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Authors: Orhan Sevimoğlu

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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.

*Corresponding Author: sevimoglu@gtu.edu.tr
[1]Gebze Technical University, Department of Environmental Engineering, Gebze, Kocaeli, Turkey. ORCID ID: 0000-0003-4861-5154

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.

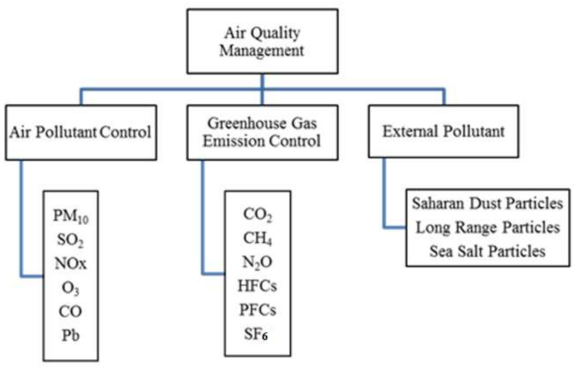

Figure 1. Control parameters in air quality management

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 μg/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 (μg m^{-3}) (O_3= ppb).

	PM_{10}	**PM_{10} winter**	**PM_{10} summer**	**PM_{10} Spring**	**NOx**	**SO_2**	**O_3**	**CO**	
TAAQS (in 2014)	**100**	**100**	**100**	**100**	**60**	**20**	**120**	**10000**	
01.1990		225				450			[87]
07.1990			45			75			[87]
1991	103.8	155				219			[16]
1993-1994						308			[17]
1994-1995						249.8			[17]
2000	65				50	30	25	1200	[18]
2002 European Side					138	38		1550	[19]
2002 Asian Side					98	18		1700	[19]
2002-2003		65.3	55.6			22.95			[20]
2005-2009	58								[21]
2007-2009					60		15.2		[22]
2007	69±27.9				91±65.1	12.1±10.1		686±428	[23]
2008	39.1	44.5	29.8						[15]
13.01.2008			129						[15]
12.04.2008				107					[15]
11.2007- 06.2009	39.1	48		55.2					[24]
01.01.2010-31.12.2012	50				56	10	29		[25]
2003-2013	53.60	57.45	49.75			10.43		718	[26]

Table 2. Major sources of air pollutants in Istanbul

Major Sources of Air Pollutants	**Criteria Air Pollutants Emission**				**GHG Emission**		**Source Type**
	PMx	**SO_2**	**NOx**	**CO**	**CO_2**	**CH_4**	
Meat-Cooking Operations	X						1
Paved Road Dust	X						1
Wood Burning	X			X	X		1
Coal Burning	X	X	X	X	X		1
Fuel Oil Burning	X	X	X	X	X		1
Tobacco Smoke	X			X	X		1
Diesel Vehicles	X	X	X	X	X		1
Gasoline Vehicles	X	X	X	X	X		1
Natural Gas Combustion	X		X		X		1
Vegetative Detritus	X						2
Maritime Emission	X	X	X	X	X		1
Landfill Gas					X	X	1
Sea Salt Particles	X						2
Saharan Dust	X						2
Aviation Emission	X	X	X		X		1

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 PM_{10} (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 $\mu g\ m^{-3}$, 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, SO_2 concentration decreased from 145 to 22 µg m^{-3} about six times less from 1994 to 2004.

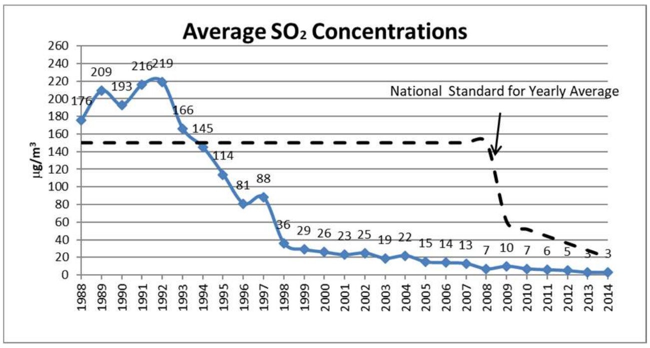

Figure 2. Yearly average of 24-h SO_2 concentrations [50].

The lignite usage degreased 18 fold and natural gas usage increased 10 fold. As a result, SO_2 concentrations drop 29 fold as of 2014. Consequently, the decrease of the SO_2 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 SO_4^{-2} significantly to the total PM mass [52]. The fuel oil combustion contributes accounting for 18% of the PM_{10} mass in the city of Colima, Western Central Mexico [53]. Cheng [54] reported that $PM_{2.5}$ 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 $PM_{2.5}$ 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 PM_{10} 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 $PM_{2.5}$ [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 $PM_{2.5}$ 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 $PM_{2.5}$ 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.

Years	**1994**	**2004**	**2014**
Number of Subscribers	300,000	2,606,300	5,660,095
Number of subscribers using gas (Unit)	215,000	2,280,704	5,357,080
Amount of Consumed Gas (Year/m^3)	353,111,160	3,025,985,565	4,943,890,773
Amount of Consumed Gas per subscriber using gas (m^3/subscriber)	1642	1326	922

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). The 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 13th of April 2008 that composed of 57% crustal material [15]. Perez [77] reported the PM elevation seen in PM_{10-1} 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 Kömürcüda 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 (Kömürcüda) [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.

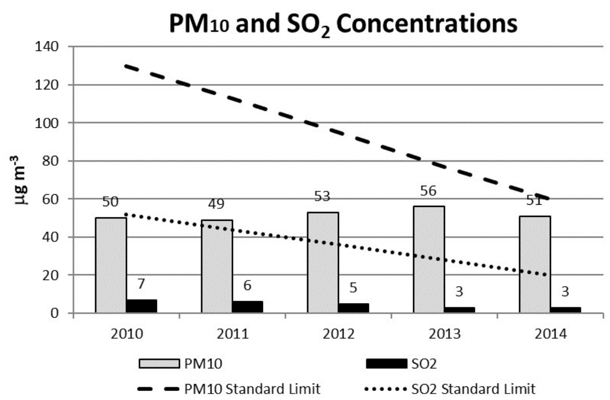

Figure 3. PM_{10} and SO_2 concentrations from 2010 to 2014 in Istanbul [79].

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 rang 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, Kömürcüoda) 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.

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