ISTANBUL TECHNICAL UNIVERSITY★EURASIA INSTITUTE OF EARTH SCIENCES

THE INVESTIGATION OF SENSITIVITY OF COPERT ESTIMATED ROAD TRANSPORT EMISSIONS ON AIR QUALITY VIA WRF/CMAQ MODELING SYSTEM OVER ISTANBUL

M.Sc. THESIS

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COPERT4 MODELİYLE HESAPLANAN KARAYOLARI EMİSYONLARININ DUYARLILIĞININ İSTANBUL HAVA KALİTESİNE ETKİSİNİN WRF/CMAQ MODEL SİSTEMİYLE BELİRLENMESİ

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FOREWORD

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ABBREVIATIONS

GDP: Gross Domestic Product
NOx: Mono-Nitrogen Oxides (Nitric oxide and Nitrogen dioxide)
NMVOC: Non-methane Volatile Organic Compounds
CO_2: Carbon dioxide
CH_4: Methane
N_2O: Nitrous Oxide
NH_3: Ammonia
SO_2: Sulfur Dioxide
PM10 : Particulate Matter (<10 μm diameter)
PM2.5 : Particulate Matter (<2.5 μm diameter)
CO: Carbon Monoxide
PAHs: Polycyclic aromatic hydrocarbons
POPs: Persistent Organic Pollutants
EPA: Environmental Protection Agency
FTP: Federal Test Procedure
NEDC: New European Driving Cycle
COPERT 4: COmputer Programme to Calculate Emissions From Road Transport
EEA: European Environment Agency
WRF: Weather Forecasting Model
CMAQ: Community Multiscale Air Quality Model
CADC: The Common Artemis Driving Cycle
EF: Emission Factor
TUVTURK: Tuvturk Motor Vehicle Inspection Inc.
EMEP: The European Monitoring and Evaluation Program
TUIK: Turkish Statistical Institute
AQM: Air Quality Models
NCAR: National Center for Atmospheric Research
NCEP: National Centers for Environmental Prediction
AFWA: Air Force Weather Agency
FAA: Federal Aviation Administration

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µg : microgram
km : Kilometer
◦C : Celcius Degree
% : Percentage

THE INVESTIGATION OF SENSITIVITY OF COPERT ESTIMATED ROAD TRANSPORT EMISSIONS ON AIR QUALITY VIA WRF/CMAQ MODELING SYSTEM OVER ISTANBUL

SUMMARY

Istanbul, the study area and the economic capital of Turkey, is the most populated city all around Europe with a population well over 14 million. The city has faced with environmental problems due to rapid urbanization and industrialization for a couple of decades. Air pollution is one of the most challenging problems for Istanbul where studies publicized that air pollution, particulate matter pollution in specific, has various serious effects on public health. Although air pollution is caused by numerous sources ranging from industrial to biogenic activities, emissions from motor vehicles have the most adverse effects on public health as they are released at the locations with certain levels where human activity is the highest.

Traffic related emissions were calculated by using COPERT 4 (**CO**mputer **P**rogramme to calculate **E**missions from **R**oad **T**ransport) which is vehicle emission computation software and supported by European Environment Agency (EEA). Model input data were obtained from Turkish Ministry of Environment and Urbanization, and TUVTURK, then the data were processed by R that is a software environment for statistical computing and graphics. Besides fleet distribution process based on EURO levels, engine volumes, and fuel type was done first time for Istanbul, COPERT 4 was also run with this high resolution data. High-resolution emission inventory for other sectors, which is prepared by Dr. Ulaş Im, were employed. It can be summarized from the results of this analysis that road transport itself is solely responsible for 32 percent of CO emissions, as well as playing a main role in NMVOC emissions with the contribution of 43 percent to the total NMVOC emissions inventory, and NOx emissions with the contribution of 40 percent to total NOx emissions inventory. Furthermore, overall CO, NOx and PM2.5 contributions by road transport are found as 51%, 42%, and 11%, respectively. It is also realized that impact of road transport on inventory is higher than other sources.

Vehicle emissions in inventory with this vitality increase the importance of determining the sensitivity and the uncertainty of calculations. To investigate the sensitivity of COPERT 4, three scenarios are determined based on temperature and speed parameters with numerous values that are strongly affecting the calculations. Then, base case emission values were compared with obtained emission values of these three scenarios. For the each scenario COPERT model was run and emissions of road transport was obtained. Then, calculated vehicle emissions used as input for air quality model. As a result of emissions for each scenario, a conclusion can be drawn that the major pollutant is NOx and minor pollutant is PM2.5 in general, where the emissions are higher in rural areas than urban areas and than the highways

When a general analysis is done on scenarios regarding to pollutants, it can be realized that there is a decrease in emissions of all kinds of pollutants except CO as

speed increases, and increase in emissions of all kinds of pollutants except CO as speed decreases. On the other hand, an obvious decrease in emissions of pollutants except NMVOC is realized in the case of temperature decrease.

After evaluating the effect of change in model parameters on emission rates, air quality model was run to determine how would the effect of variation on emission rates embody in air quality. Model was first run for base case, then it is tried to determine the impact on air quality by running the model for each case separately. $PM_{2.5}$ is analyzed since it has a significant effect on public health although it is not one of the pollutants that are caused by vehicle emissions. The day and time was examined when the gap is at maximum between the concentrations that are calculated for fundamental cases and the concentrations that are calculated within each model cell for all scenarios. It has been realized that there is 1.5 $\mu g/m^3$ (~5%) decrease in $PM_{2.5}$ concentration Istanbul-wide when results from CMAQ is analyzed within Scenario-I where the speed increased by 20%. 1.5 $\mu g/m^3$ rate might be considered insignificant when it is compared with other average concentrations; however, it plays a key role on public health. In Scenario-II, it was realized that there is an average 2$\mu g/m^3$ decrease in $PM_{2.5}$ concentration depending on decrease in speed.

This study can be advanced by obtaining higher resolution data that are employed for emission calculations of vehicles such as truck, bus, etc., by preparing more detailed emission inventory, and by employing the data suiting more accurate boundary conditions for air quality model.

COPERT4 MODELİYLE HESAPLANAN KARAYOLARI EMİSYONLARININ DUYARLILIĞININ İSTANBUL HAVA KALİTESİNE ETKİSİNİN WRF/CMAQ MODEL SİSTEMİYLE BELİRLENMESİ

ÖZET

İstanbul Türkiye'nin ekonomik başkenti ve 14 milyonu aşan nüfusuyla Avrupanın en kalabalık kentidir. Dünyanın önemli mega şehirlerinden biri olan İstanbul sosyo-ekonomik gelişmelerin beraberinde getirdiği çevre kirliliği problerini son yıllarda fazlasıyla yaşamaktadır. Bu çevresel problemlerin en önemlilerinden birisi hava kirliliği, özellikle de ulaşımdan kaynaklanan emisyonların oluşturduğu hava kirliliğidir. Hava kirliliği atmosferdeki kirleticilerin insan ve diğer canlılara zarar verecek düzeye erişmesidir. Yapılan epidemiyolojik çalışmalarda, hava kirliliğinin sağlığa olan etkileri kanıtlanmıştır. Bu çalışmalarda ölümler, hastaneye başvurular gibi sağlık göstergeleriyle havadaki kirleticilerin konsantrasyonları arasındaki ilişkiler araştırılmış ve artış veya azalışa göre doğrudan bir ilişki olduğu kanıtlanmıştır. Kirleticilere maruz kalmanın, bir yandan kalp ve akciğer hastalıklarına bağlı ölüm oranını artırırken, diğer yandan bu hastalıklara bağlı hastane başvurularını arttırdığı görülmüştür. Bunun yanında, hava kirliliğinin özellikle çocukların akciğer gelişimini olumsuz etkilediği ve kirliliğin yoğun olduğu bölgelerde astım ve kronik obstrüktif akciğer hastalığı (KOAH) gibi kronik hava yolu hastalıklarına yakalama riskini arttırdığı saptanmıştır. Hava kirliliği, kaynaklarından bağımsız olarak son derece önemli bir konu olmasıyla beraber,araçlardan kaynaklanan emisyonlar, emisyonların miktarı ve salındığı mekanın toplumun yoğun yaşadığı şehirleşmiş bölgelerde ve insan seviyesinde olması açısından diğer kaynaklara göre daha fazla önem taşımaktadır. Yapılan çalışmalarda, ulaşımdan kaynaklanan hava kirliliğinin yol açtığı sağlık etkilerinin özellikle çocuklar ve yaşlılar gibi toplumun hassas kesimlerinde son derece negatif etkilerinin olduğu tespit edilmiştir.

Bu tez çalışmasında, trafik kaynaklı emisyonların hesaplanmasında kullanılan COPERT 4 modelinin girdi parametrelerindeki değişikliklerin, İstanbulun hava kalitesine etkisinin belirlenmesi amaçlanmıştır. Bu duyarlılığın belirlenmesi için 3 değişik senaryo oluşturulmuştur. Oluşturulan bu senaryolar için hesaplanan emisyon değerleriyle WRF meteoroloji modeli ve CMAQ kimyasal tasinimi modeli kullanılmış ve hava kalitesindeki değişiklikler belirlenmiştir. COPERT 4 trafik kaynaklı emisyon hesaplama modeli, Avrupada pek çok ülke tarafından araç emisyonların hesaplanması için kullanılan bir modeldir. Modelin geliştirilmesi Avrupa Çevre Ajansı tarafından desteklenmektedir. COPERT 4 modeliyle farklı araç kategorileri için (binek araçlar, hafif ticari araç, ağır kamyon, otobüs, motosiklet ve moped) önemli hava kirleticileri (CO, NOx, VOC, PM, NH3, SO2, ağır metaller) ve sera gazi emisyonları (CO2, N2O, CH4) hesaplanabilmektedir. Bu hesaplamaların yapılabilmesi için yüksek çözünürlükte veri setine ihtiyaç duyulmaktadır.

Bu tez çalışmasının ilk bölümü olarak, İstanbuldaki araçların modele girdi oluşturulabilecek detaya getirilmesi amacıyla gerekli olan veriler Çevre ve Şehircilik

Bakanlığı ve TÜVTÜRK araç muayene istasyonlarından alınmıştır. Elde edilen bu verilerle İstanbuldaki araçların karektesitik özelliklerine göre (araç tipi, motor hacmi, yakıt tipi, EURO seviyeleri, vb.) dağılımlarını gösteren yüksek çözünürlüklü veri seti oluşturulmuş ve araçlardan kaynaklanan emisyonlar ilk defa bu çözünürlükte hesaplanmıştır. Hesaplanan emisyonlar envanterin ulaşım sektöründe kullanılarak parametrelerdeki değişikliklerin ne kadar bir etki yaptığı hava kalitesi modeli ile ortaya konulmuştur.

Hesaplanan araç emisyonlarının envanterdeki etkisine bakıldığında, trafikten kaynaklanan kirleticilerden, metan olmayan uçucu organik bileşikler (NMVOC) %43'lük ve nitrik oksit (NOx) %40'lik etkiyle emisyon envaterinde ana kaynaklar olduğu görülmüştür. Ayrıca, %32'lik bir katkıyla karbon monoksit (CO) kirleticisinin ana kirletici olmamasına rağmen envanter üzerinde etkisinin oldukça fazla olduğu görülmüştür. Hesaplanan araç emisyonlarına kendi içinde bakıldığında ise CO, NOx ve PM2.5 kirleticilerinin etkisinin sırasıyla %51, %42 ve %11 olduğu belirlenmiştir. Sonuç olarak ulaşımın diğer kaynaklardan çok daha fazla bir etkisi olduğu görülmektedir.

Araçlardan kaynaklanan emisyonların envanterde bu denli öneme sahip olması, hesaplamalardaki duyarlılık ve belirsizliğin belirlenmesinin önemini arttırmaktadır. COPERT 4 modelinin hassaslığının belirlenebilmesi için hesaplamaları en çok etkilediği belirlenen parametreler olan hız ve sıcaklık değerleri değiştirilerek 3 senaryo belirlenmiş, bu senaryolar için araç emisyonları hesaplanmıştır. Daha sonra bu senaryolar için elde edilen emisyonlarla temel durumdaki emisyon değerleri karşılaştırılmıştır. İlk senaryo için modelde girdi olarak kullanılan, her araç tipi için ayrı olmak üzere belirlenen ortalama hız değerleri, İstanbuldaki trafik durumları göz önünde bulundurulak, %20 arttırılmıştır. İkinci senaryo için birinci senaryoya benzer olarak hız değerleri %20 azaltılmıştır. Üçüncü ve son senaryo için ise, diğer bir önemli parametre olan sıcaklık değeri değiştirilmiştir. Modelde sıcaklık değeri için her ayın ortalama sıcaklık değeri kullanılmaktadır. Bu çalışmada, her ayın sıcaklıklarının maksimum değerini kullanmak yerine hava kalitesine olan etkiyi belirlemek için hava kalitesi modelinin çalıştırılacağı periyot olan kasım ayı sıcaklığı değiştirilmiş ve emisyonlar bu duruma göre hesaplanmıştır. Her üç senaryo için de hesaplandıktan sonra emisyon envanterinin ulaşım sektörü bölümüne eklenerek hava kalitesine girdi oluşturacak hale getirilmiştir. Emisyon değerleri senaryolar arasında karşılaştırıldığında görülmüştür ki; kırsaldaki yollarda belirlenen değerler, şehir merkezindeki yollarda ve otobanlarda hesaplanan değerlerden daha yüksek olup, ana kirletici NOx ve en az etkiye sahip olan kirletici PM2.5'dir. Kirleticiler için senaryolar arasında genel bir değerlendirme yapıldığında, hız arttırıldığında CO dışında bütün kirletici emisyonlarında azalma, hız azaltıldığında ise CO dışında bütün kirletici emisyonlarında artma gözlemlenmiştir. Diğer yandan, sıcaklığın arttırıldığı durumda NMVOC dışında bütün kirletici emisyonlarında azalma olduğu görülmüştür.

Model parametrelerindeki değişimin emisyonlar arasındaki etkisinin değerlendirilmesinin ardından bu etkinin hava kalitesine nasıl yansıyacağını belirlemek için hava kalitesi modeli çalıştırılmıştır. Model öncelikle temel durum için çalıştırılmış ve daha sonra her durum için ayrı ayrı tekrar çalıştırılarak hava kalitesindeki etki belirlenmeye çalışılmıştır. Etkinin belirlenmesinde, araç emisyonlarından kaynaklanan temel kirleticilerden biri olmamasına rağmen, önemli sağlık etkileri olması sebebiyle PM2.5 analiz edilmiştir. Temel durumda hesaplanan konsantrasyonlardan, bütün senaryolar için her bir model hücresinde hesaplanan konsantrasyon değerleri çıkarılarak maksimum farkın olduğu gün ve saat incelenmiştir. CMAQ sonuçlarına bakıldığında, senaryo İ'de, yani %20 arttırıldığı durumda, PM2.5 konsantrasyonlarında İstanbul genelinde ortalama 1.5 µg/m3 (~%5) bir azalma olduğu belirlnemiştir. Ortalama konsantrasyonlar karşılaştırıldığında 1.5 µg/m3 küçük bir değer gibi görülse de insan sağlığı açısından konsantrasyondaki bu azalma önemli bir etkiye sahiptir. Senaryo II'de ise hızdaki azalmaya bağlı olarak PM2.5 konsantrasyonlarında ortalama 2 µg/m3 artış görülmüştür. Senaryo III için emisyondaki etkinin diğer senaryolara göre daha az olması sabebiyle hava kalitesine olan etkisi değerlendirilmemiştir.

Bu çalışma, araç emisyonlarının hesaplanmasında kullanılan verinin özellikle otomobil dışıdaki otobüs, kamyon gibi araç tipleri için daha ayrıntılı olarak elde edilmesi, ve daha ayrıntılı emisyon envanterinin hazırlanması ve hava kalitesi modelinin sınır koşullarını daha iyi temsil eden veri kullanılarak geliştirilebilir.

1. INTRODUCTION

Istanbul, which is the largest megacity in Europe, have a population over 14 million, over an area of 6,220 square kilometers. The city is located on the Bosporus strait which connects Black Sea to Aegean Sea via Marmara Sea. The city extends both on the European and on the Asian side of the Bosporus. Istanbul is at the hearth of Turkey's fast economic growth. According to TurkStat, Population Projections for the time period of 2013-2075 the city has an annual average growth rate of 16.03(‰) compared to 9.8% growth for Turkey. Istanbul has GDP of 332,4 Billion US Dollars in 2012. Istanbul region is responsible for more than 55% of total financial services; 40% of business and personal services; 20% of trade; 27,5% of manufacturing in Turkey. Over the last decades, Istanbul has encountered a fast development in urbanization, vehicle use and industrialization thereupon pollutant emission to the atmosphere has increased. (Kanakidou, *et al*., 2011) Vehicle emissions constitute the main source of air pollution in Istanbul similar to other cities around the globe.

Figu.1 presents the important sources of CO, NO_x, NMVOC and $PM_{2.5}$ emissions. Road transport plays the major role in CO (32%), NO_x (40%), and $PM_{2.5}$ (7%) emissions, where as non-industrial combustion is the main contributor of NMVOC emissions 56%). Road transport contributes 32 % of NMVOC emissions.

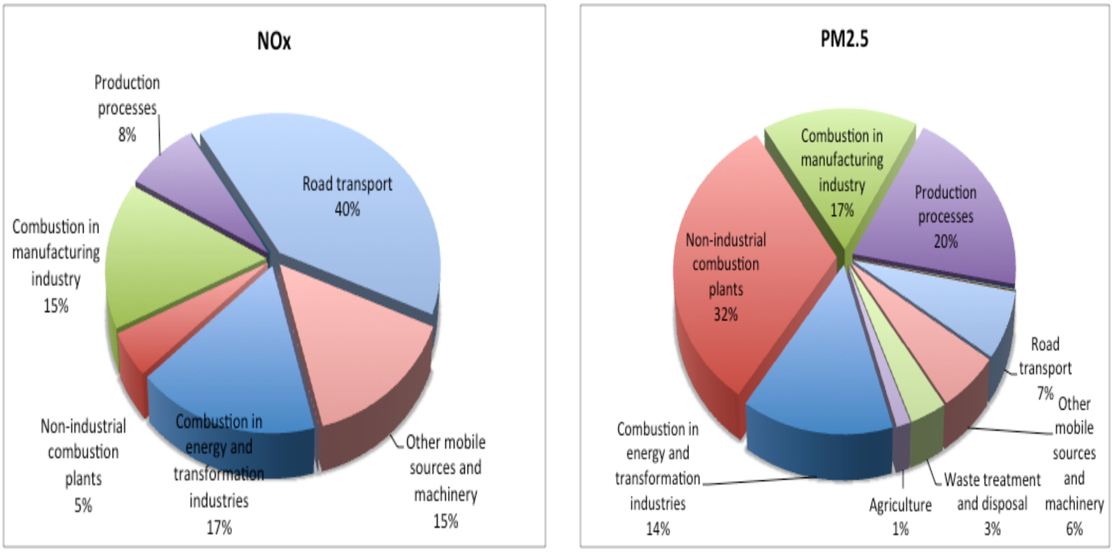


Figure 1.1 : Source contributions to NO_x , and $PM_{2.5}$ emissions

Pollutants covered include all major emission contributions from road transportation: Ozone precursors (CO, NOx, and NMVOC), greenhouse gases (C02, CH4, and N20), acidifying substances (NH3, S02), particulate matter (PM), carcinogenic species (PAHs & POPs), toxic substances (dioxins and furans) and heavy metals. In detail, the sector covers exhaust emissions of CO, NOx, NMVOC, CH4, CO2, N20, NH3, SOx, diesel exhaust particulates (PM), PAHs and POPs, Dioxins and Furans and heavy metals contained in the fuel (Lead, Cadmium, Copper, Chromium, Nickel, Selenium and Zinc). A detailed NMVOC split is also included to distinguish hydrocarbon emissions as alkanes, alkenes, alkines, aldehydes, ketones and aromatics.

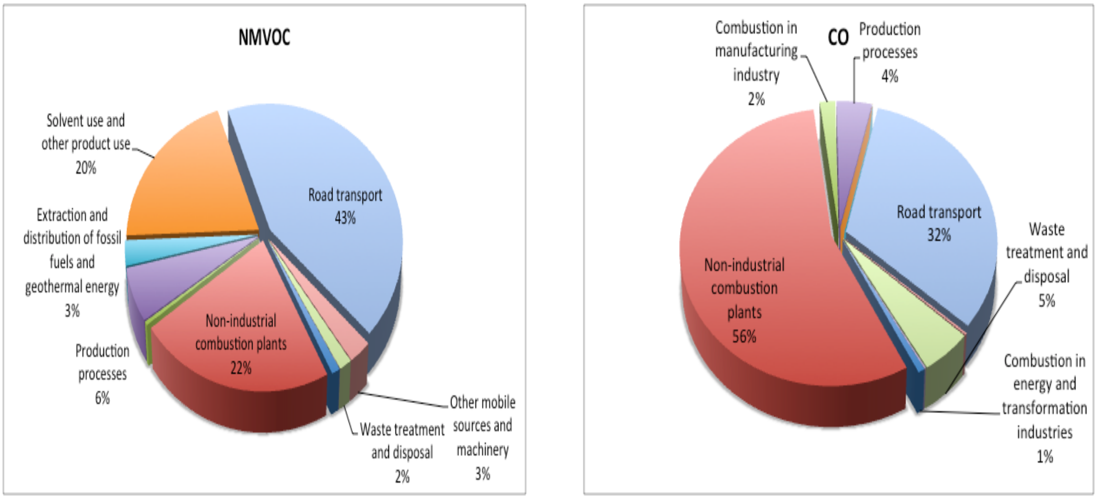


Figure 1.2 : Source contribution to NMVOC and CO emissions.

While air pollution is vitally essential as independent from its sources, air pollution caused from transportation have also much more importance than other resources because of its emission amount and dispersed area where is on people's exposure level (Zhang & Batterman, 2013). Studies have shown that air pollution caused from transportation has extremely negative effects especially on sensitive people such as children, olds or pregnants. (Shah & Balkhair, 2011; Thomas et al., 2004) In a recent study conducted by Becerra et al., on mothers who had children with autism and mothers who had children without autism focusing on effects of air pollution caused from transportation, it is found that babies who were exposed to higher levels of pollutants while in the womb had a 10% higher risk of autism than babies who had low levels of exposure.

In other study, children living near to areas have high traffic density are also eight times more likely to develop leukemia compared to children who do not. (Vinceti, M., 2012) Exposure to vehicle air pollutants has been noted as primary cause for infant mortality and morbidity. Researchers found a higher risk in premature birth (10-20%) and low birth weight for infants whose mothers lived near high traffic areas (Wilhelm, Ritz.,2002). Well documented researches state that, people can get fatal diseases that cause sudden deaths related with high PM exposure and also these diseases could lead to cardiovascular causes and alteration in control of hearth ryhthm (Donaldson, Mills, MacNee, Robinson, & Newby, 2005). Nawrot and Nemery [2007], support these findings with their own study, which found that air pollution (especially pollution from traffic) ranks four in their list of environmental triggers.

In a study conducted by Raaschou-Nielsen et al. on over 310,000 cohort members focusing on effects of air pollution on lung cancer, it is found that an increase in road traffic of 4,000 vehicle-km per day within 100m of the residence has a Hazard Ratio of 1.09 (suggesting there is significant contribution to lung cancer) include carbon monoxide, nitrogen oxides, particulate matter (fine dusts and soot), and toxic air pollutants In other studies, relation between air pollutants and reduced growth in children were analyzed. Guaderman et al. (2001) 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.

According to well documented researches, people can get fatal diseases that cause sudden deaths related with high PM exposure. These diseases could lead to cardiovascular causes and alteration in control of hearth ryhthm (Donaldson et al., 2012). Because of these reasons, more countries give priority to decrease emissions that caused from transportation.

1.1 Approaches to Estimating Motor Vehicle Emissions

The first step of developing policies for the air pollution problem caused from transportation is the identification of quantities of the emissions. Emission inventory models give dependable estimates of vehicle emissions. The most important part of estimations is providing the reliable input data. At present, four different model types are used calculate motor vehicle emission.

1.1.1 Driving cycle-based models

Driving cycle-based models are based upon emissions data for selected driving cycles that are utilized to represent a set of vehicle speed points versus time. There are three driving cycle-based vehicle emission factor models utilized for regulatory in the USA; MOBILE and EMFAC7 and in Europe; COPERT 4. Driving cycle based models are based upon emissions data for chose driving cycles There are two kinds of driving cycles; the modal cycles (the European standard NEDC, or Japanese 10-15 Mode) and the transient cycles (the FTP-75 or Artemis cycle). Transient cycles involve many speed variations, typical of on-road driving conditions. Modal cycles are an assemblage of constant speed periods and acceleration and a real driver behavior is not involved. These models require driving cycle test data for estimating emission factors. For example, MOVES is based on analysis of millions of emission test results and base emission rates are derived from the Federal Test Procedure (FTP). The FTP is the test procedure used to determine compliance of light-duty motor vehicles with federal emission standards.

However MOBILE and EMFAC models are used for regulator purposes in the USA, they have some disadvantages such as limited set of driving cycles on emission estimations and lack of consideration of the difference in engine load.

1.1.2 Modal emissions-based models

Modal emissions based models associate emissions directly to the driving dynamics of vehicles and estimates effect of operating mode related emissions. Operating modes are speeding up, constant speed (cruise), slowing down and idle (NRC, 2000; Frey et al., 2002).Several research studies have been done to develop model emission models using dynamometers and instrumented vehicles while measuring second-by-second emissions. (Barth, 1997). According to several studies a modal emissions based model is developed by setting up a matrix includes vehicle-operating modes of idle, cruise, acceleration and deceleration in different levels and identifying related emissions. These models also have some weaknesses that it does not consider other parameters that relate emissions such as road grade and relation between emissions in second by second measurements as the emission in a second could be a function of the earlier second's speed and operating modes.

Other way of developing a modal-emissions model is mapping that it uses an engine map to find instant emission rates. The processes of these models are to convert instantaneously measured speed data and trip information into vehicle rpm and load parameters as engine map, then using this map find emission rates for specific rpm and load parameters, and estimate total emissions by integrated the instantaneous emission rates with given specific set of vehicle conditions.

The modal emissions-based models have importance for evaluating micro-scale traffic conditions such as signal systems development or ramp metering in consequence of predicting emission based on vehicle operating mode.

1.1.3 Fuel-based models

In the fuel-based method emission factors are developed by standardizing fuel consumption to subgroups of vehicle classes and expressed as grams of pollutant emitted per liters of gasoline or diesel. Average emission factors for subclasses of vehicles are weighted by the fraction of total fuel consumed by each vehicle subclass so as to achieve an overall fleet-average emission factor. Pollutant emissions calculated by multiplying regional fuel consumption values by the fleet-average emission factor.

Fuel based models are compatible to the use of collection of on-road vehicles emissions data. Using fuel based approach; it is possible to apply multiplication by one by for each subgroup to calculate emissions by vehicle class. In order to obtain accurate emissions, emission factors that measured according to vehicle and driving modes should represent the entire area under study. The accuracy of a fuel-based model also depends on accuracy of age distribution that used to weight emissions data.

1.1.4 On-road data-based models

Either Remote Sensing Device or on-board instrumentation can be used to obtain on-board emissions data. The Remote sensing devices measure concentrations of exhaust emission while vehicle passes the sensor on the road by using infrared (IR) and ultraviolet (UV) spectroscopy. Opportunity of measuring large number on-road vehicles is important consideration to use Remote sensing device. Beside the advantages of remote sensing, it has some disadvantages; only instantaneous emissions where the sensor located can be obtained and while heavy traffic, it cannot be measure emissions across multiple lanes.

On-board emissions measurements are used to quantify emissions from vehicles at any locations that vehicle travels. On board instrumentation method provide data collection under real-world conditions. However, it has many advantages, On-board emissions estimation has not been generally utilized in light of the fact that it has been restrictively costly. In the most recent couple of years, endeavors have been in progress to create lower-expense instruments equipped for measuring both vehicle action and emissions.

1.2 Objective

This study demonstrated how atmospheric modeling (i.e., Models3 framework developed by USEPA) could be used to accurately determine the impact on air quality of traffic emissions calculated for different sensitivity scenarios for Istanbul. For this purpose, The COPERT 4 (**CO**mputer **P**rogramme to calculate **E**missions from **R**oad **T**ransport) model, which is supported by European Environment Agency (EEA), is used to calculate these emission sensitivity scenarios. In this study, WRF/CMAQ Model system is utilized as air quality modeling for chemistry and transport.

2. METHODOLOGY

2.1. Vehicle Emissions Calculations

2.1.1 COPERT4 (*Co*mputer *P*rogramme to Calculate *E*missions from *R*oad *T*ransport)

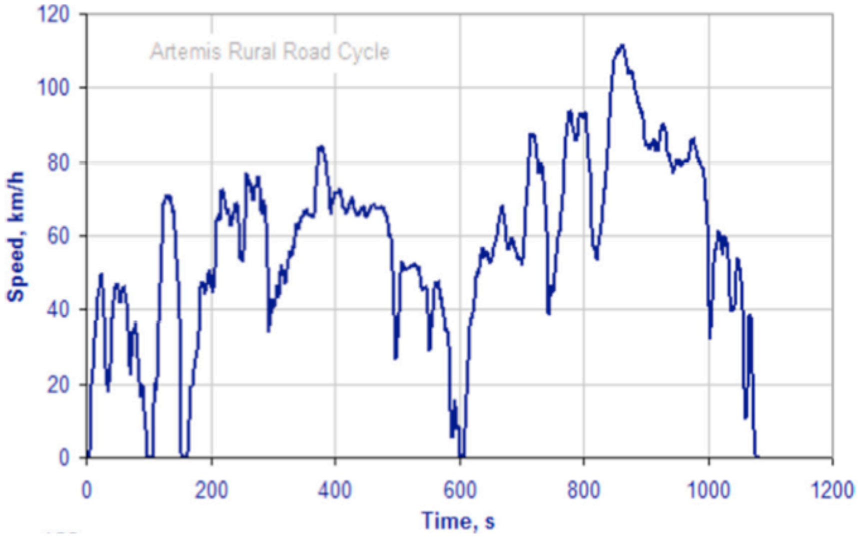
COPERT is a software program that is based on a methodology to estimate vehicle emissions. It has developed by the Laboratory of Applied Thermodynamics of the Aristotle University of Thessaloniki (www.emisia.com/copert/General.html). Emission factors of COPERT are specified by engine size, weight class, engine technology (EURO levels for Europe) and fuel, for different vehicle types (passenger cars, light duty vehicles, heavy duty vehicles, buses, motorcycles) and arranged by driving cycle (urban, rural and highway, given the reliance of the emission factors of vehicle speed).Hot emissions, cold-start emissions, and emissions due to gasoline evaporation are three different emission modes calculated by COPERT model. Non-exhaust PM emissions (tire, break) are also included latest version of COPERT 4 (10.0). COPERT 4 model uses vehicle-specific emission factors and activity data to calculate total emissions by combining them. Model requires several activity data as input and the main activity data is number of vehicles separated into different emission categories/technologies, urban, rural and highway speed conditions and the distance rolled over the same driving conditions. Required input parameters for COPERT 4 model are listed below:

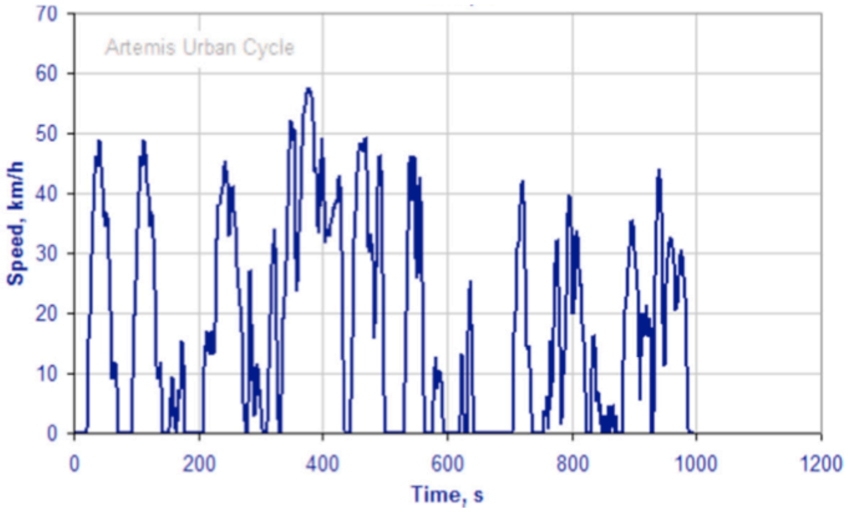
- Population
- Mileage per year
- Mean fleet mileage
- Urban road speed per hour
- Rural road speed per hour
- Highway road speed per hour
- Urban road share percentage
- Residential road share percentage

- Urban road share percentage
- Fuel tank size
- Canister size
- Fuel injection percentage
- Evaporation control percentage
- Distribution of evaporation emissions to different driving modes percentage
- Monthly minimum and maximum temperatures
- Reid Vapor Pressure (RVP)
- Annual fuel consumption
- Fuel type (content)

2.1.2 Test driving cycles of COPERT 4

The Common Artemis Driving Cycle (CADC) used to obtain the emission tests. The test emissions are consisting of the three parts Urban – Rural – Motorway.





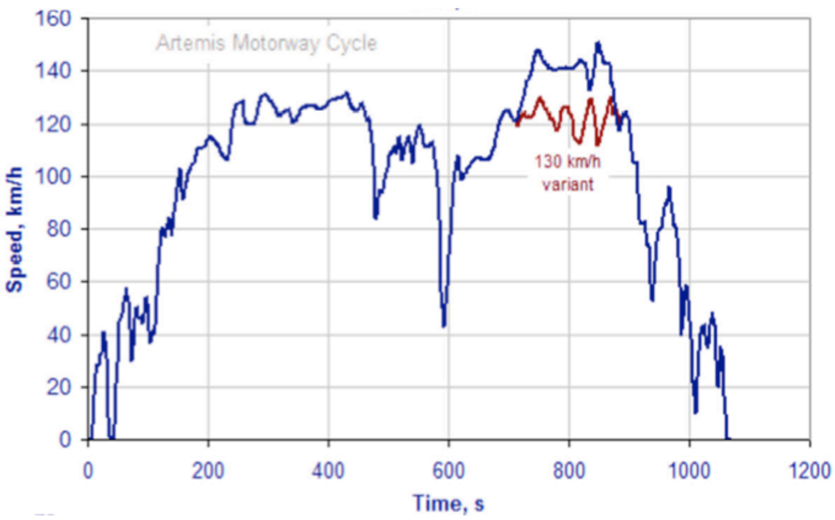


Figure 2.1 : The three parts of the CADC cycle (urban, rural, motorway) (EMISIA SA Report, 2012).

The three parts of the Common Artemis Driving Cycle for urban, rural and highway is given in the figure. Separate measurements had done for each part of the cycle and separate values of emission factors were obtained:

- The 'urban' part of the cycle (average speed 17.5 km/h).
- The 'rural' part of the cycle (average speed 57.5 km/h).
- The 'Motorway ' part of the cycle (average speed 99.7 km/h)

2.1.3 Basic equations of COPERT 4 model

The models were built on the basis of linear combinations of the variables mass, engine capacity, rated power, and power to mass ratio.

The basic formula for estimating hot emissions, using experimentally obtained emission factors is:

$$EF_{i,\ m,\ n} = \left(\frac{\alpha + \gamma\chi + \varepsilon\chi^2 + \zeta\chi^{-1}}{1 + \beta\chi + \delta\chi^2} \right) \cdot (1 - RF) \qquad \textbf{(2.1)}$$

Where, $EF_{i,\ m,\ n}$ is the emissions factor, in grams per kilometer travelled [g/km] for a given species i, of age m, and engine size n. x is the average vehicle speed in kilometers per hour, and α, β, γ, δ, ε, ζ are related to the legislative emission factors for that car i.e. Euro1, 2, 3... RF are coefficients specific to a given engine size n, and technology level m.

CO and NOx has been calculated individually for each time step using equation above and then accumulated in order to extract the average EF:

$$\text{Ave EF} = \sum EF_n / N \qquad \textbf{(2.2)}$$

where EF (n) is the emission factor each time step, N is the number of time steps. The basic equation of COPERT 4 for emission calculation:

$$\textit{Emissions [g] = emission factor [g/km]} \cdot \textit{vehicle kilometers per year [km]} \qquad \textbf{(2.3)}$$

2.1.4 Emission factors of COPERT 4

Figure 2.2 and Figure 2.3 show the emission factor variations for vehicle speed from zero to 100km/hr for the main pollutants CO and NO.

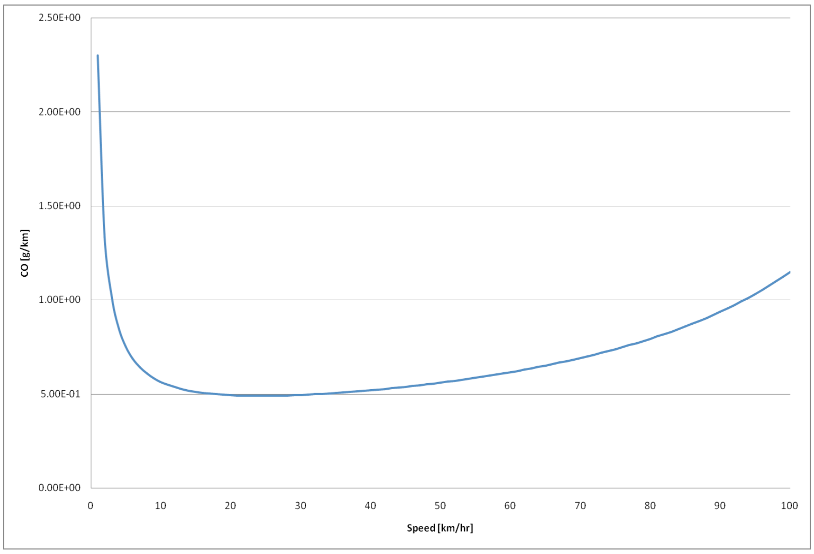


Figure 2.2 : CO vs speed in COPERT methodology (Achour, H. et al., 2011).

It has been found that CO emission has a significant emission level when the car is at idle (zero speed). In relation to NOx emissions, the variation was slightly different among speed steps including idle time.

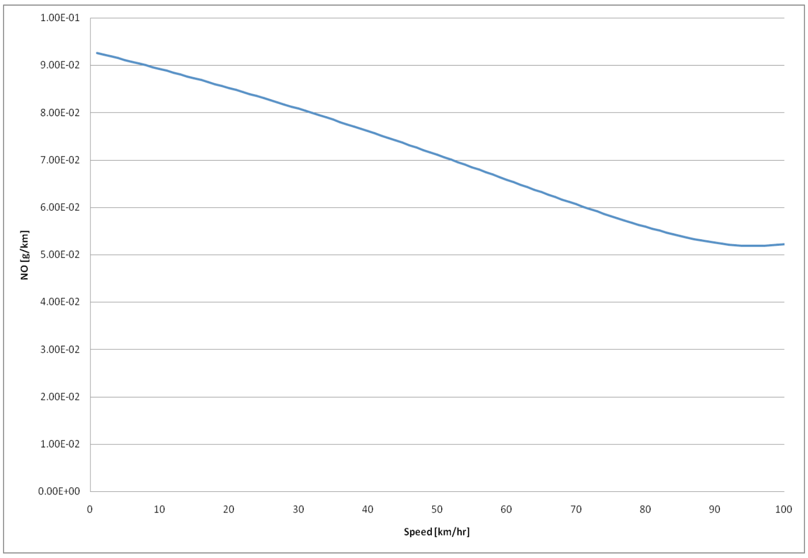


Figure 2.3 : NO vs speed in COPERT methodology (Achour, H. et al., 2011).

Table 2.1 : Speed dependency of CO emission factors for gasoline passenger cars (Tech. Rep., 1997).

Vehicle Class	Cylinder Capacity	Speed Range	CO Emission Factor [g/km]	R^2
PRE ECE	All categories	10-100	$281V^{-0,630}$	0,924
	All categories	100-130	$0,112V + 4,32$	-
ECE 15-00/01	All categories	10-50	$313V^{-0,760}$	0,898
	All categories	50-130	$27,22 - 0,406V + 0,0032V^2$	0,158
ECE 15-02	All categories	10-60	$300V^{-0,797}$	0,747
	All categories	60-130	$26,260 - 0,440V + 0,0026V^2$	0,102
ECE 15-03	All categories	10-20	$161,36 - 45,62\ln(V)$	0,790
	All categories	20-130	$37,92 - 0,680V + 0,00377V^2$	0,247
ECE 15-04	All categories	10-60	$260,788V^{-0,910}$	0,825
	All categories	60-130	$14,653 - 0,220V + 0,001163V^2$	0,613
Improved	$CC < 1,4l$	10-130	$14,577 - 0,294V + 0,002478V^2$	0,781
Conventional	$1,4l < CC < 2,0l$	10-130	$8,273 - 0,151V + 0,000957V^2$	0,767
Open Loop	$CC < 1,4l$	10-130	$17,882 - 0,377V + 0,002825V^2$	0,656
	$1,4l < CC < 2,0l$	10-130	$9,446 - 0,230V + 0,002029V^2$	0,719
	$CC < 1,4l$	10-130	$5,1534 - 0,1141V + 0,0009571V^2$	0,094
91/441/EEC	$1,4l < CC < 2,0l$	10-130	$5,0786 - 0,15623V + 0,001375V^2$	0,171
	$CC > 2,0l$	10-130	$3,5358 - 0,0793V + 0,0006092V^2$	0,109

Table 2.2 : Speed dependency of NO_x emission factors for gasoline passenger cars (Tech. Rep.,1997).

Vehicle Class	Cylinder Capacity	Speed Range	NO_x Emission Factor [g/km]	R^2
PRE ECE	$CC < 1,4l$	10-130	$1,173 + 0,0225V - 0,00014V^2$	0,916
ECE 15-00/01	$1,4l < CC < 2,0l$	10-130	$1,360 + 0,0217V - 0,00004V^2$	0,960
	$CC > 2,0l$	10-130	$1,500 + 0,0300V + 0,0001V^2$	0,972
	$CC < 1,4l$	10-130	$1,479 - 0,0037V + 0,00018V^2$	0,711
ECE 15-02	$1,4l < CC < 2,0l$	10-130	$1,663 - 0,0038V + 0,00020V^2$	0,839
	$CC > 2,0l$	10-130	$1,870 - 0,0039V + 0,00022V^2$	-
	$CC < 1,4l$	10-130	$1,616 - 0,0084V + 0,00025V^2$	0,844
ECE 15-03	$1,4l < CC < 2,0l$	10-130	$1,29e^{0,0099V}$	0,798
	$CC > 2,0l$	10-130	$2,784 - 0,0112V + 0,000294V^2$	0,577
	$CC < 1,4l$	10-130	$1,432 + 0,003V + 0,000097V^2$	0,669
ECE 15-04	$1,4l < CC < 2,0l$	10-130	$1,484 + 0,013V + 0,000074V^2$	0,722
	$CC > 2,0l$	10-130	$2,427 - 0,014V + 0,000266V^2$	0,803
Improved	$CC < 1,4l$	10-130	$-0,926 + 0,719\ln(V)$	0,883
Conventional	$1,4l < CC < 2,0l$	10-130	$1,387 + 0,0014V + 0,000247V^2$	0,876
Open Loop	$CC < 1,4l$	10-130	$-0,921 + 0,616\ln(V)$	0,791
	$1,4l < CC < 2,0l$	10-130	$-0,761 + 0,515\ln(V)$	0,495
	$CC < 1,4l$	10-130	$0,4880 - 0,00548V + 0,0000575V^2$	0,043
91/441/EEC	$1,4l < CC < 2,0l$	10-130	$0,6089 - 0,01184V + 0,0001100V^2$	0,122
	$CC > 2,0l$	10-130	$0,4767 - 0,01070V + 0,0001015V^2$	0,194

Table 2.1 and Table 2.2 shows the speed dependency of CO and NO_x emission factors for gasoline passenger cars. Using average speed value and equations in the table, emission factors are calculated for specific subgroup of cars by COPERT 4.

2.2. Data Processing For Vehicle Emission Calculations (COPERT 4)

Data collected from TUVTURK Motor Vehicle Inspection Inc. and Turkish Statistical Institute stations analyzed using statistical software R and COPERT 4 model run to investigate vehicle emissions. The methodology to prepare collected data for COPERT 4 model is presented in the following chapters.

2.2.1 Fleet number, age distribution of vehicle fleet and technology

The data in the model are vehicle numbers for each year as categorized into vehicle type and fuel type and technology. The main COPERT vehicle categories can be allocated to the UN-ECE classification as follows:

• Passenger Cars	M1
• Light Duty Vehicles	N1
• Heavy Duty Vehicles	N2, N3
• Urban Buses & Coaches	M2, M3

Table 2.3 : Turkish road transport vehicle numbers by years (TUIK, 2014).

Model year	Passenger Car	Minibus	Bus	Small truck	Truck	Motorcycle	Total
1982(1)	387 855	20 669	10 815	113 725	77 739	215 978	1 371 298
1983	38 594	1 759	1 525	5 760	6 646	30 082	114 361
1984	51 194	2 176	1 430	6 765	7 006	36 080	144 018
1985	63 456	2 382	1 428	9 300	8 335	32 086	147 799
1986	83 372	2 929	1 882	9 678	9 473	23 725	157 771
1987	106 720	3 119	1 516	9 343	7 913	28 046	191 342
1988	123 571	2 920	1 421	8 200	8 965	26 832	203 226
1989	111 842	2 658	1 623	8 176	7 273	25 495	174 869
1990	202 534	3 973	2 759	14 317	11 764	42 169	306 695
1991	189 785	4 522	3 279	17 918	12 185	48 051	297 045
1992	279 269	7 127	4 563	25 814	18 044	47 145	404 820
1993	387 607	9 121	6 399	42 788	24 630	62 964	563 862
1994	336 507	7 931	4 049	36 483	17 265	31 596	464 247
1995	204 400	5 796	2 534	18 061	13 805	21 380	301 022
1996	231 328	10 897	4 118	41 474	23 670	31 293	390 012
1997	281 222	18 923	6 718	79 306	36 855	41 096	517 602
1998	355 999	25 177	7 637	108 212	42 264	34 576	632 186
1999	259 045	21 407	5 815	74 157	19 466	31 844	449 318
2000	384 342	26 929	7 671	82 878	22 894	33 617	583 442
2001	318 581	22 160	6 258	75 603	19 948	17 116	484 203
2002	90 575	7 036	2 068	29 735	7 641	12 725	157 720
2003	146 639	11 242	3 810	59 891	12 799	21 842	268 673
2004	422 121	25 931	11 037	182 361	33 498	90 429	796 302
2005	389 871	22 873	11 448	215 734	34 615	247 193	956 100
2006	438 961	25 027	15 046	245 463	44 604	443 558	1 258 162
2007	298 481	20 726	13 110	184 404	33 158	192 052	778 760
2008	381 138	19 183	16 976	206 916	30 983	117 107	807 709
2009	308 406	11 596	13 217	151 212	23 370	94 419	618 419
2010	379 629	8 864	4 523	172 099	12 218	102 102	703 680
2011	704 852	23 166	14 638	291 899	45 791	194 551	1 342 254
2012	798 880	29 462	18 787	291 345	54 511	225 424	1 495 550
2013	527 147	14 167	11 785	114 033	26 622	120 253	856 980

Table 2.4 : Number of vehicles in Istanbul.

	Passenger Car	Minibus	Bus	Small truck	Truck	Motorcycle
Istanbul	2301548	74461	46203	597319	128056	241005

By multiplying fraction table by number of vehicles table for Istanbul (Table 2.4), vehicle distribution for Istanbul was obtained. After creating this distribution table, fractions that were directly taken from Ministry of Environment and Urbanization were used to split vehicles by categories as COPERT 4 model required by using Statistical Software R. These fractions include motor size distribution, fuel type distribution and other distributions that required for heavy-duty vehicles, buses, and motorcycles. This is how total vehicle numbers, split by type, fuel usage, and other requirements were generated for each year in the time series.

The fraction of the fleet complying with the different emission standards was calculated for each year in the time series. This was done by using annual data on sales and removals from the vehicle fleet, allowing the age profile of the vehicle fleet to be determined for each year in the time series. For example, from the vehicle numbers data that was explained how it created above, the total number of vehicles in 1990 was provided and that indicates whether they were new in 1990. In this way, it is possible to construct vehicle numbers for each year of the time series broken down by their age. As the years at which the different Euro standards were introduced in Turkey are known (Table 2.5), the ages of the vehicles were then translated into Euro standards. This enabled, for each year of the time series, the vehicle fleet to be broken down into defined technology standards for each vehicle type. Statistical software R is used for all processes.

Table 2.5 : Euro standards introduced in Turkey by years.

	Fuel type	PRE ECE	Euro1	Euro2	Euro3	Euro4	Euro5	Euro6
Passenger Car	Gasoline	1966	-	-	2002	2009	2011	2017
	Gasoline	2001	-	-	2008	2010	2016	2020
	Dizel	1966	2002	-	-	2009	2013	2017
	Dizel	2001	2008	-	-	2012	2016	2020
Truck	Dizel	1966	2002	-	-	2009	2012	2016
	Dizel	2001	2008	-	-	2011	2015	2020
Small Truck	Gasoline	1966	-	-	2002	2009	2011	2017
	Gasoline	2001	-	-	2008	2010	2016	2020
	Dizel	1966	2002	-	-	2009	2013	2017
	Dizel	2001	2008	-	-	2012	2016	2020
Bus	Dizel	1966	2002	-	-	2009	2012	2016
	Dizel	2001	2008	-	-	2011	2015	2020
Motorcycle	Gasoline	1966	2000	2004	2007	2016	-	-
	Gasoline	1999	2003	2006	2015	2020	-	-

2.2.2 Annual kilometers by vehicle type

It was not possible to obtain annual vehicle km data from official sources. So the data had to be generated with information that was available. A large dataset of vehicle data was obtained from the TUVTURK. This provided the odometer reading from a very large sample of vehicles, as well as the vehicle type and age. Theoretically, it would then be possible to use these data to deduce information about the typical annual vehicle kms driven by different vehicle types in different years. However, it was clear that the output would be very variable and that some assumptions would need to be made about smoothing the data so as to arrive at some sensible estimates. Hence the dataset was sorted so that results could be expressed according to different vehicle types. For each vehicle type, the following analysis was undertaken:

The data were screened for outliers, and where possible these were removed. The odometer readings for vehicles originating in the same year were then taken weighted averages. For example, by 2010 a HDV originating in 1998 had undertaken an average of 408,500 kms; these vehicles had been on the road for 13 years and had been driven an average of 31,423 kms/year (Note: no account was taken of the fact that newer vehicles do more kms/year than older ones; hence vkms in earlier years are likely to be underestimated whilst vkms in more recent years are likely to be overestimated). Calculations for other parameters are also given below:

- Evaporative emissions: Emissions of NMVOC arise from evaporation from petrol vehicles as well as exhaust emissions. Emissions are estimated from different evaporative components: diurnal losses, hot soak and running losses using a standard approach from the EMEP/EEA Guidebook.
- Cold start emissions: There are increased emissions of NOx and PM10 from vehicles which start cold, as opposed to vehicles which already have a warm engine. A method from the EMEP/EEA Guidebook is used to calculate the ratio of emissions including cold start over the emissions excluding cold start (Ecold/Ehot). This ratio is combined with the emissions already estimated to adjust the emission total to include the impact of cold start emissions.
- PM10 brake and tyre wear: PM10 emissions from brake and tyre wear were calculated by combining international default emission factors with vehicle-km data.

2.2.3 Emission calculations

The vehicle-kms and corresponding EFs were combined to give emissions for each year in some detail. Total emission estimates are obtained by collating the calculated emissions, on a vehicle-km basis, for the following:

- Exhaust emissions for NOx, NMVOC, NH3 and PM10
- NOx and PM10 cold start emissions
- NMVOC evaporative emissions (reported as a specific NFR category)
- PM10 tyre and brake wear emissions (reported as a specific NFR category)
- Carbon emissions (calculated on a vkm basis)
- SO2 emissions calculated by combining the fuel use and S content of fuels.

2.3 Emission Inventory

Identification of inventory of emission sources is the most important part of developing an effective air quality system. An emission inventory is a listing of the amount of air pollutants discharged into the atmosphere over a specific period by source categories including point, mobile, and area sources. Emission factors and emissions producing activity data are used to develop inventory. An emission factor is the amount of pollutant produced per unit activity. Vehicle emission factors are generally stated on grams of pollutant emitted per vehicle-km of or grams of pollutant emitted per specific time period (e.g. year) (NRC, 2000).

A high resolution emission inventory is provided from (Im et al., 2010)'s research. The inventory included emissions of CO, NO_x, NH_3, SO_2, organic and elemental carbon, sulfates, nitrates, ammonium and other particles and 23 non-methane volatile organic compounds in monthly, daily, and diurnal resolutions (Friedrich, 1997).

The inventory estimates anthropogenic emissions for the city of Istanbul at a horizontal resolution of 2 km x 2 km, it includes 7 species (CO, NO_x, SO_x, NMVOC, NH_3, $PM_{2.5}$ and PM_{10}) and 10 sectors, according to the Standardized Nomenclature for Air Pollutants (SNAP). Figure shows the distribution of total annual emissions from road transport sector of NO_x and $PM_{2.5}$, respectively. For each model grid cell that is crossed by roads, we firstly replaced the hourly distribution of traffic emissions derived from COPERT 4 Model. Because of the complex road structure of Istanbul and there is no significant difference between rural and urban road types, road types were separated only two groups (highway and rural+urban) while intersect the emissions with the grid cells.

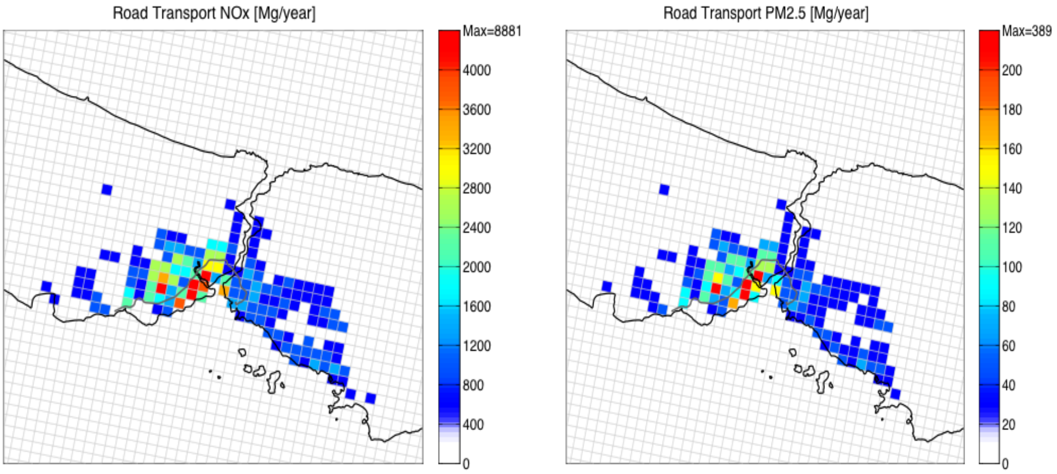


Figure 2.4 : Total annual NOx and PM2.5 emissions from road traffic.

In Figure 2.4 the emissions from road transport are presented. The very dense traffic network inside the city leads to the occurrence of maximum on-road traffic emissions around the residential and commercial regions of the domain. As discussed before, the figure shows that NO_x is the main pollutant emitted from on-road traffic sources.

2.4 Sensitivity Scenarios

For the sensitivity analysis of COPERT 4 model, 3 scenarios were determined based on the input parameters (speed and temperature) in accordance with the maximum impact on road transport emissions. It is found that temperature change and variability in speed have maximum impact on model. In the lights of this information, determined 3 scenarios are presented in Table . As Scenario-I and Scenario-II the most effective parameter of model, speed, was changed. As many megacities, Istanbul has complex traffic conditions. For all road types speed is changing significantly depending rush hours and late hours. As a result of the fluctuation of speed is that high, change rate for speed while deciding scenario was selected as %20. Although %20 is a high value for changing a parameter, in speed case it was represent Istanbul's traffic condition effectively. For the Scenario-III, other important parameter of model was changed. COPERT 4 model input for temperature was required all the average temperatures by month of all year. Because of the running air quality model for the whole is costly and time consuming, the episode month selected (November) and for this month temperature value changed in the COPERT 4 model input. In the episode selection, all conditions that can affect the local emission in air quality model such as long-range transport from Europe or Sahara Desert were considered. When all possibilities checked, November was decided as the most suitable time for the episode selection. For November maximum temperature value determined from WRF meteorological model as 20.1 °C and average temperature value (14.7°C) was changed to maximum temperature in the input file of COPERT 4 model.

Table 2.6 : Explanation of model scenarios.

COPERT 4 Model Sensitivity Scenarios	
Scenario I	% 20 increase in speed for all vehicle category and road types
Scenario II	%20 decrease in speed for all vehicle category and road types
Scenario III	maximum temperature value usage for input parameter of model

Table 2.7 : Scenario conditions by parameters

		Base-case	Scenario I	Scenario II	Scenario III
Passenger Car	Rural Speed (km/h)	61.3	74	49	61.3
	Urban Speed (km/h)	31.8	38	25	31.8
	Highway Speed (km/h)	102.5	123	82	102.5
Light Duty Vehicle	Rural Speed (km/h)	61.3	74	49	61.3
	Urban Speed (km/h)	31.8	38	25	31.8
	Highway Speed (km/h)	102	123	82	102
Heavy Duty Vehicle	Rural Speed (km/h)	52.7	63	42	52.7
	Urban Speed (km/h)	25.9	31	21	25.9
	Highway Speed (km/h)	72.2	87	58	72.2
Buses	Rural Speed (km/h)	52.6	63	42	52.6
	Urban Speed (km/h)	21.2	25	17	21.2
	Highway Speed (km/h)	76.1	91	61	76.1
Motorcycle	Rural Speed (km/h)	60	72	48	60
	Urban Speed (km/h)	30	36	24	30
	Highway Speed (km/h)	60	72	48	60
Maximum Temperature (°C)		14.7	14.7	14.7	20.1

For the each scenario COPERT model was run with the same input data (population, age distribution, Annual kilometers by vehicle type, etc.), only affected parameters that are speed and temperature was changed. Emissions of road transport were calculated for each scenario. Vehicle emissions are combined with emissions from other sources and made prepared to use CMAQ model. Except emissions all other inputs of CMAQ (Meteorology, initial and boundary conditions) are not changed. To investigate the impact of this significant road transport emissions on air quality model, WRF/CMAQ model system was run for new emission data of 3 scenarios that is set up for sensitivity analysis. Effects of change in COPERT 4 model's parameters are calculated by subtracting outputs of CMAQ model for new emission data from outputs of CMAQ model for base-case.

2.5 Modeling

Air quality simulation models are important tools for regulatory, policy, and environmental research communities.

Air quality models (AQM) require three main steps of modeling:

- Meteorological modeling
- Emission modeling
- Chemistry and transport modeling

Each of these models produces outputs that enter as inputs in the next step of modeling. The principal output of an AQM system is the concentration levels of the considered atmospheric pollutants in a given domain and timescale. The concentration levels of pollutants in a given domain are determined by both transport due to meteorological patterns and chemistry.

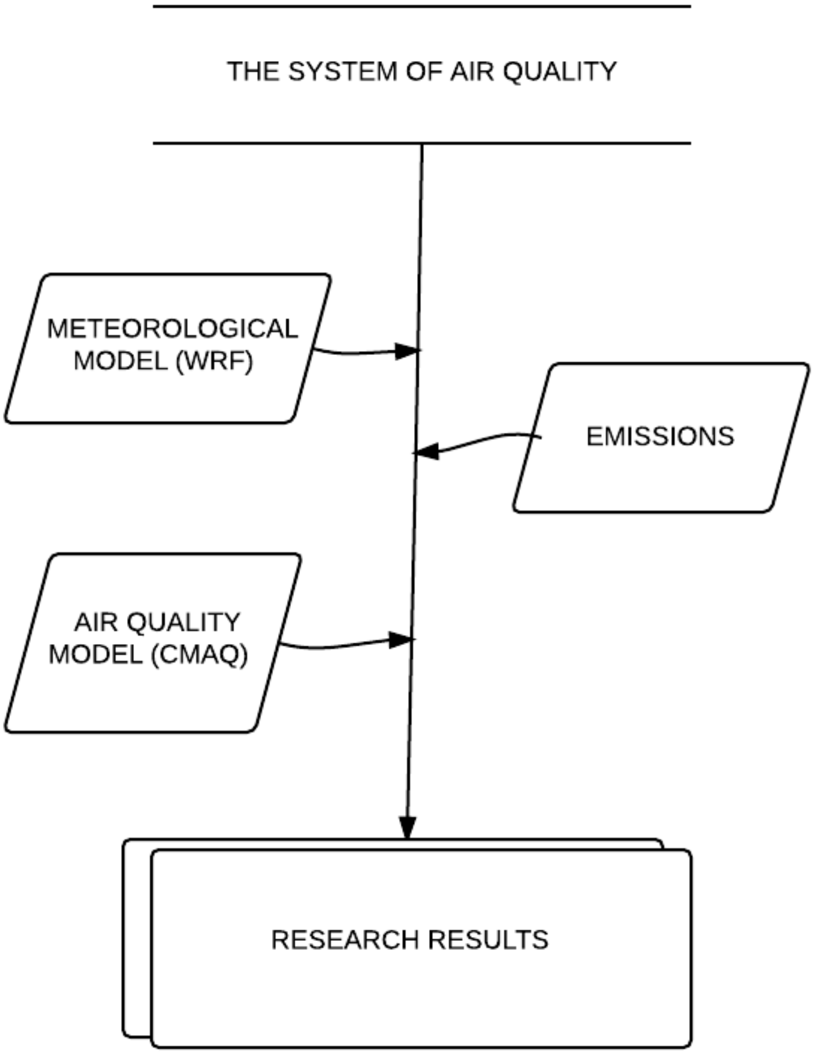


Figure 2.5 : Flowchart of air quality system

2.5.1 Weather research and forecasting data (WRF)

The Weather Research and Forecasting (WRF) Model is the next generation of the regional mesoscale model (MM5).WRF is a set of software, which is produced from 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) collabration, for numerical weather prediction method. It is open source, synoptic and 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. The model uses 3rd order Runge –Kutta time integration scheme and also offers one-way, two-way, and moving nest options (NCAR, 2010)

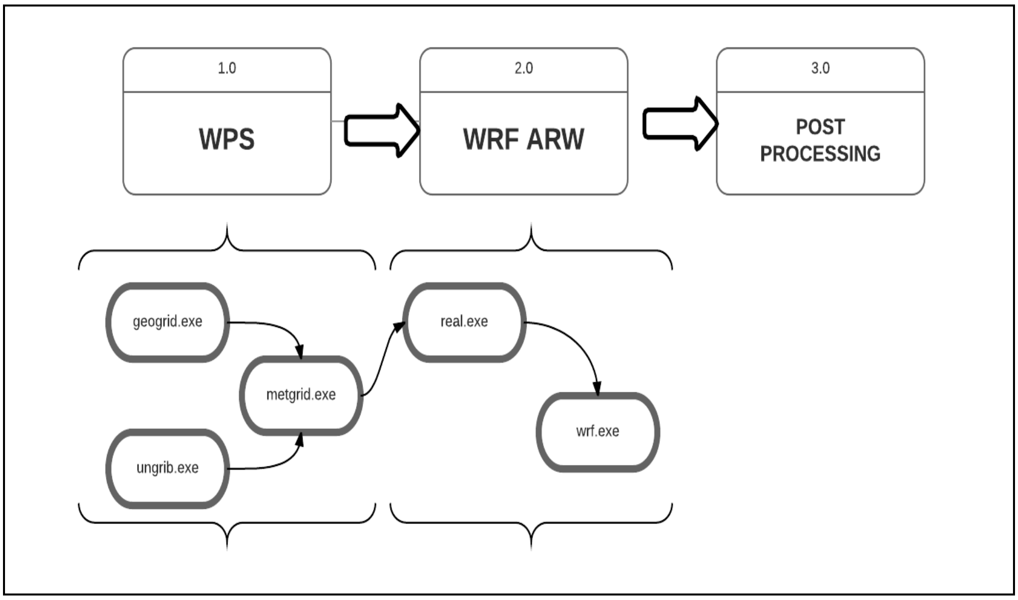


Figure 2.6 : Flowchart of WRF model.

In this study, Advanced Research WRF (Weather Research and Forecasting) Model, version 3.1 which is developed based on the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) (Grell, Dudhia, & Stauffer, 1994) is applied for meteorological modeling. For meteorological modeling system 3 domains are set up. The first and main domain has 30km spatial resolution. It covers Europe of 199 by

175 grid cells. The second domain has 10km spatial resolution and covers Balkan region of 181 by 202 grid cells. As the third and innermost domain the Greater Istanbul Area of 136 by 111 grid cells is determined on 2km resolution. (Figure) 37 sigma layers are used for the vertical resolution that is extended up from approximately 20m above of surface to 1400m heights gradually. The initial and boundary conditions that required for WRF model is provided by The National Centers for Environmental Prediction (NCEP) Final Analyses (FNL) data of 1x1°. Meteorological model is the first and one of the most important steps of air quality modeling. Concentration and dispersion of pollutants can be estimated accurately, if and only atmosphere is simulated dynamically and physically in a realistic way. To check authenticity of WRF output, model performance is done and then the result of model performance showed that outputs could be used safely.

Meteorological data (WRF) for use in CMAQ were derived from the model through the MCIP (Meteorology Chemistry Interface Program).

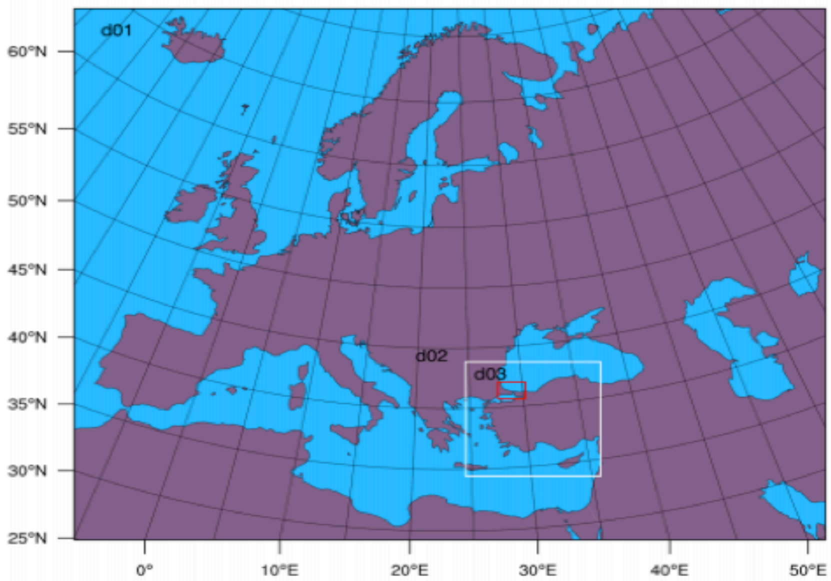


Figure 2.7 : Model domains

2.5.2 Community multi-scale air quality model (CMAQ)

The CMAQ modeling system is a powerful third generation air quality modeling and can address tropospheric ozone, acid deposition, visibility, fine particulate and other air pollutant issues in the context of one atmosphere perspective where complex interactions between atmospheric pollutants and regional and urban scales are confronted.

The primary goals for the Models-3/Community Multiscale Air Quality (CMAQ) modeling system are to improve the environmental management community’s ability to evaluate the impact of air quality management practices for multiple pollutants at multiple scales and the scientist’s ability to better probe, understand, and simulate chemical and physical interactions in the atmosphere.The Community Multi-scale Air Quality (CMAQ) modeling system has been designed to approach air quality as a whole by including state-of-the-science capabilities for modeling multiple air quality issues, including tropospheric ozone, fine particles, toxics, acid deposition, and visibility degradation. In this way, the development of CMAQ involves the scientific expertise from each of these areas and combines the capabilities to enable a community modeling practice. CMAQ was also designed to have multi-scale capabilities so that separate models were not needed for urban and regional scale air quality modeling.

The target grid resolutions and domain sizes for CMAQ range spatially and temporally over several orders of magnitude. With the temporal flexibility of the model, simulations can be performed to evaluate longer term (annual to multi-year) pollutant climatologists as well as short term (weeks to months) transport from localized sources. With the model's ability to handle a large range of spatial scales, CMAQ can be used for urban and regional scale model simulations. By making CMAQ a modeling system that addresses multiple pollutants and different spatial scales, CMAQ has a "one atmosphere" perspective that combines the efforts of the scientific community. Improvements will be made to the CMAQ modeling system as the scientific community further develops the state-of-the-science.

The CMAQ modeling system includes auxiliary programs and interface processors to incorporate the outputs of the meteorology and emission processors and to prepare the pre-required input information for initial and boundary conditions and photolysis rates to the CMAQ Chemistry Transfer Model (CCTM).

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)

CMAQ chemical-transport model use coupled ordinary differential equations to solve the changes in concentration of pollutants throughout a three-dimensional grid. The changes in concentration in each grid cell are affected by the following processes:

- Emissions from sources
- Horizontal and vertical advection
- Horizontal and vertical diffusion
- Chemical transformations
- Deposition

The US EPA Community Multiscale Air Quality (CMAQ) Model, version 4.7.1, is used as air quality modeling for chemistry and transport. It is the most widely used air quality model for regulatory as well as research purposes. For chemistry and transport modeling system 3 domains are run. Domain setup used for WRF is also used for CMAQ. The first and main domain covering Europe of 163 by 150 grid cells on 30km spatial resolution, the second domain covering the Balkan region of 140 by 155 grid cells on 10km spatial resolution, and finally, and the third and innermost domain covering the Greater Istanbul Area of 92 by 57 grid cells on 2km resolution and 20 vertical layers. The vertical resolution is stretched from approximately 93m above the surface and decreased to 16km. Carbon Bond Mechanism (CB-IV) was used for chemical mechanism for gaseous species and Aerosol Module 4 (AERO4) was used for aerosol mechanism. In running CMAQ, Yamartino scheme for advection and Asymmetric Convective Method version 2 (ACM2) scheme for vertical diffusion was used. The boundary conditions are interpolated from each hour of the previous Balkan domain simulation and the initial conditions are taken from each time step of the previous run of the İstanbul domain.

3. RESULTS

As a first step, study was started with estimation of vehicle emissions of Istanbul. Table 3.1 represents the quantities of the road transport emissions for the year 2014 as calculated by COPERT 4. The columns show the local pollutants that have main importance for air quality and for human health. CO, NMVOC, NO$_x$, and SO$_2$ forms other species such as ozone (0_3) and sulfate aerosol and by this way contributes to global warming. (IPCC, 2001).

Table 3.1 : Istanbul road transport emissions.

	CO	NOx	NMVOC	PM2.5	PM10
Passenger Cars	43965.8	12747.9	5569.1	1008.8	1203.8
LDV	21756.2	7066.5	2850.8	796.6	882.3
HDV	4718.0	20828.1	1352.0	889.3	978.7
Buses	2959.3	10726.1	1034.5	468.4	515.3
Motorcycles	5306.1	108.8	1182.6	16.5	18.9
Total	**78705.4**	**51477.4**	**11989.1**	**3179.6**	**3599.0**

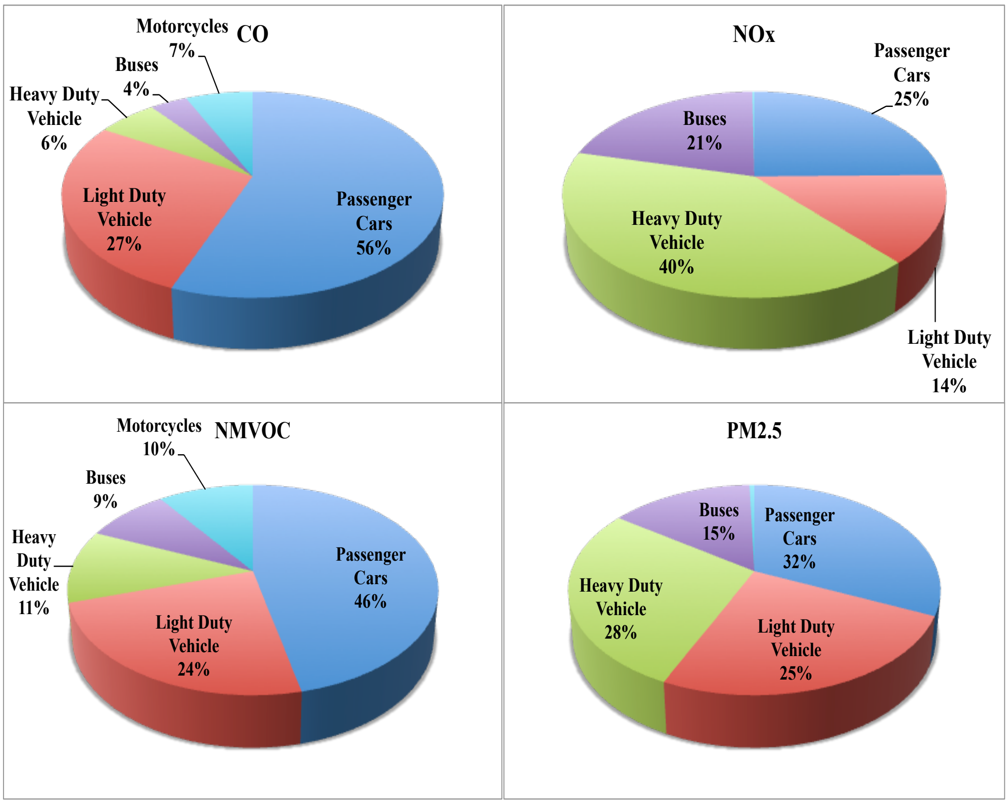


Figure 3.1 : Source contribution of vehicle types to pollutants a) NO$_x$ b) CO c) NMVOC d) PM$_{2.5}$.

By looking at Table 3.1 and Figure it can be said that passenger cars (Pass. C) are the main source responsible for CO, PM and NMVOC emissions and heavy duty vehicles (HDV) are the main source responsible for NO_X emissions of Istanbul road transport.

Table 3.2 : Istanbul road transport emissions by scenario.

		basecase	***Scenario I***	***Scenario II***	***Scenario III***
CO	**Highway**	10446.4	13981.6	8169.1	10168.4
	Urban	21986.1	20333.0	16969.4	20510.9
	Rural	46272.9	43354.0	49069.6	44997.6
NOx	**Highway**	11874.7	12561.6	11296.9	11661.6
	Urban	4968.2	4513.3	4966.9	4824.7
	Rural	34637.5	32941.9	36722.7	33977.9
NMVOC	**Highway**	1453.4	1438.6	1551.5	1531.9
	Urban	5351.0	5140.0	4896.2	5902.7
	Rural	5184.7	4535.0	6169.4	5209.0
PM10	**Highway**	689.9	717.3	683.7	681.7
	Urban	417.4	387.1	446.8	404.5
	Rural	2491.7	2295.5	2724.5	2440.9
PM2.5	**Highway**	644.7	684.5	618.2	639.0
	Urban	365.7	337.5	397.2	355.0
	Rural	2169.2	2055.8	2348.4	2132.9

Table 3.2 above presents Copert4 model output of pollutants tone per year in highway, urban and rural areas with various set of speed and temperature parameters.

The first column of table, base-case shows the pollutant emission outputs by tone per year in highway, urban and rural areas at average speed and temperature (14.7 C^o) conditions. In general, pollutant emission rates are at their highest in rural areas, and at their lowest in urban areas. Regarding only to pollutants on base-case, main pollutant is NOx with 11874.7, 4968.2, 34637.5 tone per year in highway, urban, and rural areas, respectively, while the minor pollutant is PM2.5 with the tone per year rates 644.7, 365.7 and 2169.2 in highway, urban and rural areas respectively.

The Scenario-I column depicts the tone per year data of pollutant emissions in highway, urban and rural areas at average temperatures but at 20% higher speed conditions than the average speeds. As same as in the base-case conditions, pollutant emission rates are obviously higher in rural areas and lower in urban areas. When it comes to type of pollutant, main pollutant in Scenario-1 is carbon monoxide (CO) with pollutant emission rates of 13982.6, 20333.0, and 43354.0 tones per year in highway, urban and rural areas respectively, whereas the $PM_{2.5}$ is the minor pollutant at 685.5, 337,5, and 2055.8 emission rates in highway, urban and rural areas.

In last two columns of table, Scenario-II illustrates the emission output at 20% lower speed than average speed and at average temperatures, and Scenario-III illustrates the emission data at average speed but at maximum temperature (20.1 C^o). Just as in first two different sets of conditions mentioned above, pollutant emission rates are the highest in rural and the lowest among others when compared in these two different sets of conditions as well. On the other hand, the pollutant NOx is the major pollutant where the minor pollutant is PM2.5 in both of the condition sets of Scenario-II and Scenario-III.

It will be very fundamental to compare and evaluate the emission data in between the condition sets of Scenario-I, Base-case and Scenario-2, where temperature is fixed to average value (14.7 C^o), and speed parameters decreased 20% for all type of vehicles and road conditions from average values, average values, and increased 20% for all type of vehicles and road conditions from average values. As regards the pollutants PM10 and PM2.5, emission rates of these two pollutants increases in highway, although the rates decrease in urban and rural areas as velocity increase from 80%, to 100% and then to 120% of average speeds. On the other hand, the emission of pollutants CO, NOx and NMVOC have the same tendency in urban areas resulting with increase in emission rates, reach the peak around average speed then decrease as speed increase, and in rural areas continuous decrease in pollutant emission rates as the speed increases. However; CO and NOx emission rates are increasing whereas NMVOC emission rates decrease in rural areas as speed increase.To elaborate the effect of temperature change on pollutant emission rates, the base-case and Scenario-III should be analyzed together where the temperature is set to 13.7 C^o for former and 20.1 C^o for latter and the same average velocity conditions for both. Even though the changes are very marginal with the change in temperature, it is very obvious that pollutant emissions decrease as the temperature increase for all kind of pollutants except NMVOC, which has relatively sensitive vaporizing property than other pollutants. If it is required to meet at a conclusion on this table with a couple of remarks that the major pollutant is NO_x and minor pollutant is $PM_{2.5}$ in general, where the emission rates are higher in rural areas than urban areas and than the highways. It would be very essential to indicate that almost any sort of change in conditions end up with decrease in pollutant emission rates in rural areas, which triggers the idea that more investment is needed to increase the situation in rural area

Table 3.3 : Istanbul vehicle emissions by scenario and road type

		Scenario I	Scenario II	Scenario III
CO	**Highway**	33.8	-21.8	-2.7
	Urban	-7.5	-22.8	-6.7
	Rural	-6.3	6.0	-2.8
Overall (%)		20.0	-38.6	-12.1
NOx	**Highway**	5.8	-4.9	-1.8
	Urban	-9.2	0.0	-2.9
	Rural	-4.9	6.0	-1.9
Overall (%)		-8.3	1.1	-6.6
NMVOC	**Highway**	-1.0	6.7	5.4
	Urban	-3.9	-8.5	10.3
	Rural	-12.5	19.0	0.5
Overall (%)		-17.5	17.2	16.2
PM10	**Highway**	4.0	-0.9	-1.2
	Urban	-7.3	7.0	-3.1
	Rural	-7.9	9.3	-2.0
Overall (%)		-11.2	15.5	-6.3
PM2.5	**Highway**	6.2	-4.1	-0.9
	Urban	-7.7	8.6	-2.9
	Rural	-5.2	8.3	-1.7
Overall (%)		-6.8	12.8	-5.5

Table 3.3 shows the changes in emissions between base case and each scenario that explained in detail above by percentage. While positively signed values indicate the increase in emission, negatively signed values show the decrease in emissions.

For CO emissions in Scenario-I; 33.8 percent increase in emissions at highways results in 20 percent increase overall, although there are 7.5 percent and 6.3 percent decrease in emissions at urban and rural road types. As expected in Scenario-II, just in contradiction of Scenario I, highway emissions decrease 21.8 percent as a result of decrease in speed but it is different than expected in urban emissions where decrease is observed as 22.8 percent. Only rural emission trend is realized in same way in Scenario-I and Scenario-II according to speed change (%20 increase and %20 decrease from the average values). When speed is increased 20 percent from the average, while CO emissions decrease 6.3 percent in rural areas, while 6 percent increase is observed when speed was reduced 20 percent in Scenario-II. It can be said for the CO emission that, urban emission and highway emission behave differently although the same speed change is applied for both. It is caused by non-linear relationship between emission and speed. The change in emission by speed and obtaining various results can be figured out by examining the in the previous chapter. When it is compared, variations in obtained emission results are not as significant as in Scenario-III than other scenarios. It is found that when the temperature is increased, CO emissions decrease by 2.7 percent, 6.7 percent and 2.8 percent in all road types. Urban emissions are affected more intensely by temperature change than the other road types. The causative relation of temperature increase and CO emission rate decrease can be justified as; when an engine is hot, most effective combustion occurs and it provides less CO emissions. The highest increase is observed in CO emissions on highway by 33.8 percent. For almost any types of road, the emissions of other pollutants as NOx, NMVOC, PM_{10} and $PM_{2.5}$ decrease in overall by 8.3, 17.5, 11.2 and 6.8 percent, respectively.

The NOx is one of the pollutants, which shows slight variation by alteration of speed and temperature parameters when it is compared with other pollutants. The effect of increased speed is causing obvious decrease in both urban and rural areas; however, a 5.8 percent NOx emission increase appears in highway areas. While the effect of decreased speed ends up with no emission change of NOx in urban areas, it is obvious that percentage of emission increase in rural areas is nearly balanced by the decrease in highway areas. By having the same consequences for highway, urban, and rural areas, the effect of increased temperature to maximum value cause decrease in emission of NOx, though it is very minor.

While almost any sort of alteration in parameters resulting with identical differentiation on emissions of NMVOC, for instance decrease in emissions with increased speed or increase in emission with higher temperatures in highway, urban and rural areas, singularity is lost in emission of NMVOC since reduced speed results in increase in emissions in highway and rural areas but decrease in urban areas. It is also apparent that there is net overall decrease in emissions with increased speed, and net overall increase with reduced speeds and increased temperature.

There is a net trivial PM_{10} emission decrease is observable with increased temperatures with the percentages of 1.2 for highway, 3.1 for urban, and 2.0 for rural areas. Although there is a 4.0 percent rise in PM_{10} emission in highway, 7.3 percent and 7.9 decreases are obtained as result of increased speed. While decreased speed causing very marginal decrease in emission with the percentage of -0.9 in highway, there is evident increase in emissions in urban areas by 7.0 percent, and in rural areas by 9.3 percent. Overall emission changes can be summarized for PM_{10} emission as 11.2 decreases with increased speed, -6.3 decreases with higher temperatures, and 15.5 increase with reduced speed.

When it comes to the emission of $PM_{2.5}$, there are very minor decreases are observed by temperature increase; 0.9 percent decrease for highway, 2.9 percent decrease for urban, and 1.7 percent decrease for rural areas with overall 5.5 percent decrease. For highway areas, while 20 percent decrease in speed results in 4.1 percent decrease, 20 percent increased speeds results 6.2 percent increase in $PM_{2.5}$ emission. If the same analogy is expanded; reduced speed causes 8.6 percent increase for urban areas and 8.3 percent increase for rural areas. On the other hand, increased speed leads 7.7 percent decrease for urban areas, and 5.2 percent decrease for rural areas in $PM_{2.5}$ emission. Overall, increased speed and temperature results in evident decrease in emission of $PM_{2.5}$ emission, whereas reduced speed reflects overall increase in emission of $PM_{2.5}$.

As the second part of study, calculated vehicle emissions were integrated to other emissions and gridded to prepare input for air quality model. In that point, emission difference between base case emission and for each scenarios in gridded cells, in the case of that includes all emissions from other sources are also determined to show road transport emissions impact. Because of the vital health effects of $PM_{2.5}$, analysis are done for PM2.5 and plotted.

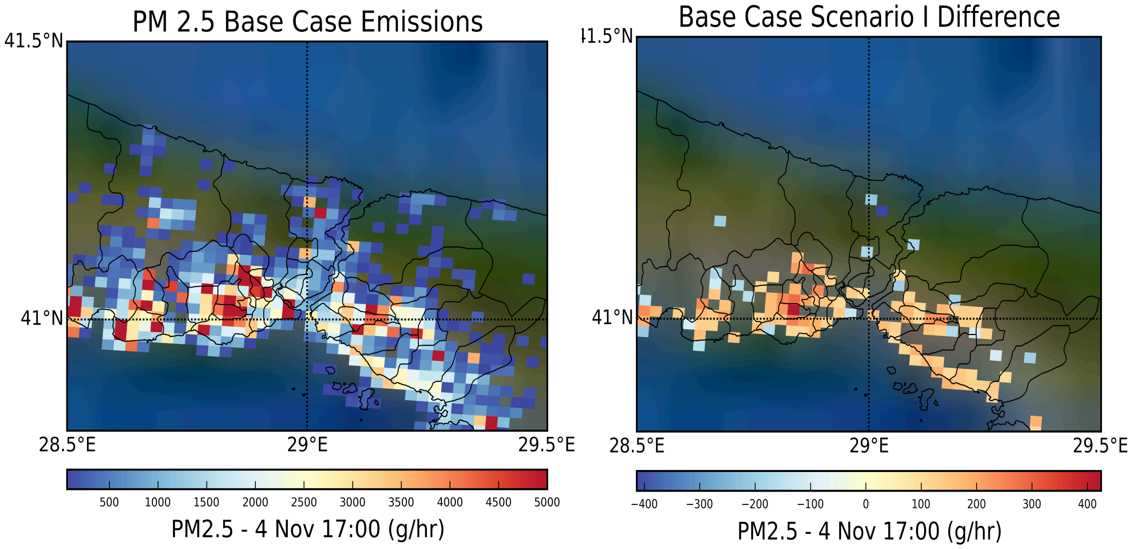


Figure 3.2 : Total annual PM2.5 emissions for base case and difference between base case and Scenario-I

Figure 3.2 shows the PM2.5 emissions over Istanbul and difference between base case PM2.5 emissions and Scenario-I PM2.5 emissions. The largest values are found in the European side of the city, which is the most densely populated and the center of the main economical and recreational activities as shown red squares on map. By subtracting Scenario-I emissions in each grid cell of inner domain from base case emissions, maximum difference is determined. Maximum difference is observed by the approximately 400 g/hr on 4th November at 17:00(Figure 3.). For this specific date and hour of day; plots of base case emissions, base case-Scenario I emission difference and base case- Scenario II emission difference are shown in Figure 3. and Figure . For base case, PM2.5 emissions range between 0 and 5000 gram per hour. In the difference case plot, It would be better to clarify for the Figure 3. above that, while the values above zero are representing decrease in emissions, the percentage values below zero represents increase in emissions. It can be said that by increasing speed 20 percent, PM2.5 emissions can be reduced up to 400 g/hr. Although the decrease in emissions are observed in model domain that is covering Istanbul in general, there is also increase observed in some grid cells. This is because of that when gridding emissions by road types, some grids have only one type of road for example urban and if for this road type increase is observed, on the map, this grid cell is appeared as red color.

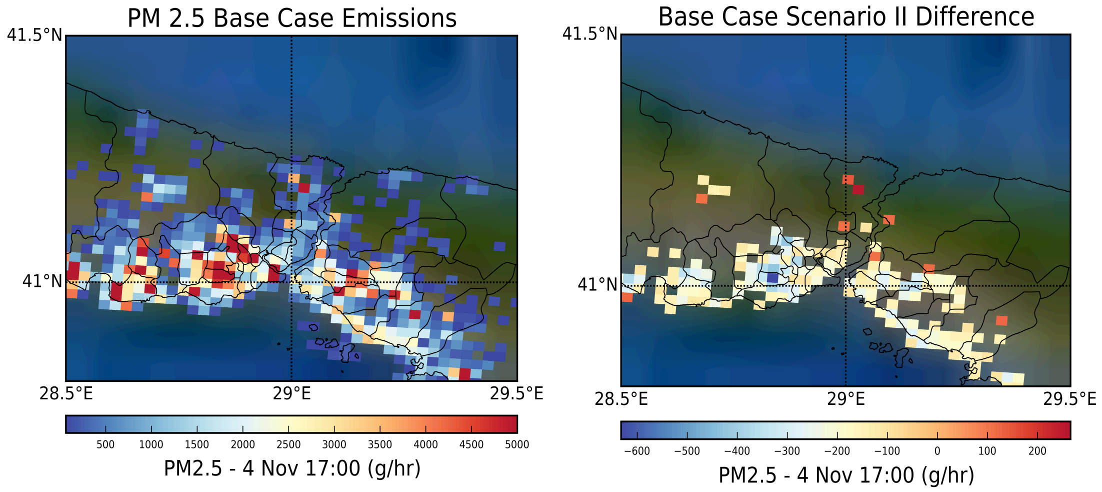


Figure 3.3 : Total annual $PM_{2.5}$ emissions for base case and difference between base case and Scenario-II

Similar to Figure 3.2, Figure 3.3 shows the $PM_{2.5}$ emissions and difference between base case $PM_{2.5}$ emissions and Scenario-II $PM_{2.5}$ emissions. In order to determine the maximum difference, emissions of Scenario-II is subtracted from base case emissions in each grid cells. As shown in scale bar of Figure , maximum difference is 600 g/hr and differences range between 600 g/hr (that indicates increase by negative sign) and 200 g/hr (that indicates decrease by positive sign). Over model domain, negative values that show increase in emission are dominant. That means that 20 percent decrease in speeds causes increase $PM_{2.5}$ emissions around 300 g/hr.

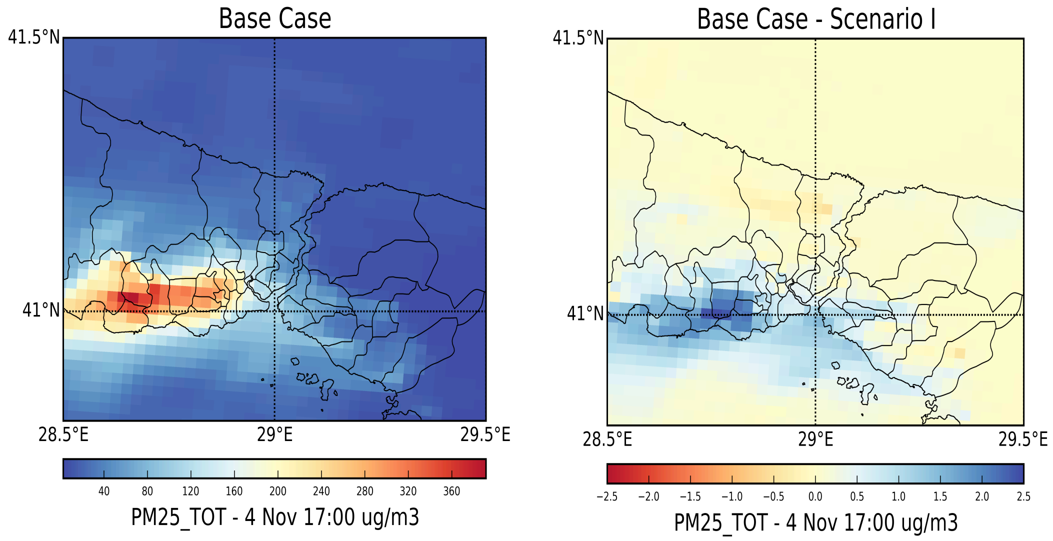


Figure 3.4 : Model output of $PM_{2.5}$ concentrations and Base case- Scenario-I difference in $PM_{2.5}$ concentrations

The average distribution of $PM_{2.5}$ concentrations as calculated for the base case and difference in concentrations between base case and Scenario-I are provided in Figure 3.4. The $PM_{2.5}$ concentrations range between 30µg/m3 and 380µg/m3. As seen in the figure, the regions of the city where the most densely populated and the center of the main economical and recreational activities, highest $PM_{2.5}$ concentrations are observed. It should be noted that the distribution of daily PM2.5 concentrations and other pollutants is highly influenced by the meteorological conditions and higher PM2.5 concentrations were simulated during the entire episode.

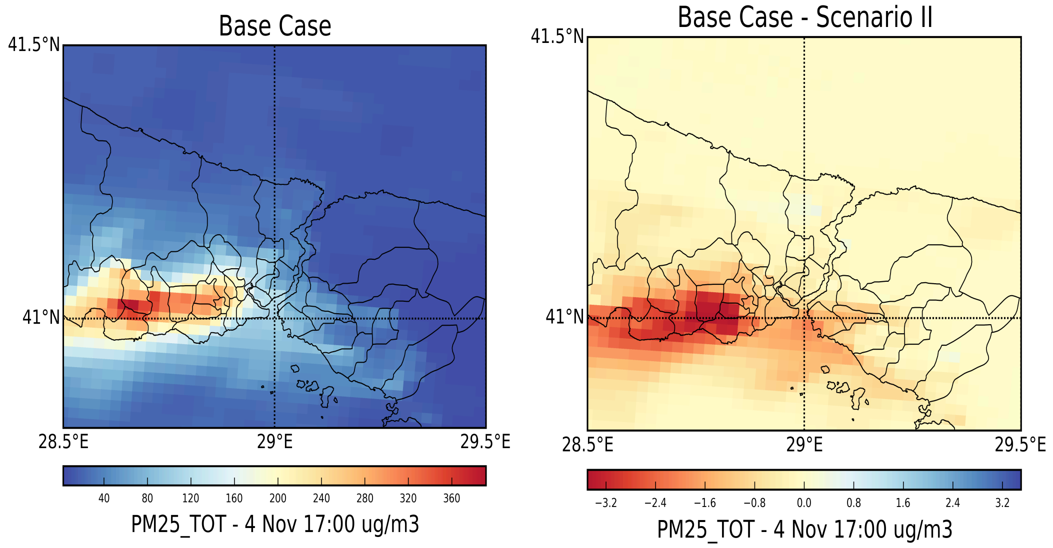


Figure 3.5 : Model output of $PM_{2.5}$ concentrations and Base case- Scenario-I difference in $PM_{2.5}$ concentrations

As a consequence, on average 1.5µg/m3 change in concentrations is observed. The effect of increasing speed has large peaks that range 2.5 $\mu g/m^3$ in some grid cells.

When it is compared to average concentrations of base case it is relatively small but if it is evaluated on the health aspects, 2.5µg/m3 decrease in concentrations has importance.

Figure 3.5 demonstrates the average distribution of $PM_{2.5}$ concentrations as calculated for the base case and the changes in PM2.5 concentrations for the model grid cells between base case and Scenario-II. On average the effect of decreasing speed approximately 2µg/m3 , while large peaks -3.5µg/m3 and 2.5 µg/m3, are also observed.

4. CONCLUSION

In this study, the objective is to quantify the impact of traffic emissions calculated by using COPERT 4 for different input parameters as sensitivity scenarios on air quality of Istanbul. COPERT 4 is the most commonly used model for road emissions calculations in Europe. Traffic related emissions were calculated by using COPERT 4 model. Model input data obtained from Turkish Ministry of Environment and Urbanization, processed using R statistical software. For the first time fleet distribution was produced according to EURO levels, motor size, and fuel type for Istanbul and using this high-resolution data COPERT 4 model was run. Moreover, high-resolution emission inventory for other sectors were acquired from Dr. Ulaş Im. Road transport, alone, is responsible for 42 percent of CO emissions. Impact of road transport on inventory is highly significant. As a consequence of that sensitivity of road transport emission model has importance. For the sensitivity analysis of COPERT 4 model, 3 scenarios were determined based on the input parameters (speed and temperature) in accordance with the maximum impact on road transport emissions. For the each scenario COPERT model was run and emissions for road transport was obtained was used as input for air quality model. To investigate the impact of this significant road transport emissions on air quality model, WRF/CMAQ model system was run for 3 scenarios. Key findings and conclusions are:

- In this study, detailed dataset obtained and prepared according to model requirements. COPERT 4 model was utilized to calculate vehicle emissions for Istanbul for the first time.
- Overall contributions of CO, NOx and PM2.5 from road transport are %51, %42, and %11, respectively. And traffic related emission has more importance than other sectors.
- For selected parameters, base case and three-scenario analysis were performed for sensitivity analysis of COPERT 4. It is found that model more sensitive to speed change than other parameters and to obtain accurate emission vehicle speed that is

given as input parameter should be determined successfully.

- Results show that pollutants behave differently according to road types, speed, and temperature. For example, CO is the most sensitive pollutant to speed, especially in highways. Optimum speed values should be determined and it should be considered when governments decide about policies that include road construction, speed limits, etc.
- Effects of these emissions differences were captured in CMAQ. To illustrate, 20% increase in speed results in 1.5 μg/m3 (approx.5%) decrease in PM2.5 concentration. When health effects of PM2.5 are considered, it is important finding to decide speed limits, road conditions and solutions for traffic problems.
- Results proved that decrease in speed causes the increase in pollutants concentrations. Drivers in Istanbul experience the worst traffic congestion. Speed reduction originated from traffic congestion affects emissions and air quality. For the better air quality in Istanbul, traffic problem should be solved and people should be encouraged to use public transportation systems.
- Since there is a non-linear relationship between speed and emissions, having upper or lower than optimum speed values affects emissions and air quality
- Road transport emissions are major source in metropolitans such as Istanbul. Hence, improvements in their absolute emissions calculation and spatial and temporal distributions are critical.

REFERENCES

Achour, H., J.G. Carton, and a.G. Olabi. (2011). “Estimating Vehicle Emissions from Road Transport, Case Study: Dublin City.” *Applied Energy* 88 : 1957–1964.

Adolf Ebel, ainer Friedrich, Henning Rodhe (1997). GENEMIS: Assessment, Improvement, and Temporal and Spatial Disaggregation of European Emission Data. Volume 7 of the series Transport and Chemical Transformation of Pollutants in the Troposphere pp 181-214.

Avol, Edward L, W James Gauderman, Sylvia M Tan, Stephanie J London, and John M Peters. (2001). “Respiratory Effects of Relocating to Areas of Differing Air Pollution Levels” 164: 2067–2072.

Barth, M., and J. Norbeck, (1997), “NCHRP Project 25-11: The Development of a Comprehensive Modal Emission Model,” Proceedings of the Seventh CRC On-Road Vehicle Emissions Workshop, Coordinating Research Council, Atlanta, GA, pp. 6.53- 6.71.

Becerra, Tracy Ann, Michelle Wilhelm, Jørn Olsen, Myles Cockburn, and Beate Ritz. (2013). “Research | Children ’ s Health Ambient Air Pollution and Autism in Los Angeles County , California” 380 (3): 380–386.

Donaldson, Ken, Nicholas Mills, William MacNee, Simon Robinson, and David Newby. (2005). “Role of Inflammation in Cardiopulmonary Health Effects of PM.” *Toxicology and Applied Pharmacology* 207: 483–8.

Frey, H. Christopher, Alper Unal, Nagui M. Rouphail, and James D. Colyar. (2003). “On-Road Measurement of Vehicle Tailpipe Emissions Using a Portable Instrument.” *Journal of the Air & Waste Management Association 53*: 992–1002.

Im, U., Markakis, K., Unal, A., Kindap, T., Poupkou, A., Incecik, S.,Yenigun, O., Melas, D., Theodosi, C., Mihalopoulos, N. (2010). Study of a winter PM episode in Istanbul using the high resolution WRF/CMAQ modeling system. *Atmospheric Environment*, 44, 26, 3085–3094.

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.

Kanakidou, Maria, Nikolaos Mihalopoulos, Tayfun Kindap, Ulas Im, Mihalis Vrekoussis, Evangelos Gerasopoulos, Eirini Dermitzaki, et al. (2011). “Megacities as Hot Spots of Air Pollution in the East Mediterranean.” *Atmospheric Environment* 45:1223–1235.

National Center for Atmospheric Research (NCAR), (2010) Annual Report

National Research Council. Modeling Mobile-Source Emissions; National Academy Press: Washington, DC, 2000

Nawrot, Tim S, Laura Perez, Nino Künzli, Elke Munters, and Benoit Nemery. (2011). “Public Health Importance of Triggers of Myocardial Infarction: a Comparative Risk Assessment.” *Lancet* (London, England) 377 (9767):732–40.

Perera, Frederica P, Zhigang Li, Robin Whyatt, Lori Hoepner, Shuang Wang, David Camann, and Virginia Rauh. (2009). “Prenatal Airborne Polycyclic

Aromatic Hydrocarbon Exposure and Child IQ at Age 5 Years." Pediatrics 124: e195–202.

Raaschou-Nielsen, Ole, Zorana J Andersen, Rob Beelen, Evangelia Samoli, Massimo Stafoggia, Gudrun Weinmayr, Barbara Hoffmann, et al. (2013). "Air Pollution and Lung Cancer Incidence in 17 European Cohorts: Prospective Analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE)." *The Lancet. Oncology* 14 : 813–22.

Shah, Prakesh S, and Taiba Balkhair. (2011). "Air Pollution and Birth Outcomes: a Systematic Review." *Environment International* 37 : 498–516.

Skamarock, W. C. and Klemp, J. B. (2008). A time-split nonhydrostatic atmospheric model for weather research and forecasting applications. *Journal of Computational Physics*, 227, 3465–3485.

Technical Guide of COPERT 4,Factors, Emission. (1997). "COPERT II Computer Programme to Calculate Emissions from Road Transport" (6).

Thomas, Duncan, D Ph, Kiros Berhane, Rob Mcconnell, Nino Kuenzli, Fred Lurmann, Edward Rappaport, Helene Margolis, David Bates, and John Peters. (2004). "New England Journal": 1057–1067.

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

Vinceti, Marco, Kenneth J Rothman, Catherine M Crespi, Antonella Sterni, Andrea Cherubini, Luisa Guerra, Giuseppe Maffeis, et al. (2012). "Leukemia Risk in Children Exposed to Benzene and PM10 from Vehicular Traffic: a Case-Control Study in an Italian Population." *European Journal of Epidemiology* 27 : 781–90.

Wilhelm, Michelle, and Beate Ritz. (2002). "Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California, 1994-1996." Environmental Health Perspectives 111 : 207–216.

Zhang, Kai, and Stuart Batterman. (2013). "Air Pollution and Health Risks Due to Vehicle Traffic." *The Science of the Total Environment* 450-451 : 307–16.

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