Title: Assessment of Major Air Pollution Sources in Efforts of Long Term Air Quality Improvement in İstanbul

Authors: Orhan Sevimoğlu
Received: 2019-07-04 10:01:18
Accepted: 2020-02-17 15:09:40

Article Type: Research Article
Volume: 24
Issue: 2
Month: April
Year: 2020
Pages: 389-405

How to cite
Orhan Sevimoğlu; (2020), Assessment of Major Air Pollution Sources in Efforts of Long Term Air Quality Improvement in İstanbul. Sakarya University Journal of Science, 24(2), 389-405, DOI: https://doi.org/10.16984/saufenbilder.586655
Access link
http://www.saujs.sakarya.edu.tr/en/issue/52471/586655
Assessment of Major Air Pollution Sources in Efforts of Long Term Air Quality Improvement in İstanbul

Orhan SEVİMOĞLU*1

Abstract

Air pollution affected quality of life and public health due to high concentration levels of air pollutants in Istanbul, especially in 1990s. Major air pollution sources in Istanbul caused elevation of the air pollutants in ambient air of the megacity. To protect human health, the levels of PM$_{10}$ and SO$_2$ were reduced by taking effective actions such as the reduction of utilization of coal, fuel oil, wood combustion for residential heating, expending natural gas network and improving the quality of diesel and gasoline. Intelligent Traffic Systems (ITS) were applied to reduce the air pollutant emission from transportation by reducing travelling time. Overall, this study evaluates air pollution sources in Istanbul based on previous source apportionment studies that guide the emission reduction strategies. The improvement on PM$_{10}$ and SO$_2$ demonstrated as 50% and 98% reduction respectively since 1990s to 2014.

Keywords: megacity, air pollution sources, emission, air quality management

1. INTRODUCTION

Air pollution is considered as one of the environmental problems in megacities due to decrease of comfort [1] and adverse health effects [2]. Air pollution researchers focus not only on outdoor/indoor air pollution [3] but also emphasize on greenhouse gas emissions from natural and anthropogenic sources that take into account the impact on climate change [4]. The dynamics of climate interactions are not completely understood, although there is a general scientific agreement that anthropogenic activities are contributing to global climate change [5] and to ambient air pollution [6].

Istanbul is a megacity with a population that elevated from 6.6 million in 1990s to 15 million up to 2015 due to increasing business and industrial activities such as road construction, skyscrapers, housing, business centers, airports, railways and metro lines. All these developments in the city are a necessity for the public and market needs. The planning and developments of megacity requires a focus on environmental awareness, sustainability and infrastructure to protect its environment and the public health.
Therefore, air quality management requires source apportionment that needs the measurement of the major air pollution parameters, trace compounds representing sources, atmospheric parameters (temperature and pressure, wind speed, and directions), and emission inventories [7]. So, a significant amount of air pollutants and Greenhouse Gases (GHG) are released to the atmosphere from natural and anthropogenic sources [8] as a result of natural decomposition, combustion, natural and industrial activities [9]. Air pollution and GHG abatement efforts should be managed together that both are from the same sources [10, 11]. For this reason, air quality management of megacities should be determined with analytical approaches by creating strategies to reduce their own air pollutants [12]. Therefore, a comprehensive control protocol focusing on multiple criteria pollutants and emission sources was proposed to mitigate air pollution in Istanbul. The variation in concentration values of the major air pollutants (PM$_{10}$, SO$_2$, NO$_x$, O$_3$, CO) in the urban air of Istanbul has been carefully monitored by the municipal experts and researchers for last 25 years.

Nonetheless, recently, the mitigation and adaptation works in air pollutant reduction have been carried out by focusing in the area of transportation, traffic, waste disposal and energy requirement for the public for the last several decades in the concept of air quality improvement. There is a significant contribution and support from the Istanbul Metropolitan Municipality (IMM) and the Ministry in reducing emissions of greenhouse gases and air pollutants.

The control efforts of air pollution emission from the sources could also reflect decreasing of the concentration of pollutants. Major reduction efforts of air pollutants have been implemented on particle sources by reducing the consumption of gasoline, natural gas, coal, fuel oil, and liquefied petroleum gas (LPG). Therefore, the mitigation works focus on improvement of transportation network such as arriving the target in a short time with public transportation and shifting coal combustion to natural gas, improvement on waste management that all these developments reflect as a decrease in the emission of major air pollutants to the atmosphere as well as GHG. This study focuses on emphasizing of assessment and identification of air pollution and GHG sources in the metropolitan city of Istanbul and explicating of the improvement works for the reduction of the concentrations of air pollutants, especially PM$_{10}$ and SO$_2$, to bring the levels of vicinity of Turkish Ambient Air Quality Standards (TAAQS) in Istanbul.

2. MATERIAL AND METHOD

2.1. Air quality management in urban area of Istanbul

Air quality management consists of controlling the criteria air pollutants, GHG emissions, and monitoring of pollutants entering from external sources (Figure 1). Air pollution of Istanbul was a critical level for public health in 1990s [13]. Istanbul Metropolitan Municipality has initiated works for the reduction of the concentrations of major criteria air pollutants; particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides. The major air pollution sources such as vehicle exhaust, road dust, combustion emission from residential heating and energy supply adversely affect air quality in the urban area of Istanbul. The implementation plans were prepared in order to control the emission of the pollutants from the sources to ambient air.

![Figure 1. Control parameters in air quality management](image-url)

On the other hand, the reduction of GHG emission is promoted by the reduction of the air pollutants that originate from GHG sources. The effort of
reducing GHG emissions result in reduction of the air pollutants as well. Istanbul is also exposed to the external particle transport through airflow path from time to time [14]. This constitutes stress on the urban air quality parameters. The external pollution sources cannot be managed in the concept of urban air quality. For instance, the particles from the Balkans and Saharan Dust should be noted as two important external sources for Istanbul. Sea salt particles should be also considered as a PM source for urban area since its three sides are covered by the sea [15]. All these PM emissions naturally occur and impact on the Megacity.

2.2. Istanbul ambient air quality background

The air quality of Istanbul was investigated and reported by many researchers in the past three decades. Researchs were conducted previously focusing on measuring criteria pollutants to determine the level of pollutants in the ambient air quality of Istanbul Metropolitan Area (IMA). Both PM$_{10}$ and SO$_2$ parameters were focused on due to the high concentration levels 155 and 219 $\mu$g/m$^3$ respectively in 1990s that obviously have adverse health effects [16]. The concentrations of air pollutants were presented on variations among the sampling years in Istanbul between 1990 and 2014 (Table 1). The reported yearly average PM$_{10}$ was mainly below TAAQS or exceeded from time to time over the years. The most significant decline was seen in SO$_2$ concentration in these two decades. NO$_x$ concentrations increased over the years due to emission from sources such as vehicle exhaust, natural gas burning, and marine vessels passing through Bosphorus.

3. RESULTS

3.1. Assessment of sources of major air pollutants in Istanbul urban area

The major sources of air pollutants and greenhouse gases in Istanbul urban area are presented based on emitting by the pollutant types in Table 2. Major air pollution sources are cooking operations, domestic heating including wood, lignite (coal), natural gas, fuel oil, traffic sources including LPG, diesel and gasoline combustion in vehicles, and dust sources such as road/surface soil dust and tobacco smoking. In addition, long-range contribution from sea salt and Saharan Dust particles were reported for Istanbul ambient air [15] that could be responsible for the elevation of PM$_{10}$ concentration [14].

Table 1. Measurements of air pollutants in previous research studies ($\mu$g m$^{-3}$) ($O_3$= ppb).

| TAAQS (in 2014) | PM$_{10}$ | PM$_{10}$ | PM$_{10}$ | PM$_{10}$ | NO$_x$ | SO$_2$ | O$_3$ | CO |
|----------------|----------|----------|----------|----------|--------|--------|------|----|
|                |          | winter   | summer   | Spring   |        |        |      |    |
| 01.1990        | 100      | 225      | 45       |          | 450    | 75     | 120  | 1000|
| 07.1990        |          |          |          |          |        |        |      |    |
| 1991           | 103.8    | 155      |          |          | 219    | 308    | 249.8|
| 1993-1994      |          |          |          |          |        |        |      |    |
| 1994-1995      |          |          |          |          |        |        |      |    |
| 2000           | 65       |          |          |          | 50     | 30     | 25   | 1200|
| 2002 European Side |      | 138      | 38       |          | 1550   | 1700   |      |    |
| 2002 Asian Side |          | 98       | 18       |          |        |        |      |    |
| 2002-2003      |          | 65.3     | 55.6     |          | 22.95  |        |      |    |
| 2005-2009      | 58       |          |          |          |        |        |      |    |
| 2007-2009      |          |          |          |          | 60     | 15.2   |      |    |
| 2007           | 69±27.9  |          |          |          | 91±65.1| 12.1±10.1| 686±428|
| 2008           | 39.1     | 44.5     | 29.8     |          |        |        |      |    |
| 13.01.2008     |          |          |          |          | 129    |        |      |    |
| 12.04.2008     |          |          |          |          |        | 107    |      |    |
| 11.2007-06.2009| 39.1     | 48       |          |          |        | 55.2   |      |    |
| 01.01.2010-31.12.2012| 50 |          |          |          | 56     | 10     | 29   |    |
| 2003-2013      | 53.60    | 57.45    | 49.75    |          | 10.43  | 718    |      |    |

Sakarya University Journal of Science 24(2), 389-405, 2020
Table 2. Major sources of air pollutants in Istanbul

| Major Sources of Air Pollutants | Criteria Air Pollutants | GHG Emission Source | Type |
|---------------------------------|-------------------------|---------------------|------|
|                                 | PMx SO₂ NOₓ CO CO₂ CH₄ |                     |      |
| Meat-Cooking Operations        | X                       |                     | 1    |
| Paved Road Dust                | X                       |                     | 1    |
| Wood Burning                   | X X X                   |                     | 1    |
| Coal Burning                   | X X X                   |                     | 1    |
| Fuel Oil Burning               | X X X                   |                     | 1    |
| Tobacco Smoke                  | X X X X                 |                     | 1    |
| Diesel Vehicles                | X X X                   |                     | 1    |
| Gasoline Vehicles              | X X X X                 |                     | 1    |
| Natural Gas Combustion         | X X X X                 |                     | 1    |
| Vegetative Detritus            | X X X                   |                     | 2    |
| Aviation Emission              | X X X                   |                     | 1    |
| Landfill Gas                   | X X X                   |                     | 1    |
| Sea Salt Particles             | X X                     |                     | 2    |
| Saharan Dust                   | X X X                   |                     | 2    |
| Maritime Emission              | X X X                   |                     | 1    |
| Vegetative Detritus            | X                       |                     | 2    |

1: Anthropogenic, controllable, 2: Natural, uncontrollable

The landfill sites are a GHG emission source in the borderline of Istanbul Province [27]. 44% of the total area of Istanbul Province is covered by forests [82] and green lands could be considered significant PM source as vegetative detritus [28]. Vegetative detritus, sea salt particles, Saharan dust particles are naturally occurring uncontrollable PM sources. Istanbul as a coastal city is under the influence at maritime emissions as well [29]. In the following sections, the assessment of the major air pollution sources and implemented emission reduction works will be discussed.

3.1.1. Cooking influence on air quality

Different types of meat cooking emit varied emission factors with chemical compositions [30]. Meat cooking is significant part of food consumption in public that is a considerable source of organic aerosol emissions to the urban air [83]. Charbroiling extra lean meat produce fine aerosol emissions of 7 g/kg of meat cooked. In contrast, frying meat generate fine aerosol emissions recorded at 1 g/kg of meat [31]. The meat consumption per person was about 13.07 kg per year and chicken meat consumption was about 19.43 kg per year in 2013 in Istanbul [32]. Fine aerosol emission was about 2148 kg per day (assumed for the meat consumption of half charbroiling and other half frying) for the population of Istanbul. The fine organic carbon particle emissions from meat cooking to ambient air were found about 1400-4900 kg per day for Los Angeles in 1982 [30]. Schauer [7] reported organic aerosol ratios for cooking as 20.78%, 13.99%, 20.29% and 21.63% in Pasadena, Downtown Los Angles, West Los Angeles and Rubidoux in 1989, respectively. Another study was conducted in Pittsburgh with average yearly OC concentration originating from meat cooking determined as 0.45 mg-C m⁻³ as 16% in total OC concentration [33]. It was reported that the cooking was also a significant OC contributor, accounting for 0.6–3.1 μg C m⁻³ in the range of 6–24% of fine OC in Hong Kong [34]. These research studies suggest meat cooking as a considerable PM source in megacities. The cooking emission was unexpressed by the researchers of the previous studies related to ambient air quality in Istanbul. However, the Particulate Organic Matter (POM) were measured from November 2007 to June 2009 and average POM was reported as 9.8 μg m⁻³ of annual average value of PM₁₀ (39.1 μg m⁻³) in Istanbul [24]. Depending on previous research, the contribution of organic matter originating from
the meat cooking or cooking operations can be evaluated as at least 3% in contribution to the POM of PM$_{10}$. Further research is necessary for true estimation of fine aerosols from meat cooking. The odor emission from facilities such as restaurants and cooking centers is controlled by applying “Causing Odor Control of Emission Regulations” [35] in the concept of air quality management.

### 3.1.2. Paved road dust particles

The research PM apportionment indicated that the road dust is a considerable source of atmospheric aerosol in ambient air [36]. There is a significant contribution to ambient air for the inhalable particle mass of road dust that contains hazardous trace elements and compounds that has adverse health effects [37, 38]. The road dust contribution to ambient air in PM$_{10}$ was reported 13% in Paris [39]. The road dust concentration out of six major sources (secondary sulfate, secondary nitrate, motor vehicle, road dust, sea salt, and oil combustion) was about 4.13 out of 16.37 µg m$^{-3}$, corresponding to 25.22% of PM$_{2.5}$ in New York City during July 2001 [40]. In another research study between October 2009 and October 2010 in Rochester, New York, the airborne soil was of 12.8% of the total PM$_{2.5}$ concentrations that was determined by Positive Matrix Factorization (EPA PMF, version 4.1) [41]. The road dust proportion was 25–27% in PM$_{10}$ aerosols that were collected during 1989 every sixth day at six sites in Santa Barbara County, CA [42]. The road dust contribution was reported of 22% to PM$_{10}$ in Istanbul [24]. Considering previous research studies, it can be stated that the road dust contributes at least 10% to atmospheric PM$_{10}$ formation. The movement of 3.5 million registered on the street and transit vehicles cause re-suspension of road dust particles that has a noteworthy proportion in PM$_{10}$ of Istanbul ambient air [84]. In order to decrease the contribution of road dust particles to the ambient PM, the mechanical street sweeping was implemented to the main streets by the IMM and the local municipalities since 2002 [43].

### 3.1.3. Wood burning

Wood is used for residential heating and industrial use [44] that is a source of particles in the residential areas [45]. The wood consumption in Istanbul was reported 350,000 ton/year in 1990 [46] and 890,857 ton/year in 2007 [47]. Although 95% of the natural gas distribution network is available for the household in Istanbul as of 2014, the use of wood for heating spaces in the residential buildings is still in use during in Fall and Winter seasons, especially in suburban areas by the low-income families. On the other side, the bakery stores use different types of wood in Istanbul [48]. There is no information about wood emission in the apportionment study of Istanbul. However, particle emission from wood burning to the ambient particles at different locations in previous studies may shed a light. For example, Pittsburgh Supersite work in 2001 [49] suggested that PM contribution from the wood burning was about % 4-5 based on PMF model. The other research study reported that the wood burning contribution was 1.4-10.4% in PM$_{2.5}$ [7]. The wood burning in residential heating and industrial use should be considered as a PM contributor even in a small fraction such as 1-2% of PM$_{10}$ for the air quality management of Istanbul. There is no ban in use of wood for the residential heating and industry, although the natural gas use is available for 95% of the metropolitan area.

### 3.1.4. Lignite coal and natural gas combustion

Lignite coal was affordable and easy to supply for the public as a major fuel of residential heating in Istanbul in 1990s. At the time consumption of lignite coal was about 5.8 Million tons per year [46]. Therefore, a large amount of PM and SO$_2$ pollutants from coal burning in the residential area caused a decrease in air quality of city by especially elevation of SO$_2$ concentration in ambient air [13]. The concentrations of SO$_2$ were high above the TAAQS in 1990s (Figure 2).

In order to reduce SO$_2$ concentrations, the natural gas network was widespread in the city of Istanbul to make available the clean energy source for residential and industrial use. Consumption of natural gas increased ten times from 1994 to 2004.
(Table 3) [79]. "Regulation on Control of Air Pollution Caused by Heating" published in 2005 determines the quality of the coal in use for heating purposes in residential area was implemented. Based on this regulation, the total sulfur content is allowed at most 2% in dry weight in at least 4800 Kcal/kg (±200 tolerance). So, SO₂ concentration decreased from 145 to 22 µg m⁻³ about six times less from 1994 to 2004.

![Figure 2. Yearly average of 24-h SO₂ concentrations [50].](image)

The lignite usage decreased 18 fold and natural gas usage increased 10 fold. As a result, SO₂ concentrations drop 29 fold as of 2014. Consequently, the decrease of the SO₂ concentration result in reducing the amount of lignite usage less than 1-million-ton coal is still in use by the public for residential heating [47]. Although natural gas network is available for the public, there is no regulation to prevent the usage of coal.

### 3.1.5. Fuel oil burning

Fuel oil (No. 6) is sometimes referred to as furnace or heavy fuel oil (HFO) or residual oil that is commonly used for residential and commercial heating purposes in steam and power generation using industrial boilers in Istanbul. During 1990s, the amount of fuel oil use was 250,000 tons per year [46]. This volume has dropped to about 30,000 tons per year in 2014 [51], which should be taken into account in terms of the amount of lower emission due to the less consumption. The combustion of HFO contributes SO₄²⁻ significantly to the total PM mass [52]. The fuel oil combustion contributes accounting for 18% of the PM₁₀ mass in the city of Colima, Western Central Mexico [53]. Cheng [54] reported that PM₂.₅ contains (~10%) fine particles from residual oil combustion in Hong Kong from 2004 to 2005. The source apportionment in five cities of Netherland revealed the residual oil combustion in PM₂.₅ is about 1-3% from 2007 to 2008 [55]. All these previous research indicate a contribution of fine particles from HFO combustion in the formation of PM₁₀ in Istanbul.

### 3.1.6. Tobacco smoke

The trace compounds of tobacco smoke were detected in ambient aerosol as a source of biomass burning [56, 83] with less than 1% in PM₂.₅ [7]. Smokers in the population of Turkey were about 14.8 million (27.1%) of 75.6 million in 2012 [57]. Though, there is no exact number of smokers in Istanbul. However, there might be about 2.66 million smokers in Istanbul in 2012 based on Istanbul population (13.6 Million). Smoking was banned in closed areas of public since 2008 in Turkey. A mean PM₂.₅ emission rate of 12.7 mg/cigarette was reported [58]. If it is assumed that one person smokes per day one cigarette in open area, 11.5 kg PM₂.₅ emits to the ambient in Istanbul. Beyond the contribution of cigarette smoke to atmospheric pollution, it is important that 27% of the smokers of the urban population were exposed by ambient air pollution in addition to direct inhalation of cigarette smoke. Therefore, the adverse effect of tobacco use on public health should be taken into account due to additional pollution exposure [59].

![Table 3. Natural gas consumption in last two decades.](image)
Hence, the necessary measures for the reduction of tobacco use should be taken even though PM proportion of tobacco smoke is very low in ambient air due to adverse health effect.

3.1.7. Diesel and gasoline vehicle emissions

One of the major sources of air pollution in the IMA is vehicle exhaust from gasoline and diesel vehicles [24]. Their exhaust emits fine particles including organic carbon (OC), elemental carbon (EC), trace metals, cations (Na\(^+\), K\(^+\), NH\(_4^+\)), and anions (Cl\(^-\), NO\(_3^-\), SO\(_4^{2-}\)) [60] as well as gaseous pollutants including NOx, VOCs, and CO. Traffic emission has a considerable proportion in the total of GHG emissions in megacities [61]. The reduction of traffic jam and transportation time will lead to the reduction of emissions of both GHG and air pollutants from vehicle exhaust. Istanbul is an important junction point connecting two continents that is an indispensable route for transit transport. The vehicle emissions are from local use and transit vehicles. The determination of their proportion is not simple. There were 3,383,812 vehicles registered in Istanbul Province in 2014. 67% of these vehicles were cars, the others include minibus, bus, truck, motorcycle, tractor, and special vehicles. In 2014, 495,714 tons of gasoline and 2,760,567 tons of diesel fuel were sold. The sold gasoline/diesel fuel ratio is 0.18. As a result, gasoline consumption is lower than diesel. It is known that significant quantities of gasoline vehicles were converted into CNG-powered vehicles to lower the fuel cost. That also reflects to lower pollution emissions originating from gasoline equipped vehicle exhaust. On the other hand, the diesel equipped vehicle exhaust is effective in decreasing air quality [85]. In order to reduce the emissions from vehicle exhaust, lowering all types fuel consumption such as follows: acceleration of the traffic flow in peak hours, increasing the use of public transport, implementation of the prohibited zone to enter in the city center, use of intelligent traffic control systems, given traffic density information for the drivers that contributes in reducing the fuel consumption by changing optimum route.

3.1.8. Vegetative detritus emission

Plants emit GHG and fine particles to ambient air. Anthropogenic and natural particles (e.g., soil and exhaust particles) sink on the leaves under suitable conditions [62]. Due to wind-induced mechanical shear and rubbing of leaves against each other, foliage and leaf deposits become airborne particles that are resuspended into the atmosphere [63]. The leaf surface abrasion particles are identified in ambient PM by measuring the trace organic markers and trace elements [64]. There is a large forest area of 2424 km\(^2\) in the northern part of Istanbul Province and 80.7 km\(^2\) green areas in the IMA. Both green areas should be considered as vegetative detritus source that emit formed particles to ambient air. Rogge [63] reported that vegetative detritus particle proportion was 1.25-2.5% in total OC of PM\(_{2.5}\) for four cities of Los Angeles. Shrivastava [33] reported biomass burning and vegetative detritus together contributing to OC of PM\(_{2.5}\) as about 8.3% in Pittsburgh Area. Due to no data reported about vegetative detritus particle contribution to ambient air for Istanbul, which is likely a minor proportion in PM\(_{10}\) needs to be determined. Vegetative detritus particles naturally occur, so there is no model to reduce emission from plants.

3.1.9. Maritime emission

Ship emissions are significantly increasing globally and have remarkable impact on air quality of seaside and inland [65]. Istanbul strait connect to the Black Sea and Marmara Sea that has an intensive maritime traffic with about 50,000 ship passing through per year. In addition to the maritime traffic on Istanbul Strait, the ships that are in use in domestic transport, fishing, sport or strolling ships should be also considered [66]. The exhaust gas emissions from ships in the Sea of Marmara and the Istanbul Strait are calculated by utilizing the data acquired in 2003. Total emissions from ships in the study area were estimated as 5,451,224 t y\(^{-1}\) for CO\(_2\), 111,039 t y\(^{-1}\) for NO\(_x\), 87,168 t y\(^{-1}\) for SO\(_2\), 20,281 t y\(^{-1}\) for CO, 5,801 t y\(^{-1}\) for VOC, 4,762 t y\(^{-1}\) for PM [65]. Bove [67] reported that the source apportionment study presented the contribution of maritime particles as 15% in the urban area of Genoa (Italy).
contributions from shipping emissions to PM and gaseous pollutant concentrations show a large spatial variability with 1-7% to annual mean PM$_{10}$ levels with maximal contributions in the Mediterranean basin and the North Sea [29]. The PM and NO$_x$ contribution from the ship emission to Istanbul ambient air should be considered as a negative impact on air quality. However, there is no legislation to control or limit the emissions of ships passing through the Istanbul Strait due to international agreements.

3.1.10. Sea salt particles

Sea-salt particles associated with ions (Na$^+$, Cl$^-$ and Mg$^{2+}$) contribute to the ambient air particles in the coastal area [68]. Sea salt aerosols, as represented by Na$^+$, were consistently confined to the coarse mode, peaking between 1–18 µm depending on location and time [69]. So, Istanbul Province has two parts and each part of its three sides is surrounded by the Marmara Sea, the Black Sea and the Istanbul Strait. The land is under the influence of winds from the north-western and the south-western/eastern sides. Sea salt particles are transported to the European and Asian parts by the wind that sweeps the sea surface and carries the sea salt particles to the inner regions. The aerosol sampling study represented ionic mass contributions up to 42% of the PM$_{10}$ mass that has 8% sodium in Istanbul [24]. So, Na ion was 3.36% in PM$_{10}$ that indicated the sea salt particles contributed to ambient particles in the coastline ambient air.

3.1.11. Long range particle transport

African dust travels over the Mediterranean Sea to impact the urban areas in cities of Europe such as Madrid (Spain) [70], Athens (Greece) [71], Istanbul (Turkey) [72, 73]. The Saharan dust episode cause the elevation of ambient PM concentration due to external PM entrance [74, 75] that effects public health [76, 80, 81]. Chemical composition of PM revealed the concentration of PM$_{10}$ reached 87 µg m$^{-3}$ in 13$^{th}$ of April 2008 that composed of 57% crustal material [15]. Perez [77] reported the PM elevation seen in PM$_{10}$ during the Saharan dust event. The Saharan particles were deposited as dry and wet deposition [78]. Therefore, Saharan Dust episode can be considered as long range particles that contribute in elevation of PM$_{10}$ in Istanbul.

3.1.12. GHG emission from landfill

About 15,000 tons/daily municipal solid waste (MSW) was disposed to landfills in the city of Istanbul in 2009 [27]. About 50 million tons and 25 Million tons of MSW were disposed to both Odayeri and Kömürçu district landfills where located in rural site of the megacity from 1995 to 2014, respectively. LFG from both landfill sites has been emitted theoretically to the atmosphere since 1995 until 2009 about 850 Million m$^3$ (Odayeri) and 400 Million m$^3$ (Kömürçu) [27]. Due to the reduction in GHG emissions in the concept of the environmental awareness by IMM, Waste-to-Energy Projects were applied to both landfills to produce electricity by utilizing LFG. After installation of power plants, the total produced electricity is about 1,112,756 MWh from 2009 to 2014 [79]. These projects aimed to reduce GHG from the landfills in the concept of adaptation work. Hence, a minimum of about 110 thousand houses are provided with the electricity from both waste to energy production plants considered as renewable energy source.

3.1.13. Aviation emission

Aviation emits gases (Nitrogen Oxides), volatile organic compounds (VOCs), sulfur oxides (SOx), soot, and other particles [88]. Emissions close to the surface have impact on the concentrations of ozone, and fine particles at the urban area [89]. Air craft emissions impact on local air quality while landing, take-off, and non-LTO (non-Landing-Take-Off) period above 1 km above from the surface [90]. In terms of city air quality, the travels of the aircraft within the city limits should be taken into consideration due to the emission of pollutants. There were two active airports in Istanbul during this study period, namely Atatürk Airport and Sabiha Gökçen Airport. These two airports emit significant greenhouse gas emissions. The calculated greenhouse gas emission values are; 904,465.32 tons CO$_2$-eq which has been verified as the
equivalent greenhouse gas emission of 2014 at Atatürk Airport [91]. The greenhouse gas emissions from Sabiha Gökçen Airport was reported as 682,916 tons of CO$_2$-eq from the transportation-related fuel consumption in 2014 [92]. The emission reduction studies of aviation-induced greenhouse gases and air pollutants should be considered carefully.

3.2. Assessment of PM$_{10}$ and SO$_2$ concentrations between 2010 - 2014

There is no significant variation in PM$_{10}$ and SO$_2$ values between 2010-2014 (Figure 3). Yearly average SO$_2$ concentrations were in the range of 3-7 µg/m$^3$ last five years which are lower than TAAQS. It is obvious that the reduction of consumption of lignite coal cause the decrease of the SO$_2$ concentration in the long term.

![PM$_{10}$ and SO$_2$ Concentrations](image)

Figure 3. PM$_{10}$ and SO$_2$ concentrations from 2010 to 2014 in Istanbul [79].

On the other hand, PM$_{10}$ values are in the range of 49-56 µg/m$^3$ which are slightly lower than TAAQS. It can be interpreted that the implementation works have reduced emissions of PM$_{10}$ which lead to a constant value. Table 4 shows the major reduction works focusing on vehicle exhaust, dust particles and residential combustion sources (natural gas, lignite, fuel oil, wood) which has the most significant sources of PM$_{10}$.

4. RESULTS

This study determined the sources of air pollutants in order to ensure an effective air quality management in the megacity of boundary. The concentration values of the pollutant parameters were examined retrospectively, and their changes were examined. Accordingly, the actions to be taken in the metropolitan area have been determined to reduce the emission values of pollutant sources.

Major air pollution sources were evaluated at the metropolitan area of Istanbul based on a long-term air quality improvement plan. Air quality management consist of controlling the emission of major sources that are cooking, road dust, wood burning, coal, natural gas, fuel oil, cigarette smoke, diesel and gasoline exhaust, and GHG emission from the landfills. These sources emit air pollutants and GHG that contribute to PM formation and other major pollutants in the urban ambient air. Vegetative detritus and sea salt particles are natural sources and long range transport particles (Saharan dust) that contribute to elevation of the concentration of PM as well.

It was a priority for air quality management to reduce the concentration of PM$_{10}$ and SO$_2$ for public health since 1990 to 2014 for the Istanbul case. PM$_{10}$ has been reduced to about 50% since 1990s. Despite all reduction efforts of PM emissions, the PM$_{10}$ has remained in the range of 49-56 µg/m$^3$ from 2010 to 2014, although there is an intensive urban growth. The stability of PM$_{10}$ is an indication that the works of the measures for air quality control management mentioned above.

The emission reduction efforts were mainly applied on reduction of fossil fuel consumption in the metropolitan area. According to the previous source apportionment studies in road dust and vehicle exhaust gases constitutes higher rate of involvement in PM$_{10}$. Contributions from these two sources should be tracked carefully by air quality researchers. Without examining major sources of air pollution, only greenhouse gas reduction efforts will not be effective in improving air quality studies. SO$_2$ was reduced
98% since 1990 to 2014 due to reduction of lignite coal consumption with high sulfur content.

Table 4. Major implementations of emission reductions.

| Major Sources of Air Pollutants | Implementations of Emission Reduction |
|---------------------------------|---------------------------------------|
| Meat-Cooking Operations         | Filter application on exhaust hood of cooking facilities, Chimney Cooker Hood in residential kitchens. |
| Paved Road Dust                 | Main artery roads cleaning to collect road dust by sufficient number of street sweepers, using multipurpose street, barriers, and tunnels washing vehicles. Germination to roadside area. |
| Wood Burning                    | New retrofitted stove design to improve combustion efficiency. |
| Coal Burning                    | New retrofitted stove design to improve combustion efficiency, regulated lignite sale with less than 2% sulfur content. Selling coal-sacks with sealed and marked. |
| Fuel oil Burning                | Improved the performance of oil-fired furnaces and boilers in fuel consumption and burning, improved the quality of fuel-oil. |
| Cigarette Smoke                 | Rehabilitation initiative worked for addicts to reduce tobacco use, informed community about the health hazard of smoking, regulated all tobacco products, established Smoke-Free Public Places Act |
| Diesel and Gasoline Equipped Vehicles | Acceleration of traffic flow in peak hours, encourage to use public transport, implementation of the prohibited zone to enter in the city center, use of intelligent traffic systems, to provide drivers with the necessary information about road conditions in order to use less fuel, established new roads and tunnels to reduce travel distance, promote public to use cars with less consume fuel, promote public to use advanced EURO model diesel vehicles. |
| Natural Gas                     | Development of intelligence heating system in residence, advanced technology in natural gas boiler, isolation of building, informed tips for public to use less natural gas and fuels. Encourage the use of natural gas, if available to access |
| Vegetative Detritus             | Naturally occurred. |
| Maritime Emission               | Promoting the use of MARPOL Annex VI compliant ships, no forced application. |
| Landfill                        | Implemented waste to energy projects to reduce GHG emission at three landfills (Hasdal, Odayeri, Kömürçüoda) in Istanbul. |
| Sea Salt Particles              | Naturally occurred |
| Saharan dust particles          | Naturally occurred |
| Aviation Emission               | Reduced the waiting time for landing and take-off of aircraft, managed the fuel consumption, improvement of aircraft models, use high quality aircraft fuel. |

This study helps assess sources for the abatement of air quality problems for the development of megacities. It requires a serious effort to reduce existing emissions, primarily, the reduction of road dust emission, vehicle exhaust emission, and residential heating emission will contribute to the reduction of both air pollutants.

Major emission reduction work was applied on both PM$_{10}$ and SO$_2$ parameters to bring them to the level of TAAQS in Istanbul area. The coal
local Turkish lignite) containing high sulfur content was used a vast amount for the domestic heating until the beginning of 1995 that promoted high SO$_2$ and PM emissions to the ambient air. On the other hand, all major sources emit particles in all ranges to ambient air that contribute to the formation of PM$_{10}$. All mentioned control parameters were applied to pollution sources to reduce these concentrations.

5. REFERENCES

[1] M. Derbez, B. Berthineau, V. Crochet, C. Pignon, J. Ribéron, G. Wyatt, C. Mandin, S. Kirchner, “A 3-year follow-up of indoor air quality and comfort in two energy-efficient houses”, Building and Environment, vol. 82, pp. 288-299, 2014.

[2] H. Altuğ, E.O. Gaga, T. Döğeroğlu, B. Brunekreef, G. Hoek, W.V. Doorn, “Effects of ambient air pollution on respiratory tract complaints and airway inflammation in primary school children”. Science of the Total Environment, vol. 479–480, pp. 201-209, 2014.

[3] S. Hasheminassab, N. Daher, M.M. Shafer, J.J. Schauer, R.J. Delfino, C. Sioutas, “Chemical characterization and source apportionment of indoor and outdoor fine particulate matter (PM2.5) in retirement communities of the Los Angeles Basin”. Science of the Total Environment, vol. 490, pp. 528–537, 2014.

[4] G. El Dib, “Impacts of atmospheric pollution on climate change – laboratory studies”. Energy Procedia, vol. 6, pp. 600-609, 2011.

[5] N. Oreskes, “The Scientific Consensus on Climate Change”, Science, vol. 306(5702), pp. 1686, 2004.

[6] M. Karaca, M. Tayanç, H. Toros, “Effects of urbanization on climate of İstanbul and Ankara”, Atmospheric Environment, vol. 29(23), pp. 3411-3421, 1995.

[7] J.J. Schauer, W.F. Rogge, L.M. Hildemann, M.A. Mazurek, G.R. Cass, B.R.T. Simoneit, “Source apportionment of airborne particulate matter using organic compounds as tracers”, Atmospheric Environment, vol. 30(22), pp. 3837-3855, 1996.

[8] A. Saral, S. Demir, Ş. Yıldız, “Assessment of odorous VOCs released from a main MSW landfill site in İstanbul-Turkey via a modelling approach”, Journal of Hazardous Materials, vol. 168(1), pp. 338-345, 2009.

[9] U. Im, N. Daskalakis, K. Markakis, M. Vrekoussis, J. Hjorth, S. Myriokefalitakis, E. Gerasopoulos, G. Kouvarakis, A. Richter, J. Burrows, L. Pozzoli, A. Unal, T. Kindap, M. Kanakidou, “Simulated air quality and pollutant budgets over Europe in 2008”, Science of the Total Environment, vol. 470–471, pp. 270-281, 2014.

[10] L. Bhagavatula, C. Garzillo, R. Simpson, “Bridging the gap between science and practice: An ICLEI perspective”, Journal of Cleaner Production, vol. 50, pp. 205-211, 2013.

[11] Z. Şen, “An application of a regional air pollution estimation model over İstanbul urban area”, Atmospheric Environment, vol. 32(20), pp. 3425-3433, 1998.

[12] S. Kumar, S.A. Gaikwad, A.V. Shekdar, P.S. Kshirsagar, R.N. Singh, “Estimation method for national methane emission from solid waste landfills”, Atmospheric Environment, vol. 38(21), pp. 3481–3487, 2004.

[13] M. Tayanç, “An assessment of spatial and temporal variation of sulfur dioxide levels over İstanbul, Turkey”, Environmental Pollution, vol. 107(1), pp. 61-69, 2000.

[14] T. Kindap, A. Ünal, S.-H. Chen, Y. Hu, M.T. Odman, , M. Karaca, “Long-range aerosol transport from Europe to İstanbul, Turkey”,
Atmospheric Environment, vol. 40(19), pp. 3536–3547, 2006.

[15] M. Koçak, C. Theodosi, P. Zarmpas, U. Im, A. Bougiatioti, O. Yenigun, Mihalopoulos, N. “Particulate matter (PM10) in Istanbul: Origin, source areas and potential impact on surrounding regions”, Atmospheric Environment, vol. 45(38), pp. 6891-6900, 2011.

[16] S. İncecik, “Investigation of Atmospheric Conditions in Istanbul Leading to Air Pollution Episodes”, Atmospheric Environment, vol. 30(15), pp. 2739-2749, 1996.

[17] Y.S. Ünal, S. İncecik, Y.Borhan, S. Mentes, “Factors Influencing the Variability of SO2 Concentrations in Istanbul”, Journal of Air Waste Management Association, vol. 50(1), pp. 75-84, 2000.

[18] G. Onkal-Engin, İ. Demir, H. Hiz, “Assessment of urban air quality in Istanbul using fuzzy synthetic evaluation”, Atmospheric Environment, vol. 38(23), pp. 3809–3815, 2004.

[19] H. K. Ötçan, “Long Term Variations of the Atmospheric Air Pollutants in Istanbul City”, International Journal of Environmental Research and Public Health, vol. 9(3), pp. 781-790, 2012.

[20] Ü.A. Şahin, O.N. Ucan, C. Bayat, O. Tolluoğlu, “A New Approach to Prediction of SO2 and PM10 Concentrations in Istanbul, Turkey: Cellular Neural Network (CNN)”, Environmental Forensics, vol. 12(3), pp. 253-269, 2011.

[21] Y.S. Ünal, H. Toros, A. Deniz, S. İncecik, “Influence of meteorological factors and emission sources on spatial and temporal variations of PM10 concentrations in Istanbul metropolitan area”, Atmospheric Environment, vol. 45(31), pp. 5504-5513, 2011.

[22] U. İm, S. İncecik, M. Güler, A. Tek, S. Topcu, Y.S. Ünal, O. Yenigün, T. Kindap, M.T. Odman, M. Tayanç, “Analysis of surface ozone and nitrogen oxides at urban, semi-rural and rural sites in Istanbul, Turkey”, Science of the Total Environment, vol. 443, pp. 920–931, 2013.

[23] T. Elbir, N. Mangir, M. Kara, S. Simsir, T. Eren, S. Ozdemir, “Development of a GIS-based decision support system for urban air quality management in the city of Istanbul”, Atmospheric Environment, vol. 44(4), pp. 441-454, 2010.

[24] C. Theodosi, U. Im, A. Bougiatioti, P. Zarmpas, O. Yenigun, N. Mihalopoulos, Aerosol chemical composition over Istanbul. Science of the Total Environment, vol. 408, pp. 2482–2491, 2010.

[25] H. Toros, H. Erdun, Ö. Çapraz, B. Özer, E.B. Daylan, A.I. Öztürk, “Air Pollution and Quality Level in Metropolitan Turkey for Sustainable Life”. European Journal of Science and Technology, vol. 1(2), pp. 12-18, 2013.

[26] E. Yurtseven, S. Vehid, M. Bosat, S. Köksal, C.N. Yurtseven, “Assessment of Ambient Air Pollution in Istanbul during 2003-2013”, Iranian Journal of Public Health, vol. 47(8), pp. 1137-1144, 2018.

[27] O. Sevimoğlu, “Assessment of Limiting Factors for Potential Energy Production in Waste to Energy Projects”, Fresenius Environmental Bulletin, vol. 24(7), pp. 2362–2373, 2015.

[28] P. Fu, K. Kawamura, M. Kobayashi, B.R.T. Simoneit, “Seasonal variations of sugars in atmospheric particulate matter from Gosan, Jeju Island: Significant contributions of airborne pollen and Asian dust in spring”, Atmospheric Environment, vol. 55, pp. 234-239, 2012.

[29] M. Viana, P. Hammingh, A. Colette, X. Querol, B. Degraeuwe, I. Vlieger, J.
Aardenne, “Impact of maritime transport emissions on coastal air quality in Europe”. Atmospheric Environment, vol. 90, pp. 96-105, 2014.

[30] W.F. Rogge, L.M. Hildemann, M.A. Mazurek, G.R. Cass, B.R.T. Simoneit, “Sources of fine organic aerosol. 1. Charbroilers and meat cooking operations”, Environmental Science Technology, vol. 25(6), pp. 1112–1125, 1991.

[31] L.M. Hildemann, G.R. Markowski, G.R. Cass, “Chemical composition of emissions from urban sources of fine organic aerosol”. Environmental Science Technology, vol. 25(4), pp. 744-759, 1991.

[32] Turkey Statistical Institute (TSI), “Turkey's Statistical Yearbook”, 2013, http://www.turkstat.gov.tr/Kitap.do?metod=KitapDetay&KT_ID=0&KITAP_ID=1, [Accessed: Feb. 12, 2020].

[33] M.K. Shrivastava, R. Subramanian, W.F. Rogge, A.L. Robinsona, “Sources of organic aerosol: Positive matrix factorization of molecular marker data and comparison of results from different source apportionment models”, Atmospheric Environment, vol. 41(40), pp. 9353–9369, 2007.

[34] Y.-C. Li, J.Z. Yu, S. Sai, H. Ho, J.J. Schauer, Z. Yuan, A.K.H. Lau, P.K.K. Louie, “Chemical characteristics and source apportionment of fine particulate organic carbon in Hong Kong during high particulate matter episodes in winter 2003”, Atmospheric Research, vol. 120–121, pp. 88–98, 2013.

[35] Gazette, “Causing Odor Control of Emission Regulations”, No: 27692, 4 September 2010.

[36] W.F. Rogge, P.M. Medeiros, B.R.T. Simoneit, “Organic Compounds in Dust from Rural and Urban Paved and Unpaved Roads Taken During the San Joaquin Valley Fugitive Dust Characterization Study”, Environmental Engineering Science, vol. 29(1), pp. 1-13, 2012.

[37] S. Han, J.-S. Youn, Y.-W. Jung, “Characterization of PM10 and PM2.5 source profiles for resuspended road dust collected using mobile sampling methodology”, Atmospheric Environment, vol. 45(20), pp. 3343-3351, 2011.

[38] K. Hussain, M. Rahman, A. Prakash, R.R. Hoque, “Street dust bound PAHs, carbon and heavy metals in Guwahati city – Seasonality, toxicity and sources”, Sustainable Cities and Society, vol. 19, pp. 17-25, 2015.

[39] F. Amato, O. Favez, M. Pandolfi, A. Alastuey, X. Querol, S. Moukhtar, B. Bruge, S. Verlhac, J.A.G. Orza, N. Bonnaire, T. Le Priol, J.-F. Petit, J. Sciare, “Traffic induced particle resuspension in Paris: Emission factors and source contributions”, Atmospheric Environment, vol. 129, pp. 114-124, 2016.

[40] Z. Li, P.K. Hopke, L. Husain, S. Qureishi, V.A. Dutkiewicz, J.J. Schwab, F. Drewnick, K.L. Demerjian, “Sources of fine particle composition in New York City”, Atmospheric Environment, vol. 38(38), pp. 6521–6529, 2004.

[41] Y. Wang, P.K. Hopke, X. Xia, O.V. Rattigan, D.C. Chalupa, M.J. Utell, “Source apportionment of airborne particulate matter using inorganic and organic species as tracers”, Atmospheric Environment, vol. 55, pp. 525-532, 2012.

[42] J.C. Chow, J.G. Watson, D.H. Lowenthal, R.J. Countess, “Sources and chemistry of PM10 aerosol in Santa Barbara County, CA”, Atmospheric Environment, vol. 30(9), pp. 1489-1499, 1996.

[43] E. Avşar, A. Hanedar, I. Toroz, K. Alp, B. Kaynak, “Investigation of P10 Concentrations And Noise Levels of The Road Sweepers Operating In Istanbul-Turkey: A Case Study”, Fresenius
Environmental Bulletin, vol. 19(9), pp. 2033-2039, 2010.

[44] J. Zhou, T. Wang, Y. Zhang, N. Zhong, P.M. Medeiros, B.R.T. Simoneit, “Composition and sources of organic matter in atmospheric PM10 over a two year period in Beijing”, Atmospheric Research, vol. 93(4), pp. 849-861, 2009.

[45] M.A. Bari, G. Baumbach, J. Brodbeck, M. Struschka, B. Kuch, W. Dreher, G. Scheffknecht, “Characterisation of particulates and carcinogenic polycyclic aromatic hydrocarbons in wintertime wood-fired heating in residential areas”, Atmospheric Environment, vol. 45(40), pp. 7627-7634, 2011.

[46] K. Alp, V. Eroğlu, O. Borat, “İstanbul da hava Kirlenmesi ve önleme tedbirlerinin değerlendirilmesi (in Turkish)”, In Proceedings Air Pollution Control Symposium, Istanbul Technical University, 8-18 March, 1993

[47] M. Kara, N. Mangır, A. Bayram, T. Elbir, A Spatially High Resolution and Activity Based Emissions Inventory for the Metropolitan Area of Istanbul, Turkey”, Aerosol Air Quality Research, 14, 10–20, 2014.

[48] B.M. Didyk, B.R.T. Simoneit, L.A. Pezoa, M.L. Riveros, A.A. “Flores, Urban aerosol particles of Santiago, Chile: organic content and molecular characterization”, Atmospheric Environment, vol. 34(8), pp. 1167-1179, 2000.

[49] N.J. Pekney, C.I. Davidson, A. Robinson, L. Zhou, P. Hopke, D. Eatough, W.F. Rogge, “Major Source Categories for PM2.5 in Pittsburgh using PMF and UNMIX”, Aerosol Science and Technology, vol. 40(10), pp. 910-924, 2006.

[50] O. Sevimoğlu, “Greenhouse Gas Mitigation Works and Measures Taken Against Climate Change: Case of Istanbul”, VII. Atmospheric Science Symposium, Istanbul, pp. 686-697, 28-30 April 2015.

[51] Enerji Piyasaları Denetleme Kurulu (EPDK), Petrol Piyasası Sektör Raporu, 2014. https://www.epdk.org.tr/Detay/Icerik/3-0-107/yillik-sektor-raporu, [Accessed Feb. 14, 2020].

[52] S. Becagli, D.M. Sferlazzo, G. Pace, A. Di Sarra, C. Bommarito, G. Calzolai, C. Ghedini, F. Lucarelli, D. Meloni, F. Monteleone, M. Severi, R. Traversi, R. Udisti, “Evidence for heavy fuel oil combustion aerosols from chemical analyses at the island of Lampedusa: a possible large role of ships emissions in the Mediterranean”, Atmospheric Chemistry and Physics, vol. 12, pp. 3479–3492, 2012.

[53] A.A. Campos–Ramos, A. Aragon–Pina, A. Alastuey, I. Galindo–Estrada, X. Querol, “Levels, composition and source apportionment of rural background PM10 in western Mexico (State of Colima)”, Atmospheric Pollution Research, vol. 2(4), pp. 409-417, 2011.

[54] Y. Cheng, S., Lee, Z. Gu, K. Ho, Y. Zhang, Y. Huang, J.C. Chow, J.G. Watson, J. Cao, R. Zhang, “PM2.5 and PM10-2.5 chemical composition and source apportionment near a Hong Kong roadway”, Particuology, vol. 18, pp. 96-104, 2015.

[55] D. Mooibroek, M. Schaap, E.P. Weijers, R. Hoogerbrugge, “Source apportionment and spatial variability of PM2.5 using measurements at five sites in the Netherlands”, Atmospheric Environment, vol. 45(25), pp. 4180-4191, 2011.

[56] W.F. Rogge, L.M. Hildemann, M.A. Mazurek, G.R. Cass, B.R.T. Simoneit, “Sources of fine organic aerosol. 6. Cigarette smoke in the urban atmosphere”, Environmental Science Technology, vol. 28(7), pp. 1375–1388, 1994.
[57] Worlds Health Organization (WHO), “Report on the Global Tobacco Epidemic, 2013: Enforcing bans on tobacco advertising, promotion and sponsorship”, 2013. https://apps.who.int/iris/bitstream/handle/10665/85380/9789241505871_eng.pdf;jsessionid=50136D6997B82D936E43969DD43B897D?sequence=1. [Accessed Feb. 14, 2020].

[58] W.W. Nazaroff, N.E. Klepeis, “Environmental tobacco smoke particles. In: Lidia Morawska and Tunga Salthammer (eds), Indoor Environment: Airborne Particles and Settled Dust”, Wiley-VCH, Weinheim, pp. 467, 2003.

[59] S. Mentese, N.A. Mirici, M.T. Otkun, C. Bakar, E. Palaz, D. Tasdibi, S. Cevizci, O. Cotuker, “Association between respiratory health and indoor air pollution exposure in Canakkale, Turkey”, Building and Environment, vol. 93(1), pp. 72-83, 2015.

[60] J.G. Watson, J.C. Chow, L.W.A. Chen, D.H. Lowenthal, E.M. Fujita, H.D. Kuhns, D.A. Sodeman, D.E. Campbell, H. Moosmueller, D. Zhu, N. Motallebi, “Particulate emission factors for mobile fossil fuel and biomass combustion sources”. Science of the Total Environment, vol. 409(12), pp. 2384-2396, 2011.

[61] J.H., Lee, S. Lim, “The selection of compact city policy instruments and their effects on energy consumption and greenhouse gas emissions in the transportation sector: The case of South Korea”, Sustainable Cities and Society, vol. 37, pp. 116-124, 2018.

[62] S. Önder, S. Dursun, “Air borne heavy metal pollution of Cedrus libani (A. Rich.) in city center of Konya (Turkey)”, Atmospheric Environment, vol. 40(6), pp. 1122-1133, 2006.

[63] W.F. Rogge, L.M. Hildemann, M.A. Mazurek, G.R. Cass, B.R.T. Simoneit, “Sources of fine organic aerosol. 4. Particulate abrasion products from leaf surfaces of urban plants”, Environmental Science and Technology, vol. 27(13), pp. 2700–2711, 1993.

[64] J.C. Chow, J.G. Watson, D.H. Lowenthal, P.A. Solomon, K.L. Magliano, S.D. Ziman, L.W. Richards, “PM10 source apportionment in California’s San Joaquin valley” Atmospheric Environment, vol. 26(18), pp. 3335-3354, 1992.

[65] C. Deniz, Y. Durmuşoğlu, “Estimating shipping emissions in the region of the Sea of Marmara, Turkey”, Science of the Total Environment, vol. 390(1), pp.255-261, 2008.

[66] U. Kesgin, N. Vardar, “A study on exhaust gas emissions from ships in Turkish Straits”. Atmospheric Environment, vol. 35(10), pp. 1863-1870, 2001.

[67] M.C. Bove, P. Brotto, F. Cassola, E. Cuccia, D. Massabò, A. Mazzino, A. Piazzalunga, P. Prati, “An integrated PM2.5 source apportionment study: Positive Matrix Factorisation vs. the chemical transport model CAMx”, Atmospheric Environment, vol. 94, pp. 274-286, 2014.

[68] S. Tsunogai, “Sea salt particles transported to the land”, Tellus, vol. 27(1), pp. 51–58, 1975.

[69] K. Anlauf, S.-M. Li, R. Leaitch, J. Brook, K. Hayden, D. Toom-Sauntry, A. Wiebe, “Ionic composition and size characteristics of particles in the Lower Fraser Valley: Pacific 2001 field study”, Atmospheric Environment, vol. 40(15), pp. 2662–2675, 2006.

[70] A. Tobias, L. Pérez, J. Diaz, C. Linares, J. Pey, A. Alastreuy, X. Querol, “Short-term effects of particulate matter on total mortality during Saharan dust outbreaks: A case-crossover analysis in Madrid (Spain)”. Science of the Total Environment, vol. 412–413, pp. 386-389, 2011.

[71] E. Remoundaki, A. Bourliova, P. Kokkalis, R.E. Mamouri, A. Papayannis, T. Grigoratos,
C. Samara, M. Tsezos, “PM10 composition during an intense Saharan dust transport event over Athens (Greece)”, Science of the Total Environment, vol. 409, pp. 4361-4372, 2011.

[72] D.W. Griffin, N. Kubilay, M. Koçak, M.A. Gray, T.C. Borden, E.A. Shinn, “Airborne desert dust and aeromicrobiology over the Turkish Mediterranean coastline”, Atmospheric Environment, vol. 41(19), pp. 4050-4062, 2007.

[73] S.-H. Chen, J. Dudhia, J. S. Kain, T. Kindap, E. Tan, “Development of the online MM5 tracer model and its applications to air pollution episodes in Istanbul- Turkey and Sahara dust transport”, Journal of Geophysics and Research, vol. 113, pp. D11203, 1-24, 2008.

[74] B. Kabataş, A. Ünal, R.B. Pierce, T. Kindap, L. Pozzoli, “The contribution of Saharan dust in PM10 concentration levels in Anatolian Peninsula of Turkey”, Science of the Total Environment, vol. 488–489, pp. 413-421, 2014.

[75] T. Agacayak, T. Kindap, A. Unal, L. Pozzoli, M. Mallet, F. Solmon, “A case study for Saharan dust transport over Turkey via RegCM4.1 model”, Atmospheric Research, vol. 153, pp. 392-403, 2015.

[76] G. Cadelis, R. Tourres, J. Molinie, Short-Term Effects of the Particulate Pollutants Contained in Saharan Dust on the Visits of Children to the Emergency Department due to Asthmatic Conditions in Guadeloupe (French Archipelago of the Caribbean), Plosone, vol. 9(3): pp. e91136, 2014.

[77] N. Pérez, J. Pey, X. Querol, A. Alastuey, J.M. López, M. Viana, “Partitioning of major and trace components in PM10–PM2.5–PM1 at an urban site in Southern Europe”, Atmospheric Environment, vol. 42(8), pp. 1677-1691, 2008.

[78] S. Tilev-Tanriover, A. Kahraman, “Saharan dust transport by Mediterranean cyclones causing mud rain in Istanbul”, Weather, vol. 70, pp. 145-150, 2015.

[79] İstanbul Metropolitan Municipality (IMM), Progress Report, pp. 159, 2014 https://www.ibb.istanbul/Uploads/2016/12/ibb_faaliyetraporu2014.pdf, [Accessed Feb. 14, 2020]

[80] S. Mallone, M. Stafoggia, A. Faustini, G.P. Gobbi, A. Marconi, F. Forastiere, “Saharan Dust and Associations between Particulate Matter and Daily Mortality in Rome, Italy”, Environmental Health Perspective, vol. 119(10), pp.1409–1414, 2011.

[81] A. Karanasiou, N. Moreno, T. Moreno, M. Viana, F. De Leeuw, X. Querol, “Health effects from Sahara dust episodes in Europe: Literature review and research gaps”, Environment International, vol. 47, pp. 107-114, 2012.

[82] Orman Atlası, Orman ve Su İşleri Bakanlığı, Orman Genel Müdürlüğü, 2013, https://www.ogm.gov.tr/ekutuphane/Yayinlar/Orman%20Atlasi.pdf, [Accessed Feb 12, 2020]

[83] X. Wu, T.V. Vu, Z. Shi, R.M. Harrison, D. Liu, K. Cen, “Characterization and source apportionment of carbonaceous PM2.5 particles in China - A review”, Atmospheric Environment, vol. 189, pp. 187-212, 2018.

[84] Türkiye İstatistik Kurumu (TÜİK), Seçilmiş Göstergelerle İstanbul 2013, Yayın No: 4182, ISSN: 1307-0894, 2013.

[85] C. Louis, Y. Yao Liu, P. Tassel, P. Perret, A. Chaumond, M. André, “PAH, BTEX, carbonyl compound, black-carbon, NO2 and ultrafine particle dynamometer bench emissions for Euro 4 and Euro 5 diesel and gasoline passenger cars”, Atmospheric Environment, vol. 141, pp. 80-95, 2016.
[86] D. Rutherford, L. Ortolano, “Air quality impacts of Tokyo’s on-road diesel emission regulations”, Transportation Research Part D: Transport and Environment, vol. 13(4), pp. 239-254, 2008.

[87] A. Akkoyunlu, F. Ertürk, “Evaluation of air pollution trends in Istanbul”, International Journal of Environment and Pollution, vol. 18(4), pp. 388-397, 2002.

[88] M. Mazaheri, G.R. Johnson, L. Morawska, “An inventory of particle and gaseous emissions from large aircraft thrust engine operations at an airport”, Atmospheric Environment, vol. 45(20), pp. 3500-3507, 2011.

[89] M.A. Cameron, M.Z. Jacobson, S.R.H. Barrett, H. Bian, C.C. Chen, S.D. Eastham, “An intercomparative study of the effects of aircraft emissions on surface air quality”, Journal of Geophysical Research: Atmospheres, vol. 122, pp. 8325-8344, 2017.

[90] D. Phoenix, A. Khodayari, D. Wuebbles, K. Stewart, “Aviation impact on air quality present day and mid-century simulated in the Community Atmosphere Model (CAM)”, Atmospheric Environment, vol. 196, pp. 125-132, 2019.

[91] Devlet Hava Meydanları İşletmesi (DHMİ), İSTANBUL ATATÜRK HAVALİMANI, Sera Gazı Beyanı Doğrulama Açıklaması (2014 Yılı Dönemi). Web:https://ataturk.dhmi.gov.tr/Sayfalar/icerek-detay.aspx?oid=1231, [Accessed Feb 12, 2020]

[92] Pendik Belediyesi Strateji Geliştirme Müdürlüğü, “Pendik İlçesi Karbon Ayak Izi Çalışması”, İstanbul, 2014, http://www.skb.gov.tr/wp-content/uploads/2017/01/Pendik-Ilcesi-Karbon-Ayak-Izi.pdf, [Accessed Feb 12, 2020].