality rate according to the map, which is nearly 250 to 400 deaths per 1 million people.


Deaths attributable to urban air pollution, 2004

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: Global Health Risks, WHO 2009.
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Figure 1.1 : Urban air pollution related deaths over the world (World Health Organization, 2009).

In order to examine the effects of air pollutants sources of these pollutants should be determined. There are several sources that contribute air pollution. In general, pollutants are classified as man-made (anthropogenic) and natural origin. Anthropogenic sources are classified as combustion in energy and transformation industries, non-industrial combustion plants, combustion in manufacturing industry, production processes, extraction and distribution of fossil fuels and geothermal energy, solvents and other product use, road transport, other mobile sources and machinery, waste treatment and disposal and agriculture (European Environment Agency, 2013). According to a study by Im (2009) sectors are determined and source contribution has been done for Istanbul based on anthropogenic emissions. There are residential heating, industry, road transport, maritime, waste management, solvent use, off-road vehicles, energy production and fuel extraction as emission sources. Most important sources of particulate matter are industrial activity (65 %) and traffic (17 %). An important portion of Non-methane volatile organic compound (NMVOC) (45 %), NO_x (80 %) and CO (83 %) is from the transportation sector while energy production can be considered as the main source of SO_2 (36 %). Results of the study demonstrated that transportation is one of the most important source of pollution.

Emissions from motor vehicles are different from industrial emissions since road emissions are emitted at ground level. Regions which have high traffic density also have high population. In other words, traffic emissions are directly affecting people compared to other emissions. Highest levels of traffic related air pollution is observed within 300 to 500 meters of the main way (Beckerman et al., 2008). Therefore, people living closer to traffic are under risk. Direct exposure to traffic related air pollutants causes significant health problems. Relationship between asthma, lung function disorders, cardiovascular mortality and morbidity with traffic related emissions has been proved by studies (Health Effects Institute, 2010). As the value of human health increases, many countries have implemented traffic emission management strategies to obtain improved air quality.

Today; many countries are trying to develop methods for the reduction of emissions from motor vehicles (Health Effects Institute, 2010). These improvements can be grouped as technology-based, behavioral and policy-oriented.

Technology based mitigation measures are the control mechanisms using newly developed advancements in science. One of those technological improvements is increasing the fossil fuels quality. Proportions of hydrocarbons, sulphur and other additives in fuel can effect the level of pollution. For example $PM_{2.5}$ emissions are reduced by 33 % when going from 500 ppm to 50 ppm of sulphur in diesel (Dieselnet, 2015). Another technology based advancement is improved vehicle technology. Vehicles are grouped by calculating the amount of emissions from their exhaust. This calculation is a kind of standardization. For example European Emission Standards is a system that determines the upper limit of the exhaust emissions of vehicles. Incompatible vehicles cannot be sold in the EU member states. However new standards do not apply to vehicles in traffic. Euro standards are being implemented in stages according to vehicle weight and vehicle and fuel types as seen from 1.1. The first EURO standard was introduced in 1992 for passenger cars and in 1993 for light duty vehicles. Light duty vehicles are separated according to their weights. In 2000 motorcycles and mopeds were added to this group. For trucks and buses EURO 5 standard which was brought into force in 2007 is still valid. EURO 4, EURO 5 and EURO 6 standards were declared in 2005, 2008 and 2013, respectively for passenger cars (EEA, 2010). There are shifts in the transition to the EURO standards in Turkey.

Table 1.1 : EURO emission standards for vehicles and dates. *1:*Stated EURO standard spans only diesel fueled light commercial vehicles.

Vehicle type	**EURO 1**	**EURO 2**	**EURO 3**	**EURO 4**	**EURO 5**	**EURO 6**
Passenger Cars	1992	1996	2000	2005	2008	2013
Light commercial vehicles < 1t	1993	1996	2000	2005	2009	2014[1]
Light commercial vehicles > 1t	1993	1996	2001	2006	2009	2015[1]
Trucks and buses	1992	1995	1999	2005	2007	
Motorcycle	2000	2004	2007			
Mopeds	2000	2004	2007			

Euro emission standards of air pollutants (e.g. nitrogen oxides and particulate matter to be reduced gradually as seen from Figures 1.2 and 1.3.

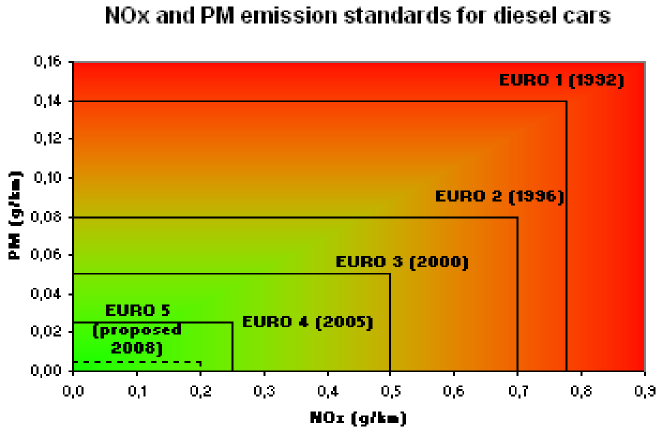


Figure 1.2 : Limits for NOx and PM on diesel cars until EURO 5.

NO_x emissions are more restrictive in petroleum vehicles than diesel vehicles. For example NO_x limit value is 0.18 g/km in EURO 5 to EURO 6 standards for diesel cars and 0.06 g/km in EURO 5 to EUR0 6 standards for petroleum cars. There was no limit for PM in gasoline powered vehicles until EURO 5 standards. This rule, applying only on injection-type engines, is corresponding 0.005 g/km for EURO 5 and EURO 6. PM

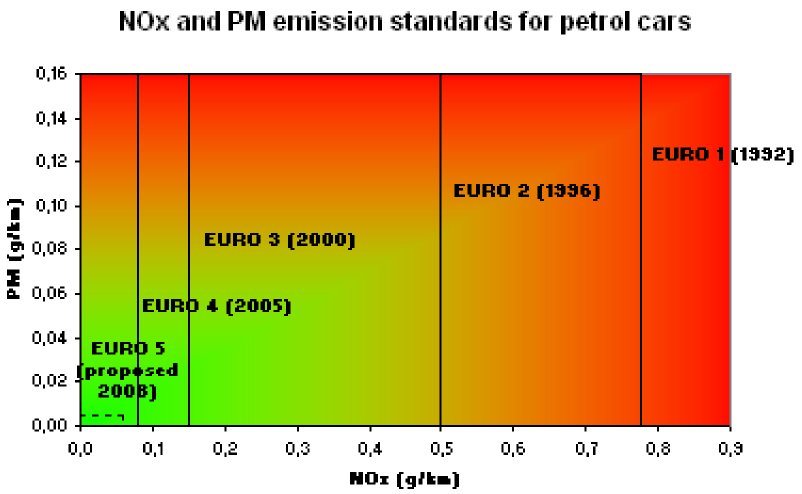


Figure 1.3 : Limits for NOx and PM on petroleum cars until EURO 5.

limit value is 0.005 g/km for EURO 6 standards in diesel cars. In addition to these limitations, CO limit for diesel vehicles is 0.50 g/km in EURO 4 to EURO 6 which is more strict than petroleum vehicles (i.e. 1 g/km). Third one is exhaust emission control that can be provided by using filters called after treatment, this technique is significant for the vehicles which are on the traffic all day. For example EURO 5 requires that particle filters should be used on old diesel passenger cars and light duty vehicles which were used before EURO 5.

Personal measures taken in traffic to reduce traffic-related air pollution by using vehicles efficiently considered as behavioral measures. These measures are trying to reduce emissions by regulating the people behaviour in traffic. Examples of behavioral measures can be considered as eco-driving culture that includes better vehicle maintenance and non-aggressive driving habits. Eco-driving means saving energy while driving. In other words eco-driving is a way that uses less fuel to travel same distance. Eco-driving provides comfort and safety as well as reduction of the green house gases. First, maintenance of vehicle is important. Engine condition, tyre pressures and gas cap should be checked continuously. Low efficiency motors and flat tires cause extra fuel consumption. Open gas caps after refueling cause VOC pollution and decreased efficiency. Non aggressive driving can be extended as keeping on steady speeds, changing gear properly, avoiding useless air conditioning and keeping aerodynamic balance. Based on the results of a study; significant increases were observed on HC, CO, and PM_{10} emissions during aggressive driving (Tzirakis, Zannikos, & Stournas, 2007).

Implementation of legislation to improve air quality by controlling traffic emissions of air pollutants is called policy oriented measures. In fact, all of the measures which are described above, can be applied by law which means measures are mostly policy-oriented.

Limiting the main air pollutants by enacting policies have significant impacts on regional air quality and human health. For example if no standard was not applied to vehicles, emissions from road transport would have been 60 % higher in 2005 (EEA, 2010). Governments also issue directives about lead and sulphur contents of fuels as well as EURO standards (Dieselnet, 2015). Generally, policy makers are projecting major strategies such as: urban and transport planning, car use reduction, public transit, vehicle emission controls, cleaner fuels and low emission transport models (Ellison, Greaves, & Hensher, 2013).

- Urbanization needs to be extend to proper places in order to reduce traffic density. This is done with a proper urban planning.
- Construction of the efficient and convenient roads to avoid traffic jams, management of parking fees and places, integrated and intelligent transport system can be achieved by entirely efficient transport planning.
- Tax boost and congestion price that is a application that means charging the vehicles which enters a specific region can reduce car using. Also encouraging customers to purchase clean fuel vehicles can reduce air pollutant emissions. When hybrid or electric vehicles are supported by tax reductions, important steps will be taken for vehicular emission control.
- Improving transportation facilities such as developing more underground transport, expanding bus and light-rail train network and other measures fall into transport planning. Developing and improving public transport can affect many people.
- Constructing more bike and pedestrian ways provide low emission transport models.
- Increasing gasoline prices, shifting leaded fuels to unleaded, alternative fuels, using Compressed Natural Gas (CNG) in vehicles as fuel, hybrid-only parking areas, two-stroke to four-stroke motorcycles provide more cleaner and greener vehicle fleet and environment.
- Vehicle emission control options involve limiting exhaust emissions by law(e.g. EURO standards).

Low Emission Zone (LEZ) is a combination of technological, behavioral and policy-based methods (Ellison et al., 2013). Definition of Low Emission Zone is defined area that prohibits the entry of dirty vehicles while allows the entry of hybrid or electric vehicles to meet air quality standards. Low Emission Zone is used to reduce the road traffic emissions in a specific area by government. The purpose of establishing these zones is to get rid of heavy traffic in city center, which makes air quality significantly poor. Low Emission Zone schemes are being implemented or will be implemented over 8 countries and 70 cities in Europe. Usually, classification and restriction of heavy diesel vehicles is done in these areas. Because they contribute to air pollution much more than the other vehicles. Banned or penalized vehicle types may vary from region to region in low emission zones but all Low Emission Zone's affect heavy duty good vehicles (CLARS, 2015). Low Emission Zone control option was proposed in this study to control vehicle emissions. However a study was conducted in Dutch country through them Boogard et al. (2012) found that low emission zone is not effective in reducing pollution alone, it should be supported with a variety of traffic enforcements. Examples will be presented in this section for low emission zones. In recent years LEZ has been the subject of numerous studies, especially in Europe. LEZ are applied in many places throughout Europe, however, applied features are different. For example; entries of lorries and heavy vehicles are limited in Vienna City Center. In this area LEZ is determined by road signs and vehicles use stickers according to their EURO standards to enter reduced emission area. LEZ is operating 365 days a year and controlled by police in Vienna. Another example is all vehicles, including vehicles with less than four wheels, are affected by this traffic regulation in Prague. Gasoline vehicles which fit to EURO 1 standard are using green label, diesel vehicles which fit to EURO 3 standard are using yellow sticker. Heavy trucks can not enter the city center of Sofia at certain times. In Copenhagen all diesel vehicles above 3.5 tonnes should use certified particulate filter or EURO 4 sticker on windscreen. If they do not comply with rules, penalty would be the same price as particulate filters. In Helsinki buses and garbage trucks are affected by these regulations called Environmental Zone. For buses EURO 3 standard and for garbage trucks EURO5 standards are required. All diesel vehicles must comply with the EURO 4 standards and all gasoline vehicles must comply with the EURO 1 standards from 1st of July 2014 in Cologne. All vehicles must be registered and carry a sticker from authorised local garages, vehicle test organisations or websites. Vehicles without proper sticker should pay €80 for driving and parking in LEZ (CLARS, 2015).

1.1 Objective

The purpose of this study is quantify the impact of Low Emission Zone on regional air quality of candidate areas.Low emission zone was implemented for the first time for Istanbul on modeling environment.This study surveyed most suitable areas for implementation of zone and effects of regulations over selected environmental zone.

1.2 Organization of Thesis

The organization of the thesis can be summarized as follows:

In chapter 2, information of the study area, air quality modeling system and methodology of low emission zone establishment are presented.

In chapter 3, results of meteorological model, emission model and chemical transport model are visualized. Effects low emission zone and model performance are examined.

Finally, chapter 4 summarizes the study and discusses possible developments of the model system and low emission zone.

2. DATA & METHODOLOGY

2.1 Study Area

Istanbul is located at the confluence of Europe and Asia where Black Sea is connected to the Marmara sea via Istanbul strait (i.e. Bosporus) as seen in Figure 2.1. Both Asian and European side of Bosporus is highly urbanized covering 6,220 square kilometers.

Figure 2.1 : Satellite view of Istanbul.

The city is ranked 22nd in the world among world mega cities with a population of over 14 million (Brinkhoff, 2015). Istanbul had a population of 1.5 million in 1960's, doubled in 1980's reaching 3 million as seen in Figure 2.2. About in 10 years time the population has doubled again, reaching 7 million in 1990. As of 2014, the population in Istanbul has doubled again reaching 14 million (Turkish Statistical Institute , 2013). Due to rapid increase in population and economic development, number of motor vehicles has increased significantly as well. Although in 1990 there were 3,750,000 vehicles in the entire country, as of today 3,300,000 vehicles are registered only in Istanbul (Turkish Statistical Institute, 2014). It should be noted that every day 600 new vehicles are added to Istanbul traffic (Istanbul Metropolitan Municipality, 2009).

Istanbul's climate is humid subtropical climate, which is warm and dry in summer and cold and wet in winter. Summer and winter average temperature are 28 °C and 8 °C, respectively (Ezber, Sen, Kindap, & Karaca, 2007). Average annual precipitation and average wind speed are about 693 mm and 17 km/h (Ozdemir et al., 2009).

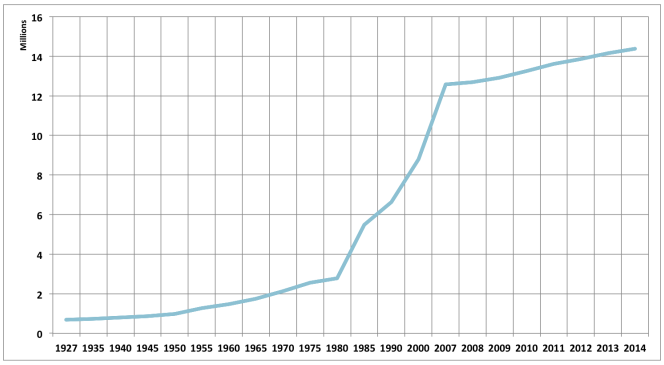


Figure 2.2 : Population growth in Istanbul according to years (Turkish Statistical Institute , 2013).

2.2 Air Quality Status in Istanbul

Istanbul has an air quality monitoring network of 26 stations which can be seen in Figure 2.3. All of the stations are measuring SO_2 and PM_{10}. In some of these stations temperature, wind measurements, nitrogen Oxides (NO, NO_2, NO_x), CO and O_3 are measured fully automatically as well (Ministry of Environment and Urbanization , 2015). Hourly data received from the station is transferred to the laboratory via a special network. Monthly and yearly reports are prepared and published by using verified data.

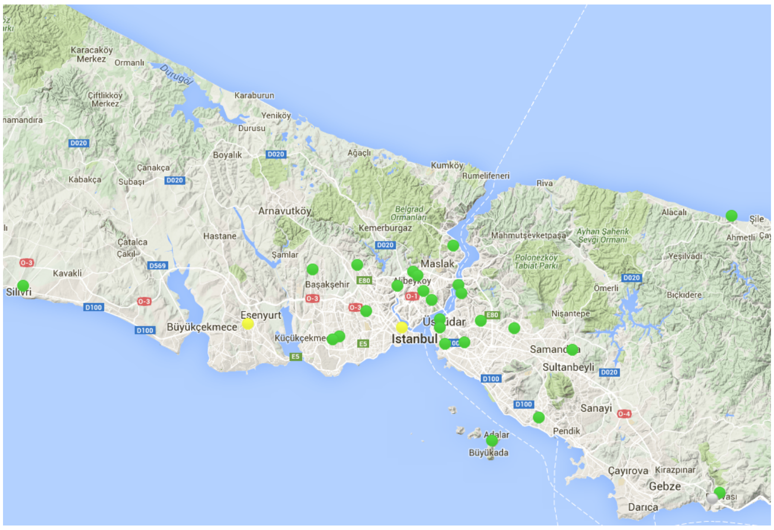


Figure 2.3 : Geographic information map of the stations (Ministry of Environment and Urbanization , 2015).

The daily average PM_{10} measurements obtained from 10 stations in Istanbul between the years 2009-2015 are shown in Figure 2.4. About 60 percent of the measurements are above the European Union Ministry of Environment and Urbanization threshold (i.e. $50\mu g/m^3$). Moreover, especially, during winter PM_{10} values are above $100\mu g/m^3$ even some days these values are higher than $200\mu g/m^3$.

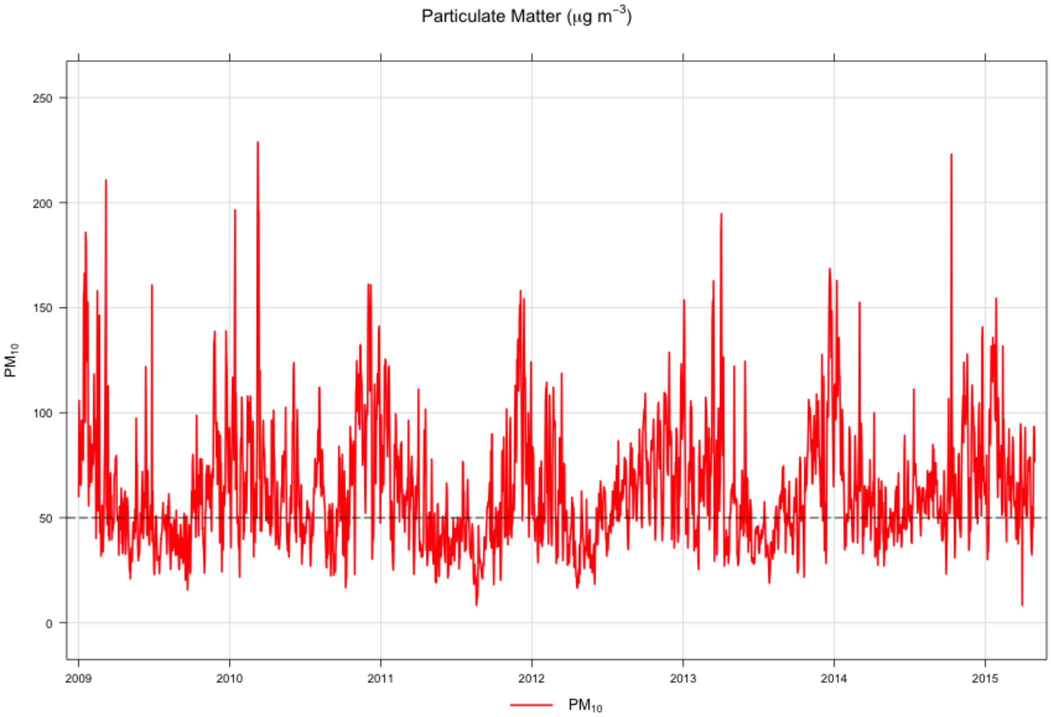


Figure 2.4 : Daily time series plot of PM_{10} at Istanbul.

2.3 Modeling Structure

Air quality model (AQM) mathematically analyzes atmospheric reactions, transportation and diffusion of pollutants. These models need meteorological and topographic information as well as an emission inventory. AQMs were first introduced in the 1970s and since then continuously improved (Seinfeld & Pandis, 2006). The region, which will be modeled, is divided into three dimensional grids. Vertical length changes according to vertical layers, which are used in AQM. Horizontal length of these grids can be up to a few kilometers for urban applications. There are mathematical limits for the size of horizontal grid size and number. Increasing the grid cell number causes computer cost. Horizontal grid size should be reasonable because emissions interactions with winds and other meteorological parameters are solved in this grid for a given time. In fact as urban scale models use a few kilometer resolution, regional scale models use ten or more kilometer resolution.

AQMs have 3 main parts; meteorological modeling, emission modeling and chemical transport modeling (Figure 2.5). Each of these models produce output for the next step. The output of AQMs is calculated concentrations for a model domain and specific time. Concentration values are created by numerous chemical reactions, which are connected with meteorological conditions.

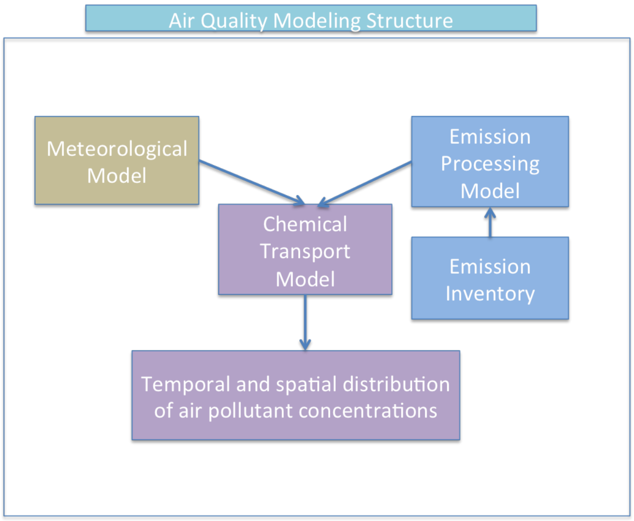


Figure 2.5 : Air Quality Modeling System.

2.3.1 Meteorological modeling

Meteorological models are developed to investigate climatic events and produce input data for chemical transport models. According to Zannetti (1990) there are mainly two kinds of meteorological model: physical and mathematical. As physical models resolve atmospheric movements, mathematical models use meteorological equations. Numerical models are part of mathematical models which are calculating linear and nonlinear variables. As computer and data assimilation techniques develop, numerical models have become more popular.

2.3.1.1 The weather research & forecasting model(WRF)

WRF is a set of software, which is produced by National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA) collaboration for numerical weather prediction method. It is an open source and synoptic model that is creating climate projections. WRF involves two computational cores that are known as WRF ARW (Advanced Research WRF) and WRF NMM (Nonhydrostatic Mesoscale Model) for solving atmospheric differential equations. Model resolution changes meters to thousands of kilometers. Researchers may use real data (observations) or ideal case data to create simulations. Figure 2.6 is showing steps during running WRF. Geogrid creates terrestrial-based static data, ungrib opens meteorological data and metgrid interpolates the meteorological data horizontally onto model domain. Real part interpolates data onto model domain vertically, wrf is the main program which calculates the last results.

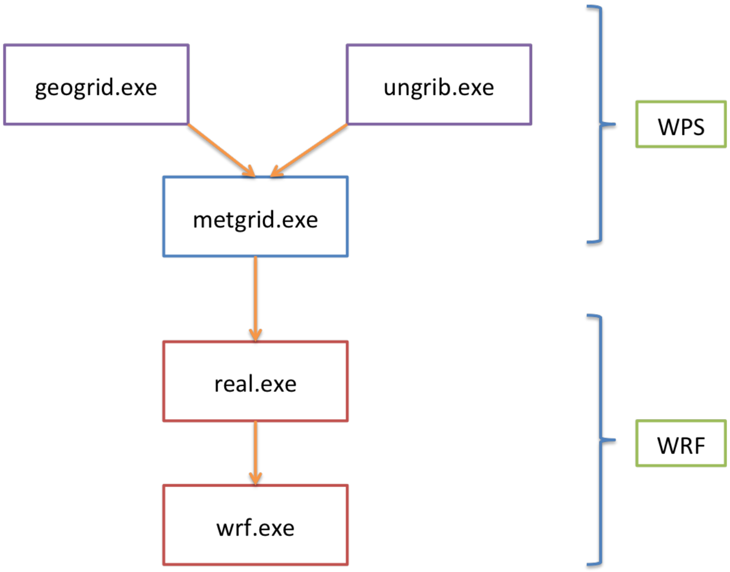


Figure 2.6 : General expression of WRF model flow (University Corporation for Atmospheric Research, 2014).

3-nested WRF simulations were performed in this thesis. The meteorological model domains are shown in Figure 2.7. Mother domain (30 km x 30 km resolution) includes Europe, North Africa and most part of East Asia; second domain(10 km x 10 km resolution) covers a Balkans and Turkey. The smallest domain contains 93 x 58 horizontal grid cells on whole Istanbul with 35 vertical layers, which is our study area with 2 x 2 km resolution. The National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) data (with 1 degree by 1 degree resolution) were used for boundary and initial conditions. Mainly physical options are as follows: simple, efficient scheme with ice and snow processes for mother domain, the high resolution scheme with ice, snow and graupel processes for inner domains, Rapid Radiative Transfer Model as long wave scheme, Mellor-Yamada Nakanishi and Niino Level 2.5 as planetary boundary layer, Kain-Fritsch scheme as cumulus parameter. Meteorology – Chemistry Interface Processor (MCIP v3.6) was used to make WRF output data ready for chemical transport model. WRF model version 3.5 was set up for days between 00:00 UTC November 2, 2010 and 00:00 UTC November 12, 2010. The terrestrial input data is from U.S. Geological Survey (USGS) and The European Centre for Medium-Range Weather Forecasts (ECMWF) operational data was used as an input data for WRF simulation.

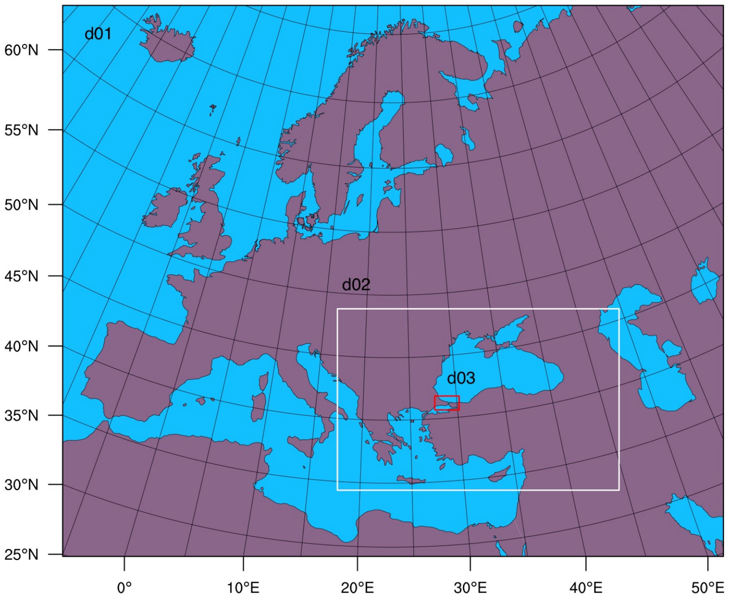


Figure 2.7 : The 3-nested Models-3 domains.

2.3.2 Emission modeling

In order to get more accurate results from AQMs, current and reliable emission inventory should be used. Emission inventory is a list that contains air pollution sources and amounts for a given time and area. Emission inventory is prepared by using emission factors which are based on sources' activity level (Seinfeld & Pandis, 2006). Emission sources are divided into mainly four groups by looking emitting characteristics:

- Point
- Area
- Mobile
- Biogenic

Point sources can be defined as the points in the spatial sense. Power plants, steel and metal industry, mining industry, chemical industry, paper industry, textile Industry, cement Industry and petroleum industry are considered as point sources. They are major source of NO_x.

Area sources are immobile and distributed over a geographic area. It is not possible to collect emissions data from each of these sources. Therefore calculations are made based on areal information. Commercial and consumer-oriented solvent using, stationary combustion plants, material storage and distribution, treatment and disposal, industrial cooling towers, farming, forest fires, construction, gas stations, hospitals and other industrial production activities are considered as area sources. Area sources are responsible for mostly particulate matter emissions.

Mobile sources classified as highway and other vehicles. Highway vehicles are responsible for CO, HC, NO_x and PM emissions especially in the cities (Unal, Frey, & Rouphail, 2004). Other vehicles include construction equipments, military vehicles, boats, trains, aircrafts, agricultural vehicles, forest vehicles. Air traffic is responsible for CO, NO_x, VOC and SO_x emissions. Marine traffic is responsible for NO_x, SO_x, CO, CO_2, VOC and PM.

Biogenic Volatile Organic Compounds (BVOCs) are emitted from vegetation to the atmosphere. Importance of BVOCs to the air quality model as an input is due to their significance in the formation of secondary pollutants such as ozone and secondary organic aerosols. Global-Model of Natural Volatile Organic-Compound Emissions was developed by A. Guenther et al. in 1995 and named MEGAN. In years, along with developments in technology and measurement techniques MEGAN was also improved, having updated isoprene, terpene, and other VOC values, etc. Latest version of MEGAN is version 2.10 , which is also used in this study to provide biogenic emissions to our model run (A. B. Guenther et al., 2012).

2.3.2.1 Emission inventory

The TNO emission inventory that contains Combustion Industry, Non-industrial Combustion Plants, Combustion in Manufacturing Industry & Production Processes, Extraction and Distribution of Fossil Fuels and Geothermal Energy, Solvent and Other Product Use, Road Transport, Other Mobile Sources and Machinery, Waste Treatment and Disposal, Agriculture sectors, was used for coarse CMAQ domains. Istanbul-specific emission inventory which is prepared by Im was used in the fine domain for all sectors except traffic.

Computer programme to calculate emissions from road transport (COPERT 4) has run for emissions of the transport sector for 2km-domain. COPERT 4, developed by European Environment Agency (EEA), is a tool that calculates emissions from road transport (Gkatzoflias, Kouridis, Ntziachristos, & Samaras, 2012). This model is an updated version of COPERT III. Traffic related emission inventory can be created by using COPERT 4 simulations. Methodology of COPERT 4 is based on EMEP -

EEA emission inventory and IPCC 2006 guidelines. Program calculates , NO_x, VOC, PM, N_2O, NH_3, SO_2, NMVOC pollutants and fuel consumption on Windows-based operating systems. TUVTURK and TUIK datasets, which consist distributions of vehicles, were used to calculate vehicle emissions. COPERT produce emissions according to type of roads (i.e. highway, arterial, residential). Steps for distribution of traffic emission onto our study area by using MATLAB and Python codes are presented below:

- Grids with 1 km x 1 km resolution were created for Turkey
- The region which covers Istanbul was cut from Turkey domain
- Istanbul domain was intersected with highway, arterial and residential shape-files to calculate how much road falls into a specific cell.Then, this domain was intersected with the main Istanbul domain with 2 km resolution
- Kilometers were read for highway, arterial and residential roads.
- COPERT emissions were distributed into these type of roads
- Emissions were created for only sector 7 which consists traffic-related emissions

In this study DUMAN model was used as emission-chemistry interface module. DUMAN was prepared according to information about Turkey in terms of spatial and temporal view by using country based profiles by Istanbul Technical University. Euro Delta temporal profiles was used in simulations on DUMAN environment.

2.3.3 Chemical transport model

Air quality measurements give values which are belong to one time and location. Legislation can not be made without knowing atmospheric condition. Measurements are not enough to develop efficient control strategies.

Mathematical models can be used to understand atmospheric processes and interactions. Models which represent chemical transformation and removal processes should be used to examine the changes in pollution concentrations when emission source control has been done. Atmospheric chemistry models follow transport of emissions and photochemical reactions of air pollutants.

Also Eulerian models should be used in order to get species information for all points in a domain as a function of time, because only one air parcel is selected and followed in Lagrangian models. Model simulates different species for different times.

2.3.3.1 The community multi scale air quality model (CMAQ)

USEPA has started Models-3 project and developed CMAQ modelling system that deals with atmosphere -land interactions, transformation and deposition. CMAQ combines three different models : meteorological model that represents climatic events, emission model that represents anthropogenic and natural sources on atmosphere and chemical transport model that represents the fate of air pollutants in various meteorological conditions. CMAQ serves as multi-pollutant and multi-scale model compare to other air quality models (Ching & Byun, 1999). CMAQ is a three-dimensional Eulerian model that can simulate multiple pollutants such as ozone, particulate matter (PM), toxic airborne pollutants, visibility, and acidic and nutrient pollutant species throughout the troposphere (CMAS, 2014). As shown in the Figure 2.8, Meteorology-Chemistry Interface Processor (MCIP) converts outputs of a meteorological model to a new data-set that is suitable for CMAQ, Photolysis Rate Processor (JPROC) calculates clear sky photolysis rates, Initial Condition (ICON) creates chemical conditions at the beginning of the simulation, Boundary Condition (BCON) also creates chemical conditions but especially for the horizontal boundaries for the domain. 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). Chemical Transport Model (CCTM) calculates chemical, transport and deposition processes by combining all the information related about atmosphere and domain.

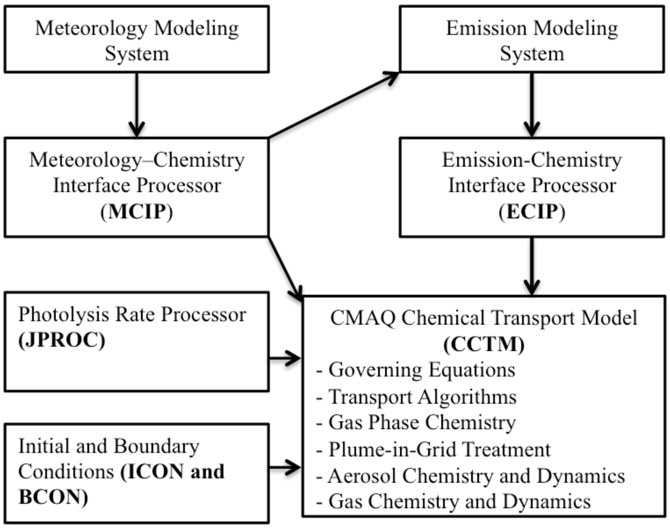


Figure 2.8 : The Models-3 Emissions, Meteorology, and the CMAQ Modeling Systems (Ching & Byun, 1999).

CMAQ version 4.7, released in June 2010,was used in this study to figure out regional air quality. 35 vertical layers used in WRF simulation were reduced to 24 layers for the CMAQ simulation. CB05 mechanism was used to model ozone, particulate matter, visibility, acid deposition and air toxic issues (Yarwood, Rao, Yocke, & Whitten, 2005). Global mass conserving scheme Yamo was used for vertical and horizontal advection. Vertical diffusion was represented by an updated version of Asymmetric Convective Method (Pleim, 2007). Chemical kinetics was solved by using Euler backward approximation (EBI) that is based on nonlinear differential equations (Hertel, Berkowicz, Christensen, & Hov, 1993). AERO5 and ACM modules were used for aerosol and cloud simulation option, respectively.

2.4 Methodology for Quantifying the Impact of Possible Low Emission Zone

The methodology has been constituted in Figure 2.9. Emission inventory for the base case has been prepared for Istanbul by using (Markasis et al., 2012) study. This inventory's part about traffic, was changed with data obtained from COPERT to have more accurate emission data. CMAQ was run using these emissions and concentration distribution was obtained.

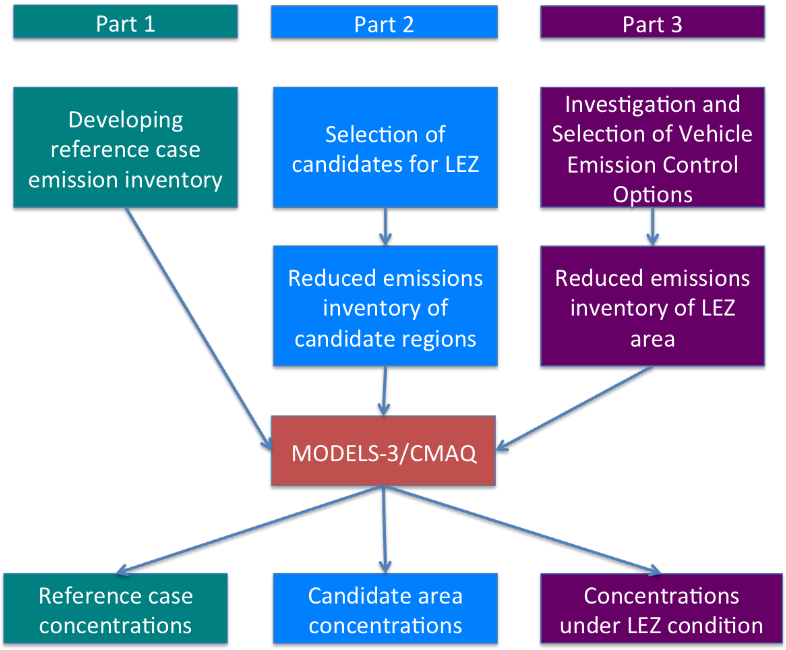


Figure 2.9 : Flow diagram for evaluate the impact of control policy on air quality.

In the second step of the study the regions which have high density of population and work places has been determined. These places attract a lot of traffic because of these features. The map was prepared by using the building data generated by Istanbul

Metropolitan Municipality. As seen from Figure 2.10 red and grey zones are showing workplaces and roads, respectively. Historical Peninsula, Kadikoy and Maslak have densities in the number of workplaces and the road network. These regions have high day-time population due to being business and trade center. Therefore, Historical Peninsula, Kadikoy and Maslak are selected as candidates and emission reductions have been applied to these areas. For the Low Emission Zone study, a sensitivity analysis was conducted to see the effects of regulations in these three regions.

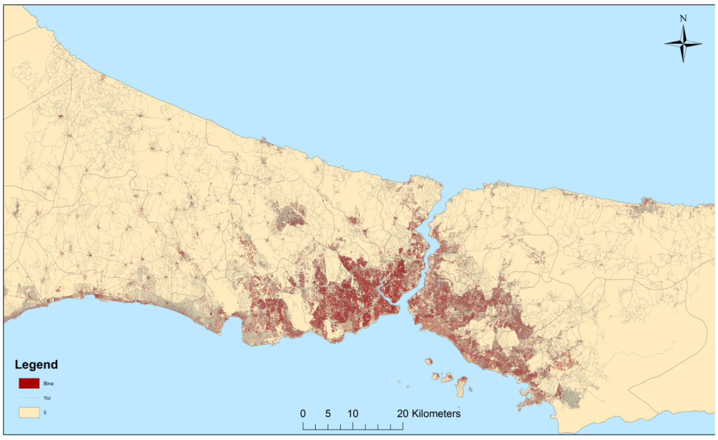


Figure 2.10 : Building and road distribution in Istanbul.

How much reduction will be made in the transport sector emissions was determined by researching studies about London Low Emission Zone which is the oldest and most effective one. For various scenarios were constructed to take control of vehicle emissions, average emission reductions were observed ranging from 30% to 70% (Mediavilla-Sahagun & ApSimon, 2003). The transport sector emissions were reduced by 30% and given to DUMAN model.The output of the chemical transport model were visualized to examine which area is the most affected. The maximum difference between the reference state and low emission zone status is shown as following Figures 2.11, 2.12 and 2.13.

Maximum concentration difference has occurred on 4^{th} of November and reached to $7\mu g/m^3$ for Kadıkoy. Maximum concentration difference was on 5^{th} of November and reached to $3\mu g/m^3$ for Maslak. Maximum concentration difference has occurred on 4^{th} of November and reached to $10\mu g/m^3$ for Historical Peninsula. Historical Peninsula is the place where highest PM_{10} concentration change was seen. Vehicle emission control plan of this region could create more impact than the other candidate regions. Furthermore number of people who works and live in this region is the highest among all. Daytime population is known to be 2.5 million in this region (Embarq, 2014).

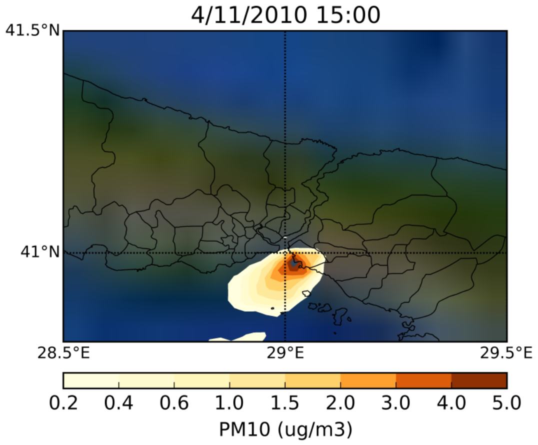


Figure 2.11 : Concentration difference between low emission zone case with reference situation in Kadıkoy.

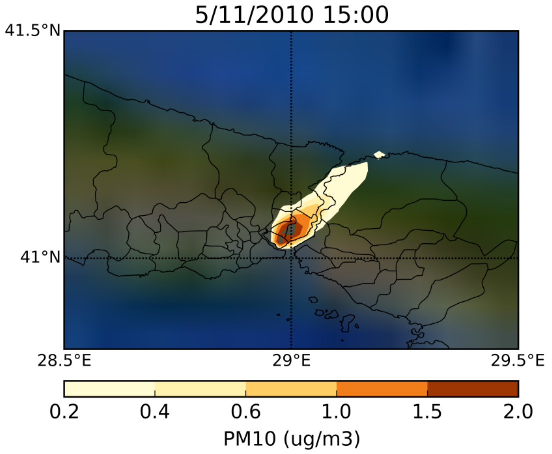


Figure 2.12 : Concentration difference between low emission zone case with reference situation in Maslak.

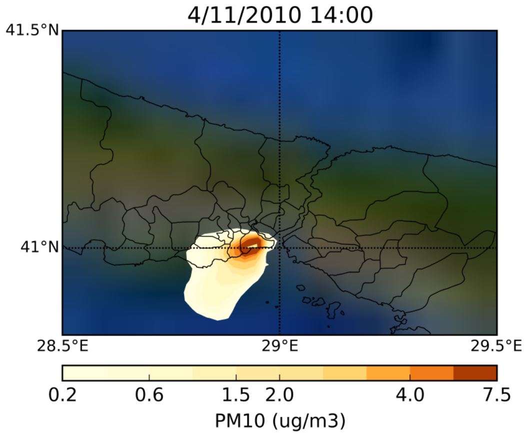


Figure 2.13 : Concentration difference between low emission zone case with reference situation in Historical Peninsula.

As seen from figures, emission reductions affect not only Low Emission Zone area, but also nearby districts. That shows Low Emission Zone is effective on regional air quality.

A low emission zone in the Historical Peninsula will be a clean air region that more people can benefit. In third stage, some strategies which are shown in Table 2.1 have been created to limit vehicle emissions.

Table 2.1 : Rules that can be applied to the low emission zone.

Measures	**Reduction in PM_{10} emissions%**
Buses with diesel particulate filter	15
Prohibition of entry of the vehicles under the EURO 3 standard	85
Electric powered buses	18
Increasing parking fees in the zone	2
Congestion charge	3
Signal improvement	10
Extended public transportation and limiting use of private cars	18

While preparing list of rules, vehicle distribution should be considered. As shown in Figure 2.14, percentage of passenger vehicles is maximum (68 %). The effect of policy will be more significant on passenger cars than the others.

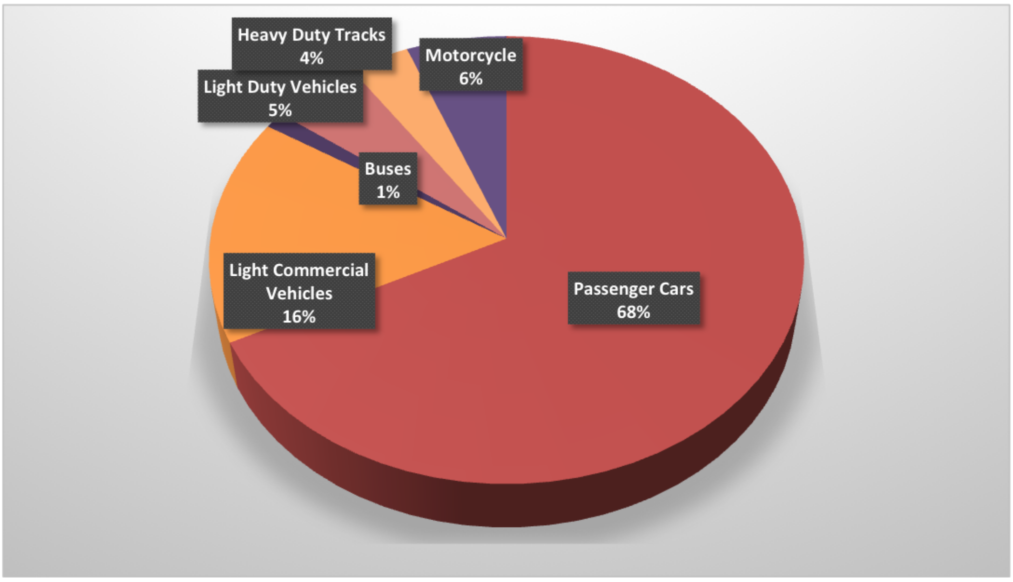


Figure 2.14 : Vehicle distribution in Istanbul.

At this stage, particulate matter, which is the most important pollutant for our health, were focused on for reductions. One of the precautions is using diesel particulate filter that traps particulate matter in buses.These filters capture parts of soot caused by diesel fuel in exhaust gas. Retained particles are burnt into ashes at very high temperatures. In case of all diesel buses use filters in low emission zone, PM emissions from these buses reduce by 15 % according to COPERT results.

Another method for reduction traffic emissions is identify and distinguish vehicles according to their EURO standards to enter region. EURO standards are established to limit air pollutants (i.e. CO, NO_x, HC, PM) in the exhaust of vehicles.These standards are significant for low emission zone air quality because this measure prevents directly the entry of pollution sources. For this thesis EURO 3 has been selected as the standard for all vehicle types. COPERT results showed that if the vehicles under EURO 3 standard not allowed to enter the Historical Peninsula, PM emissions has decreased by 85 %.

Third measure is using alternative fuel vehicles that are powered by different fuel instead of gasoline or diesel. This fuel sources can be electricity or solar energy. Because of air pollution and oil scarcity these vehicles are encouraged to use by government and vehicle manufacturers. According to COPERT results if all of the buses used in public transport in Historical Peninsula use electric power PM emissions has decreased by 18 %.

Increasing the parking fees as a method of traffic regulation can be effective if strictly enforced for both public and residential areas. According to Mediavilla-Sahagun and ApSimon (2003) study this measure provides a 2 % reduction in particulate matter emissions.

Furthermore, congestion price is a method of imposing charges on vehicles which enter to low emission zone. Motor vehicles can enter the zone if they pay congestion charge the day before. If unpaid vehicles are detected, they must pay penalty. Control of this system is done through sticker or plate control. According to Mediavilla-Sahagun and ApSimon (2003) study this measure provides a 3 % reduction in particulate matter emissions. Improvement in the signal system provides reduction in vehicle emissions. Because, an improved signalization can be solution to traffic congestion and reduces fuel consumption. Signal improvements reduce emissions of particulate matter by direct proportion (Unal, Rouphail, & Frey, 2003). For example if 10 % improvement is projected, 10 % reduction in particulate matter emissions is obtained. Buses uses less fuel per person carried than passenger cars. Trains and trams have lower air pollution capacity. Through a well-organized network of public transport, traffic congestion is reduced and pollution can be prevented. In case of restricting entry of passenger cars to region and having only public transport option, PM emissions have fallen by 18 %.

As a result, applying EURO 3 standard is the most effective method. Depending on the distribution of vehicles in terms of EURO standards, older vehicles which are under EURO 3 standard has majority Figure 2.15. 48 % of passenger cars, 72 % of light commercial vehicles, 96 % of buses, 91 % of light duty vehicles, 100 % of heavy duty trucks and 76 % of motorcycles are under EURO 3 standard. The method of banning the vehicles more polluted and high in number is an effective measure.

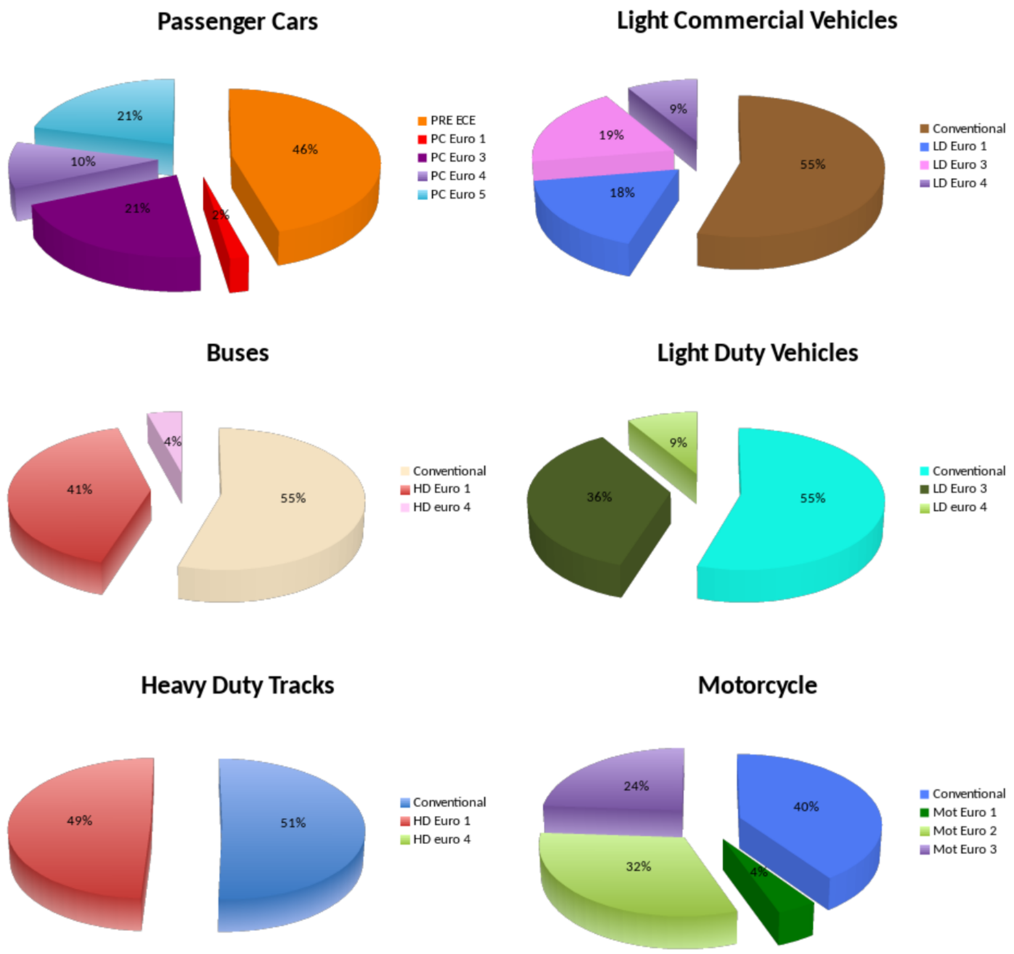


Figure 2.15 : Vehicle distributions based on EURO standards.

3. RESULTS & DISCUSSION

3.1 Meteorological Model

3.1.1 Model performance

The time series of model output temperature were compared with daily observations provided by national air quality monitoring network in Istanbul: Ataturk Airport station (40.9 N and 28.8 E) and Goztepe station (40.9 N and 29.05 E), which fall into the inner most WRF domain. The wrf grid cells that cover these meteorological stations are i=42 and j=21 grid cell for Ataturk Airport station and i=51 and j= 22 grid cell for Goztepe Station at Istanbul domain.The comparison between WRF results and 2 meter temperature observations was presented in Figure 3.1 and Figure 3.2. Figures show that model has overestimated and underestimated values for both stations, though the rising trend well captured after 9^{th} of October. Average observed temperature value is 16.5 °C, modeled value is 15.7 °C for Ataturk Airport. Average observed temperature value is 15.1 °C, modeled value is 15.6 °C for Goztepe station. The average values are quite close each other.

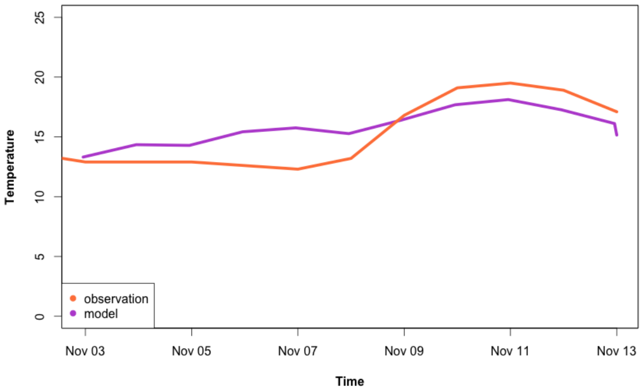


Figure 3.1 : WRF model output vs observation at Ataturk Airport.

To express the difference between the model and measurements mathematically, statistical analysis was performed accordingly to equations 3.1, 3.2, 3.3, 3.4 3.5. These statistical functions are mean bias (MB), normalized mean bias (NMB), root

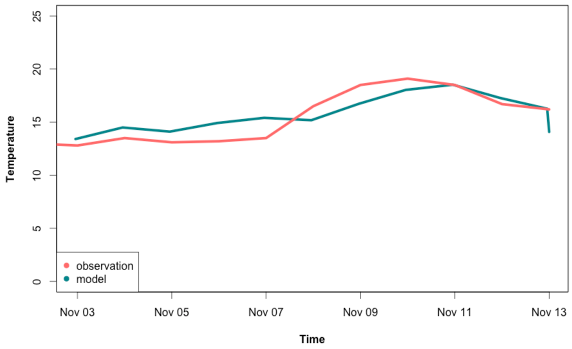


Figure 3.2 : WRF model output vs observation at Goztepe.

mean square error (RMSE), absolute error (ABSE) and index of agreement (IOA). Cm is model output variable and Co is the observation. N is the total number of time step.

$$MB = \frac{1}{N} x \sum_{i=1}^{N} Cm_i - Co_i \tag{3.1}$$

$$NMB = \sum_{i=1}^{N} \frac{Cm_i - Co_i}{Co_i} \tag{3.2}$$

$$RMSE = \sum_{i=1}^{N} \sqrt{(Cm_i - Co_i)^2 x \frac{1}{N}} \tag{3.3}$$

$$ABSE = \frac{1}{N} x \sum_{i=1}^{N} |Cm_i - Co_i| \tag{3.4}$$

$$IOA = \sum_{i=1}^{N} 1 - \left(\frac{(Cm_i - Co_i)^2}{|Cm_i - \bar{Cm_i}| + (|Co_i - \bar{Co_i}|)^2}\right) \tag{3.5}$$

These physically meaningful and simple equations enable comparisons over a common unit for all works (Mao et al., 2006). Calculations are presented in the following Table 3.1. R_1 is the ratio of BIAS to ABSE, R_2 is the ratio of ABSE to RMSE. R_1 value equals to zero when model and observations results equal each other, which represents best model performance. R_1 value greater than 0 represents positively biased values. Aspect ratio of error R_2 falls within 0 and 1. Temperature values for stations are clearly positively biased, indicating that WRF generally overestimates temperature. IOA values indicate acceptable agreement for 2-meter temperature, around 62 %. Like R_1 value IOA value is expected to be 1 for proper simulation.

Table 3.1 : Statistical comparison of WRF model simulated temperature observations for Ataturk Airport and Goztepe air qaulity stations.

Measures	Ataturk	Goztepe
MB	0.51	0.6
NMB	0.03	0.04
RMSE	2.23	2.19
ABSE	1.81	1.67
R_1	0.28	0.35
R_2	0.81	0.76
IOA	0.62	0.62

The reason of the differences between the measurement and the model results is model gives only one value for 4 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. Nevertheless; WRF is capable of simulating meteorology even in higher resolutions.

3.1.2 Model results for the episode days

10^{th} of November from November 2 to 12 2010, was selected for post-processing. The horizontal wind vectors and relative humidity distribution at 850 mb level, surface temperature and 24-hour total precipitation for the Istanbul domain are presented in Figures 3.3, 3.4 and 3.5.

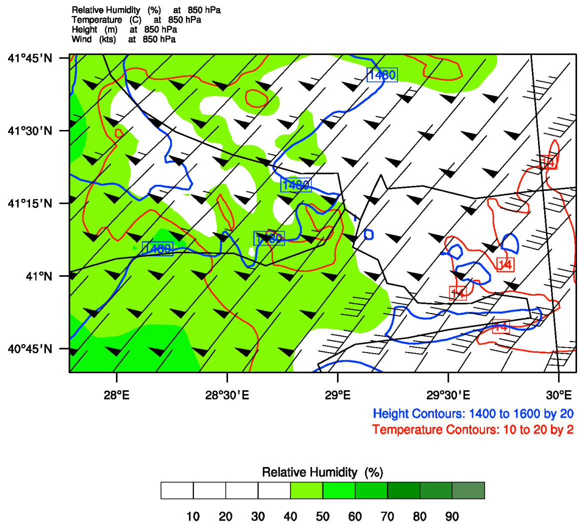


Figure 3.3 : 850 mb level wind vectors and relative humidity.

Strong easterly winds, nearly 50 knot, were observed especially on the western part of Istanbul and the humidity levels were below 70% as seen in Figure 3.3 so no precipitation was expected. 5 hours in 10th of November were presented in a panel for ground temperature in Figure 3.4. 14 to 16° C temperature values were seen throughout the region. The temperature in the north of Istanbul were found to be lower. Figure 3.5 shows that there is no precipitation event in 10th of November.

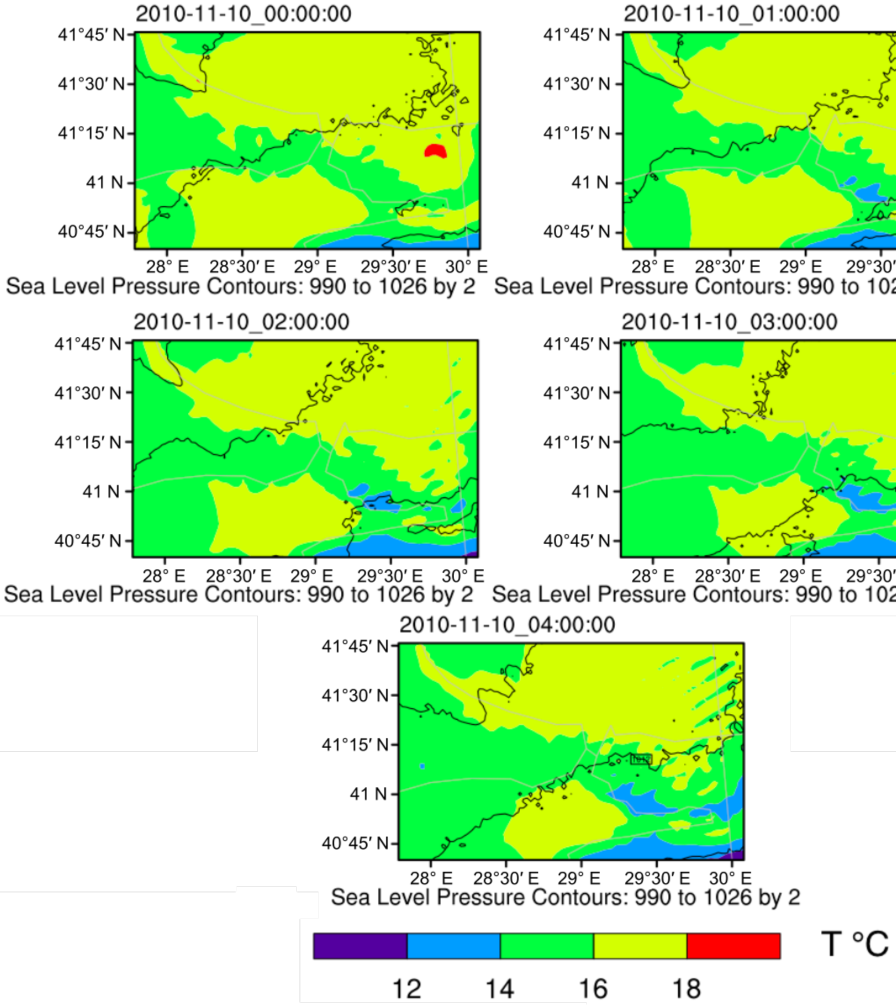


Figure 3.4 : 2 meter horizontal temperature.

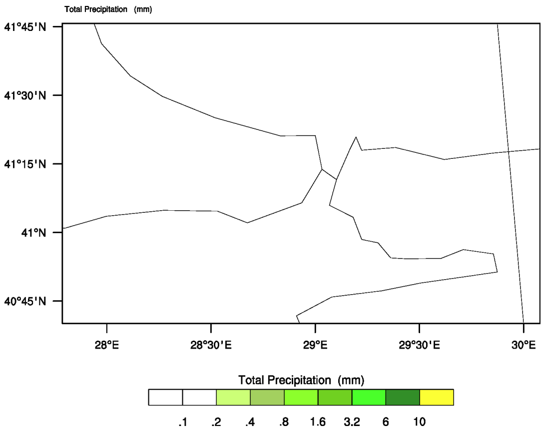


Figure 3.5 : 24-hour precipitation on 10th November 2010.

3.2 Emission Model

The annual emission calculation for the aggregated pollutant groups of CO, NO_x, SO_2, NMVOC, NH_3, PM coarse (particulates between PM_{10} and $PM_{2.5}$) and $PM_{2.5}$ for each source category are presented in Figure 3.6. It is clear that road transport sector plays an important role on air quality. Road transport is responsible for 79 % per cent of CO emissions (82 tons). The second major source of carbon monoxide is non industrial combustion plants responsible for 12.5 % of the total CO emissions (13 tons). Combustion in manufacturing industry is the second important sector for air quality that is contributing to 34 % of the SOx. The figure also represents that 34 % of NMVOC emissions come from road transport and 42 % come from solvent use sector.

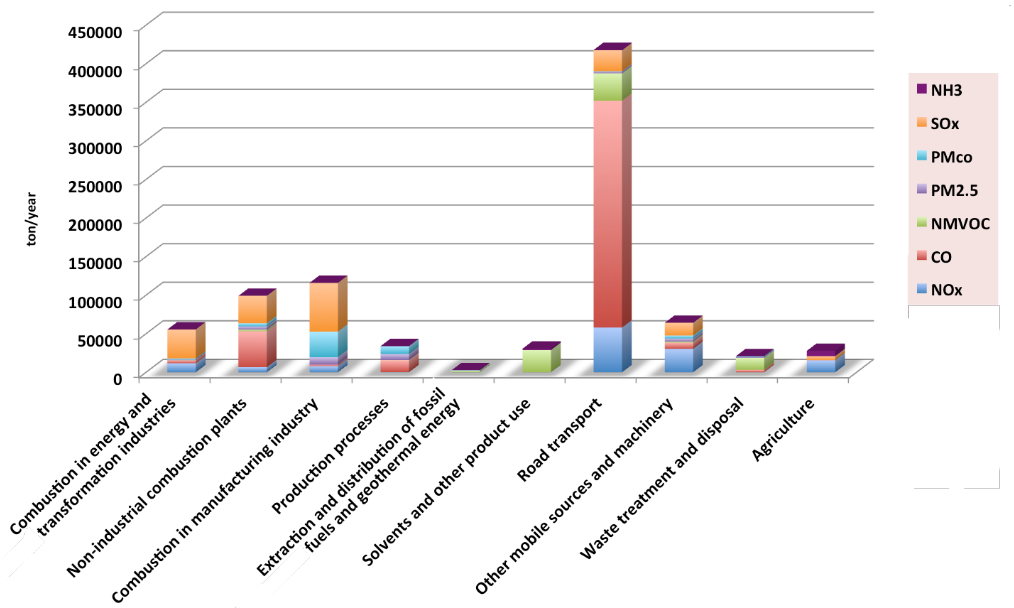


Figure 3.6 : Annual aggregated emissions per sector.

Figure 3.7 shows sources of CO, NO_x, SO_2, NMVOC, PM_{10} and $PM_{2.5}$ emissions. As previously stated, road transport plays a major role in CO (79 %),NO_x (45 %) and NMVOC (41 %) emissions. Road transport is 8 % of PM2.5 and 1 % of PMco emissions. COPERT simulations represent quite lower contributions of PM compared to Im's (2009) emission inventory (70 % for $PM_{2.5}$ and 60 % PM_{10}). Combustion in manufacturing industry plays the main role in SO_2 emissions (34 %).

The spatial distributions of CO, NO_x, SO_2, NMVOC, PM_{10} and $PM_{2.5}$ from road transport are presented in Figure 3.8. High traffic emissions are seen especially around dense highways, residential and commercial areas. As mentioned before CO is the main pollutant comes from transportation sector (373 000 tons/year). Magnitudes of emissions are different from each other, but the places where they emit are the same. Yearly NO_x emissions is nearly 58 000 tons from road transport.

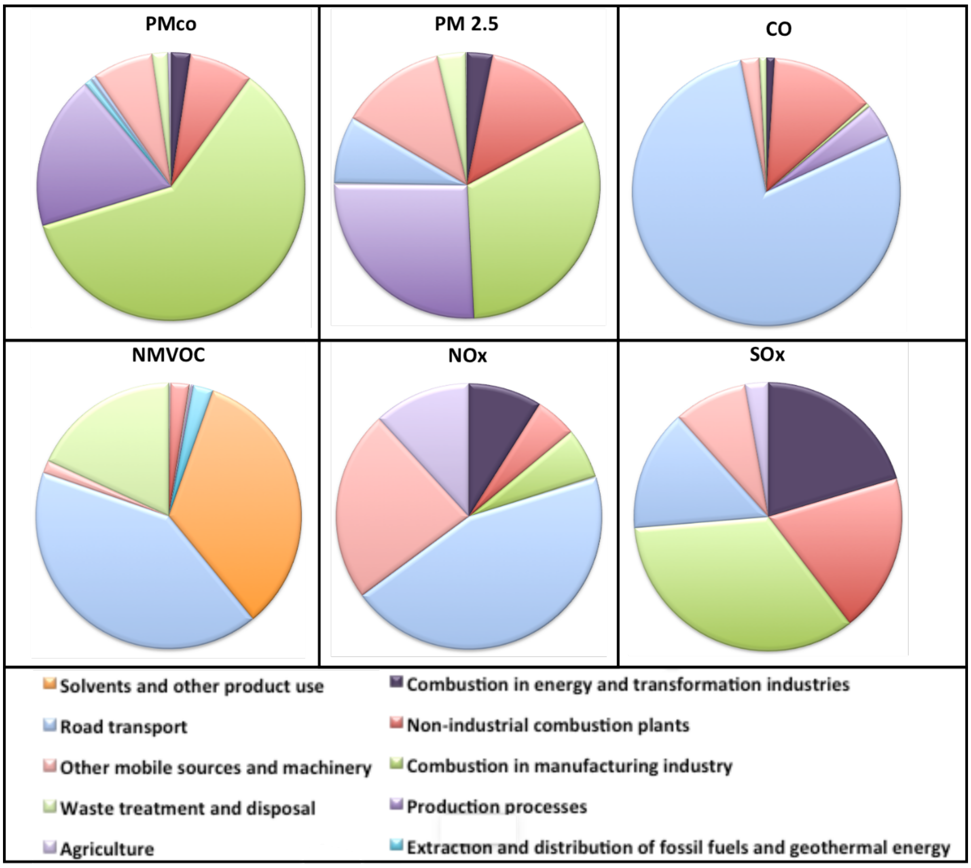


Figure 3.7 : Source contribution to CO, NO_x, SO_2, NMVOC, PM_{10} and $PM_{2.5}$ emissions.

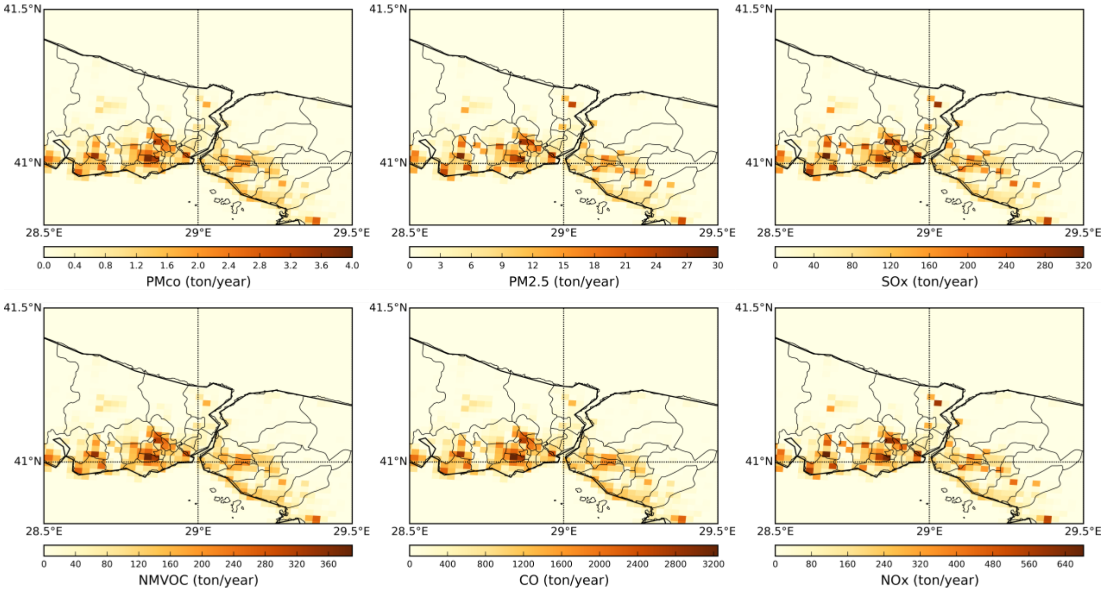


Figure 3.8 : Spatial distributions of CO, NO_x, SO_2, NMVOC, PM_{10} and $PM_{2.5}$ emissions from road transport.

3.3 Chemistry and Transport Model

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. Model calculated PM10 results were compared with Aksaray (41 latitude, 28.95 longitude) air quality station (see Figure 3.9). Model generally simulated the hourly trends of the observed data. Values are close to each other in terms of magnitude. Differences may be due to improper temporal profiles used in mother domain for Istanbul. Because of the evaluation is done by using one point observation with an average value calculated for each grid cell. There are some differences values reaching $100\mu g/m^3$.

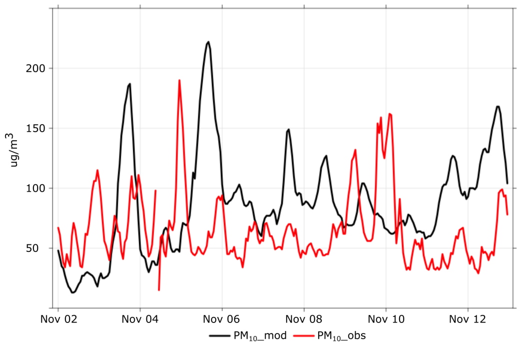


Figure 3.9 : Observed vs modeled hourly PM_{10}, concentrations at Aksaray in European domain.

Turkey domain is covering 244 grids in x–direction and 157 grids in y–direction with a 10 km resolution. It is noted that the emissions for 10 km domain was calculated by downscaling of 30 km emissions. In Figure 3.10 more accurate results were obtained due to increased resolution.

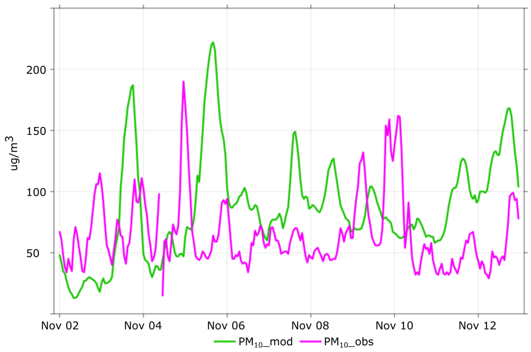
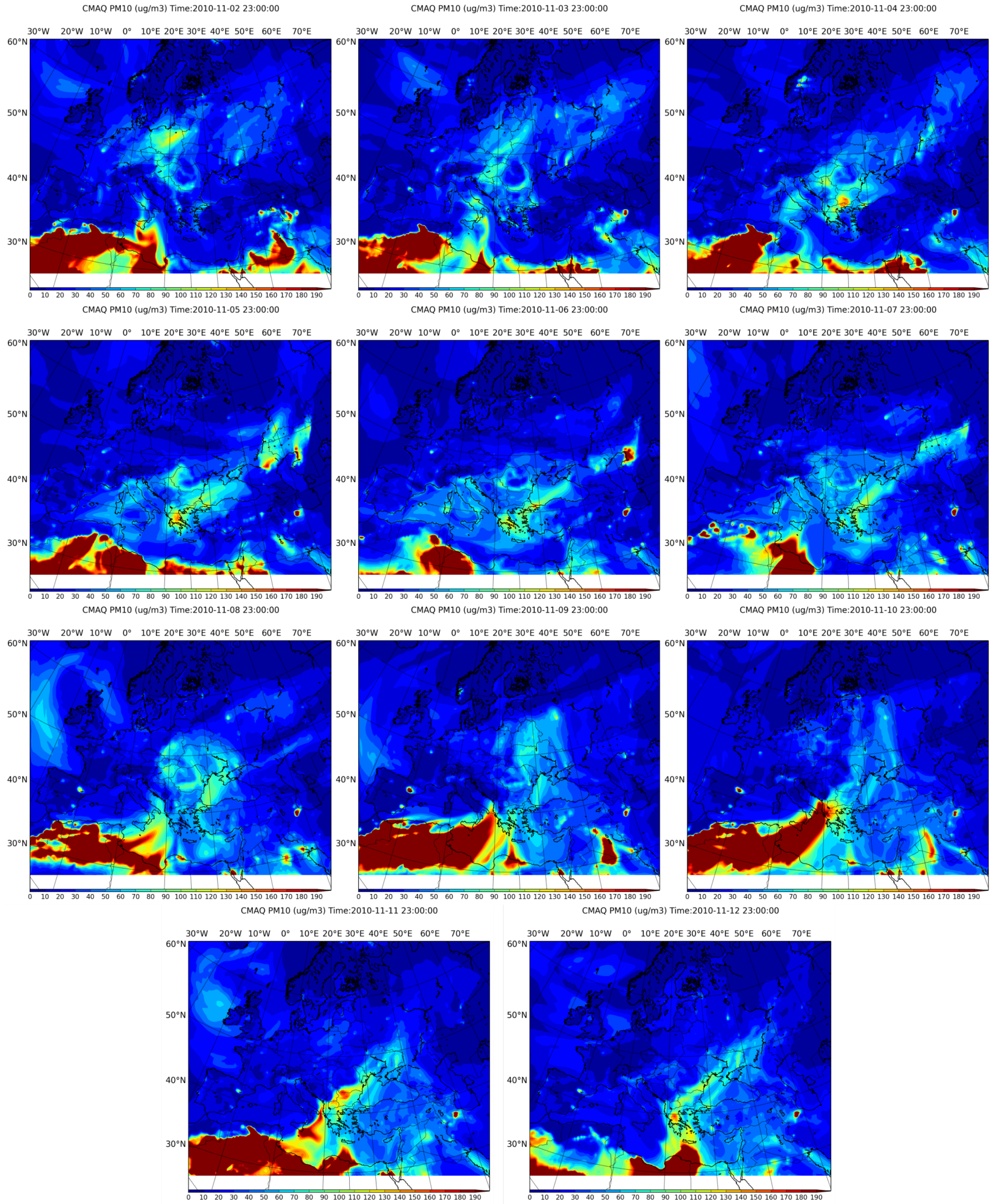


Figure 3.10 : Observed vs modeled hourly PM_{10} concentrations at Aksaray in Turkey domain.

There are still differences between model and observation. Average difference is $20\mu g/m^3$. Measurement errors, averaging values, model, chemical mechanism, and emission uncertainty might be the reason of difference (Kındap, 2005).

Daily PM10 concentrations in European domain calculated by CMAQ for the period from 2 to 12 November, 2010, are presented in Figure 3.11. Istanbul and Southern Greece are important hot spots for PM_{10} pollution. PM_{10} pollution is reached $150\mu g/m^3$ over Istanbul. Westerns coasts of Turkey,also, has high PM_{10} concentrations. It should be noted that North Africa and deserts are strong PM_{10} pollution sources as can be seen from maps.


CMAQ PM10 (ug/m3) Time:2010-11-02 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-03 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-04 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-05 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-06 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-07 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-08 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-09 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-10 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-11 23:00:00

CMAQ PM10 (ug/m3) Time:2010-11-12 23:00:00

Figure 3.11 : 24-hour average PM_{10} concentrations for mother domain.

In order to focus study area Istanbul on the Turkey domain, the 10 km simulation results for daily PM_{10} concentrations are presented in Figure 3.12. In all figures, Istanbul has more PM_{10} concentrations compared to other cities in Turkey. Between 2 and 12 November, 2010, high PM_{10} concentrations were modeled for the Greater Istanbul Area.

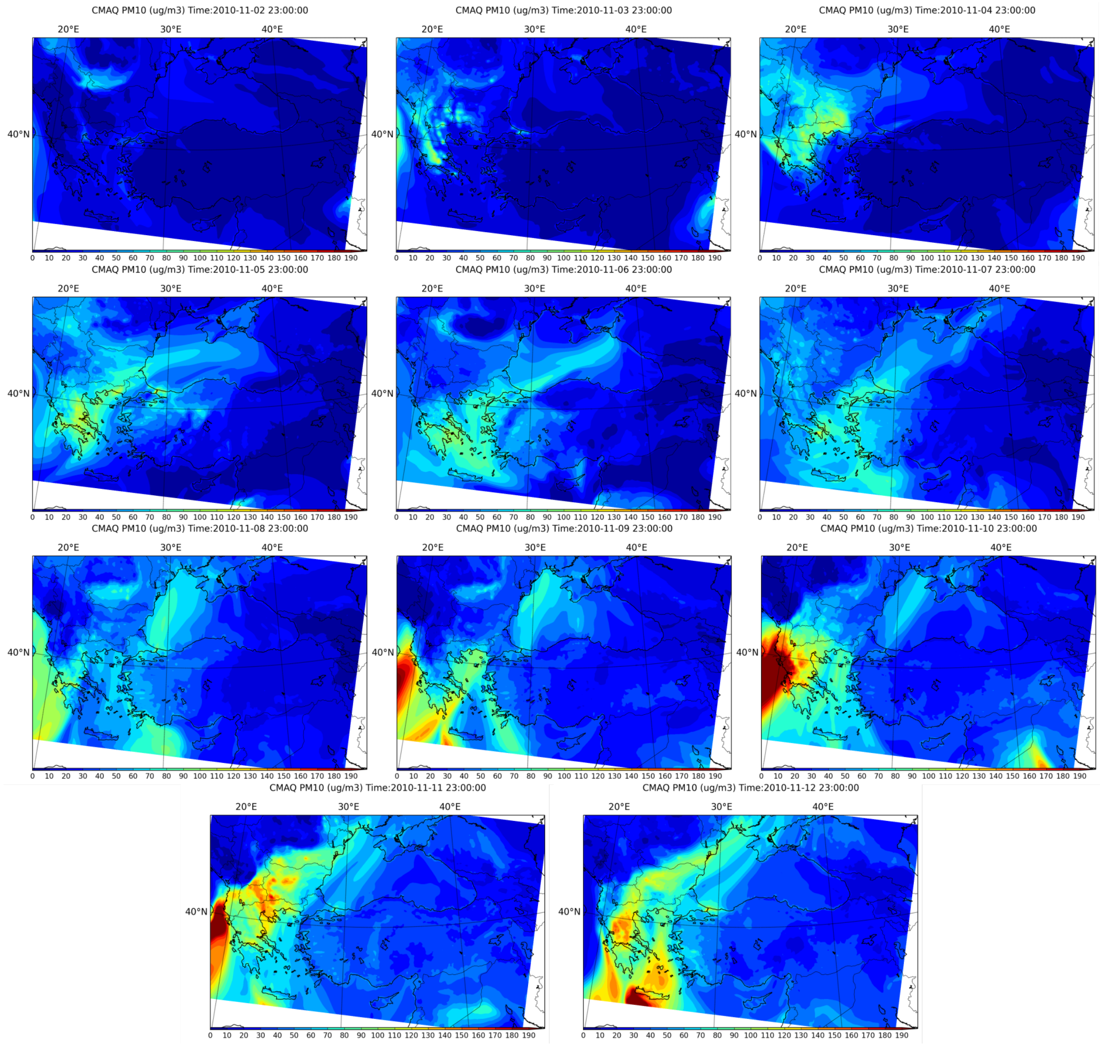


Figure 3.12 : 24-hour average PM_{10} concentrations for Turkey domain.

The boundary conditions were used from previous Turkey domain simulations and the initial conditions were taken from each time step of the previous day of the Istanbul domain. As for European and Turkey domains, model evaluation was done for Istanbul domain. The time series plot has showed that the concentration calculated for Aksaray has differences (see Figure 3.13). The comparison between the model and the observations for Aksaray station represents that the model over estimated the PM_{10} values. The reason for this difference may be high-resolution emission inventory. Road transport emissions obtained from COPERT model may create uncertainties in terms of detailed vehicle number and properties. These uncertainties affect the transport-related PM_{10} concentrations.

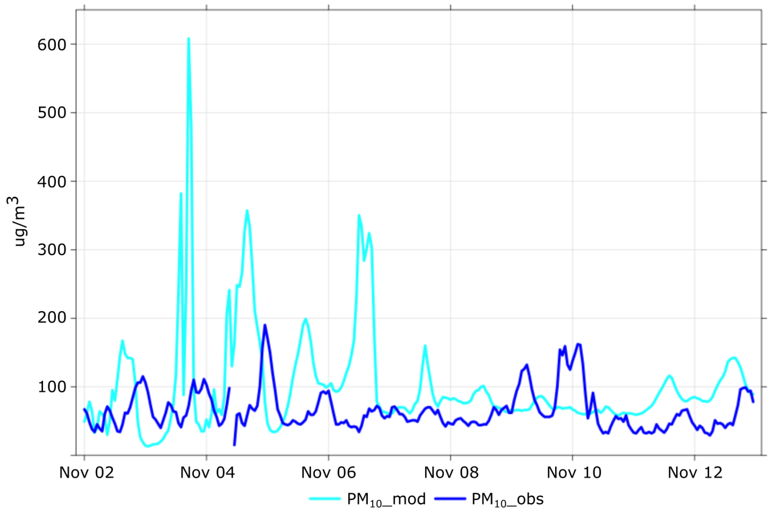


Figure 3.13 : Observed vs modeled hourly PM_{10} concentrations at Aksaray in Istanbul domain.

The statistical measures are presented in Table 3.2. Low performance were observed in terms of statistical performance. Satisfactory results could not be obtained in terms of PM in comparison with literature (Smyht, Jiang, Yin, Roth, & Giroux, 2006). The results reveal that the model over estimated for Aksaray air quality station, around $60\mu g/m^3$. Measure of the difference between values called RMSE is 92 and IOA is $-0.27\,\%$ that indicates low agreement. R_1 should be bounded between -1 and 1. R_1 value greater than 0 represents positively biased values. Aspect ratio of error R_2 should be fall within 0 and 1 which is 0.64.

Table 3.2 : Statistical comparison of model results vs observations for Istanbul domain.

Measures	Aksaray
MB	36.3
NMB	0.56
RMSE	92
ABSE	59
R_1	0.62
R_2	0.64
IOA	-0.27

Distribution of daily PM_{10} concentrations for Istanbul domain is presented in Figure 3.14. The highest concentrations (reaching $200\mu g/m^3$) were seen in the European side especially around Historical Peninsula. Regions where dense industrial activities and population were seen has high PM pollution as in the spatial emission distribution. Central zones in Anatolian side also have high PM concentrations.

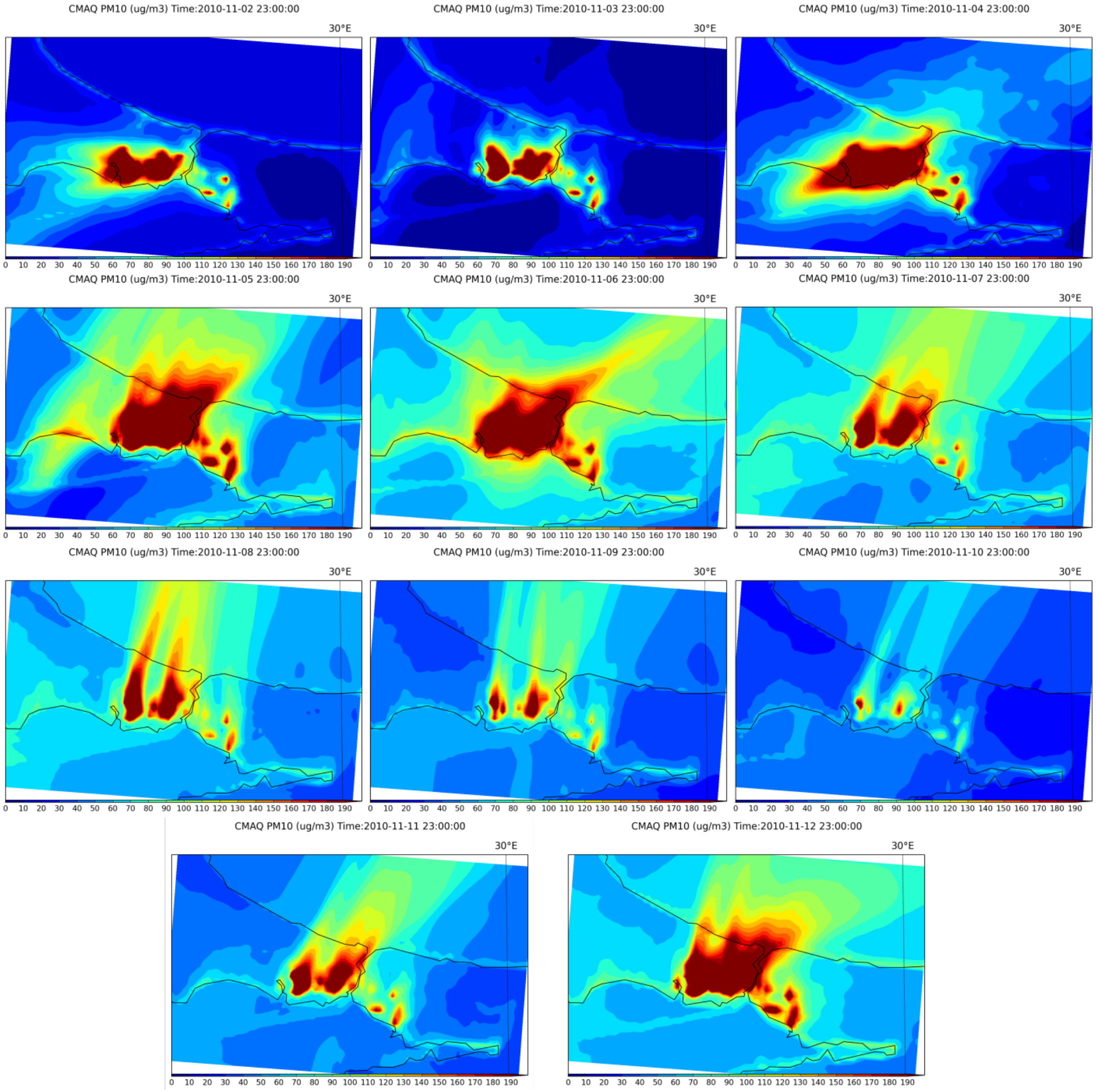


Figure 3.14 : 24-hour average PM_{10} concentrations for Istanbul domain.

3.3.1 Sensitivity analysis

Low emission zone scenario was simulated in order to understand the response of PM_{10} concentration to changes in emissions under EURO 3 standard. In Figure 3.15 , the spatial distribution of changes of PM_{10} concentration in response to 85 % decrease of PM emissions is presented based on daily averages. Maximum change in daily PM concentrations was calculated in $15 \mu g/m^3$. The highest differences are observed on the 5^{th} and 6^{th} of November.

As expected, in response to decrease in PM emissions PM_{10} concentration has decreased ranging from $-2 \mu g/m^3$ to $35 \mu g/m^3$ in Historical Peninsula based on hourly values. The highest decrease ($35 \mu g/m^3$) was found on 5^{th} of November at 14:00 (see Figure 3.16). Application of EURO 3 limit in the Historical Peninsula, provides a significant reduction in PM_{10} concentrations.

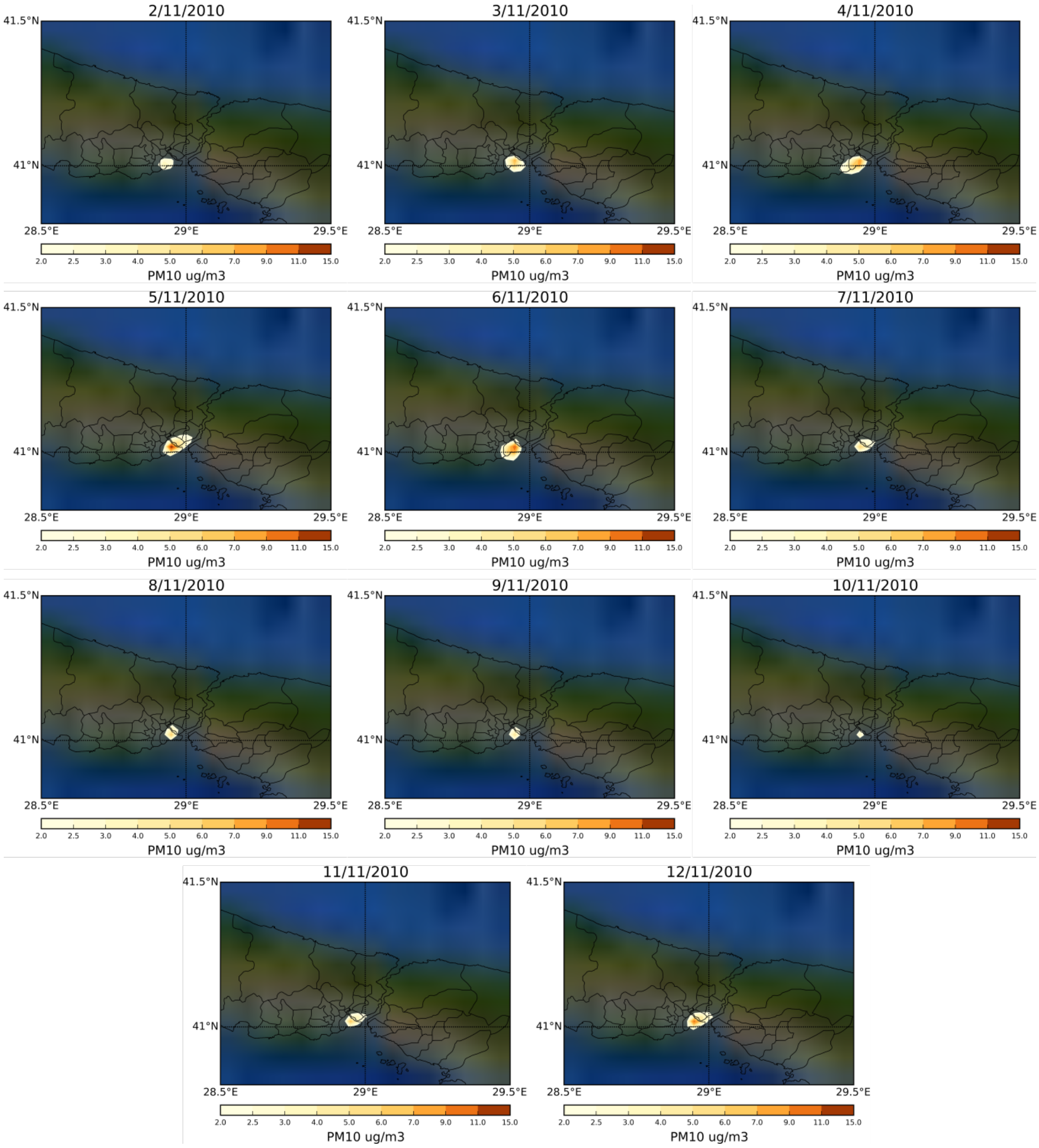


Figure 3.15 : 24-hour average PM_{10} changes in response to 85 per cent decrease of all PM emissions

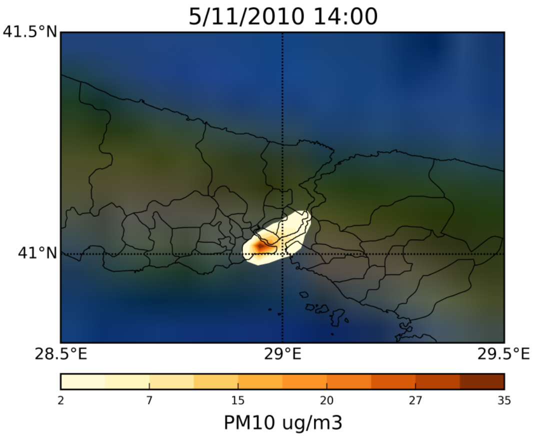


Figure 3.16 : Maximum PM_{10} concentration difference for Historical Peninsula.

4. CONCLUSIONS

The effect of Low Emission Zone establishment was investigated using air quality model includes WRF meteorological model, COPERT road transport emission model and CMAQ chemistry and transport model. 2 km resolution emission inventory was used for this thesis. This study was conducted for the first time in Istanbul.

Emission modeling system has revealed that road transport is one of the most important sources of air pollution in Istanbul. Most of the pollution has seen on both sides of Bosporus where population is dense. Pollution concentrates in Kadıkoy on the Asian side and city's oldest settlements (Historical Peninsula), organized industrial zones and center of workplaces (Maslak) on the European side. These places also attract high traffic load. Various strategies have been developed to manage the traffic-related air pollution. Low emission zone, most common method around the world, was selected for Historical Peninsula since this region has high day time population and suitable for traffic management.

The WRF simulation results were compared with observations from Ataturk Airport and Goztepe stations. Statistical analysis showed that model could capture surface temperature. Closer results can be obtain by testing parametrization options. Model results overestimate until 8^{th} of November, underestimate from this date for both stations.

To compare between simulations and observations for PM_{10} levels, daily averages were calculated from the CMAQ results. The reason of poor statistical performance may connected with short period for Istanbul domain. The results confirm that the model over estimated Aksaray around $60 \mu g/m^3$. The IOA value is around $-0.27\,\%$, indicating a poor agreement.

Each method used to manage road transport emissions were calculated to investigate their reduction effects.Through them, the EURO 3 standard was found to be the most powerful method that leads to 85 % decrease in PM emissions. When this method was applied, up to $35 \mu g/m^3$ drops were monitored hourly basis in Historical Peninsula.

This thesis presents the results of the validation of the high resolution emission inventory and sensitivity analyses for low emission zone. According to results the inventory also needs to be developed. As mentioned before, being the most important source of air pollution, traffic-related emissions introduces high uncertainties due to obtaining from COPERT. This model has been included in the Istanbul specific emission inventory for the first time. Besides Istanbul specific emission inventory has been prepared for only anthropogenic emissions. Biogenic emissions were calculated in MEGAN model and boundary conditions were provided from the EU project MACC. These values may not correspond to the emission inventory of study area. Dynamic boundary conditions can be used to better represent the air quality system. Another discrepancy belongs to comparison purposes that is about location of the observation stations. The location of the station should be appropriate in terms of geography and land use. However most stations are located in urban for Istanbul. Measurements should be conducted in rural or suburban areas to provide and understand background pollution to develop better performance evaluation.

This study submits first results of low emission zone by using MODELS-3 system for Istanbul. Still, it should be noted that this is an ongoing study, focusing on different methods and their effects.The physical options should be optimized for the region because of the meteorology based uncertainty is high in high resolution domains. Higher resolution data should be collected in the emission inventory, which is currently being done by an ongoing project called Development of National Emissions Inventory Management System for Turkey (KAMAG). Natural and biogenic emissions should be included in emission inventory to be more representative, and more region-specific boundary conditions should be used. Long-term model performance analysis may introduce statistically significant results. This study presents a quantitative methodology framework to desing such a zone that can be guideline to decision makers.

REFERENCES

Atkinson, R., Anderson, H., Sunyer, J., Ayres, J., Baccini, M., Vonk, J., . . . Katsouyanni, K. (2008). Acute effects of particulate air pollution on respiratory admissions. *American Journal of Respiratory and Critical Care Medicine*.

Beckerman, B., Jerrett, M., Brook, R., Verma, D., Arain, M., & Finkelstein, M. (2008). Correlation of nitrogen dioxide with other traffic pollutants near a major expressway. *Atmospheric Environment*.

Bell, M., McDermott, A., Zeger, S., Samet, J., & Dominici, F. (2004). Ozone and short-term mortality in 95 us urban communities, 1987-2000. *JAMA*.

Boogard, H., Janssen, N. A., Fischer, P. H., Kos, G. P., Weijers, E. P., Cassee, F. R., . . . Hoek, G. (2012). Impact of low emission zones and local traffic policies on ambient air pollution concentrations. *Science of the Total Environment*.

Brinkhoff, T. (2015). *The principal agglomerations of the world.* Retrieved from http://www.citypopulation.de

Ching, J., & Byun, D. (1999). *Introduction to the models-3 framework and the community multiscale air quality model (cmaq)* (Tech. Rep.).

CLARS. (2015). *Urban access regulations in europe.* Retrieved from http://urbanaccessregulations.eu

CMAS. (2014). *Cmas model documentation* (Tech. Rep.). Retrieved from https://www.cmascenter.org

Dieselnet. (2015). *Cars and light trucks.* Retrieved from http://www.dieselnet.com/standards/eu/ld.php

EEA. (2010). *Impact of selected policy measures on europe's air quality* (Tech. Rep.). Retrieved from http://www.eea.europa.eu/publications/impact-of-selected-policy-measures

Ellison, R. B., Greaves, S. P., & Hensher, D. (2013). Five years of london's low emission zone: Effects on vehicle fleet composition and air quality. *Transportation Research Part D: Transport and Environment*.

Embarq. (2014). *Tarihi yarımada yayalaştırma projesi.* Retrieved from http://www.embarqturkiye-yasanabilirsehirler.org

EPA. (2015a). *Ground level ozone.* Retrieved from http://www3.epa.gov/ozonepollution/

EPA. (2015b). *Particulate matter basic infomation.* Retrieved from http://www3.epa.gov/pm/basic.html

European Environment Agency. (2013). *Emep/eea air pollutant emission inventory guidebook* (Tech. Rep.). Retrieved from http://www.eea.europa.eu/publications/emep-eea-guidebook-2013

Ezber, Y., Sen, O. L., Kindap, T., & Karaca, M. (2007). Climatic effects of urbanization in istanbul: a statistical and modeling analysis. *International Journal of Climatology*.

Gkatzoflias, D., Kouridis, C., Ntziachristos, L., & Samaras, Z. (2012). *Computer programme to calculate emissions from road transport* (Tech. Rep.). Retrieved from http://emisia.com/sites/default/files/COPERT4v9_manual.pdf

Guenther, A., Hewitt, N., Erickson, D., Fall, R., Geron, C., Graedel, T., ... Zimmerman, P. (1995). A global model of natural volatile organic compound emissions. *J. Geophys. Res.*

Guenther, A. B., Jiang, X., Heald, C. L., Sakulyanontvittaya, T., Duhl, T., Emmons, L. K., & Wang, X. (2012). The model of emissions of gases and aerosols from nature version 2.1 (megan2.1): an extended and updated framework for modeling biogenic emissions. *Geoscientific Model Development.*

Health Effects Institute. (2010). *Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects* (Tech. Rep.). Retrieved from http://emisia.com/sites/default/files/COPERT4v9_manual.pdf

Hertel, O., Berkowicz, R., Christensen, J. H., & Hov, O. (1993). Test of two numerical schemes for use in atmospheric transport-chemistry models. *Atmospheric Environment.*

Im, U. (2009). *Mesoscale modeling of aerosol levels in istanbul using a high resolution mm5/cmaq air quality modeling system* (Unpublished doctoral dissertation). Bogazici University.

Istanbul Metropolitan Municipality. (2009). *Istanbul air quality strategy* (Tech. Rep.).

Kındap, T. (2005). *Long-range aerosol transport from europe to İstanbul, turkey* (Unpublished doctoral dissertation). Istanbul Technical University.

Maisonet, M., Correa, A., Misra, D., & Jaakkola, J. (2004). A review of the literature on the effects of ambient air pollution on fetal growth. *Environmental Research.*

Mao, Q., Gautney, L. L., Cook, T. M., Jacobs, M. E., Smith, S. N., & Kelsoe, J. J. (2006). Numerical experiments on mm5–cmaq sensitivity to various pbl schemes. *Atmospheric Environment.*

Markasis, K., Im, U., Unal, A., Melas, D., Yenigun, O., & Incecik, S. (2012). Compilation of a gis based high spatially and temporally resolved emission inventory for the greater istanbul area. *Atmospheric Pollution Research.*

Mediavilla-Sahagun, A., & ApSimon, H. M. (2003). Urban scale integrated assessment of options to reduce pm10 in london towards attainment of air quality objectives. *Atmospheric Environment.*

Ministry of Environment and Urbanization . (2015). *Cbs haritası.* Retrieved from http://www.havaizleme.gov.tr/Default.ltr.aspx

Mudway, I., & Kelly, F. (2000). Ozone and the lung: a sensitive issue. *Molecular Aspects of Medicine.*

Ozdemir, H., Im, U., Kostandinos, M., Agacayak, T., Unal, A., Kindap, T., & Khan, M. (2009). Impacts of istanbul emissions on regional air quality: Quantification using model-3 framework and trajectory analysis..

Pleim, J. E. (2007). A combined local and nonlocal closure model for the atmospheric boundary layer. part i: Model description and testing. *Journal of Applied Meteorology and Climatology.*

Pope III, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: Lines that connect. *Air & Waste Management Association.*

Raub, J. A., Mathieu-Nolf, M., Hampson, N. B., & Thom, S. R. (2000). Carbon monoxide poisoning — a public health perspective. *Toxicology.*

Seinfeld, J. H., & Pandis, S. (2006). *Atmospheric chemistry and physics: From air pollution to climate change, 2nd edition*. Wiley.

Smyht, S. C., Jiang, W., Yin, D., Roth, H., & Giroux, E. (2006). Evaluation of cmaq o3 and pm2.5 performance using pacific 2001 measurement data. *Atmospheric Environment*.

Studnicka, M., Hackl, E., Pischinger, J., Fangmeyer, C., Haschke, N., Kuhr, J., … Frischer, T. (1997). Traffic-related no2 and the prevalence of asthma and respiratory symptoms in seven year olds. *European Respiratory Society*.

Turkish Statistical Institute . (2013). *Temel İstaistikler* (Tech. Rep.). Retrieved from www.tuik.gov.tr/

Turkish Statistical Institute. (2014). *Temel İstatistikler.* Retrieved from http://www.tuik.gov.tr

Tzirakis, E., Zannikos, F., & Stournas, S. (2007). Impact of driving style on fuel consumption and exhaust emissions: defensive and aggressive driving style. In *Proceedings of the 10th international conference on environmental science and technology.*

Unal, A., Frey, H. C., & Rouphail, N. M. (2004). Quantification of highway vehicle emissions hot spots based upon on-board measurements. *J. Air Waste Manage*.

Unal, A., Rouphail, N., & Frey, H. (2003). Effect of arterial signalization and level of service on measured vehicle emissions. In *82nd annual meeting of the transportation research board.*

University Corporation for Atmospheric Research. (2014). *Wrf arw online tutorial.* Retrieved from http://www2.mmm.ucar.edu/wrf/OnLineTutorial/index.htm

Valavanidis, A., Fiotakis, K., & Vlachogiani, T. (2008). Airborne particulate matter and human health: Toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *Journal of Environmental Science and Health.*

WHO. (2006). Air quality guidelines global update 2005. *World Health Organization*.

World Health Organization. (2009). *Global health risks* (Tech. Rep.). Retrieved from http://www.who.int/heli/risks/urban/en/uapmap.1.pdf?ua=1

Yarwood, G., Rao, S., Yocke, M., & Whitten, G. Z. (2005). *Updates to the carbon bond chemical mechanism: Cb05* (Tech. Rep.).

Zannetti, P. (1990). *Air pollution modeling theories, computational methods and available software*. Springer.

APPENDICES

APPENDIX A.1: History of Regulation

APPENDIX A.1

In Turkey “Ensuring Economy in Fuel Consumption and Reduction of Air Pollution caused by Heating Plant” “Yakıt Tüketiminde Ekonomi Sağlanması ve Şehirlerde Isıtma Tesislerinin Sebep Olduğu Hava Kirliliğinin Azaltılmasına Dair Yönetmelik” was prepared by Ministry of Energy and Natural Resources in 1972. “Protection of Air Quality Regulation” “Hava Kalitesinin Korunması Yönetmeliği” entered into force in 1986 and purpose of this law is to eliminate the negative effects of pollutants released into the atmosphere by taking control. Then, the following regulations have been applied in our country :

- Industrial Air Pollution Control Regulation - Endüstriyel Kaynaklı Hava Kirliliğinin Kontrolü Yönetmeliği (2004)
- Gasoline and Diesel Fuel Quality Directive - Benzin ve Motorin Kalitesi Yönetmeliği (2004)
- Regulation of Control of Air Pollution Caused by Heating - Isınma Kaynaklı Hava Kirliliğinin Kontrolü Yönetmeliği (2005)
- Regulation of Control of Air Pollution Caused by Industrial Plants - Endüstri Tesislerinden Kaynaklanan Hava Kirliliğinin Kontrolü (2006)
- Air Quality Assessment and Management Regulation - Hava Kalitesi Değerlendirme ve Yönetimi Yönetmeliği (2008)
- Industrial Air Pollution Control Regulation - Sanayi Kaynaklı Hava Kirliliğinin Kontrolü Yönetmeliği (2009)
- Exhaust Gas Emissions Control Regulations - Egzoz Gazı Emisyonu Kontrolü Yönetmeliği (2009)
- Clean Air Action Plan – Temiz Hava Eylem Planı (2010-2013)

Apart from these national legal regulations for the prevention of air pollution there are international aggrements :

- Convention on Long Range Transboundary Air Pollution – Uzun Menzilli Sınır Ötesi Hava Kirliliği Sözleşmesi (1983)
- Vienna Convention for the Protection of the Ozone Layer - Ozon Tabakasının Korunmasına Dair Viyana Sözleşmesi (1990)
- The Montreal Protocol on Substances that Deplete the Ozone Layer - Ozon Tabakasını İncelten Maddelere Dair Montreal Protokolü (1990)
- United Nations Framework Convention on Climate Change - BM İklim Değişikliği Çerçeve Sözleşmesi (2004)
- Kyoto Protocol (2009)

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