ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ – ΤΜΗΜΑ ΒΙΟΜΗΧΑΝΙΚΗΣ ΔΙΟΙΚΗΣΗΣ & ΤΕΧΝΟΛΟΓΙΑΣ
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Ανασχεδιασμός Δικτύου Περιβαλλοντικού Ελέγχου

(Redesign of Environmental Monitoring Network)

Διπλωματική Εργασία

του Ιωάννη Μαρκουδάκη

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Περιεχόμενα

Πρόλογος

Ο σχεδιασμός δικτύου παρακολούθησης της ρύπανσης του αέρα και των υδατικών αποδεκτών έχει αποτελέσει αντικείμενο εκτεταμένης έρευνας όπως φαίνεται τόσο από τις σχετικές επιστημονικές δημοσιεύσεις όσο και από τις υποδείξεις επίσημων εθνικών ή διεθνών φορέων που ασχολούνται με την άσκηση περιβαλλοντικής πολιτικής. Ο σχεδιασμός αυτός αφορά κυρίως στη βελτιστοποίηση της χωροθέτησης *n* σταθμών με προκαθορισμένο εύρος προδιαγραφών ανά ρύπο, σύμφωνα με διεθνή (κυρίως Ευρωπαϊκά) πρότυπα και συνιστώμενες πρακτικές, ώστε να διασφαλίζεται χωροχρονικά η συγκρισιμότητα των αποτελεσμάτων. Ωστόσο η βιβλιογραφία θέσης και επίλυσης του αντιστρόφου προβλήματος, δηλαδή όχι της συνολικής πρώτης εγκατάστασης ή προσθήκης αλλά της αφαίρεσης σταθμών μέτρησης (με ή χωρίς αντικατάσταση) υπάρχοντος δικτύου, είναι σχεδόν ανύπαρκτη ενώ ενδιαφέρει άμεσα την πράξη. Η επισήμανση του αντίστροφου προβλήματος και του τρόπου επίλυσής του οφείλεται στο διδάσκοντα σχετικά θέματα στο ΜΠΣ ομότιμο καθηγητή κ. Φραγκίσκο Μπατζιά, ο οποίος μου το εμπιστεύθηκε θεωρώντας ότι έχω την απαιτούμενη γνώση λόγω της θέσης μου ως αναλυτής περιβαλλοντικών θεμάτων στη Διεύθυνση Κλιματικής Αλλαγής και Ποιότητας της Ατμόσφαιρας στο Υ.Π.Α.Π.ΕΝ. και παράλληλα μηχανικού ανάπτυξης μικροϋπολογιστικών συστημάτων. Η σχετική έρευνα πραγματοποιήθηκε από Σεπτέμβρη 2014 έως και Απρίλιο 2015 υπό τη δημιουργική καθοδήγηση του αναπληρωτή καθηγητή κ. Δημήτριου Σιδηρά, ως υπεύθυνου των περιβαλλοντικών μαθημάτων του ΜΠΣ, τον οποίο και θερμά ευχαριστώ. Επίσης θα ήθελα να ευχαριστήσω τους συναδέλφους στο Υ.Π.Α.Π.ΕΝ. κ.κ. Χρήστο Αντωνόπουλο και Δημήτρη Ιατρού, την οικογένειά μου για τη συμπαράστασή τους, καθώς και τον ομότιμο καθηγητή κ. Φραγκίσκο Μπατζιά για την πολύτιμη συνεισφορά του.

Chapter 1 – Introduction

Over the last half of the 20th century air pollution has become a political issue and a severe health problem in most of the developed economies of the world. The concentrations of toxic pollutants reached levels that pose risks to human health, together with overpopulation gathered in megacities and as an aftermath the massive industry activities.

The potential for serious consequences of exposure to high levels of ambient air pollution was made clear in the mid-20th century, when cities in Europe and the United States experienced episodes of air pollution, such as the infamous London Fog of 1952 and Donora Smog of 1948 that resulted in large numbers of excess deaths and hospital admissions. In the last years, problems connected with air quality in great urban areas and with the stresses that the atmospheric pollution cause on the human health, have urged the European Community to create a framework to establish criteria for air quality data collection and analytical techniques with particular reference to the location and the **minimum number of sampling sites**. In particular, it has been proposed that **air quality monitoring focused on the protection of human health**, must be performed in areas where the exposition to the high levels of pollution is maximum for a significant period of time and that the areas chosen for monitoring should be representative of other similar areas.

The re-design/optimization of an existing **Air Quality Monitoring Network (AQMN)** by excluding or relocating monitoring stations with specified methods and criteria is a complicated procedure. The present work attempts to examine and define some of these criteria together with an evaluation model developed using the method of multiple linear regression.

In order to achieve this purpose, two air pollution episodes are going to be studied; the first is a **photochemical ozone episode** in the city of Athens and the second one is **a Particulate Matter smog episode** in the city of Istanbul. Both cities are in the east Mediterranean territory with more or less similar climate characteristics, typical for their specific geographic location. Each of these cities has also specific and unique cultural and topographic characteristics that have to be taken in account. Both of these areas are very important for studies which evaluating the relationships between monitoring sites in urban environments and their utility for environmental monitoring programs and epidemiologic studies. Most of the studies are trying to establish uniform criteria for classifying and designating locations for air monitoring stations. Sometimes these criteria are not applicable in such areas with certain particularities.

The city of Athens has the unique particularity of the **classical Antiquities** scattered in the center of the city and the suburbs, facing the significant issue for their protection from various traffic and industrial pollutants. On the other hand the city of Istanbul is the largest city in the European territory with **serious environmental problems** due to heavy air pollution since the beginning of industrialization of the area. The protection of sensitive receptors in a very densely populated city without methodically arranged spatial planning until recently, is another particularity that has to be considered.

The objectives of a new **Air Quality Monitoring Station (AQMS)** setup are presented here and we are trying to categorize the proposed Macro and Micro scale siting criteria for relocating an AQMS. Simultaneously, these criteria could be useful for a possible exclusion/elimination from the network of an AQMS in operation. An active AQMS should be a candidate for exclusion if it is characterized as "redundant". A redundant AQMS is a less "statistical representative" or a "least informative" one. The measurements of the specific site should not be representative according to its current classification and this is also studied with the assistance of the applicable evaluation model, during the aforementioned air pollution episodes at **chapter 7**.

The initial **classification of monitoring sites** from the governmental authorities is another subject of the present work and it is discussed further in such cases, as we'll see in Athens AQMN, where the initial classifications of most of the stations had been done without future development predictions in the early 80's. **A deficient classification or "a not further updated one" through the years reflects a poor representative site**. The classification of those AQMSs from Athens' AQMN was preferred to be analyzed against Istanbul's sites because for the former there is additional information and historical data since 1984 and there is also significant information for the spatial structure and planning of the city of Athens.

The necessities and objectives of an AQMN have been reported in literature (Liu et al., 1986; Liu et al., 1977; Modak, and Lohani, 1985; Ludwig et al., 1976) and can be summarized as: (1) Planning and implementing air quality protection and air pollution control strategies; (2) Ensuring that the air quality standard is achieved; (3) Preventing or responding quickly to air quality deterioration; (4) Evaluating the exposure population and other potential receptors; (5) Controlling emissions from significantly important sources. These objectives also cover the minimization of network cost. It is difficult to design an AQMN covering all the objectives stated above. **Most of the reported methods applied to specific situations wherein one or two of the previous objectives are considered.**

The role of AQMNs in early warning systems is also discussed in this study and we will try to recommend a monitoring station as the most representative of the network as a **"pilot" indication of a potentially evolving air pollution (PM_{10}) episode.**

The assessment of **how representative (for a specific pollutant)** is a part of an active monitoring network (although it is difficult to assess using monitoring data only) in certain areas is also discussed.

Finally at Annex I and Annex II of the present work, are referenced some case studies and the **implementation of contingency plans**. **Annex III illustrates the international air quality real time information web-sites**, with concentration levels for most of the public related pollutants, maps and in some cases pollution forecasts.

The time-series raw data for ozone concentrations are officially provided from the web-site of the Greek Ministry of Productive Reconstruction, Environment and Energy. The Turkish Ministry of Environment and Urban Planning also provided the particulate matter time-series data from its web-site.

1. Air Pollutants and sampling methods

1.1. Urban area environment

Managing sustainable urban development with respect to health, environment, and climate effects is the most pressing problem in mega-cities. The urban atmosphere in particular is very often affected by pollution from various anthropogenic sources and consequently the health of inhabitants is endangered (Yu et al., 2011). Particulate matter (PM) is a component that has been linked consistently with serious health effects and importantly levels of which can be estimated worldwide. Exposure to PM has been associated with a wide range of effects on health, but effects on mortality are arguably the most important, and are also most amenable to global assessment (Aaron J. Cohen, 2005).

In urban areas, PM comes from a variety of sources such as car, trucks, buses, factories, construction sites, unpaved roads, stone crushing, and burning of wood. A common measure of particles used to quantify pollution concentrations and their effects is the PM_{10} value. Janssens et al. (1997) found that the larger diameter component consists of urban PM_{10} consisted mainly of locally deposited carbon and road dust. An epidemiological study by Schwartz et al. (1996) has suggested that atmospheric **PM in urban area has a clear correlation with number of a daily deaths** and hospitalizations as a consequence of pulmonary and cardiac disease response. Particulate pollution, one of the major environmental health problems, causes approximately three million deaths per year in the world (Borrego et al., 2006).

Combustion of fossil fuels for transportation, power generation, and other human activities produces a complex mixture of pollutants comprising literally thousands of chemical constituents (Derwent 1999; Holman 1999). Exposure to such mixtures is a ubiquitous feature of urban life. The precise characteristics of the mixture in a given locale depend on the relative contributions of the different sources of pollution, such as vehicular traffic and power generation, and on the effects of the local geoclimatic factors.

The **relative contribution of different combustion sources** is a function of economic, social and technological factors, but all mixtures contain certain primary gaseous pollutants, such as sulfur dioxide (SO2), nitrogen oxides (NOX) and carbon monoxide (CO), that are emitted directly from combustion sources, as well as secondary pollutants, such as ozone (O3), that are formed in the atmosphere from directly-emitted pollutants. **Quantifying the magnitude** of these health impacts in cities worldwide, however, presents considerable challenges owing to the limited availability of information on both effects on health and on exposures to air pollution in many parts of the world. Man-made urban air pollution is a complex mixture with many toxic components.

Long-range transportation of dust particles, which usually have a median diameter considerably less than 10 mm, has been identified as an important contribution to the regional and global air pollution, the global fluxes of chemical elements and climate (Walata et al., 1986) Every year **the Mediterranean territory** is facing “red dust” episodes by long range transported Sahara’s desert dust, which is the main global source of atmospheric mineral dust and produces about half of the annual mineral dust. Sahara dust transport can lead to PM levels that substantially exceed the established limit values. The review of the literature shows that the association of fine particles, $PM_{2.5}$, with total or cause-specific daily mortality is not significant during Saharan dust intrusions. However, regarding coarser fractions PM_{10} and $PM_{2.5–10}$ an explicit answer cannot be given. Some of the published studies state that they increase mortality during Sahara dust days while other studies find no association between mortality and PM_{10} or $PM_{2.5–10}$.

1.2. Industrial area environment

Despite many years of environmental regulation, atmospheric emissions and other effluents from either industrial processes or fuel combustion in industrial units impose risks and cause serious impacts on human health and on the natural and social environment (e.g. crops, forests, water resources, natural ecosystems, buildings, historical monuments, etc.). These impacts induce costs on society, which are, to a large extent, external costs as they are not reflected in the market price of the commodities and are not taken into account in the allocation of economic resources (S. Mirasgedis, V. Hontou, E. Georgopoulou, 2007)

The industrial areas designated by zoning regulations for use by industry, are often located in suburban areas and supplied with infrastructures consenting to efficiently carry out production and related business activities. Taking into account the quantities of air pollutants released on an annual basis at a group of installations level as well as the technological and structural characteristics of the corresponding typical installation, the incremental concentrations of air pollutants due to the operation of the industrial units under consideration are calculated by using the appropriate dispersion models. Such models are used independently or integrated, inside tools that calculate long-range transmission of air pollutants. Some of them are: The **Industrial Source Complex Model** (ISC), which is a Gaussian plume model used for transport modeling of primary air pollutants (PM10 , SO2, NOx, etc.) on a local scale (i.e. at distances up to 50 –100 km from the source) using a grid of 10×10 km; **The Windrose Trajectory Model (WTM)**, which models the chemical reactions of primary pollutants in the atmosphere and is used to estimate the concentration of primary and secondary air pollutants as well as acid deposition on a regional scale (covering all Europe and part of Asia); The **Source-Receptor Ozone Model (SROM)**, which estimates on a regional scale the concentrations of ozone formed due to atmospheric chemical reactions between NMVOCs and NOx in the presence of sunlight.

Air pollutants emitted by the various industrial activities are in continuous surveillance for their impact on human mortality and morbidity, agriculture, materials and climate change. The effect of the enhanced concentrations on the different receptor categories is estimated by using appropriate dose- or exposure- response functions. So, for example, impacts on human health result from a series of exposure-response functions developed on the basis of epidemiological studies of the relationship between pollutant concentration and health parameters of specific risk groups. In a similar way, effects on agriculture and on materials are calculated through functions relating crop yield changes or material degradation with changes in pollutants concentrations.

More recently, some studies have also presented compelling evidences that the level of *industrialization* (and not merely urbanization) is also related to poorer health (Downey and Van Willigen, 2005 and Evans and Kantrowitz, 2002). A good example of research showing the effect of industrial contexts on health is the large-scale study conducted by Boardman and colleagues (Boardman et al., 2008). In this study, and in agreement with expectations, results showed a positive correlation between living close to industrial activities and stress levels, even after controlling for the effect of several demographic variables such as gender and level of income. Studies that explore the relationship between industrial activities and health are especially important because there seems to be an unequal distribution of physical sites according with several demographic variables. In this sense, some studies suggest that poorer people, from underprivileged minorities, are the ones who end up living in the most industrialized and polluted places (Adeola, 1994, Brulle and Pellow, 2006 and Lima, 2008).

The Integrated Pollution Prevention and Control (IPPC) Bureau issued a specific Best Available Techniques Reference Document (BREF) for ranking Best Available Techniques (BAT) in the various industrial sectors on the basis of their cost effectiveness and environmental performance, considering the availability of relevant external cost estimates as a powerful tool to assist policy and decision-making process (European Commission, 2005a).

In the greater Athens area are located (2007) approximately 9200 industrial units, constituting the 44% of the total number of industrial units in Greece and contributing 38% of the total gross value added by this sector nationally (2007). **However, in a later survey and admeasurement there is a serious reduction in industrial activity due to the later and continuing economic crisis. Thus, the total number of industrial facilities that are still operating in 2015 is approximately 6500 units, with a trend for further decline (source: Industry Association of Athens & Piraeus, 2015).**

Industrial sectors and installations are diverse, varying from small handicraft shops up to large industrial units (e.g. refineries, iron and steel plants etc.) out of which, approximately 800 are legally characterized as of ‘ medium and high environmental burden ’. According to recent legislation (Law 3325/2005), all these units were obliged to apply BAT within the next 4 years and switch to natural gas when their connection to the gas pipeline network becomes technically feasible. On the basis of data and environmental factors collected in the framework of a recent project (Epem et al., 2001), it has been estimated that the 800 industrial installations identified as being of high and medium environmental burden emit approximately 3.1 kt PM_{10} , 17.4 kt SO_2 , 6.0 kt NOx , 28.0 kt VOC and 3.7 Mt CO_2 annually. These emissions constitute a significant part of the total quantities of air pollutants emitted in the greater area of Athens (Fig. 1.2a), corresponding to 57% for PM 10 , 54% for SO2 , 41% for VOC, 29% for CO2 but only 9% for NOx , of the total emissions. Most of the rest is emitted by road transport. The contribution of particular industrial sectors to the total emissions from industrial activities in the wider area of Athens is shown in Fig. 1.2**b.**

The oil processing sector, comprising two major refineries located in the area and a number of smaller units producing asphalt products and mineral oils, is responsible for the majority of SO2 (79.4%) and for half of NOx and CO2 emissions in Athens; its contribution to VOC emissions is also significant (29.8%) due to leakage from the fuel storage tanks located within the boundaries of the refineries. In addition to the VOC emissions from the tanks at refinery installations, fuel storage is responsible for a further 38% of total VOC emissions. Almost 67% of PM 10 emissions comes from the sector of non-metallic minerals (cement, ceramics and lime), which emits also significant quantities of NOx and CO2 (34% and 33% of total emissions respectively). Considerable quantities of PM_{10} are also emitted by metal processing installations (13.6% of the total). Chemical industry installations generate emissions of limited scale except for VOC (9%), while the contribution of the rest sectors to air pollutants ranges from 6% of SO x to 11% of VOC (S. Mirasgedis et al, 2008).

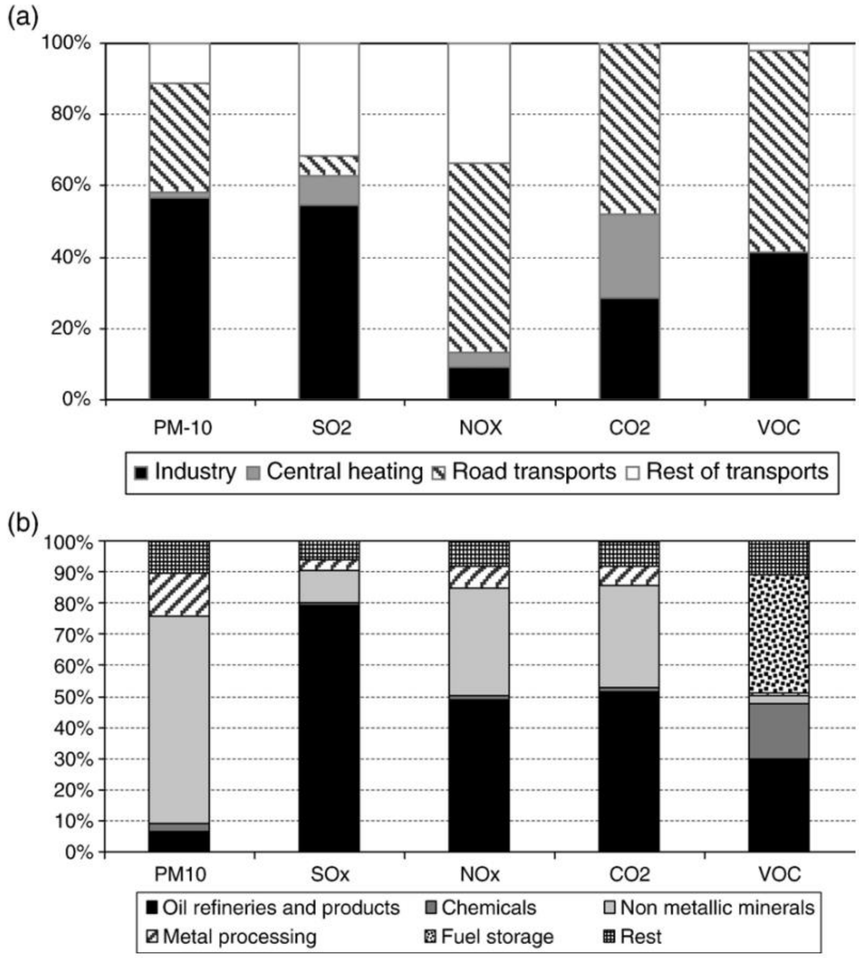
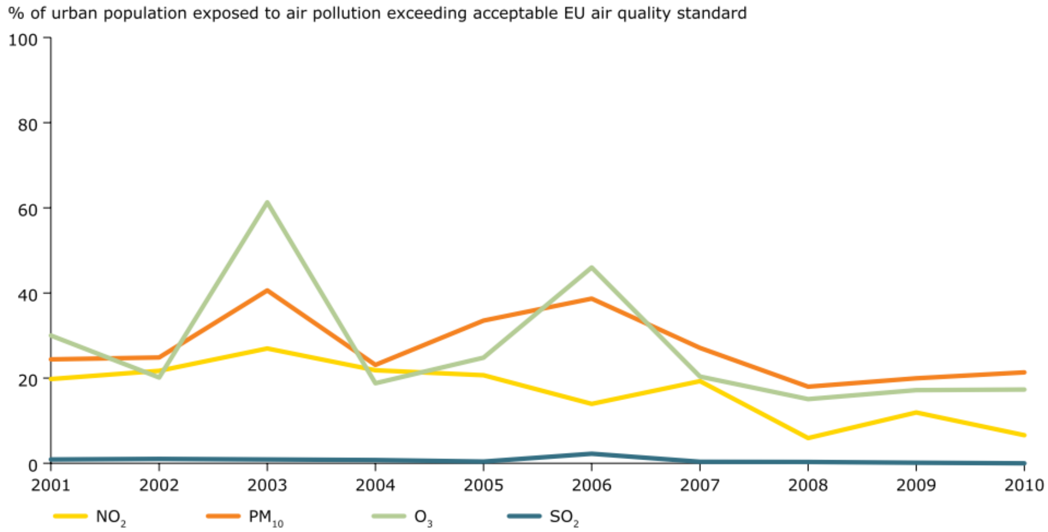


Fig. 1.2: Contribution of total emissions of air pollutants in the greater Athens area, disaggregated by (a) sector of economic activity and (b) sector/subsector of industrial activity. Source: S. Mirasgedis et al. / Environmental Impact Assessment Review 28 (2008)

1.3. Effects of air pollution on health

In extreme situations, air pollution episodes cause widespread public apprehension and are associated with measurable effects on health. Air pollution is usually the direct or indirect consequence of burning fuel for transport, industry, or domestic use, but may also come from other sources such as forest fires or volcanic eruptions. Episodes of pollution from the burning of fuel tend to occur not because of an increase in emissions, but because stagnant weather conditions impair their dispersal. In the developed world, episodes that occurred in the postwar decades are unlikely to be repeated, but there remains the risk of less severe episodes and of other disasters such as forest fires and volcanic eruption.

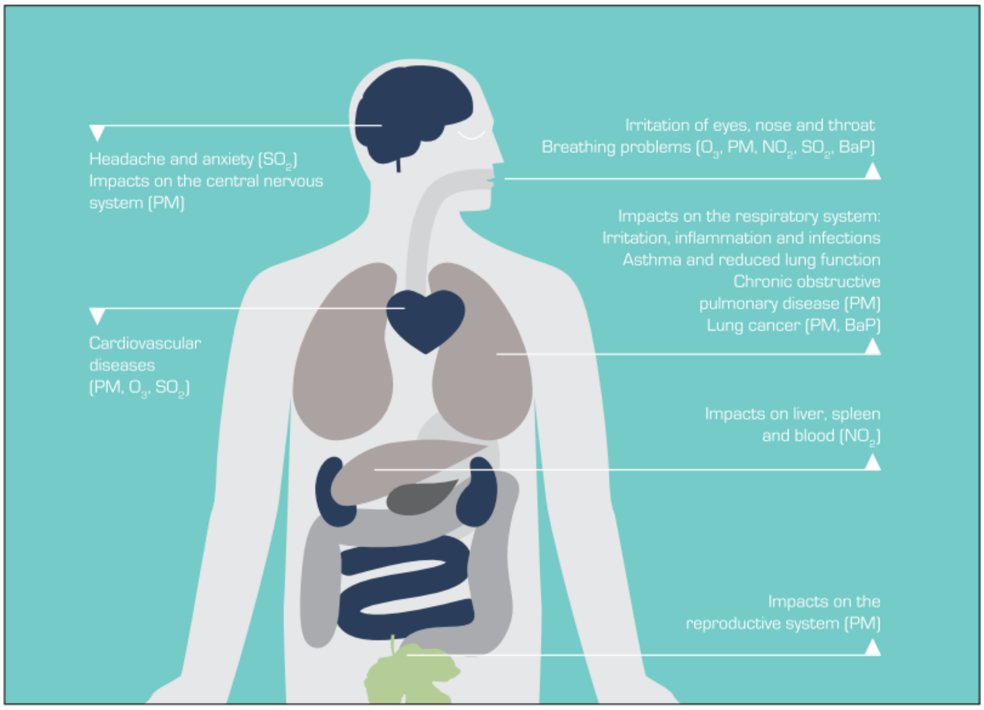


Episodes give information about the effects of pollution mixtures in different contexts. Unfortunately, this heterogeneity has not been successfully exploited for identifying the most harmful constituents of pollution or for investigating exposure-response relationships. The epidemiological principles of investigating episodes are straightforward, but in practice, there are many difficulties and assumptions that make comparison of different studies or meta-analysis very difficult (Anderson, 1999)

Although the **adverse consequences of particulate matter** on human health have been well documented, recently, special attention has been given to mineral dust particles, which may be a serious health threat. The main global source of atmospheric mineral dust is the Sahara desert, which produces about half of the annual mineral dust.

Sahara dust transport can lead to PM levels that substantially exceed the established limit values. A review was undertaken using the ISI web of knowledge database with the objective to identify all studies presenting results on the potential health impact from Sahara dust particles. The review of the literature shows that the association of fine particles, PM2.5, with total or cause-specific daily mortality is not significant during Saharan dust intrusions. However, regarding coarser fractions PM10 and PM2.5–10 an explicit answer cannot be given. Some of the published studies state that they increase mortality during Sahara dust days while other studies find no association between mortality and PM10 or PM2.5–10. The main conclusion of this review is that health impact of Saharan dust outbreaks needs to be further explored. Considering the diverse outcomes for PM_{10} and $PM_{2.5–10}$, future studies should focus on the chemical characterization and potential toxicity of coarse particles transported from Sahara desert mixed or not with anthropogenic pollutants. The results of this review may be considered to establish the objectives and strategies of a new European directive on ambient air quality. An implication for public policy in Europe is that to protect public health, anthropogenic sources of particulate pollution need to be more rigorously controlled in areas highly impacted by the Sahara dust. (A. Karanasiou, 2012)

The contribution of economic crisis enhanced the above mentioned problems caused by PM especially in Athens where during the winter months several episodes of PM smog appeared. The source of PM smog in the Greater Athens Area (GAA) is the massive burning of unsuitable wooden biomass.



Source: EEA, 2013f.

1.4. Effects of air pollution on ecosystems

Air pollution also harms the environment, and it is estimated that 71 % of the EU Natura 2000[1] area was exposed to eutrophication in 2010 (EC, 2013a). **Ground-level O3** can damage crops and other vegetation, impairing their growth. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. Acidification may lead to an increased mobilization of toxic metals increasing the risk of uptake in the food chain. Table 1.4 summarizes the main effects of air pollutants on the environment. The deposition of nitrogen compounds can also lead to eutrophication, an oversupply of nutrients that may lead to changes in species diversity and invasions of new species. In addition, toxic metals and POPs may have severe impacts on ecosystems. This is mainly due to their environmental toxicity, but in some cases it is also due to their tendency to bioaccumulate, a process whereby the toxin cannot be digested and excreted by animals, and therefore slowly accumulates in the animal's system, causing chronic health problems. The impacts of air pollution on the environment depend not only on the air pollutant emission rates but also on the location and conditions of the emissions. Factors such as meteorology and topography are also important, as these determine the transport, chemical transformation and deposition of air pollutants. Furthermore, the environmental impacts of air pollution also depend on the sensitivity of ecosystems to O_3 exposure, acidification, eutrophication, and toxic metals.

O_3 is formed near the ground, due to the emissions of precursor gases which can result from both human activity and natural processes. Downward transport of O3 that exists in the stratosphere or intercontinental transport of O3 may also contribute to higher background O3 concentrations at ground level, but probably not to peak O3 episodes originated at a regional scale. The principal mechanism for removing O3 from the atmosphere is deposition on the earth's surface, in particular through absorption by plants. This absorption damages plant cells,

[1] Natura 2000 is an EU-wide network of nature protection areas (EEA, 2012a) established under the 1992 Habitats Directive (EC, 1992). The aim of the network is to ensure the long-term survival of Europe's most valuable and threatened species and habitats.

impairing their ability to grow. In some sensitive plants, O3 can cause leaves to exhibit what appear to be burn marks. By impairing plants' reproduction and growth, high levels of O3 can thus lead to reduced agricultural crop yields, decreased forest growth, and reduced biodiversity.

Pollutant	Environmental effects
Particulate matter (PM)	Can affect animals in the same way as humans. Affects plant growth and ecosystem processes. Can cause damage and soiling of buildings. Reduces visibility.
Ozone (O_3)	Damages vegetation, impairing plant reproduction and growth, and decreasing crop yields. Can alter ecosystem structure, reduce biodiversity and decrease plant uptake of CO_2.
Nitrogen oxides (NO_x)	Contributes to the acidification and eutrophication of soil and water, leading to changes in species diversity. Acts as a precursor of ozone and PM, with associated environmental effects. Can lead to damage to buildings.
PAHs, in particular benzo-a-pyrene (BaP)	Is toxic to aquatic life and birds. Bioaccumulates, especially in invertebrates.
Sulphur oxides (SO_x)	Contributes to the acidification of soil and surface water. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of PM with associated environmental effects. Damages buildings.
Carbon monoxide (CO)	May affect animals in the same way as humans. Acts as a precursor of ozone.
Arsenic (As)	Highly toxic to aquatic life, birds and land animals. Soil with high arsenic content reduces plant growth and crop yields. Organic arsenic compounds are persistent in the environment and are subject to bioaccumulation.
Cadmium (Cd)	Is toxic to aquatic life. Cadmium is highly persistent in the environment, and bioaccumulates.
Lead (Pb)	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Effects on animal life include reproductive problems and changes in appearance or behaviour.
Mercury (Hg)	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Can affect animals in the same way as humans. Very toxic to aquatic life.
Nickel (Ni)	Nickel and its compounds can have highly acute and chronic toxic effects on aquatic life. Can affect animals in the same way as humans.
Benzene (C_6H_6)	Has an acute toxic effect on aquatic life. It bioaccumulates, especially in invertebrates. Leads to reproductive problems and changes in appearance or behaviour. It can damage leaves of agricultural crops and cause death in plants.

Table 1.4: Environmental Effects of air pollutants

1.4.1. Estimated impacts of ozone on vegetation

The direct exposure to O_3 is considered to be more damaging to vegetation than exposure to any other air pollutant (Ainsworth et al., 2012), with significant effects on the growth of trees, vegetation in general, and important crops such as wheat, soybean and rice (Ainsworth et al., 2012; Mills et al., 2011; Wilkinson et al., 2012). Harmens and Mills (2012) concluded that today's levels of O_3 exposure in northern and central Europe have the potential to reduce the rate of increase in forest living biomass by roughly 10 %, as compared to pre-industrial O_3 exposure levels. Trees are a significant carbon sink, and many studies have shown that O_3 reduces tree growth.

Harmens and Mills (2012) estimated that between 1990 and 2000, the reduction in carbon stored in vegetation that can be accounted for by O_3 concentrations was around 6 % globally and almost 4 % in Europe. Carbon storage by vegetation is still difficult to quantify, especially for forest ecosystems. There is a need to better understand how O_3 acts within the mix of climate, other pollutants and biotic stresses (e.g. insect pests and fungal diseases) that occur presently, and are also more likely to occur in future, in the context of a changing climate. Mills and Harmens (2011) calculated that (assuming soil moisture is not limiting to production), O3 impacts on wheat resulted in European losses in production of 27 million tons of grain in 2000. The study showed that effects would be greatest in parts of central Europe (e.g. Germany, France and Poland), as well as in some Mediterranean countries (e.g. Italy and Spain). Ozone-induced growth reductions also result in an economic loss for forest owners. For example, the annual economic loss for owners of Swedish forests has been estimated to be approximately EUR 40 million (Karlsson et al., 2005).

1.5. Air pollution effects on climate change

Atmospheric pollution and climate change are distinct problems, but they are linked in several key ways. GHGs, which cause global warming, generally have long lifetimes in the atmosphere, with CO_2 lasting about 100 years and CH_4 about 12 years. Traditional air pollutants, like SO_2, PM, O_3 and NO_X are short-lived, having lifetimes of a few days to weeks. Tropospheric O_3, BC — a constituent of PM — and CH_4 have a warming effect on climate and have relatively short lifetimes. They are therefore known as short-lived climate pollutants (SLCPs). **Table 1.5** summarizes the main effects of air pollutants on climate; it includes only pollutants regulated by the Air Quality Directive (EU, 2008c).

Tropospheric O_3 contributes directly to global warming as it absorbs some of the infrared energy emitted by the earth and creates warming effects in its immediate surroundings. Emissions of precursors to O_3 formation (CH_4, NMVOC, NOX and CO) are therefore important in this context. In addition, ozone's effects on vegetation decrease photosynthesis, thereby also reducing plant uptake of CO_2, which further enhances warming indirectly. Vegetation is a key terrestrial carbon sink, and O_3 impairs vegetation growth.

It is estimated that the indirect impacts of O_3 on the potential for global warming via its negative impacts on vegetation are of similar magnitude as its direct impacts as a greenhouse gas (GHG) (Sitch et al., 2007). Of the O_3 precursors, CH_4 has the largest influence leading to warming. As an O_3 precursor, NO_X contributes with positive radiative forcing (RF), leading to warming, but as a PM precursor (see below), it contributes to negative RF, leading to cooling

Also, the impact of NO_X on shortening the CH_4 lifetime contributes to negative RF. CO emissions contribute to positive RF due to its oxidation in the atmosphere to CO_2, by increasing the lifetime of CH_4 and due to its role in O_3 formation. Among the O_3 precursors, the smallest climate effect is caused by NMVOC emissions. Fine PM also has significant climate impacts. BC is one of the constituents of fine PM and has a warming effect, while other PM constituents (for instance, sulphates and nitrates) may cool the climate.

The largest contribution is formed by the emissions of BC, with a combination of BC having a direct positive RF effect due to its presence in the atmosphere and a positive indirect RF due to its deposition on snow and ice. BC is a product of incomplete combustion of organic carbon, and is emitted from traffic, fossil fuels and biomass burning (e.g. from domestic heating, agricultural or forest fires), and industry. The second-largest impact is by SO_2 emissions, which due to their role in sulphate aerosol formation, contribute to negative RF. The emissions of organic carbon and mineral dust both have a negative RF. Due to their role in nitrate aerosol formation, NO_X and NH_3 contribute to negative RF. Fine PM can also cause RF indirectly, by changing cloud properties like cloud reflectivity, distribution, formation, and precipitation.

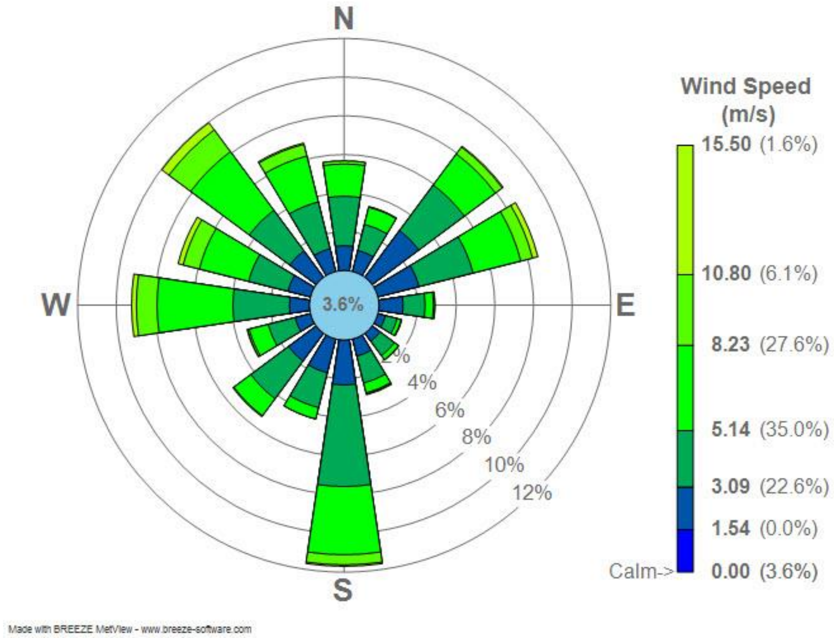
Pollutant	Climate effects
Particulate matter (PM)	Climate effect varies depending on particle size and composition: some lead to net cooling, while others lead to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo (the ability of the earth to reflect radiation from sunlight).
Ozone (O_3)	Ozone is a greenhouse gas contributing to warming of the atmosphere.
Nitrogen oxides (NO_x)	Contributes to the formation of ozone, with associated climate effects. It also contributes to the formation of nitrate particles, cooling the atmosphere.
Sulphur oxides (SO_x)	Contributes to the formation of sulphate particles, cooling the atmosphere.
Carbon monoxide (CO)	Contributes to the formation of greenhouse gases such as CO_2 and ozone.
Benzene	Benzene might give a small contribution to radiative forcing, as it contributes to the formation of ozone (positive forcing) and secondary organic aerosols.

Table 1.5: Effects of regulated air pollutants on climate. (Source: EU report 2014)

1.6. Effect of meteorological parameters on pollution

The parameters of meteorology affecting drastically the shaping of air pollution levels is the wind direction and wind speed, the stability of the atmosphere and especially for photochemical pollutants, the intensity of solar radiation and sunshine duration. Other parameters that modulate the levels of air pollution are the meteorological precipitation and amount of precipitation (rain, snow, etc.), the relative humidity and the temperature indirectly.

- **Wind speed** is the velocity attained by a mass of air traveling horizontally through the atmosphere. Wind speed is often measured with an anemometer in kilometers per hour (kmph), miles per hour (mph), knots, or meters per second (mps).
- **Wind direction** is measured as the direction from where a wind comes from. For example, a southerly wind comes from the south and blows to the north. Direction is measured by an instrument called a wind vane. Both of these instruments are positioned in the atmospheric environment at a standard distance of 10 meters above the ground surface. For this we can use what is called a "**Wind Rose**", which is derived from compass readings and can use azimuths (degrees of direction) for many purposes. As in a circle with 360°, wind directions can be gauged on these "azimuths" to find out exact degrees of flow. Winds are named according to the compass direction of their source. Thus, a wind from the north blowing toward the south is called a northerly wind.



Typical “Wind Rose”

Upper-air wind speed, wind direction, and temperature can be collected by **in-situ systems** or by **remote sensing instruments**. The most commonly used in-situ systems rely on a balloon-borne sensor (radiosonde), carried aloft by a freely ascending weather balloon to measure atmospheric pressure, temperature, and moisture (relative humidity or wet bulb temperature). These thermodynamic variables are used to compute the altitude of the balloon. Wind speed and direction aloft are determined by measuring the position of the balloon as it ascends. The position data can be obtained by tracking the balloon from a fixed ground station using radio direction finding techniques (RDF) or optical tracking, or they can be obtained using one of the radio navigation (NAVAID) networks, such as loran or Global Positioning System (GPS). By measuring the position of the balloon with respect to time and altitude, horizontal wind vectors can be computed that represent the layer-averaged wind speed and wind direction for successive layers. Balloons can also measure relative humidity, which is not detected by proven remote sensing methods.

Atmosphere serves as the medium through which **pollutants are dispersed**. While being transported, the pollutants undergo chemical reactions, which may be lethal or scavenged by chemical or physical process/method. But it all exclusively depends upon meteorological conditions (Lee et al., 1994). The location, duration of release, height as well as the pollutant concentrations are also important, which effect the secondary pollutant transformation under the influence of meteorological conditions, but the atmospheric behavior is independent of their sources (Holzworth, 1974). **Fogs and clouds** are important in creating particles and as vehicles for particle removal. Ideally, the droplet number, droplet size, liquid water content (LWC) and chemical content of fogs and clouds would be measured to determine the chemistry associated with plume conversion. The effective technology for such measurements is limited with respect to feasibility, practicality, and accuracy.

Solar radiations influences the atmospheric chemical processes. Free radicals are formed by photo-dissociation of molecules. And these are highly reactive unstable intermediates. Although, solar radiations plays crucial role in the generation of free radical yet water vapor and temperature also influence the particular chemical pathways. **Micrometeorological**

parameters such as wind speed, wind direction, temperature, atmospheric pressure and relative humidity have a **great effect on the movement of particulate matter** as well as the concentration level at any particular area. **Sedimentation, diffusion, turbulence, washout**, occult depositions are the processes, which remove particulate matter from air (Beckett et al., 1998).

Humidity indicates the amount of water vapor in the air. The most common reference for this property of the air is the relative humidity (RH), the ratio of the amount of water vapor actually in the air to the amount the air could hold at a given temperature and pressure, that is, the ratio of the actual to the saturated vapor pressure. Accurate measurements at high RH (>85%) is important to atmospheric transformations and to visibility reduction. An accuracy of 2-3% RH is needed to adequately estimate aerosol properties. An 2-3% accuracy for RH over the 90-100% RH is attainable by several RH sensors (e.g. Vaisala, Rotronics) and corresponds to ±0.5°C when expressed as dewpoint temperature. Motor-aspirated radiation shields ensure adequate ventilation and exposure rates (U.S. EPA, 1989).

1.7. Sampling Methods

Air quality measurements are implemented with various methods and analytical techniques. Generally, they can be classified according to the following **parameters**:

- Compound type and its concentration level,
- Measurement mode (continuous or periodical),
- Period of investigation (long- or short-term measurements),
- Automation level of measurements,
- Measurement sites (in situ, in laboratory),
- Manner of measuring (directly in sample or in secondary matrix),
- Sampling mode,
- Type of appliances used for sampling.

On the basis of literature research, it can be concluded that analytics and monitoring of atmospheric air are those areas of environmental studies that are expanding most rapidly. The **procedure of ambient air pollution sampling** should also include information on qualitative and quantitative data on the local sources pollution, population distribution, geomorphology, topography, climatology, land use pattern etc. depending upon the objectives of the survey or measurement campaign.

Sampling locations are discussed in other chapters of the present work but in general governed by factors like objectives, method of sampling and resources available. If the objective is to study health hazards and material damages, then locations should be kept close to the objects where the effects are being studied and should be kept at breathing level in the population centers, hospitals, schools, etc. For vegetation, it should be at foliage level. For background concentration, sampling location should be away from the sources of pollution. It can also be done by gridding the entire area to get statistically recommended values.

European legislation defines the **frequency and duration of sampling for each pollutant**. It should be such that the measurable quantities are trapped in the sample at the end of the sampling. It is preferable to observe sampling period consistent with the averaging times for which air quality standards of the given pollutants are specified (J. Namieśnik, W. Wardencki, 2001).

1.7.1. Common measured pollutants

Table 1.3 presents the most common pollutants covered by the European Environment Agency (EEA) and US Environmental Protection Agency (EPA) legislation and their sampling methods. Monitoring stations are operating in a 24h basis and automated analyzers provide a response time of one minute. Mean values every hour are calculated by microprocessors which are embedded inside the analyzer's circuit. Then data acquisition is implemented by telemetry and thus a continuous observation of the pollution level of the covered area is achieved.

Pollutant	Sampling Method
Carbon Monoxide (CO)	Non-dispersive infrared sensor (NDIR sensor) Simple spectroscopic sensor
Nitrogen oxides (NO_x)	Chemiluminescence
Ozone (O_3)	UV absorption
Sulfur Dioxide (SO_2)	Fluorimetry
Particulate Matters (PM_{10} – $PM_{2.5}$)	B-radiation absorption
Benzol (C_6H_6)	Gas Chromatography

Table 1.3, source: Greek Ministry of Environment, Annual Emission Report 2013

The major difficulties involved in the **sampling of volatile components** relate to the efficiency of the methods used, the concentrations which is necessary to attain and the subsequent separation of other components in order to analyze the volatile substances.

The collected sample may show statistical and dimensional properties completely different from what they are in reality, due to possible volatile dust or particulate matter amassment and break up. In order to eliminate sources that cause sampling error the procedure should be carried out under conditions which are isokinetic as possible, above all when the particles are very small. This signifies that sampling should be performed in such a way that, as far as possible, the gas stream carrying along the particulate matter should undergo no disturbance or change of speed on entering the collecting device. However the perfect isokinetic[2] conditions cannot be met, since the final container will always represent a disturbing factor (F.Cambi, 1961). Thus sampling takes pace practically always under more or less anisokinetic conditions, which may lead to inevitable errors in the determination of both the quantity and the dimensions of the suspended matter.

[2] Sampling at such a rate, that the velocity and the direction of the gas entering the sampling nozzle is the same as that of the gas in the duct / stack at the same sampling point.

1.7.1.1. Carbon Monoxide (CO)

Carbon monoxide is emitted due to incomplete combustion of fossil fuels and biofuels and enters the body through the lungs. Exposure to CO can reduce blood's oxygen-carrying capacity, thereby reducing oxygen delivery to the body's organs and tissues. The atmospheric lifetime of CO is about three months. The relatively long lifetime allows CO to slowly oxidize into carbon dioxide (CO_2), also forming O_3 during this process. CO therefore contributes to the atmospheric background concentration of O_3, with associated effects on health and ecosystems.

1.7.1.2. Nitrogen oxides (NO_x)

Nitrogen oxides are emitted during fuel combustion, such as by road transport and industrial facilities. Of the chemical species that comprise NOX it is NO_2 that is associated with adverse effects on health, as high concentrations cause inflammation of the airways and reduced lung function. NO_X also contributes to the formation of secondary inorganic PM and O_3 with associated effects on health and ecosystems. Nitrogen (N) reactive compounds, emitted as NO_X and NH_3, are now the principal acidifying components in our air and cause eutrophication of ecosystems. The sensitive ecosystem area in Europe affected by eutrophication due to excessive atmospheric N has only diminished slightly over the last two decades. On the other hand, the area of sensitive ecosystems affected by excessive acidification from air pollution has fallen considerably in the past two decades (mainly due to the strong reduction in SO_2 emissions and partly due to reduction in NOX emissions). NOX and NH_3 emissions continue to cause significant ecosystem impacts in Europe. Estimates calculated for 2010 show that 69 % of the total sensitive ecosystem area in the EU was at risk of eutrophication and 11 % was at risk of acidification (Hettelingh et al., 2008).

1.7.1.3. Ozone (O_3)

Ozone is a secondary pollutant formed in the troposphere, the lower part of the atmosphere, from complex chemical reactions following emissions of precursor gases such as NOX and non-methane VOC (NMVOC). At the continental scale, methane (CH_4) and CO also play a role in O_3 formation. Ozone is a powerful and aggressive oxidizing agent, elevated levels of which cause respiratory health problems and lead to premature mortality. High levels of O_3 can also damage plants, leading to reduced agricultural crop yields and decreased forest growth.

Ozone in Europe results also from precursor gases emitted elsewhere. For example, increased global emissions of CH_4 lead to higher concentrations of CH_4 in Europe which in turn contribute to the formation of O_3. There is a discrepancy between the cuts in O3 precursor gases emissions in Europe and the change in observed average O3 concentrations in Europe. Reasons include increasing inter-continental transport of O3 and its precursors in the northern hemisphere which are likely to mask the effects of European measures to reduce O_3 precursor emissions.

Moreover, the relationship of O_3 concentrations in Europe to the emitted precursors in Europe is not linear. Exposure to O_3 has not decreased since 2001. This excludes the estimated exposures in 2003 and 2006. Variations between years are influenced by meteorological factors. Summers in 2003 and 2006 had favorable meteorological conditions for O_3 formation resulting in exceptionally high concentrations. In other words, while emissions of gases that contribute to the formation of O_3 dropped in Europe, O_3 concentrations have not dropped. Larger emission reductions of O_3 precursor gases are necessary to achieve reductions in O_3 concentrations. Between 15 % and 61 % of the EU urban population was exposed to O_3 concentrations above the EU target value for protecting human health in the period 2001–2010 (Figure ES.2). Furthermore, between 22 % and 69 % of agricultural crops in the EEA-32 were exposed to O_3 levels above the EU target value for protecting vegetation from 2001 to 2009. High O_3 concentrations are most pronounced in southern Europe.

1.7.1.4. Sulfur Dioxide (SO_2)

Sulphur dioxide is emitted when fuels containing sulphur are burned. The key manmade contributions to ambient SO_2 derive from sulphur containing fossil fuels and biofuels used for domestic heating, stationary power generation, and transport. Volcanoes are the most important natural source. Epidemiological studies suggest that SO_2 can affect the respiratory system and lung functions, and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis, and makes people more prone to infections of the respiratory tract. Mortality and hospital admissions for cardiac disease increase on days with higher SO_2 levels (WHO, 2008).

Sulphur dioxide contributes to **acidic deposition**, causing adverse effects on aquatic ecosystems in rivers and lakes, damage to forests, and acidification of soils. The major effects of deposited sulphur compounds are the loss of acid neutralization capacity in soils and waters, loss of nutrients such as potassium or magnesium from soils, and the release of aluminium to the soil and waters. In certain biogeochemical conditions, sulphur can initially be stored in soils with subsequent slow release, a process known as postponed acidification. Thus, SO_2 emission reduction measures can take many decades before they have a positive effect.

1.7.1.4.1. Trends in SO_2 concentrations and emissions

Reported SO concentrations decreased steadily in the period 2002 to 2011, falling on average by about one third in the EU. At nearly all urban background and traffic stations a statistically significant trend is observed from 2001 to 2010 (de Leeuw, 2012). In last year's overview, an analysis showed that a decade ago the average concentration at traffic stations was about 1 µg/m3 higher than at urban background stations. This gap between traffic stations and urban background stations narrowed to only 0.3 µg /m3 in 2010, suggesting a decreasing contribution of SO_2 emissions from road traffic. EU emissions of SOX (a family of gases that includes SO and SO_2) have fallen substantially since 2002 (Figure 1.6.2).

Total EU emissions of SO_X in 2011 were 50 % less than in 2002. The reduction of EEA-32 emissions of SO_X in the same period was 34 %. Sulphur dioxide emissions in 2011 in the EU were approximately 42 % lower than the aggregated emissions ceiling for the

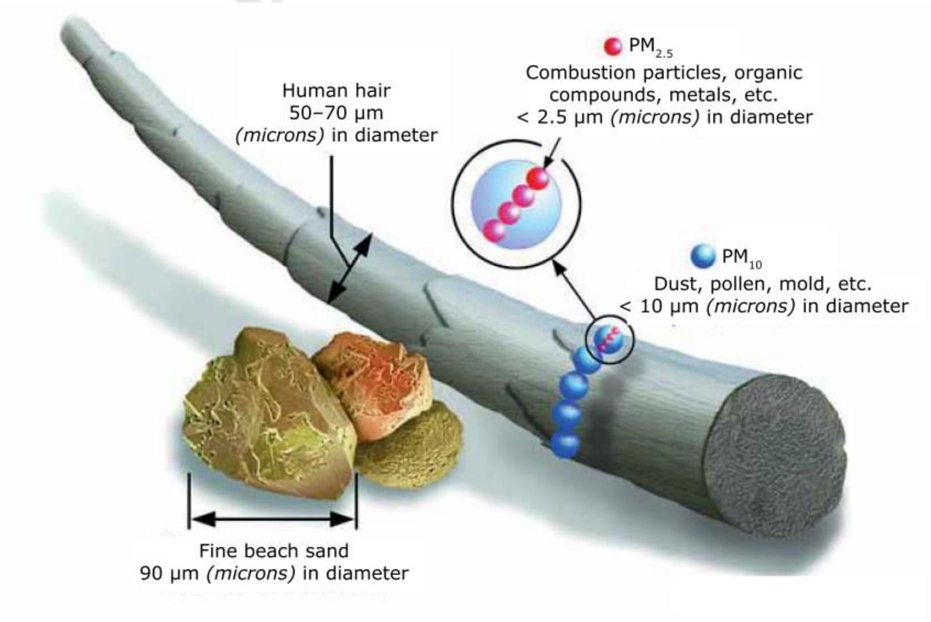
EU set for 2010 in the NEC Directive. Observed SO_2 concentrations fell by 35 % at traffic stations during the period 2002–2011, and by 27 % and 35 % at urban and rural stations, respectively. The fall observed at industrial stations was even higher, with a 46 % decrease in average concentrations between 2002 and 2011. These data correspond well with the reported emissions reductions (EEA report 2013).

1.7.1.5. Particulate Matters (PM_{10} – $PM_{2.5}$)

In terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system and can lead to health problems and premature mortality. PM in the air has many sources and is a complex heterogeneous mixture whose size and chemical composition change in time and space, depending on emission sources and atmospheric and weather conditions. PM in the atmosphere originates from:

- Primary particles emitted directly;
- Secondary particles produced as a result of chemical reactions involving so-called PM precursor gases: SO_2, NO_X, NH_3 and volatile organic compounds (VOC).

PM is measured in microns. The largest particles of concern are 10 microns in diameter or smaller (PM_{10}). The group of particles of most concern is 2.5 microns in diameter or smaller ($PM_{2.5}$). Some of these are small enough to pass from the lung into the bloodstream just like oxygen molecules. By comparison, the diameter of a human hair is 50–70 microns as seen on the below figure:



Source: EPA, 2010.

1.7.1.5.1. Emissions of primary PM

Emissions of primary PM_{10} and PM2.5 decreased by 14 % and 15 %, respectively in the EU and in the EEA-32 countries between 2001 and 2010. More **monitoring stations measure PM10** than PM2.5. For $PM_{2.5}$ in 2010 there were 754 stations fulfilling the criterion of more than 75 % data coverage. (The data coverage gives the fraction of the year for which valid concentration data are available at each location). Compared to 2009, 150 additional stations measured $PM_{2.5}$ in 2010. The $PM_{2.5}$ concentrations were higher than the annual target value to be met by 2010 (red and orange dots in Fig 1.6.1) at several stations in Bulgaria, the Czech Republic, Italy, Poland and Slovakia and at several stations in other countries. The stricter value of the WHO guidelines for annual mean PM were exceeded (pale green, yellow, orange and red dots in in Fig 1.6.1) at most of the monitoring stations across continental Europe but less commonly in Nordic countries.

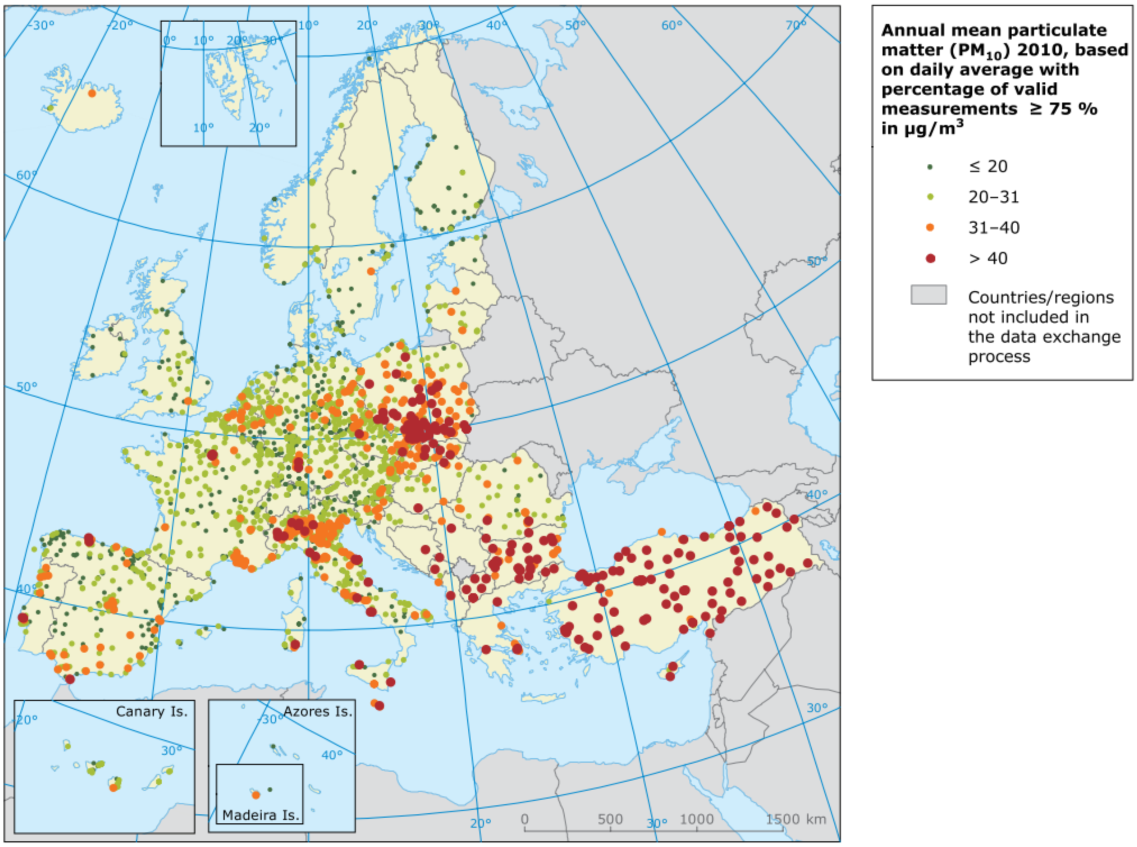
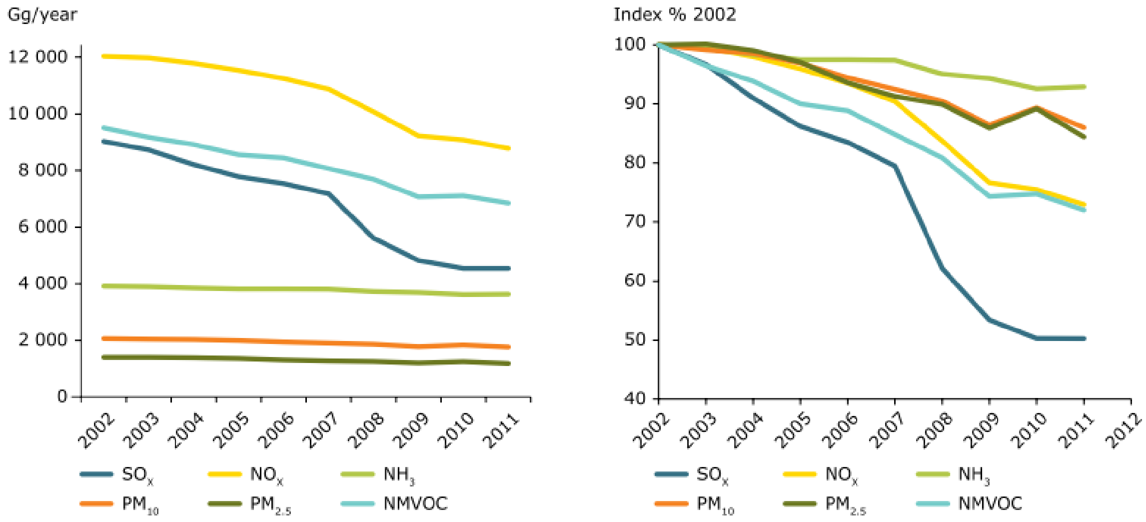


Figure 1.6.1, Source: EEA report 2012

When explaining trends in PM concentrations in the air, emission trends for both primary **PM and precursor gases** must be considered. In addition to anthropogenic and natural emissions, meteorology plays an important role. A certain fraction of the emitted precursor gases forms particles in the air, depending on atmospheric conditions (temperature, sunlight, humidity, reaction rate). Dispersion and atmospheric conditions differ also from year to year. The European anthropogenic **emissions inventory**[3] of primary PM is almost complete, with the exception of nonexhaust emissions (tyre and road wear), which have not been fully reported by all countries. Natural primary emissions of PM (primarily sea salt and naturally suspended soil dust including desert dust) are not part of this inventory. The EU emissions inventory for the period 1990–2011 was published by the EEA (2013b).



Source: EEA.

Figure 1.6.2, EU Emissions of primary PM and of PM precursor gases

1.7.1.6. Benzol (C_6H_6)

Incomplete combustion of fuels is the largest source of C6H6. Benzene is an additive to petrol and 80–85 % of C6H6 emissions are due to vehicle traffic in Europe. Other sources are domestic heating, oil refining and petrol handling, distribution and storage. In general the contributions from domestic heating are small (about 5 %) but with sharp geographic patterns. Wood combustion can be an important local source of C6H6 where wood burning can account for more than half of the domestic energy needs (Hellén et al., 2008). Removal of C6H6 from the atmosphere mainly occurs through the photochemical degradation of C6H6 which also contributes to O3 formation, although the chemical reactivity of C6H6 is relatively low. An atmospheric lifetime of several days is sufficient for C6H6 to be transported over long distances.

Health effects of C_6H_6

Inhalation is the dominant pathway for C_6H_6 exposure in humans, with smoking representing a large source of personal exposure. Food and water consumption is only a minor source. Benzene is a carcinogenic pollutant. The most significant adverse effects from prolonged exposure are damages to a cells' genetic material which can cause cancer. Chronic exposure to C_6H_6 can depress bone marrow and cause hematological effects such as decreased red and white blood cell counts.

[3] A record of what types of emissions are being released by what sources and in what quantities

Pollutant	Health effects	Environmental effects	Climate effects
Particulate matter (PM)	Can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias, affect the central nervous system, the reproductive system and cause cancer. The outcome can be premature death.	Can affect animals in the same way as humans. Affects plant growth and ecosystem processes. Can cause damage to buildings. Reduced visibility.	Climate effect varies depending on particle size and composition: some lead to net cooling, while others lead to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo.
Ozone (O_3)	Can decrease lung function; aggravate asthma and other lung diseases. Can lead to premature mortality.	Damages vegetation, impairing plant reproduction and growth, and decreasing crop yields. Can alter ecosystem structure, reduce biodiversity and decrease plant uptake of CO_2.	Ozone is a greenhouse gas contributing to warming of the atmosphere.
Nitrogen oxides (NO_x)	NO_2 can affect the liver, lung, spleen and blood. Can aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection.	Contributes to the acidification and eutrophication of soil and water, leading to changes in species diversity. Acts as a precursor of O_3 and PM, with associated environmental effects. Can lead to damage in buildings.	Contributes to the formation of O_3 and PM, with associated climate effects.
Sulphur oxides (SO_x)	Aggravates asthma and can reduce lung function and inflame the respiratory tract. Can cause headache, general discomfort and anxiety.	Contributes to the acidification of soil and surface water. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of PM with associated environmental effects. Damages buildings.	Contributes to the formation of sulphate particles, cooling the atmosphere.
Carbon monoxide (CO)	Can lead to heart disease and damage to the nervous system and cause headaches, dizziness and fatigue.	May affect animals in the same way as humans.	Contributes to the formation of greenhouse gases such as CO_2 and O_3.
Arsenic (As)	Inorganic As is a human carcinogen. It can lead to damage in the blood, heart, liver and kidney. May also damage the peripheral nervous system.	Highly toxic to aquatic life, birds and land animals. Soil with high As content, reduces plant growth and crop yields. Organic As compounds are persistent in the environment and subject to bioaccumulation.	No specific effects.
Cadmium (Cd)	Cadmium, especially cadmium oxide is likely to be a carcinogen. It may cause damage to the reproductive and respiratory systems.	Toxic to aquatic life. Cadmium is highly persistent in the environment and bioaccumulates.	No specific effects.
Lead (Pb)	Can affect almost every organ and system, especially the nervous system. Can cause premature birth, impaired mental development and reduced growth.	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Effects on animal life include reproductive problems and changes in appearance or behaviour.	No specific effects.
Mercury (Hg)	Can damage the liver, the kidneys and the digestive and respiratory systems. It can also cause brain and neurological damage and impair growth.	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Can affect animals in the same way as humans. Very toxic to aquatic life.	No specific effects.
Nickel (Ni)	Several Ni compounds are classified as human carcinogens. It may cause allergic skin reactions, affect the respiratory, immune and defence systems.	Nickel and its compounds can have highly acute and chronic toxicity to aquatic life. Can affect animals in the same way as humans.	No specific effects.
Benzene (C_6H_6)	A human carcinogen, which can cause leukaemia and birth defects. Can affect the central nervous system and normal blood production, and can harm the immune system.	Has an acute toxic effect on aquatic life. It bioaccumulates, especially in invertebrates. Leads to reproductive problems and changes in appearance or behaviour. It can damage leaves of agricultural crops and cause death in plants.	Benzene is a greenhouse gas contributing to the warming of the atmosphere. It also contributes to the formation of O_3 and secondary organic aerosols, which can act as climate forcers.
Benzo-a-pyrene (BaP)	Carcinogenic. Other effects may be irritation of the eyes, nose, throat and bronchial tubes.	Is toxic to aquatic life and birds. Bioaccumulates, especially in invertebrates.	No specific effects.

Table 1.6, Source: EEA annual report, 2012

1.7.2. Sampling Duration and Frequency

The period and frequency of sampling should be such that statistically reliable averages can be obtained with the data. U.S. National Ambient Air Quality Standards (NAAQS) states that annual average should be computed of 104 measurements taken twice a week of 24 hours duration. One of the objectives of monitoring under NAMP is to determine compliance to the NAAQS so monitoring should be done for 24 hours and minimum 104 days in a year. The pollutants vary diurnally and seasonally and these variations should be taken into account for determining frequency of sampling. The precision required in the data is also important in determining frequency of sampling. Sampling should be more frequent than the frequency of variation of pollutants.

Particulate matter levels are higher during the months due to domestic heating. Air pollutants such as CO levels are higher during winter months due to lower mixing heights resulting in less volume of troposphere available for mixing and hence higher concentrations. Thus measurements should be conducted in all the seasons so that in annual average all the seasons are represented equally. In general minimum 20% of the reading should be taken in each season (EPA).

1.7.3. Calibration of Automatic Analyzers

Calibration involves testing the proper functioning of the instruments and their regulation. The calibration is based on the transmission through the gas instrument with known concentration of the respective pollutant. This preparation of standard gas is made by dynamic dilution device, which is connected firstly to a source of "clean" air and the other with a flask containing a mixture of said gas with nitrogen at a known standard concentration. The "clean air" i.e. air from the main pollutants, produced by supplying air through special filters retaining the pollutants. Varying the supply of "clean" air and gas of the bottle is possible to obtain mixtures of gases containing the respective pollutant in known concentrations.

The calibration of **ozone analyzers** is done by a system of standard ozone calibration (primary UV calibration). In this procedure a photometer measures the fraction of UV radiation emitted by lamp Hg, which was absorbed by ozone in a 3 meters optical path, a methodology based solely on fundamentals. The calibration of the **particulate analyzers** is based on absorption of beta radiation of known mass standard samples. The calibration procedures are made at regular intervals, as refer to relevant technical standards, or after maintenance or repair of an analyzer (Annual Emission Report, 2013).

1.7.4. European policies, measures on air pollutant emissions and legislation

During the 2001–2010 decade, environmental policies and measures at the European level have affected the development of air pollutants emissions and the occurrence of air pollution. The EU has developed a series of six Environment Action Programs (EAPs), starting in 1973. During the 1990s, the EU developed and adopted a series of directives on air quality management and assessment, setting, for example, the air quality limit and target values, and methods to monitor and assess air quality. These directives have paved the way for the effective exchange of data on air quality and station networks that have enabled the overview of European air quality as presented in this report. The setting of health-related air quality limit and target values specified in the air quality directives benefited from the work and studies carried out under the Clean Air for Europe (CAFE) Programme, in cooperation with the World Health Organization (WHO), on the health effects of air pollutants (EEA, 2012 report).

Over the last decade European emission mitigation policies have followed a multi-pollutant approach and will continue to do so. The scientific air quality community still focuses on individual pollutants, although we are exposed to a complex mixture of pollutants. The move towards a multi-pollutant approach is described by this community as challenging. Additional research is needed to understand and quantify the possible additive, synergetic or antagonistic effects between pollutants which are encountered simultaneously in the ambient air. New exposure-response functions for pollutant combinations are thus required to help us characterize more fully the complexity of the exposure and its impacts. That will be the first step towards resolving the relative impacts of air pollutants and achieving a holistic multi-pollutant approach to air quality decisions.

In recent decades, the EU has introduced and implemented various legal instruments to improve air quality. The different legal mechanisms for air quality management comprise limits or targets for ambient concentrations; limits on total emissions (e.g. national totals); and regulating emissions from specific sources or sectors either by setting emission limits (for e.g. vehicle emissions) or by setting requirements on product quality (e.g. sulphur (S) and C6H6 in fuel). The European directives currently regulating ambient air concentrations of main pollutants are designed to avoid, prevent or reduce harmful effects of air pollutants on human health and the environment. They comprise:

• Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which regulates ambient air concentrations of SO_2, NO_2 and NO_X, PM_{10} and $PM_{2.5}$, Pb, C_6H_6, CO and O_3 (EU, 2008c); This new Directive includes the following key elements:

- The merging of most of existing legislation into a single directive (except for the fourth daughter directive) with no change to existing air quality objectives*
- New air quality objectives for $PM_{2.5}$ (fine particles) including the limit value and exposure related objectives – exposure concentration obligation and exposure reduction target
- The possibility to discount natural sources of pollution when assessing compliance against limit values
- The possibility for time extensions of three years (PM_{10}) or up to five years (NO_2, benzene) for complying with limit values, based on conditions and the assessment by the European Commission.

• Directive 2004/107/EC relating to As, Cd, Hg, Ni and PAH (including BaP) in ambient air (EU, 2004b).

The **Framework directive** 96/62/EC and the associated daughter directives (1999/30/EC, 2000/69/EC, 2002/3/EC, 2004/107/EC) on air quality in the European Union not only force member states to monitor and report on their air quality but also to (actively) inform the public on the status of the ambient air quality (EU, 2007). The daughter directives set limit values and attainment dates for a range of pollutants. Some of the pollutants covered are particulate matter (currently PM_{10} is regulated, $PM_{2.5}$ is to be added in the near future), nitrogen dioxide, ozone and a number of heavy metals. The "**right to know**" your air quality, described in the directives is further reinforced by the Aarhus convention (ratified by the EU in 2005). Over the past years a good number of cities and countries have started to display monitored or modelled air quality data on the Internet. For most of the monitoring organizations, the Internet is the easiest way to meet the dissemination of information requirements of the European (and/or national) legislation. The fact that so much air quality information is available on the Internet makes it tempting to compare different cities in different countries. Though this is feasible for a scientist understanding the measurements of the different pollutants, it is particularly difficult for the general public or for local authorities. Apart from the European Environmental Agency's ozone website (EEA, 2007a) there are no possibilities to compare cities/countries side by side in near real time. Even if one surfs from one site to the other, comparison is not easy: air quality is presented in different ways using different interpretation criteria and a different typology of stations, which is usually not clearly explained (Sef van den Elshout, 2008).

Chapter 2 – Ambient air quality monitoring Networks

2. Definitions

Air pollution reduction policies are in general developed through processes involving monitoring of air pollutants through specifically designed monitoring networks, comparison of monitoring data with air quality standards and development of emission inventories (Mazzeo et al., 2005).

Many countries have monitoring networks to measure the levels of different pollutants in the air. These networks are fundamentally structured around a country's regulatory obligation to report monitored air quality data and modelled predictions in accordance with requirements of national/European (in the case of members of the EU), regional and local legislation. For example, EU directives dictate the pollutants measured, quality control, monitoring technique and the number and location (roadside, urban background, rural) of sites. Outside of this regulatory framework, different monitoring networks have specific objectives, scope and coverage, with some providing near real-time data for the public, others providing details of pollution chemistry or composition, whereas some will measure concentrations over a day or month, thereby providing invaluable data to assess levels and impacts across a larger area (F.Kelly, 2011).

Air quality modelling techniques compliment the monitoring networks by being able to predict concentrations of air pollutants and this in turn, enables air quality to be assessed across a greater geographical area than that possible with monitoring data alone. For example, air quality forecasting of long-range transport provides knowledge of pollution sources many hundreds of kilometers from the forecast location. In addition, air quality assessment across rural areas very often relies upon models, while a combination of monitoring and modelling can assist air quality forecasting in heavily trafficked urban locations. Various forecasting approaches, of varying complexities are in use around the world. These can be broadly divided into statistical approaches and deterministic models (F.Kelly, 2011).

The **Air Quality Monitoring Network (AQMN)** consists of several **air quality monitoring stations (AQMS)** which covers a metropolitan area with permanent and some mobile stations. Each country as a member of the European Union is obliged by National and European Legislation to operate such AQMNs in most of their cities. The location where an AQMS is operating often called "**monitoring site**" and the most common pollutants which traced by AQMNs are Carbon Monoxide(CO), Ozone(O_3), Oxides of Nitrogen(NO_x), Particulate Matters (PM_{10} and $PM_{2.5}$) and Sulfur dioxide (SO_2).
For example, in Athens the AQMN includes fourteen AQMSs and there are also two additional assistant AQMSs for cross-border pollution transfer detection.
In the United States the Environmental Protection Agency (EPA) has the supervision, in compliance with NAAQS and provides guidance for development of AQMN with extended siting criteria in most of the U.S territories.

Principal factors governing the locations of the sampling stations are the objectives, the particular method of instrument used for sampling, resources available, physical access and security against loss and tampering. Air quality monitoring should be done in areas where pollution problem exists or is expected i.e. mainly in industrial areas, urban areas, traffic intersections etc. One of the objectives of monitoring is to determine status and trends and the air quality monitoring should be done in metropolitan cities and other urban areas so as to compare their levels and determine trends. Selection of site is very important as an incorrect location may result in data that may not meet the objectives of monitoring and will be of limited value. The siting criteria of a new AQMS are described in chapter 4 of the present work. In general the following requirements should be satisfied for site selection **(EPA):**

A. <u>Representative Site</u>

A site is representative if the data generated from the site reflects the concentrations of various pollutants and their variations in the area. It is not easy to specify whether the location of the station is satisfactory or not, however it may be checked by making simultaneous measurements at some locations in the area concerned.

There is ample evidence that the location of a monitoring station can affect the magnitude of the concentrations measured at the station, particularly for carbon monoxide and other vehicular air pollutants. This is because the location of the station (both height and distance) relative to sources affects the values observed at the station. The station should be located at a place where interferences are not present or anticipated. In general the following conditions should be met:

1. The site should be away from major pollution sources. The distance depends upon the source, its height and its emissions. The station should be at least 25 m away from domestic chimneys, especially if the chimneys are lower than the sampling point; with larger sources the distance should be greater (WHO, 1977).

2. The site should be away from absorbing surfaces such as absorbing building material. The clearance to be allowed will depend on the absorbing properties of the material for the pollutant in question, but it will normally be at least 1m (WHO, 1977).

3. The objective of monitoring is often to measure trends in air quality and measurements are to be conducted over a long time; thus the site should be selected such that it is expected to remain a representative site over a long time and no landuse changes, rebuilding etc. are foreseen in near future.

The instrument must be located in such a place where free flow of air is available. The instrument should not be located in a confined place, corner or a balcony.

B. <u>Comparability</u>

For data of different stations to be comparable, the details of each location should be standardized[4].

i. On all the sides it should be open, that is the intake should not be within a confined space, in a corner, under or above a balcony.
ii. For traffic pollution monitoring the sampling intake should be 3m above the street level. The height of 3m is recommended to prevent re-entrainment of particulates from the street, to prevent free passage of pedestrians and to protect the sampling intake from vandalism.

[4] The following is recommended in Guidelines for Ambient Air Quality Monitoring, CENTRAL POLLUTION CONTROL BOARD Indian MINISTRY OF ENVIRONMENT & FORESTS

iii. Sampling in the vicinity of unpaved roads and streets results in entrainment of dust into the samplers from the movement of vehicles. Samplers are therefore to be kept at a distance of 200 m from unpaved roads and streets.

C. <u>Physical requirement of the monitoring site</u>

Following physical aspects of the site must be met:

i. The site should be available for a long period of time
ii. Easy access to the site should be there anytime throughout the year. Site sheltering and facilities such as electricity of sufficient rating, water, telephone connection etc. should be available.
iii. It should be vandal proof and protected from extreme weather

Highest concentrations and concentration gradients of carbon monoxide are likely to be in the vicinity of roads, highways. The gradients vary in both time and space on the micro and on the neighborhood scale.

D. <u>Topographical and Meteorological Factors</u>

Topographical and meteorological factors must also be considered for selecting a monitoring site. The topographical factors that must be considered are mountains, valleys, lakes, oceans and rivers. These factors cause a meteorological phenomenon that may affects air pollutants distribution. Winds caused by daytime heating and nighttime cooling may affect pollutant transport causing either buildup of pollutants or dilution. Canyons or valleys may channel the local winds into a particular direction resulting in increase in wind speed. The presence of large water bodies may cause a land-sea breeze wind pattern which may determine pollutant transport. The mountain or hilly terrain may cause precipitation that may affect pollutant concentration.

These criteria is for reference only, actual criteria followed at site must be based on compromise between available resources and site specific parameters such as nearby sources, concentration gradients of the pollutants, topographical features etc.

In **general the following requirement** may be met for siting the monitoring station.

i. Height of the inlet must be 3 – 10 m above the ground level.
ii. The sampler must be more than 20 m from trees.
iii. Distance of the sampler to any air flow obstacle i.e. buildings, must be more than two times the height of the obstacle above the sampler.
iv. There should be unrestricted airflow in three of four quadrants
v. There should be no nearby furnace or incinerator fumes.

Once an area has been selected for locating AQMS, the site can be selected by finding maximum concentration using air quality modeling. Modeling refers to the mathematical expression for the fate of pollutants when they are released into the atmosphere taking into consideration the various aspects of atmospheric effects such as dispersion, advection etc. Air quality models are capable of predicting the temporal and spatial distribution of pollutants for a given domain of interest. Air quality modeling can be applied to ground level sources, elevated points sources, line sources, areas sources, flying sources under unlimited mixing, limited mixing, inversion, fumigation, trapping and also on complex terrain, flat terrain and coastal areas. The methodology is different in each case. Maximum ground level concentrations can be calculated where the air quality monitoring station can be located.

2.1. Evolution of Monitoring Networks

Over the years since the commencement of air monitoring, the nature of monitoring and overall objectives have changed. This reflects international trends in monitoring, including increasing concern with smaller particles and hazardous air pollutants, improved instrumentation, and an improved understanding of air quality in Megacities. The main changes that have affected the monitoring network over the past 20 years include:

- <u>Shift to monitoring smaller particles</u>

  Initially particulate monitoring was comprised solely of total suspended particulates (TSP) monitoring, as the main concern was soiling from dust as opposed to health impacts from finer inhalable or respirable dust. In 1987, EPA replaced the earlier TSP air quality standard with a PM-10 standard. The new standard focuses on smaller particles that are likely responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. In parallel, PM is one of the pollutants over time covered by the European Council Directive on Air Quality Assessment and Management. Council directive 80/779/EEC set the basis for suspended particulate concerning and assessment followed by several directives (among them and most considerable: 92/72/EEC, 96/62/EC) until directive 2008/50/EC which defined the present concentration limits.

- <u>Change in focus for gaseous pollutants</u>

  Due to technological evolution in commercial vehicle diesel engines, lower fossil fuel consumption in general and the expansion of new generation public transport means, led to lower sulfur dioxide (SO_2) levels in most of the European countries **(EEA report-4.2012)**. Carbon monoxide (CO) concentrations have also generally fallen in recent years (with improved vehicle technologies) and, although monitoring of CO will continue because there is still the potential for exceedances to occur, it is likely that this part of the networks will be reduced as instruments are retired. Following international trends and concerns about the effects of nitrogen dioxide (NO_2) directly on human health, the number of NOx monitoring sites has slowly increased over the European region. **Diesel passenger cars were only recently allowed in Athens** and, therefore, NO_2 trends should be carefully monitored since a possible increase in primary NO_2 may affect compliance with NO_2 air quality standards **(Mavroidis, 2012)**

- Concern about photochemical smog

  Climate change together with increasing numbers of vehicles, are causing air quality problems in most industrialized cities of the southern Europe.

  Photochemical smog was characterized by high O_3 due to complex and non-linear chemistry and meteorology. Photochemical smog is related to the very complex reactions between NOx and volatile organic compound (VOC) species under solar radiation (Sillman, 1999). In simple terms, O_3 is produced by combining an oxygen molecule with an oxygen atom that is supplied from the photolysis of nitrogen dioxide (NO_2) by solar radiation (Ulaş İm, 2008). In the Mediterranean territory photochemical episodes are often occurred due to more frequent sunny conditions. The highest ozone concentrations were observed in summer periods having sunny days and maximum temperatures above 25°C, and the episodes were mainly characterized by southwesterly surface winds during the day and northeasterly surface winds during the night. Ozone levels in the southern European and Mediterranean regions have been studied by Klemm et al. (1998), Güsten et al. (1997), and Peleg et al. (1997). Kalabokas and Bartzis (1998) studied the Aegean region.

- Move to more frequent and continuous monitoring

  Continuous sampling is necessary when considering human health risk so instruments were developed accordingly. Further upgrade is done in most European AQMNs over the past few years so that most of the PM_{10} monitoring sites are now continuously monitoring using modern technology[5]. Most $PM_{2.5}$ monitoring sites will also be upgraded to continuous monitoring. For $PM_{2.5}$, the Directive (EU, 2008c) introduced a target value, to be attained by 2010, which will become a limit value starting in 2015. Moreover, the same directive established the national exposure reduction target for human exposure based on the average exposure indicator (AEI) set at the national level. The AEI is the averaged level measured at urban background (non-traffic and non-industrial) monitoring stations over a three year period (EEA, 2012 report).

- Changes in air quality guidelines and standards: International air quality standards for particulate matter and nitrogen dioxide have become more stringent in the last ten years because health studies have shown that the previous standards were not sufficient to protect the health of sensitive populations.

2.2. Classification of Monitoring sites

Classification is the grouping of monitoring stations (or in more general terms, geographical locations) according to certain properties of the station which are relevant for the interpretation of the measured data (W. Spangl, 2007). **Classification criteria** are external parameters providing relevant information on the location of a monitoring site. In principle, each location should be classifiable – at least those locations which fulfil the siting criteria of the Air Quality Directives

[5] http://aqicn.org/map/europe/

(AQD). J. Monjardino, F. Ferreira (2005) aimed to validate and clarify air quality monitoring stations classification, through objective methodologies based upon a common procedure that assure a harmonized interpretation of the definitions, from region to region, in compliance with European legislation. The stations classification must obey to a set of common rules in order to increase the compatibility and comparability of the data transmitted.

The **purpose of each AQMS is different regarding its given classification** and it is an important prerequisite for the assessment and interpretation of AQ data. Classifications of AQ monitoring stations are useful for various applications:

1. AQ assessment requires the grouping of monitoring stations into classes which can be characterized by external investigation of the sources of air pollution and information about other parameters influencing AQ.
2. Grouping monitoring stations into classes influenced by the same parameters is of interest for the development of abatement measures.
3. Information about receptors present in the vicinity of the monitoring station can be used as a first approximation for exposure assessment.
4. **Classification can be the basis for an assessment of representativeness**.

According to the Annexes of Council Decision 97/101/EC on Exchange of Information, as revised by Commission Decision 2001/752/EC of 17 October 2001, air quality monitoring stations should be classified in relation to the dominant emission sources influencing the air pollutant concentrations at the station: **Traffic -** located such that its pollution level is determined predominantly by the emissions from nearby traffic (roads, motorways, highways); **Industrial** - located such that its pollution level is influenced predominantly by emissions from nearby single industrial sources or industrial areas with many sources; **Background** - located such that its pollution level is not influenced significantly by any single source or street, but rather by the integrated contribution from all sources upwind of the station; And according to the area type where they are located: **Urban** - continuously built-up area; **Suburban** - largely built-up area: continuous settlement of detached buildings mixed with non-urbanized areas (small lakes, woods, agricultural); **Rural** - all areas that do not fulfil the criteria for urban or suburban areas are defined as rural areas. Potential criteria for classification are those influencing air pollution concentration levels. Some of these factors are pollutant-specific.

The latest European Legislation[6] **and literature** proposed mainly six major siting categories, separated by quantitative criteria:

- **Urban-Traffic**: Located in the central business district (CBD) of the urban area, with canyon-type streets, tall buildings and high traffic with **Average Daily Travel** (**ADT**)>10000 vehicles/day. The monitoring probe is about 3.5 meters high from the ground level.
- **Urban-Background**: Located in the CBD of the urban area but no street with ADT exceeding 500vehicles/day, can be less than 100 meters from the monitoring station. Typical locations are parks, malls, or landscaped areas having no traffic. The U.B station provides information for exposure analysis and it’s relevant with regard to public health aspects (European_Commision, 2013).

[6] Directive 2008/50/EC

- **Suburban**: Located in a suburban or residential area with a distance not less than 100 meters from any street with low traffic.
- **Suburban-background:** As the upper mentioned U.B station, the selected site should not significantly influenced by any major pollution sources(industry, highways), located in a suburban area, more than 500 m from any street with low traffic.
- **Suburban-Industry:** Located such that its pollution level is influenced predominantly by emissions from nearby single industrial sources (like power generation, incinerators and waste treatment plants) or industrial areas with many sources. Air sampled at industrial sites must be representative of air quality for an area of at least 250 m × 250 m.
- **Background:** Located in a remote territory, outside the urban or suburban areas (at least 5km), with no traffic or industrial activity and its purpose is mostly for cross border pollution detection and trend analysis. Background monitors are also intended to measure $PM_{2.5}$ concentrations that are not dependent on upwind sources, although the particles they quantify will be a mixture of natural and manmade source material. These stations should be distant from identified emitters, and may be at higher elevations than the urban-scale community exposure monitors. Properly sited background stations should measure $PM_{2.5}$ typical of the lowest ambient concentrations in a state or region. These sites should not be along transport pathways, though in densely populated or industrialized regions a given sample may or may not be along such a pathway depending on which way the wind is blowing.

Additional classes such as **"Rural"** can be met in certain networks. Those sites are dedicated for the protection of vegetation and natural ecosystems and shall be sited more than 20 km away from agglomerations and more than 5 km away from other built-up areas, industrial installations or motorways or major roads, so that the air sampled is representative of air quality in a surrounding area of at least 1.000 km^2 (Directive 2008/50/EC).

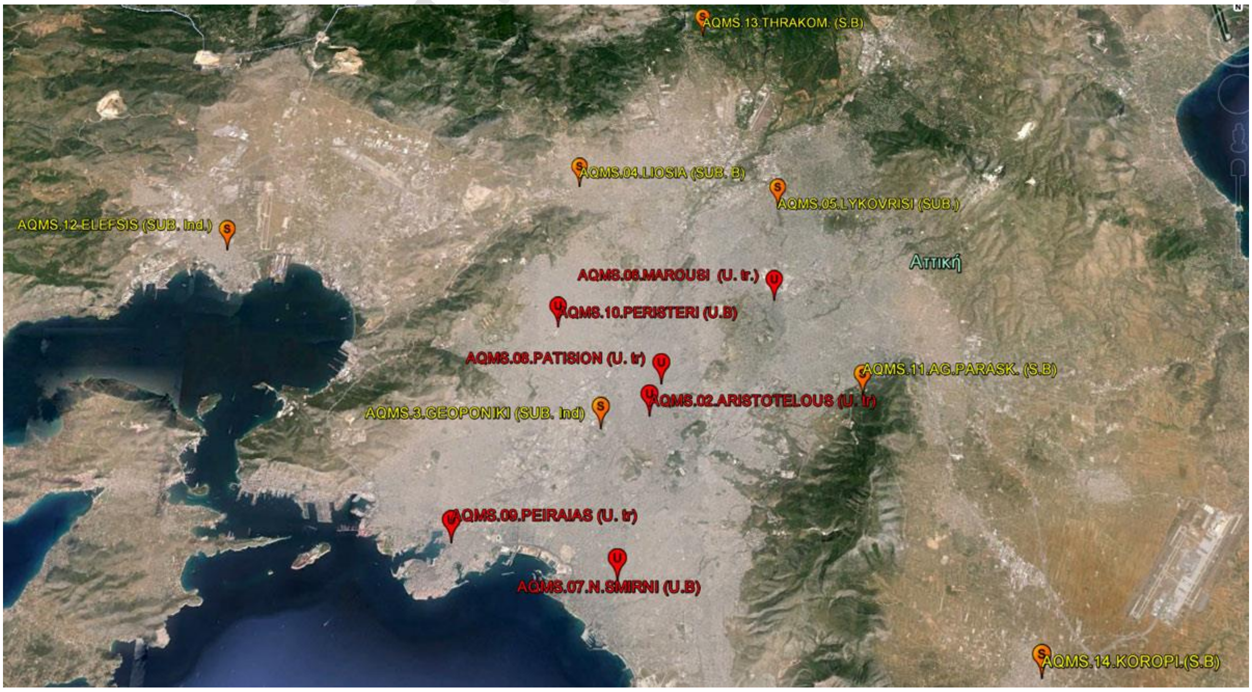


Figure 2.2, (Monitoring Stations on Athens Metropolitan Network)

The Greek ministry of environment has incorporated the upper categories for classifying the AQMSs in the Greater Athens Area (GAA). However the sites cannot be considered as representative of the air quality in the GAA, due to later large construction development and public works which has differentiated the initial topology of the areas in the vicinity of the AQMSs. Other AQMNs are operating in other cities in the country such as Thessaloniki (GTA), Volos, Larissa, Kozani and Patra.

The systematic measurement of certain air pollution parameters in Athens area started in 1970 by a network of monitoring stations, which installed by the Meteorological Institute of the Athens Observatory. At network was added in 1973 the network of Pollution Control Program Environment Athens (PERPA, later EARTH, current Climate Change and Ambient Air Quality Direction). In 1984 the network of PERPA modernized with the use of automatic air measuring pollution analyzers, and 1987 installed telemetric system by which measurements made at various stations by wire transferred to Service server (Y.PE.CHO.DE. 1997).

2.3. Update of Classification

The classification shall be reviewed at least every five years in accordance with procedures laid down by legislation. After the classification of the AQMS, the number of pollutants being monitored, the traffic, industry or domestic related pollutants and the influence of different dispersion conditions are in consideration.

The **presence of confounding air pollutant sources** may exclude otherwise suitable candidate sites. According to legislation "A monitoring station is representative of a location if the difference between the values of the annual average concentration at the station and at the location is less than a certain threshold value over a specified number of years". Classification „updates" following changes of the relevant emissions (e.g. construction of a new road) and the correction of former errors – as part of the fulfilment of EC legislation -

Any classification refers to the state in a certain reference year (or period) when the assessment was performed. This reference year is usually not documented in Airbase - nor is there any information about changes of the classification. Therefore, the following points should be discussed further:

- The necessity to re-classify monitoring stations after a certain period
- Documentation of the previous classification, once a new classification comes into force.

But it has to be kept in mind that classification as a requisite for data analysis can, in any case, refer only to one specific reference year. A trend analysis of a group of e.g. "Traffic stations" covers stations classified as "traffic" for a certain year and cannot use information on changes of the class in earlier times – since this would not comply with the concept of trend analysis, namely that the same data set is analyzed over time. The only easy way to deal with strongly changing emissions at single monitoring stations is to exclude these stations from the trend analysis.

2.4. Representativeness

The selected site of an installed AQMS **after its classification should be representative for the selected area and its emission sources**. Based on several criteria, a monitoring station is representative of a location if the characteristic of the differences between concentrations over a specified time period at the station and at the location is less than a certain threshold value or the differences between characteristics are less than a threshold due to **common reasons** (W. Spangl, 2007). It is considered an essential part of the definition that a monitoring site is representative of other locations with similar concentrations only in the case that these concentrations are determined by similar emissions and dispersion situation (due to meteorological and topographic features) and is limited to an area related to the transport distance of air masses within a certain time period. The definition of representativeness follows the additional specifications:

- Representativeness is specific to each pollutant.
- Representativeness is constant over time, i.e. it does not include temporal variations due to random or diurnal, weekly or annual variations of meteorological conditions or emissions.
- Representativeness is therefore clearly related to annual averages or annual percentiles, and not to short-term values (e.g. related to information or alert values, which are specified as 1 hour mean values).

"Common" reasons for similar concentrations are a necessary element of the definition of representativeness. The reasons for (causes of) the observed concentration level (and its temporal variation) can be classified as:

- emissions;
- atmospheric processes: dispersion situation – for which buildings and the topographic situation may be crucial –, atmospheric formation; transport; depletion;

It should be noted that the dispersion situation does not refer to meteorological conditions, which may vary on a short time scale, but to dispersion due to buildings, topography and climate, which is constant over time. The impact of these factors and associated atmospheric processes, which determine dispersion, formation and depletion, can only be assessed in detail by modelling. Modelling would be the optimum method for determining representativeness; W. Spangl, (2007) presented a methodology that covers also applications where modelling is not available but GIS information instead such as emission inventories, land-use and population density. This information is linked both to concentrations and the dispersion situation by semi-empirical relations. The regional background concentration – resulting from medium- to long-range transport and atmospheric formation (ozone, PM10) may also be used as an external parameter. The regional background concentration refers to a scale of some 50 to 100 km. Atmospheric processes on a smaller scale can be assessed more easily by expert judgement on the basis of GIS information (W. Spangl, 2007).

2.5. Complementarity to the main network – Mobile Stations

Studies have demonstrated that the pollution concentrations recorded by fixed monitors may not reflect the values of the surrounding areas and therefore are inadequate for assessing population exposure

Mobile monitoring techniques can evaluate air quality while in transit, using specialized vehicles. Air is collected during transit and analyzed on-board for pollutant concentrations. Mobile monitoring techniques are **a powerful addition to air quality data obtained from stationary monitoring networks**, because of the ability to move to many collection locations. The complementarities between mobile and stationary monitors allow for a more detailed picture of air pollution impacts to be constructed. Data collection mobility is particularly important because short-term peak exposures to air pollution can have serious detrimental health impacts (Atkinson et al. 2006; Dominici et al. 2006; Pope et al. 2006). For example, the mobile unit can roam city-wide

(Wallace et al. 2009); or focus on specific locations of concern such as areas with high amounts of road dust (DeLuca et al. 2012) and areas undergoing temperature inversions. Mobile surveys can be conducted in any location with road infrastructure and may help to improve assessment of population exposure in high pollution areas. This is particularly important in areas where there is a spatial differential in source emissions, such as regions with localized industries and a dispersed road network over a sprawled urban area. (Wallace et al. 2010).

3. Correlation between fixed-site stations

The **correlation coefficient characterizes the similarity** of the temporal variation of two time series, irrespective of the absolute level. It is close to 1 for parallel time series, close to 0 for time series with no relation and close to -1 for contrary time series.

The **coefficient of divergence (COD)** is the square root of the sum of the squared differences of the simultaneous values at **two monitoring sites** divided by the squared sum of these values. It takes account of the absolute concentration difference between two monitoring sites. It is low (close to zero) for „similar" time series and close to 1 for strongly differing time series. Since the sum of the concentrations is put in the denominator, pairs of highly polluted sites result in very low CODs. In addition the root of the **mean square difference (MSD)**, which is in fact the numerator of the COD, represents the difference between simultaneous values at two sites (the square is calculated to gain only positive values, the root for re-gaining numerical values in the measurement unit). The root MSD is low (close to zero) for „similar" time series and high for strongly different time series; there is no upper boundary, and the range of values depends on the variation of the concentration values. Since the root MSD has the same unit as the measured concentrations, it is quite an illustrative parameter for the „differences" of time series (W. Spangl, 2007).

The root mean square difference can be used as a proxy for the two criteria for the definition presented in chapter 2.4, since it covers both the similarity of the absolute concentration (related to the annual mean or an annual percentile) and the influence of common reasons. Common external factors – emissions, dispersion situation, and regional background concentration – lead to a similar temporal variation of the measurement values and therefore to low MSDs. Emissions from different types of sources show characteristic temporal variations, and thus the similarity of measurement time series characterizes the influence from the same emissions.

Meteorological conditions show similar temporal characteristics in geographical vicinity, and thus restrict the area of representativeness to geographical regions of a limited extent. Also the dispersion situation imposed by the topographic structure leads to geographically limited areas of representativeness. In the same way, similar regional background concentrations impose a spatial structure on the statistical parameter used for the assessment of representativeness.

3.1. Early Warning and Alert/forecasting services

Research confirming the detrimental impact of poor ambient air quality and episodes of abnormally high pollutants has on public health, plus differential susceptibility, calls for improved understanding of this complex topic among all walks of society. The public and particularly, vulnerable groups, should be aware of their quality of air, enabling action to be taken in the event of increased pollution. **Policy makers must have a sound awareness of current air quality and future trends**, to identify issues, guide policies and monitor their effectiveness. These attitudes are dependent upon air pollution monitoring, forecasting and reporting, serving all interested parties. Apart from the underlying national regulatory obligation a country has in reporting air quality information, data output serves several purposes. Future warning systems has to focus on provision of real-time data and advanced warnings of potentially health-damaging events, in the form of national air quality indices and proactive alert services. Some of the challenges associated with designing these systems include technical issues associated with the complexity of air pollution and its science. These include inability to provide precise exposure concentrations or guidance on long-term/cumulative exposures or effects from pollutant combinations. Other issues relate to the degree to which people are aware and positively respond to these services (F. Kelly, 2011). The ultimate aim should be to empower people to modify behavior—for example, when to increase medication, the route/mode of transport taken to school or work or the appropriate time to pursue outdoor activities—in a way that protects their health as well as the quality of the air they breathe.

Early warning (EW) is “the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response.”, and is the integration of four main elements, (from International Strategy for Disaster Reduction (ISDR), United Nations (UN), 2006):

1. Risk Knowledge: Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.

2. Monitoring and Predicting: Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.

3. Disseminating Information: Communication systems are needed for delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. The messages need to be reliable, synthetic and simple to be understood by authorities and public.

4. Response: Coordination, good governance and appropriate action plans are a key point in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

Air pollution alert services are systems that proactively alert registered users of impending pollution events, rather than leaving it up to the user to find the information elsewhere. As would be expected, these information tools are targeted towards susceptible groups in a community or simply individuals who have limited access to media that routinely reports AQI information. Examples of such systems are **airALERT**[7] and **airTEXT**[8] operating in the UK, **Luftkvalitet**[9] in Sweden and the American-based **EnviroFlash**[10]. Those who register to this service can choose to receive the alerts via a home phone (voice message), mobile phone (short message service, smart phone application) or computer (Really Simple Syndication feed or email). Another method of information delivery is via smart phone apps, an example of which is ‘London Air’, developed by the Environmental Research Group at King’s College London for the iPhone and Android market. ‘London Air’ displays pollution concentrations in real-time from 100 monitoring stations located across Greater London and is fully integrated with Google Maps enabling user-friendly ‘locate-me’ and postcode finder features. Users can also subscribe to receive notifications when pollution exceeds ‘Moderate’ concentrations at a site(s) of their choice, and be informed as to how a site has performed each year in relation to the UK air quality objectives (F. Kelly, 2011).

The **monitoring, forecasting and reporting of air quality** has become increasingly sophisticated and accurate and this will undoubtedly continue **into the future** with the use of more individualized

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[7] **airALERT**. Air quality early warning system. Available from URL: http://www.airalert.info/

[8] **airTEXT**. Your Air for London. 2011. Available from URL: http://www.airtext.info/index.php

[9] **Luftkvalitet**. info. Air Quality in Norway. Available from URL: http://www.luftkvalitet.info/

[10] **EnviroFlash**. Air Quality Notifications. 2011. Available from URL: http://www.enviroflash.info/

measures of exposures. AQIs and alert systems sourced by monitoring sites are always going to be limited by location, spacing and density. Within urban areas, the reliability of forecasts will improve by increasing the number of sites but monitoring networks will, however, rarely achieve a density that reflects the spatial distribution of pollutants in a city. Added to this, an increasing trend among the public for more information probably means that the type of data provided by present systems will need to progress. For example, we should expect a greater use of sophisticated mapping incorporated into proactive alert services, enabling people to gain feedback as to the outdoor activities appropriate to be undertaken during a given day or what route their children should take to and from school. Although urban walking route websites 81 already provide some advice, this information needs to reach the user in a proactive way and be linked into real-time air quality measurements (F. Kelly, 2011).

3.2. Common Air Quality Index

The EU directives on air quality force member states to inform the public on the status of the ambient air quality. The Internet is commonly used for this purpose and often air quality is being presented as **an index ranging from good to bad**. A review of existing websites and air quality indices shows that the way air quality is interpreted differs considerably. The CAQI is a set of two indices: one for roadside monitoring sites and one for average city background conditions.

The **CAQI** or **Common Air Quality Index** was proposed to facilitate the comparison of air quality in European cities in real-time. There are many air quality indices in use in the world. All are somewhat different in concept and presentation and comparing air quality presentations of cities on the internet was virtually impossible. The CAQI and the accompanying website www.airqualitynow.eu and app were proposed to overcome this problem in Europe. The CAQI characterizes a city by a roadside and urban background situation. It also insists on a minimum number of pollutants to be included in the calculation (Sef van den Elshout, 2013).

4. Objectives of a new AQMS setup – Macro scale Criteria Categorization

The selection of monitoring objectives for optimal allocation of AQMS may have to cover several design principles. The required design principles usually consist of the considerations of "protection capability" for regions with higher population density and significant area with higher economic growth as well as the "detection capability" of higher pollution concentrations, higher frequency of violation of stipulated standards, and the major industrial/traffic sources in the metropolitan region. In addition, differing pollutants may present different characteristic variabilities due to its specific emission patterns, rate of dispersion, and the behavior of transport and transformation.

The costs for siting a pollutant-specific monitoring network would be higher than that for a common monitoring network with respect to several pollutants simultaneously. Thus, for practical reasons, most monitoring networks install different detection instruments together in a common monitoring network that could be viewed as more economic and feasible applications. In general, differing decision-makers may have different objectives, criteria, and pollutants of interest so that the considerations of cost, effectiveness and efficiency can be satisfied at the same time when siting AQMS in the urban region (C.C. Tseng, N.B. Chang, 2001)

In consideration of the purpose of the provisions on siting criteria, the macro-scale siting criteria are essential as they define the primary objectives regarding the siting of monitoring stations. As an example, an improved understanding of air quality in Athens since the inception of air monitoring, concluded that gaseous pollutants related to traffic (annual mean concentrations levels) such as sulphur dioxide (SO_2) and carbon oxide (CO) have decreased. The concentrations are now generally low and therefore the network is not being expanded.

But over the years, the nature of monitoring and overall objectives in air quality standards and guidelines has changed. This includes increasing concern for smaller particles and hazardous air pollutants due to unforeseen circumstances in what is usual in domestic heating as a result of economic crisis. The siting of a new AQMS should provide representative information about the particle smog which appears during the winter months.

4.1. Site logistics

In consideration: Security, electrical supply, installation and maintenance costs, insurance, financial issues, private property permissions, easiness in access and other technical factors. The AQMS is preferred to be installed in public buildings such as schools, fire stations, police stations, recreation halls, and hospitals. The previous mentioned often have more stability and a motive for public service than do private or commercial buildings. Equipment must be situated so that field technicians have the space to conveniently conduct operation and repair activities, without disturbing the function of other instrumentation and equipment.

4.2. Representativeness (External Siting)

4.2.1.**Classification** of monitoring stations according to emissions or population.

"Classification" of air quality monitoring sites is a prerequisite for any interpretation of AQ data. The station should usually be representative of a wider area of at least several square kilometers:

- **"Type of area"** (urban/suburban/rural) refers to the environment and the presence of receptors of interest (human population, ecosystems, vegetation) on a scale of several kilometers
- **Type of station** (traffic/industrial/background) refers to the impact (or absence) of near-by emissions (and is pollutant-specific in 2011/850/EU).

Any classification has to deal with the problem that for uniform application across Europe, well-defined quantifiable parameters and clear thresholds between classes based on such parameters are required.

4.2.2.**The monitor should be outside the zone of influence of sources located within the designated zone of representation for the monitoring site. The concentration of the pollutant(s) should be representative for the pattern of spatial distribution. Three sub-issues should be under scrutiny:**

i. **Distance from nearby emitters**. A minimum distance from pollution sources highways, railways, airports, industrial sites, landfills etc, is required, mainly for background stations.

ii. **Topology/Geomorphology:** The location of the AQMS should not be obstructed by buildings, trees or any other objects, sound barriers, vegetated embankments etc. In the near future there should not be any planned large construction development or re-development or major changes in public transport itineraries or public works which differentiate the initial topology of the area in the vicinity of the AQMS. There is also considerable evidence, that the height of a sampling point affects the concentration observed, especially if measurements are made in the vicinity of major streets. **The closed topography** of the Athens basin hampers ventilation and diffusion of pollutants due to the existence of mountains, and as a result, the prevailing wind direction is either North or Northwestern (open to the northeast between Parnitha and Penteli mountains and south of the Saronic Gulf). In each case strong winds may incrementally affect the levels of particle pollution particularly in case of proximity of the station to earth ground. Such sites should be avoided for siting an AQMS.

iii. **Meteorology/Climate**: Prevailing winds, upwind/downwind sites should be considered, too.

4.3. Potentially confounding air pollutant sources

After the classification of the AQMS, the number of pollutants being monitored, the traffic, industry or domestic related pollutants and the influence of different dispersion conditions are in consideration, as mentioned in chapter 2.3

4.4. Social Criteria / Population Coverage / Legislation limits/ Sensitive Receptors (Evaluation through GIS interpolation) of a candidate site

- **The EU Legislation limits** & Sustainable development factors are balancing social, environmental and economic objectives (which they often come in conflict). Each one of them is actually a sum of sub-objectives with different weights. In order to apply those, the background information of the candidate site should be collected.
- **The collected data (environmental, social, economic) of a specific area** should provide details of sources and emissions (quantity of industry or traffic emissions, variation range of pollutant concentration etc.), traffic volume, health status, demography, population growth, number of sensitive receptors (inc. schools and hospitals), landuse pattern, epidemiological studies, confirmed respiratory infections at district level, lost working days due to ambient pollution, etc. Such prior information will provide immense help to identify the likely effects and in particular health impacts resulting from population exposure to air pollutants. The spatial patterns of air pollutants (distribution of concentrations) combined with population patterns produce the desired exposure patterns. Thus:
- A **densely populated area** should be selected so the data collected can represent the air quality being exposed by the majority of people in the district. By macroscale siting requirements is meant that areas with the highest concentrations to which the population is likely to be exposed, need to be covered by an AQMS directed at the protection of human health, sited in such a way, avoiding measuring very small micro-environments. The sampling points should also provide data on levels in other areas within the zones and agglomerations which are representative of the exposure of the general population. Additionally regarding **the environmental objective**, AQMS should be installed in areas with high concentrations of air pollutants and near major air pollution sources.

4.5. Contribution to overlap minimization between stations (statistically predicted if possible)

AQMS should not overlap each other's area of coverage, so the distance between two of **the same class monitoring stations** should be long enough. If the area is small it may not be worthwhile to maintain a monitoring station on operation. In opposite, such a station is needed to monitor ambient air quality.

The sphere of influence (SOI) methodology (Liu et al, 1987), defines the extent of the area around each station in which the station's measurements can be regarded as representative. This procedure is based on an analysis of the correlation of air quality at the stations and at points in the vicinity of the station: The SOI eliminates redundant monitoring sites. In conclusion the distance between two of the same class monitoring stations should be long enough.

4.6. Contribution to Network's Reliability (Standard deviation results in case of station exclusion – SEE)

The implementation of statistical methods for specific pollutant timeline series between different AQMS assists in a possible exclusion of a (redundant) monitor from the network, proposed by legislation or other reasons:

The **correlation level** between the temporal trends of the measuring sites, highlight the strong relationship between the concentrations measured by different stations or the similarity of the temporal variation of several time series. A **practical correlation level** between pre-sited AQMS, at the Athens' metropolitan air quality monitoring network, can be met only in a few cases (Aristotelous-Athinas-Patission sites - Further discussion in chapter 7).

In addition the reliability of statistical regressions between different sites should be verified and their utility for optimizing the use of short time measurements for urban pollution mapping. **Short time measurements** with mobile instrumentation can track traffic intensity/load on major streets and sites or increased particle concentrations when no AQMS is installed nearby.

The **accuracy of predictions** is another factor between AQMS. The candidate AQMS for exclusion is the dependent variable (pollutant concentration) and the independent variables are the other AQMSs of the network in a multiple regression procedure. The results of the performance of the regression procedure between different sites, estimate pollution levels in a site with short or long-term time measurements.

4.7. Contribution to area's network coverage (mean values)

4.7.1. Protection of Human Health in Low income population areas

AQMS should be installed in "**Low income population areas**" which are mainly near to industries or traditional working areas (at western or south-western Athens, such as Piraeus, Elefsina, and Aspropirgos).

Major internal migration during 1950-1960 decades, resulted in a heavily growth population accumulated in Athenian regions, initially with the absence of spatial planning and street layout those years, without infrastructures and environmental considerations for the protection of human health. The aforementioned candidate sites, have been deployed near heavy industries or harbors, with high concentrations of air pollutants, and later, significant public works developed, including highways, transport stations, railways etc, in support of those areas, which led to new air pollution sources.

4.7.2. Protection of Antiquities

A unique specificity of Athens is the archaeological sites, scattered in the city and the Attica basin. The candidate sites are mostly inside the Athenian basin but there are also several important regions outside the city of Athens and all over the county of Attica where is found an intense residential and industrial development over the last decades. Such sites in the city of Athens and in nearby regions should be supervised for traffic pollutants which cause the corrosion, fading, discoloring or deterioration of the materials from which cultural properties are made. The monitoring station should be classified as urban/traffic or urban/background.

Former Environment, Energy and Climate Change Minister Yiannis Maniatis has benchmarked 71,000 euros for the funding of a project aimed at "**researching and addressing environmental parameters in the materials of ancient monuments.**"

The project's goal is to create a network of monitoring stations measuring corrosion and the coating of materials due to atmospheric pollution as a way of protecting historical and cultural monuments. The first and main monitoring station will operate at the University of Athens. It will initially cover the region of Attica and will then expand to other areas, with the emphasis cast on locations of historic significance. The network will research the effect of atmospheric pollution on selected materials that are manmade, including those of historical monuments. A database with information concerning the impact of pollution and climate change on these materials will be created in order to allow for the adoption of effective deterrent policies. The network also hopes to determine the socioeconomic impact of material decay, as a result of the atmospheric pollution and climate change. Ultimately, the results of the project will help to formulate legislation on a national and European level so as to determine the limits of pollution allowed in urban and rural areas to deter material corrosion. The project is funded as part of the programme "Technical Help with Funding Programmes" from the Green Fund.

4.8. Combination with meteorological features, connected with collected data

For example, the closed topography of the Athens basin hampers ventilation and diffusion of pollutants due to the existence of mountains, and as a result, the prevailing wind direction is either North or Northwestern (open to the northeast between Parnitha and Penteli mountains and south of the Saronic Gulf). In each case strong winds may incrementally affect the levels of particle pollution particularly in case of proximity of the station to earth ground. Such sites should be avoided for siting an AQMS.

4.9. Contribution to Network's Redesigning (due to technological progress)

As the technological equipment is aging, the proper functioning of equipment and the reliability on the representativeness of measurements should be under periodical tests. The AQMS should maintain compatibility and ability to measure the correct parameters:

- Required quantity and quality of the data.
- Correct time scale.
- Compatibility with the site design (outdoor or indoor environment).
- Compatibility with other equipment, for example: interfacing continuous emissions monitors and meteorological instrumentation with a data acquisition system, new generation data loggers and communication protocols.

4.9.1. Statistical Representativeness

4.9.1.1. Multicollinearity

Multicollinearity (or, as it is sometimes abbreviated, collinearity) describes a condition that may appear when analysts simultaneously consider more than one explanation for a social outcome**. It occurs when two or more of the explanatory variables in a sample overlap**. Because of the overlap, the methods of analysis cannot fully distinguish the explanatory factors from one another or isolate their independent influence. Social scientists **usually apply the term when discussing multiple (linear) regression**, in which case it refers to a situation in which **one independent variable is fully or partially a linear function of the others**; however, many forms of quantitative and qualitative analysis have their own version of the multicollinearity problem. Thus, although this entry explores multicollinearity formally using the notation of linear regression, it outlines the analytical issues more broadly as well (Stephen Voss, 2005).

Full multicollinearity: When two or more explanatory variables overlap completely, with one a perfect linear function of the others, such that the method of analysis cannot distinguish them from one another. This condition prevents a multiple regression from estimating coefficients and the equation becomes unsolvable, also called perfect multicollinearity.

Partial multicollinearity: When two or more explanatory variables overlap, such that they are correlated with one another in a sample but still contain independent variation. This condition limits the extent to which an analysis can distinguish their causal importance, but does not violate any assumptions required for regression.

Multicollinearity stands out among the possible pitfalls of empirical analysis for the extent to which it is poorly understood by practitioners. At its extreme, when explanatory variables overlap completely, multicollinearity violates the assumptions of the classical regression model (CRM). Full (or perfect) multicollinearity is easy to detect, however, because it prevents the estimation of coefficients altogether; an equation becomes unsolvable. This is not the sort of multicollinearity that customarily worries analysts. Full multicollinearity rarely appears in social science data unless the sample is exceedingly small. Otherwise, it generally results from some kind of simple error in the data handling or model specification, one that is easy to diagnose and painless to address. When practitioners speculate about a possible ‘‘multicollinearity problem,’’ therefore, they mean some sort of linear relationship among explanatory variables that falls short of complete overlap. Partial multicollinearity—the use of overlapping variables that still exhibit independent variation—is ubiquitous in multiple regression. Two random variables will almost always correlate at some level in a sample, even if they share no fundamental relationship in the larger population.

4.9.1.2. Durbin Watson statistic

In statistics, the Durbin–Watson statistic is a test statistic used to detect the presence of autocorrelation (a relationship between values separated from each other by a given time lag) in the residuals (prediction errors) from a regression analysis. Durbin and Watson (1950, 1951) applied **this statistic to the residuals from least squares regressions**, and developed bounds tests for the **null hypothesis** that the **errors are serially uncorrelated** against the alternative that they follow a first order autoregressive process. Later, John Denis Sargan and Alok Bhargava developed several von Neumann–Durbin–Watson type test statistics for the null hypothesis that the errors on a regression model follow a process with a unit root against the alternative hypothesis that the errors follow a stationary first order autoregression (Sargan and Bhargava, 1983). Note that the distribution of this test statistic does not depend on the estimated regression coefficients and the variance of the errors.

If $\boldsymbol{e_t}$ is the residual associated with the **observation at time *t***, then the test statistic is

$$d = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})^2}{\sum_{t=1}^{T} e_t^2},$$

Where *T,* is the number of observations. Note that if one has a lengthy sample, then Statistical Ideas site shows this can be linearly mapped to the Pearson correlation of the time-series data with its lags. Since d is approximately equal to $2(1 - r)$, where r is the sample autocorrelation of the residuals, ***d* = 2 indicates no autocorrelation**. The value of d always lies between 0 and 4. If the Durbin–Watson statistic is substantially less than 2, there is evidence of positive serial correlation. As a rough rule of thumb, if Durbin–Watson is less than 1.0, there may be cause for alarm. Small values of d indicate successive error terms are, on average, close in value to one another, or positively correlated. If $d > 2$, successive error terms are, on average, much different in value from one another, i.e., negatively correlated. In regressions, this can imply an underestimation of the level of statistical significance.

To test for **positive autocorrelation** at significance α, the test statistic d is compared to lower and upper critical values ($d_{L,\alpha}$ and $d_{U,\alpha}$):

- If $d < d_{L,\alpha}$, there is statistical evidence that the error terms are positively autocorrelated.
- If $d > d_{U,\alpha}$, there is **no** statistical evidence that the error terms are positively autocorrelated.
- If $d_{L,\alpha} < d < d_{U,\alpha}$, the test is inconclusive.

Positive serial correlation is serial correlation in which a positive error for one observation increases the chances of a positive error for another observation.

To test for **negative autocorrelation** at significance α, the test statistic $(4 - d)$ is compared to lower and upper critical values ($d_{L,\alpha}$ and $d_{U,\alpha}$):

- If $(4 - d) < d_{L,\alpha}$, there is statistical evidence that the error terms are negatively autocorrelated.
- If $(4 - d) > d_{U,\alpha}$, there is no statistical evidence that the error terms are negatively autocorrelated.
- If $d_{L,\alpha} < (4 - d) < d_{U,\alpha}$, the test is inconclusive.

Negative serial correlation implies that a positive error for one observation increases the chance of a negative error for another observation and a negative error for one observation increases the chances of a positive error for another.

The critical values, $d_{L,\alpha}$ and $d_{U,\alpha}$, vary by level of significance (α), the **number of observations, and the number of predictors** in the regression equation. Their derivation is complex—statisticians typically obtain them from the appendices of statistical texts.

5. Evaluation Methods & Statistical Models

To handle the increasing variety and complexity of forecasting problems, many forecasting techniques have been developed in recent years. Each has its special use, and care must be taken to select the correct technique for a particular application. The forecaster has a role to play in technique selection; and the better he/she understands the range of forecasting possibilities, the more likely it is that the forecasting efforts will bear fruit.

The selection of a method depends on many factors—the context of the forecast, the relevance and availability of historical data, the degree of accuracy desirable, the time period to be forecast and the time available for making the analysis. These factors must be weighed constantly, and on a variety of levels. In general, for example, the forecaster should choose a technique that makes the best use of available data. Some of these methods are presented below:

5.1. Simple Multi Linear Regression

(This is the method that we are intend to apply in our evaluation model in Chapter 7 at both cities of Athens and Istanbul)

Simple linear regression is a method that enables you to determine the relationship between a continuous process output (Y) and one factor (X). The relationship is typically expressed in terms of a mathematical equation such as Y = b + mX. Multi Linear regression **fits a linear model of the form:**

Y= b0 + b1 X1 + b2 X2 + ... + bk Xk + e

where Y is the dependent variable (response) and X1, X2, ..., Xk are the independent variables (predictors) and e is random error. b0, b1, b2, bk are known as the regression coefficients, which have to be estimated from the data. The multiple linear regression model chooses regression coefficients so as to minimize the difference between predicted values and actual values.

Multiple regression estimates how the changes in each predictor variable relate to changes in the response variable. Importantly, regression automatically controls for every variable that you include in the model, which means that when you look at the effect of one variable in the model, you are holding constant all of the other predictors in the model. You explain the effect that changes in one predictor have on the response without having to worry about the effects of the other predictors. In other words, you can isolate the role of one variable from all of the others in the model. And, you do this simply by including the variables in your model.

P-values for the predictors: In regression, **low p-values indicate terms that are statistically significant**. After you fit and verify that you have a good model, all you need to do is look at the p-value and coefficient for each predictor. **"Reducing the model"** refers to the practice of including all candidate predictors in the model, and **then systematically removing the term with the highest p-value one-by-one until you are left with only significant predictors**. If the **p-value** is low (usually < 0.05), **the predictor is significant**. Coefficients represent the mean change in the response for one unit of change in the predictor while holding other predictors in the model constant.

For a good regression model, you want to include the variables that you are specifically testing along with other variables that affect the response in order to avoid biased results.

Adjusted R-squared and Predicted R-squared: Generally, you choose the models that have higher adjusted and predicted R-squared values. These statistics are designed to avoid a key problem with regular R-squared—it increases *every* time you add a predictor and can trick you into specifying an overly complex model.

- The **adjusted R squared** increases only if the new term improves the model more than would be expected by chance and it can also decrease with poor quality predictors.
- The **predicted R-squared** is a form of cross-validation and it can also decrease. Cross-validation determines how well your model generalizes to other data sets by partitioning your data.

In order to assess the strength/validity for a parametric linear model, it is common to calculate the coefficient of determination R^2, which can be interpreted in terms of **percentage of variance explained by the model**. If the number of parameters is large compared to the number of observations, however, R^2 will be systematically and artificially inflated. This is why R^2 is often routinely replaced (or supplemented) with the "adjusted R^2", which does not suffer from this inflation problem. Yet the adjusted-R^2 informs on the variance explained by the true model, i.e. the model with known parameters, not by the fitted one (V. Rousson, 2006). Thus, for those who intend to use the fitted model for prediction, the **adjusted R^2** will still be too large since it does not take into account the fact that the parameters in the model are being estimated (they are not known). In order to assess goodness of fit, one usually compares predicted with observed values using the coefficient:

$R^2=1-(SSR/SST)$, where $SSR = \Sigma(Y_i-\hat{Y}_i)^2$ is the "sum of squared residuals" (the criterion minimized by least-squares), $SST = \Sigma(Y_i-\bar{Y})^2$, sum of squares total and $\bar{Y} = \Sigma(Y_i)/n$.

n=number of observations
$\bar{Y}$=mean value
$\hat{Y}_i$=predicted value
Y_i= actual value

Additional goodness of fit assessment or "accuracy of predictions" can be measured by SEE (standard error of the estimate). Recall that the regression line is the line that minimizes the sum of squared deviations of prediction (also called the *sum of squares error*). The standard error of the estimate is closely related to this quantity and is defined below:

$$\textbf{SEE} = \sqrt{\frac{\sum_{i=1}^{n} \hat{e}_i^2}{n-2}} = \sqrt{\frac{SSE}{n-2}}$$

Where,

SSR= $\Sigma (\hat{Y}_i - \bar{Y})^2$, sum of squares due to Regression or The explained sum of squares (ESS) is the sum of the squares of the deviations of the predicted values from the mean value of a response variable, in a standard regression model

SSE = $\Sigma(Yi - \hat{Y}i)^2$, sum of squares due to error (RSS residual sum squares)

$Yi - \hat{Y}i$ = unexpected deviation from the mean (higher than even from estimated, Actual value from regression line) = $\hat{e}$

SST= sum of squares total, SST = SSR + SSE = $\Sigma (Yi - \bar{Y})^2$ (Distance of Actual data to the mean or total deviation to the mean) or TSS

As we've seen, regression analysis can handle **predictors that are correlated**, also known as **multicollinearity.** Moderate multicollinearity may not be a problem. However, **severe multicollinearity** is problematic because it can increase the variance of the regression coefficients, making them unstable and difficult to interpret.

Correlation and Regression: Simple linear regression is similar to correlation in that the purpose is to measure to what extent there is a linear relationship between two variables. The major difference between the two is that correlation makes no distinction between independent and dependent variables while linear regression does. In particular, the purpose of linear regression is to "predict" the value of the dependent variable based upon the values of one or more independent variables.

5.2. Fuzzy Multi Linear Regression

The regression analysis dealing with **fuzzy data** is usually called fuzzy regression analysis. The aim of this dissertation is to develop regression models among fuzzy data variables. There are two motivations for developing fuzzy regression analysis. The first motivation results from the realization that it is not often realistic to assume that a crisp function of a given form can be used to represent the relationship between the given variables.

Fuzzy relationship which is even though less precise, seems intuitively more realistic. The second motivation results from the fact that the nature of data in many cases have inherent characteristic of uncertainty.

5.3. Artificial Neural Network Approximation

The multi-layer perceptron or feed-forward ANN has a large number of processing elements called neurons, which are interconnected through weights (w_{iq} , v_{qj}). The neurons expand in three different layer types: the input, the output, and one or more hidden layers. The signal flow is from the input layer towards the output. Each neuron in the hidden and output layer is activated by a nonlinear function that relies on a weighted sum of its inputs and a neuron-specific parameter, called bias, b. The response of a neuron in the output layer as a function of its inputs is given by Equation (3), where f1 and f2 can be sigmoid, linear or threshold activation functions.

$$y_i = f_1\left(\sum_{q=1}^{l} w_{iq} f_2\left(\sum_{j=1}^{m}(v_{qj}x_j + b_j)\right) + b_q\right)$$

The strength of neural networks lies in their ability to simulate any given problem from the presented example, which is achieved from the modification of the network parameters through learning algorithms. The most important issue concerning the introduction of ANN in time series forecasting is "generalization", which refers to their ability to produce reasonable forecasts on data sets other than those used for the estimation of the model parameters. This problem has two important parameters that should be accounted for. The first is data preparation, which involves pre-processing and the selection of the most significant variables. The second embraces the determination of the optimum model structure that is closely related with the estimation of the model parameters. Although, there is no systematic approach, which can be followed, some useful insight can be found using statistical methods such as the correlation coefficients.

5.4. Multi-criteria Decision Analysis (MCDA)

MCDA is both an approach and a set of techniques, with the goal of providing an overall ordering of options, from the most preferred to the least preferred option. The options may differ in the extent to which they achieve several objectives, and no one option will be obviously best in achieving all objectives. In addition, some conflict or trade-off is usually evident amongst the objectives; options that are more beneficial are also usually more costly, for example. Costs and benefits typically conflict, but so can short-term benefits compared to long-term ones, and risks may be greater for the otherwise more beneficial options. MCDA can be practical to public decision makers and are increasingly being used by Governmental authorities in many countries for the appraisal of options for policy and other decisions, including but not limited to those having implications for the environment. Decision making about proposals for future action should normally follow a stage sequence, with each stage being discrete from previous or following ones. Identifying the objectives, options and criteria to be used to compare the options, are the most important points of the process for the development of a policy or decision.

The use of multi-criteria decision analysis (MCDA) techniques provides a reliable methodology to rank alternative projects in the presence of numerous objectives and constraints (Haralambopoulos and Polatidis, 2003; Huang et al., 1995; Lootsma et al., 1990; Siskos and Hubert, 1983). Despite, however, the large number of available MCDA methods, none of them is considered the best for all kinds of decision-making situations (Guitouni and Martel, 1998; Salminen et al., 1998; Simpson, 1996). There are no better or worse techniques, only techniques that fit better to a certain situation or not. Nevertheless, different methods, when applied to the same problem using similar data, often produce differing results.

In most multicriteria methods, **a numerical value is assigned to each criterion expressing its relative importance**. This reflects the corresponding criterion weight. The analysis of weights and their interpretation completely depends on the selected decision model.

A key feature of MCA is its emphasis on the judgement of the decision making team, in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion. The subjectivity that pervades this can be a matter of concern. Its foundation, in principle, is the decision makers' own choices of objectives, criteria, weights and assessments of achieving the objectives, although 'objective' data such as observed prices can also be included.

A standard feature of multi-criteria analysis **is a performance matrix, or consequence** table, in which each row describes an option and each column describes the performance of the options against each criterion. The individual performance assessments are often numerical, but may also be expressed as 'bullet point' scores, or colour coding. In a basic form of MCA this performance matrix may be the final product of the analysis. The decision makers are then left with the task of assessing the extent to which their objectives are met by the entries in the matrix. Such intuitive processing of the data can be speedy and effective, but it may also lead to the use of unjustified assumptions, causing incorrect ranking of options.

Chapter 6 – Case studies[11]

6. Historical Air Pollution Episodes

Besides the health effects caused by day-to-day concentrations of urban pollution, premature death and morbidity are experienced during and following **pollution 'episodes'—periods** of prolonged and abnormally high concentrations of one or more outdoor air pollutants. They arise as a consequence of poor atmospheric dispersion conditions generated by still air and/or unusually high emissions following incidents such as wildfires, dust storms, local traffic congestion and construction, as well as long-range (1000 km or more) trans-boundary air pollution.

Wintertime episodes are characterized by elevated concentrations of PM, NO_2 and/or SO_2. Notable examples are those experienced by London in 1952 and 1991 and parts of West Germany in 1985, claiming lives prematurely and increased morbidity from respiratory and cardiovascular causes. Examples of summertime episodes are the photochemical smogs, arising from the action of sunlight on NOx and hydrocarbons released from vehicle exhaust. These episodes, characterized by elevated ambient O_3 and PM concentrations, are also associated with excess death, as exemplified by the impact of the heat wave that affected much of Europe in 2003. Different types of pollution episodes are caused by wildfires and dust storms, which carry particulate pollution over several thousand kilometers and impact health across wide geographic areas.

Associations have been reported between wildfire particulates and an excess of respiratory complaints and/or hospitalizations in Australia, Lithuania, United States and Southeast Asia. Reported links to mortality and cardiovascular outcomes are less consistent. Dust storms are brought about under certain weather conditions, where for example sand originating in the deserts of Mongolia and China is carried eastward by cold pressure systems, creating episodes of elevated PM in Taiwan. Studies investigating the health impact of these dust events in the Taiwanese capital of Tapai, have observed significant effects on emergency visits for cardiovascular disease and trends towards increased mortality and hospital admissions. As reviewed by Brunekreef and Forsberg, data originating from the United States and Europe on dust storms and wind-blown dust suggest an association with outpatient visits and hospital admissions for respiratory conditions.

In many communities, **residential wood heating is an important contributor to wintertime pollution** (Naeher et al. 2007). Because wood burning typically occurs in residential areas, the intake fraction (the ratio of the total mass of a pollutant inhaled to the mass of the pollutant emitted) of woodsmoke PM with an aerodynamic diameter of ≤ 2.5 μm ($PM_{2.5}$) is higher compared with $PM_{2.5}$ from other sources, such as traffic (Ries et al. 2009); This suggests that reducing woodsmoke emissions can effectively reduce $PM_{2.5}$ exposures. To address this, in many countries woodstove exchange programs that encourage residents to replace older stoves with newer, cleaner burning models have been broadly implemented.

6.1. Photochemical Episodes

Photochemical smog is present in the urban environment. It forms when oxides of nitrogen (present in motor vehicle exhaust) and hydrocarbons (from various anthropogenic and biogenic sources) react in the presence of sunlight to produce a mixture of aerosols and gases. By-products of this reaction include O_3, formaldehyde (CH_2O), ketones, and PAN (peroxyacetylnitrates). These

[11] Further episode case studies at Annex I of the present work

substances irritate the eyes and damage the respiratory system. Anthropogenic hydrocarbons result from the evaporation of solvents and fuels, as well as incomplete combustion of fossil fuels. Natural hydrocarbons are produced by vegetation. Recent studies suggest that such natural hydrocarbons may play an important role in the formation of photochemical smog.

The normal levels of ozone at the earth's surface average about 0.02 ppm while in in thick photochemical smog, ozone concentration may exceed 0.5 ppm. Chronic exposure to ozone may cause lung disease. It also degrades rubber and fabrics, and damages some crops.

In view of the harmful effects of photochemical pollution of the lower levels of the atmosphere, the European Council adopted Directive 92/72/EEC of 21 September 1992 on air pollution by ozone (EC, 1992). That directive was succeeded by Directive 2002/3/EC (EC, 2002), also known as the third daughter directive to the Air Quality Framework Directive (Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management) (EC, 1996). It set LTOs and TVs, and an 'alert' threshold and an 'information' threshold for ozone (Table 1.1) for the purpose of avoiding, preventing or reducing harmful effects on human health and the environment. It provided common methods and criteria for assessing ozone concentrations in ambient air, and ensured that adequate information be made available to the public on the basis of this assessment. It also promoted cooperation between Member States in reducing ozone levels.

On 14 June 2008, Directive 2008/50/EC (EC, 2008) came into force. The provisions of earlier AQ directives remained in force until 11 June 2010, when they were repealed by Directive 2008/50/EC. The new directive did not change the levels of the existing TVs, LTOs, alert threshold or information threshold for ozone.

6.1.1. Tenth anniversary of the 2003 ozone episode in Europe

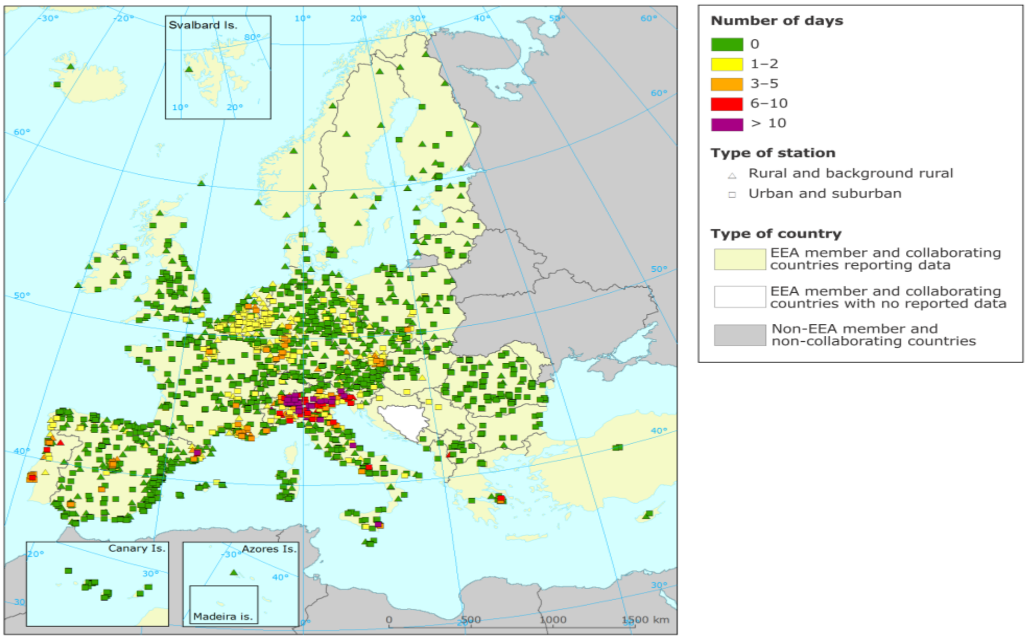
An **exceptionally long-lasting period of high ozone concentrations** was reported in the first half of August 2003 by all countries, excepting those in northern Europe. During this episode, hourly ozone concentrations exceeded as much as 240 µg/m3 at a large number of sites in northern-western and central Europe. The most affected areas were those with a high density of ozone precursor emissions from traffic and industrial production.

The **ozone episode was caused by stagnant meteorological conditions** combined with exceptionally high temperatures (even at nights) across large parts of southern, western and central Europe. The meteorological situation was characterized by a long-lasting, high air-pressure area above south-western Europe; the axis of the high pressure ridge was located above France, western Germany, Switzerland and northern Italy. These meteorological conditions remained almost unchanged for the whole first half of August. A number of scientific papers (e.g. the ECDC's (2005) and the EPI's (2006)) have studied the adverse impact on public health of the 2003 heat wave. Up to 52 000 excess deaths were attributed to the heat wave, and even if high temperatures appear to have been the main cause, it is clear that exposure to elevated air concentrations of particulate matter (PM), and especially ozone, were also associated. The mortality impact of the heat wave was greatest on the elderly (over 75 years of age) and, among the elderly, rates were higher in females. (EEA Technical report 3/2014)

6.1.2. Summer 2013, ozone concentrations in Europe

During summer 2013[12], concentrations of ground-level ozone significantly exceeded a number of European Union (EU) standards for protecting human health (see Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe). However, the number of exceedances was lower than in many previous years, continuing the long-term downward trend observed over the last 24 years (EEA Technical report 3/2014)

As in previous years, in summer[13] 2013, the threshold of 120 μg/m3 maximum daily 8-hour mean was again exceeded on more than 25 days, across a significant part of Europe. This is the threshold that will be used in future to assess whether countries meet the EU target value (TV) for protecting human health[14]. Exceedances of this threshold occurred in 19 EU Member States (Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, France, Germany, **Greece**, Hungary, Italy, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia and Spain) and 5 other countries or territories (the former Yugoslav Republic of Macedonia, Kosovo (under UNSCR 1244/99), Montenegro, Serbia and Switzerland). **As in previous years, the most widespread exceedances occurred in the Mediterranean area** (EEA Technical report 3/2014). The so-called **information threshold** (a 1-hour average ozone concentration of **180μg/m^3**) was exceeded at approximately 26 % of all operational stations, one of the lowest percentages since 1997. In northern Europe, there were no exceedances of the information threshold in 2013. The **alert threshold** (a 1-hour average ozone concentration of **240μg/m^3**) was exceeded 27 times, again one of the lowest numbers of exceedances on record (EEA Technical report 3/2014).



Number of days on which ozone concentrations exceeded the information threshold during summer 2013 (provisional data) (Source: Air pollution by ozone across Europe during summer 2013, EEA.3.2014)

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[12] Ozone levels in summer 2013 were compared with the summer ozone concentrations from 1997 to 2012. Summer ozone concentrations from 1997 to 2011 are validated and stored in the EEA's public air quality database (AirBase). Summer ozone concentrations for 2012 and 2013 are provisional at the time of writing. Differences between provisional and validated summer ozone data for the same year tend to be minimal.

[13] Following Directives 2002/3/EC (EC, 2002) and 2008/50/EC (EC, 2008), 'summer' in this report refers to the period from April to September, i.e. the warm part of the year.

[14] Directive 2008/50/EC sets the 'target value for the protection of human health' (TV). Specifically, as of 2010, the maximum daily 8-hour mean concentration of ozone should not exceed 120 µg/m 3 on more than 25 days per calendar year, averaged over 3 years. It further specifies that the TV will first be calculated using validated data from 2010 and the following years. As such, it will not be possible to fully assess exceedance of the TV in 2011 until data for 2011, 2012 and 2013 have been compiled and validated. References in this report to the 'target value threshold' pertain only to provisional ozone concentrations in 2013 (i.e. not more than 25 days with a maximum 8-hour average exceeding 120 µg/m 3), rather than to the 3-year validated data average used in assessing exceedance of the TV.

6.2. Historical Smog Episodes

6.2.1. London Smog. 1952

Twelve thousand people died from the so-called killer fogs of London, produced by the condensation of water on the daily 2,000 tons of sulfur dioxide and pollutants produced by coal-burning industrial furnaces and home heating systems in the city. The fatal conditions began on Thursday, December 4th. A high-pressure system moved over Britain, bringing dry air, cold temperatures, and light winds. During the night, the winds stopped and the Thames River basin experienced a severe temperature inversion, trapping cold air near the ground beneath a warm humid air layer. Heavy fog then began to form. For the next four days, tons of particulate matter from the furnaces entered this air mass, turning the sky yellow, amber, brown, and finally almost black. The air consequently became a blinding, suffocating cloud of gas that choked breathing passages and stung eyes with enough acidity to cause skin irritation. Cars were stopped in the roads as visibility dropped to a few feet. Air poured through window cracks and under doorways to permeate homes and buildings. Thousands, especially those with respiratory trouble, became seriously ill. The British Committee on Air Pollution reported, "The number of deaths over and above those normally expected in the last three weeks of December indicates some 4,000 people died of the 'smog'. As many as 8,000 others died later as a result of respiratory complications." Since this disaster, stricter restrictions have been placed on coal-burning furnaces. Antipollution laws are strongly enforced, and today London's "pea-soupers" have been nearly eliminated.

6.2.2. Donora, Pennsylvania 1948

Donora, Pennsylvania, located near Pittsburgh, was the site of two US steel facilities. In October 1948, emissions from these facilities during unusual weather conditions led to a severe and prolonged air pollution episode that resulted in significant health impacts, including 20 deaths.

The incident assumed national importance and was the subject of investigations by state and federal authorities. It served as an early warning of the potential health impacts of air pollution and contributed to the enactment of state and federal regulations for controlling such pollutants. A meeting occurred between the operators of the plants and the town officials. Burgess Chambon requested the plants temporarily cease operations. The superintendent of the plants, L.J. Westhaver, said the plants already began to shut down operation at around 6am that morning. With the rain alleviating the smog, the plants resumed normal operation the following morning.

Researchers analyzing the event have focused likely blame on pollutants from the zinc plant, whose emissions had killed almost all vegetation within a half-mile radius of the plant. Dr. Devra L. Davis, director of the Center for Environmental Oncology at the University of Pittsburgh Cancer Institute, has pointed to autopsy results showing fluorine levels in victims in the lethal range, as much as 20 times higher than normal. Fluorine gas generated in the zinc smelting process became trapped by the stagnant air and was the primary cause of the deaths.

6.2.3. Northern China Episodes 2013

In January 2013, five hazardous air-pollution episodes occurred, which were considered the most serious pollution events since 2000 (with the exception of dust episodes). These episodes led to the cancellations of hundreds of flights, warnings to avoid all out-door activities and a spike in respiratory disease cases. Although the domestic and foreign media have reported the severity of this episode and emergent response measures for air pollution, a scientific and professional analysis of these episodes is necessary to recognize the evolving process of air pollution and to evaluate the rationality of instituting policy.

Starting from early January 2013, Beijing experienced multiple prolonged periods of severe smog. An important measure of the intensity of these mixtures of smoke and fog is the peak hourly concentrations of ambient fine particulate matter ($PM_{2.5}$) which reached over 800mg/m3 or more than 32 times higher than the World Health Organization's (WHO) recommended level (25mg/m3). These smog episodes affected a region that extended far beyond the Beijing metropolitan area. There is growing awareness that these episodes can cause health problems. For example, as Beijing suffered a sixth day of hazardous-level air pollution in February 2014, the World Health Organization urged the residents of the capital city to stay indoors. However, the WHO officials cautioned that they could not link recent pollution levels with local media reports of specific cases of lung cancer and other ailments (Maigeng Zhou, 2014).

This result demonstrates that the Chinese government should take immediate action to address regional air pollution and bring a long-term improvement as a first step, by adjusting the energy supply structure, installing desulfurization and denitrification systems in power plants, step-ping up the control of emissions from industrial sources and further tightening motor vehicle emissions and fuel standards.

6.3. Contingency Plans and Air pollution prevention/corrective actions

The purpose of an **Air Pollution Episode Plan** is to protect human life and health by preventing or eliminating dangerous levels of air pollution. **The objective** is to provide control both during long term air stagnation conditions and for short term and small area episodes. Flexibility and operational capability should not be reduced by procedures outlined in the plan. Personnel must act with initiative and judgement to cope with any condition that may develop. Local Municipalities or Governmental Authorities are charged with the primary responsibility to insure that Air Pollution Episodes are controlled. As in any local problem, it is expected that **local officials will also properly inform the public and the news media**. The question of medical care and medical facilities is not within the purview of a Contingency Plan. The Medical Profession through its professional association, the hospital community and the various health groups or associations must develop the techniques and services to administer to the victims of an air pollution episode. Every effort will be made to alert these organizations of the episode. **As with any plan, experience, new data, and operational requirements will dictate revisions in the future**. As other pollutants are defined and control techniques developed, they will be included. Every effort will be made during this evolutionary process to refine the procedures so that the citizens will be protected but also that unnecessary burdens and costs will not be created.

Official Contingency plans are embedded in local State Legislation only in United States (by EPA guidelines and rules) mainly for Photochemical and PM pollution episodes. When **the accumulation of air pollutants in any place is attaining or has attained levels** which could, if such levels are sustained or exceeded, lead to a substantial threat to the health of persons**, the Executive Director** (Technical Secretary or the responsible Governmental Officer) for the Specific State Air Control Board will declare an "Air Pollution Episode". The **three stages of episodes** are AIR POLLUTION ALERT, AIR POLLUTION WARNING, and AIR POLLUTION EMERGENCY. The ancillary situations are the ATMOSPHERIC STAGNATION ADVISORY and TERMINATION. **Regulations such as the "CONTROL OF AIR POLLUTION EPISODES" of Texas control board, "**California air pollution emergency plan", **outlines the guiding criteria**. Conditions justifying the proclamation of an air pollution alert, air pollution warning, or air pollution emergency shall be deemed to exist when the Technical Secretary determines that **the accumulation of air pollutants is attaining or has attained levels** which could, if such levels are sustained or exceeded, lead to a substantial threat to the health of persons. In making this determination, the Technical Secretary will be guided by the criteria as described in section B of Annex II "International Case Response – Contingency Plans – Rules"

Respectively, **the European directives currently regulating ambient air concentrations of the main pollutants are designed to avoid, prevent or reduce the harmful effects of air pollutants on human health and the environment by implementing limit or target values for ambient concentrations of air pollutants.** European air pollution is a well-established environment policy area; applied over decades, it has resulted in decreased emissions of air pollutants and has led to noticeable improvements in air quality. There are indirectly predictions for prevention of pollution episodes with **activity boundaries and emission ceilings**. There is no adequate information for the obligations of each Member State regarding the implementation of Remedial Action for pollution episodes. In the case of non-compliance with the air quality limit and target values stipulated in European legislation, **air quality management plans must be developed and implemented in the areas where exceedances occur** (Air quality in Europe — 2014 report).

The plans aim to bring concentrations of air pollutants to levels below the limit and target values. To ensure overall coherence, and consistency between different policies, **air quality plans should be consistent (where feasible) and integrated with plans and programs in line with the directives regulating air pollutant emissions**. The air quality plans may additionally include specific measures aiming to protect sensitive population groups, e.g. children.

Except the main policy instruments on air pollution within the EU (ambient air quality directives, 2004 and 2008c) and the National mission Ceilings (NEC) Directive (EU, 2001), there is **Source-specific legislation** which is focusing on industrial emissions, road and off-road vehicle emissions, fuel quality standards, etc. Emissions are also addressed internationally under the 1979 LRTAP Convention, the Marine Pollution Convention and other conventions. In addition, several legal instruments are used to reduce environmental impacts from different activities or promote environmentally friendly behavior, and these also **contribute indirectly to prevent air pollution.**

In case of photochemical ozone formation, it depends mainly on meteorological factors and on the concentrations of NOX and VOCs. Ozone concentrations in urban areas with high NOX emissions are generally lower than in the countryside. For ozone, there is a significant contribution in terms of intercontinental transport of air pollution. Other factors **counteracting the possible positive effects of European measures to reduce ozone precursor emissions** from anthropogenic sources are biogenic non-methane volatile organic compound (NMVOC) emissions, fire plumes from forest and other biomass fires (EEA, 2010c). Ozone pollution as a global or hemispheric problem is addressed by the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) (UNECE, 2010). The Gothenburg Protocol to the LRTAP Convention (UNECE, 1999) **contains emission ceilings** for the pollutant NOX, NMVOCs, sulphur oxides (SOX) and ammonia (NH3) that parties to the protocol must meet by 2010.

In addition to the ceilings for individual countries, the protocol also specifies ceilings for the European Union, which is itself a party to the protocol. **Member States report data** on emissions of air pollutants annually to the European Commission (with copies to EEA) under Directive 2001/81/EC of 23 October 2001 of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants (EC, 2001). This NEC Directive contains national emission ceilings that, for the EU Member States, are either equal to or slightly more ambitious than those in the Gothenburg Protocol. The ceiling applies to the EU-15 grouping of Member States that constituted the European Community at the time the Gothenburg Protocol was agreed. Emissions of three air pollutants primarily responsible for the formation of harmful ground-level ozone in the atmosphere fell significantly in the period from 1990 to 2009: CO (62 % reduction), MVOCs (55 % reduction) and NOX (44 % reduction).

Emission reductions have been achieved from the road transport sector for all three pollutants, primarily through legislative measures requiring abatement of vehicle tailpipe emissions (EEA, 2011c). On the other hand, for another ozone precursor, CH4, concentrations increased continuously during the 20th century, before growth slowed after 1990 and eventually stabilized between 1999 and 2007. Since 2007, however, measurements suggest that concentrations have started to rise again. CH4 is a well-mixed pollutant globally, carried across long distances. Isolated local and regional abatement of CH4 emissions may therefore have limited impact on local ozone concentrations (EEA, 2011f). Formation of tropospheric zone from increased concentrations of CH4 may contribute to the sustained ozone levels in Europe. European countries have significantly reduced anthropogenic emissions of ozone precursor gases since 1990, albeit briefly. **In general, however, ambient air measurements in urban and rural areas of Europe do not show any downward trends in ground-level ozone (EEA, 2009b; EEA, 2011f).**

6.3.1. An example of pollution remedial Action: Cloud of Athens. 1980's

In the late 70s the problem of air pollution in Athens becomes visible and is given the name "cloud of Athens" in proportion to the smog of London and Los Angeles. The junta has allowed in freedom now to express opinions, to study the phenomenon, to press for his treatment. Then equipment had bought from former named Ministry of Housing, Spatial Planning and the Environment (YCHOP) and Environmental Services established in this, to measure pollution and ultimately to take measures to face the problem of air pollution Attica. Such measures have actually started to apply from 1978 and had aimed at reducing the price of sulfur dioxide and particulate lead, two pollutants extremely aggravating for public health, which appeared at very large values (Technical Chamber of Greece, 2005).

The pollutant which originally was therefore a priority to address was sulfur dioxide. For this pollutant in Athens mainly responsible industry and central heating and even if only considering the cold months of year, November to April, the central heating is the main source of this dirt while also become the main sources BS smoke emissions (Kalabokas et al., 1988). The central heating of apartment buildings in Athens designed to use fuel oil as the most economical fuel. This option and this, at a time before the oil crises generally when oil cost was cheap, will probably have to join the quest for low-cost housing conditions in Athens. Treatment of sulfur dioxide was originally started with prohibiting the use of fuel oil in heating and then continuous reductions in the sulfur content of both fuel oil and diesel. Especially in the area of the Athens' Basin, fuel oil which may be consumed only in industry, is from 1983 low sulfur (0.7%), while high sulfur content for the rest of the country was (3.5%) and now (3%) (TCG, 2005).

Confrontation of lead particles was achieved with continuous reductions of lead content in gasoline. This effort brought results that were quite significant (TCG, 2005) and completed in some way with the introduction through tax incentives catalytic cars and therefore the use of unleaded gasoline, although the augmentation of vehicles in absolute numbers and especially the negligence of drivers as the use-maintenance-replacement catalysts, put the problem of lead and particles as constituents of air pollution in Attica.

The measures to combat air pollution in Athens focused on the first stage (late 80s) in Industry. The main legislative measure was the PD 84/84 which sought limiting industry development in the Attica region, and then to the Law 2965/01, environmental conditions established for the same purpose. Other measures since launched to tackle air pollution in Attica was a change in operating permits for some of the 120 industries of GAA with new environmental rules. The new environmental rules which then instituted the installation of pollution control systems in selected manufacturing processes, construction of closed storage of raw materials, intermediate products and finished products, construction of floating roof storage tanks of volatile petroleum products, the prohibition of the combustion residues during regeneration etc. of oils (TCG, 2005).

Within the predicted measures which were taken, was the inspection of large industries with mobile industrial greenhouse gas measurement laboratory, the operation of which, began in 1991, but later was inactivated. After 1990 began the effective implementation of the institution of Environmental Studies Impact of industrial and commercial facilities, while predicting relevant laws, economic incentives has given to the industry for pollution control projects. New legislation applied for stationary, industrial and non-industrial furnaces, environmental operating conditions and emission limits for heaters of buildings and steam production hot water and air, the proper operation of boiler rooms and associated controls. At times there were information awareness campaigns for the proper functioning of the central plant heating (TCG, 2005).

Regarding the air pollution from transports measures turned first to the quality and composition of fuel. Additional efforts for fuel quality improvements have been taken outside the reduction of lead in gasoline and the content of sulfur in diesel for which has already been made. Thus, the use of specific diesel introduced for buses and then the separation of diesel in two types: transport and heating and also the control of fuel quality throughout the spectrum allocation, distribution, marketing and use of fuels (TCG, 2005).

The use of **natural gas** is another measure of long-term. The natural gas due to the substitution of liquid fuels, it is expected to bring reduction of pollutants released today, mainly in limiting the levels of sulfur dioxide and particulate matter in the atmosphere. Measures for pollution reduction from passenger cars, are mainly repressive by introducing rotational movement center city (the famous ring, now disputed by many to effectiveness). Even the **total traffic prohibition is anticipated**, when some pollutants exceed the alarm limits under the provisions of Law.1327/83. There is also the obligation for regular checking of vehicles from the Vehicle Inspection Centers (K.T.E.O.), and control of exhaust emissions on the road.

Finally, with regard to interventions in the city's functionality to combat air pollution, they fitted all projects concerning the improvement of traffic and transport infrastructure and instruments such as construction of interchanges, introducing bus lanes, mitigation measures traffic in the center and launch mini-buses. A series of interventions to the functioning of the city also included the treatment of ambient pollution in Athens, in an indirect way but inconclusive measures such as of those which aimed at better distribution of movements during a working day (shopping hours and services). For emergencies, however, there were all these years emergency measures (under the provisions of Law. 1327/83) with simpleminded projections of the sources that caused air pollution (Industry, car, building heating) and other restrictions relating to the discontinuation of various polluting operations within the city (e.g. operation furnaces, excavation work, etc.) (TCG, 2005).

In 1994 it was drafted and implemented an action plan called "ATTICA SOS », which is divided into nine sections and includes actions across the spectrum of environmental problems of Attica and the lack of land use planning.

6.3.1.1. Applicable statutory limits in Greece

In **Greece applicable statutory** limits for pollutants sulfur dioxide, smoke, particulate matter, nitrogen dioxide, lead, ozone, carbon monoxide atoms, benzene according to air quality limits established the European Union. These limits refer to both protect human health and ecosystems. A set of instructions issued for the emergency measures making boundaries indicatively the following:

- Directive 1996/62/EC on the assessment and management quality ambient air has been incorporated into Greek law by **Common Minister Decision (CMD)**, (CMD.3277/209/2000, Gov.180/B/17.2.2000).
- Directive 1999/30/EC on limit values for sulfur dioxide, oxides of nitrogen, particulate matter and lead in ambient air has incorporated into Greek law by (PYS 34 / 30.05.2002, Gov.125/A/06.05.2002)
- Directive 2000/69/EC on limit values for benzene and carbon monoxide carbon in ambient air has been incorporated into Greek law to (CMD. 9238/332, Gov.405/B/27.2.2005).
- Directive 2002/3/EC relating to ozone in ambient air has incorporated into Greek law by (CMD.38638/2016, Gov.1334/B/09.21.2005).
- Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic hydrocarbons in ambient air.
- For the CO, in accordance with Directive 2000/69 / EC (integrated in the National Law by CMD 9238/332/2004) no alarm limit provided. With article 13 of the CMD 9238/332/2004, the provisions of the CMD 11824/1993 for emergency measures referred to CO, are abolished.
- With the Common Minister Decision 11824/1993 institutionalized action plan for tackling air pollution episodes and put "limits extraordinary

measures "to reduce pollution where mainly due to extremely bad weather expected increased pollution price. The measures taken when the measured values exceed or approach the contingency limits (alarm) while there is provision for conditions favorable conservation or increased pollution values for the next or the next days. The above Common Minister Decision amended and limit values for emergency measures, were replaced with the new limit values set out in Annex XII **Directive 2008/50/EC** (CMD.14122/549 / E103, Gov.488V / 03.30.11).

The alert thresholds for temporary measures applicable to the treatment of air pollution are presented below:

Pollutant	Time Base	Alert Threshold
NO_2	1 Hour	400 μg/m^3 excess of this value for 3 continuous hours
SO_2	1 Hour	500 μg/m^3 excess of this value for 3 continuous hours
O_3	1 Hour	240 μg/m^3 excess of this value for 3 continuous hours for implementation of action plans

Since Community law has no population information and alert thresholds for PM10 and air pollution treatment by particulate matter, the CMD issued 70 601 (Gov.3272V/ 23.12.2013), which establishes levels of particulate matter concentrations PM_{10} sets information measures and protection of the population and measures to reduce emissions of particulate matter from combustion, industry-crafts and vehicles depending on the levels of concentrations.

Updated alert threshold contingency measures currently to tackle air pollution in the GAA presented in the table below:

Pollutant	Time Base	Alert Threshold
PM_{10}	24h	51-75 μg/m^3 recommendations for vulnerable population groups
		76-100 μg/m^3 recommendations for vulnerable population groups and general population
		101-150 μg/m^3 recommendations for vulnerable population groups and general population, emission reduction measures particulate matter from combustion, industrial-crafts and traffic
		>150 μg/m^3 recommendations for vulnerable population groups and general population, emission reduction measures particulate matter from combustion, industrial-crafts and traffic

7. Introduction

Silva and Quiroz (2003) attempt to optimize Santiago's atmospheric monitoring network by **excluding the least informative stations** with respect to the variables under study: CO, PM_{10}, O_3 and SO_2. To accomplish this, an index of multivariate effectiveness, based on Shannon information index, is applied to that network. The possible exclusion of those monitoring stations appearing as ‘‘the least informative’’ and, if possible, to find out an optimal configuration of stations, meaning a smaller set of stations that provides adequate information for administrative purposes. Perez-Abreu and Rodrıguez (1996) did a similar work for Mexico City using a 15 days campaign collecting data on four gaseous pollutants. Tasco and Zampilloni (2005) on their study for the design of an AQMN in Roman urban area (Italy), used a statistical approach to process air quality map, census data and pollutants data derived by existing monitoring stations. Data coming from different sources were normalized and referred to the same territorial unit. This method allowed the production of a critical state index map. To select the areas more suitable for monitoring station locations, pollutants distribution due to vehicular traffic was also taken into account. According to European Criteria a new monitoring network was planned also using for micro-scale territorial analysis several orthophotos of the city. Moreover this procedure allowed verifying the effectiveness of the positions of the existing monitoring stations. The monitoring network of the roman territory seems to follow the European criteria, particularly concerning macro-scale criteria.

Air quality models are powerful tools to predict the fate of pollutant gases or aerosols upon their release into the atmosphere. Dispersion is primarily controlled by turbulence, which is random by nature, thus cannot be precisely described or predicted by means of basic statistical properties. As a result, there is spatial and temporal variability that naturally occurs in the observed concentration field. On the other hand, uncertainty in the model results can also be due to factors such as errors in the input data and model formulation. Because of the effects of uncertainty and its inherent randomness, it is not possible for an air quality model to ever be “perfect”, and there is always a base amount of scatter that cannot be removed (Chang and Hanna, 2004). Nevertheless, air quality models need to be properly evaluated before their predictions can be used with confidence, since model results often influence decisions that have large public to models health and economic consequences.

In the present study **we are applying a simple multi linear regression model for a possible exclusion of a redundant site in the GAA**, considering the siting criteria of Chapter 4.

7.1. Athens – Photochemical Episode Summer 2013

Athens, the largest city in Greece with almost half the country's population, has been facing air pollution problems due to the concentration of air pollution sources and especially traffic, its complex geomorphology and its subtropical Mediterranean climate (Progiou and Ziomas, 2011).

The municipality (City) of Athens had a population of 664,046 (in 2011, 796,442 in 2004) [ELSTAT] within its administrative limits, and a land area of 39 km^2. The urban area of Athens (Greater Athens and Greater Piraeus) extends beyond its administrative municipal city limits, with a population of 3,090,508 (in 2011) [ELSTAT] over an area of 412 km^2. The heritage of the classical era is still evident in the city, represented by ancient monuments and works of art.

The Athens Metropolitan Area consists of 58 densely populated municipalities, sprawling around the municipality of Athens (the city center) in virtually all directions. For the Athenians, all the urban municipalities surrounding the city center are called suburbs. According to their geographic location in relation to the City of Athens, the suburbs are divided into four zones; the northern suburbs (including Agios Stefanos, Dionysos, Ekali, Nea Erythraia, Kifissia, Maroussi, Pefki, Lykovrysi, Metamorfosi, Nea Ionia, Nea Filadelfeia, Irakleio, Vrilissia, Melissia, Penteli, Chalandri, Agia Paraskevi, Galatsi, Psychiko and Filothei); the southern suburbs (including Alimos, Nea Smyrni, Moschato, Kallithea, Agios Dimitrios, Palaio Faliro, Elliniko, Glyfada, Argyroupoli, Ilioupoli, Voula and Vouliagmeni); the eastern suburbs (including Zografou, Dafni, Vyronas, Kaisariani, Cholargos and Papagou); and the western suburbs (including Peristeri, Ilion, Egaleo, Agia Varvara, Chaidari, Petroupoli, Agioi Anargyroi and Kamatero).

To investigate the characteristics of pollutant behavior in the Greater Athens Area, monitoring data of Ozone are used here. **Data were obtained from the extended air pollution measurement network which operates in the greater Athens conurbation**, under the supervision of the Hellenic Ministry of the Environment, Energy and Climate Change (HMEECC). The network of ambient monitoring stations was launched in the mid-80's to cover the need for a systematic analysis of meteorological and air quality observations from the Athens area, by the then Hellenic Ministry for the Environment, Physical Planning and Public Works and has much developed since.

Each monitoring station is measuring certain criteria air pollutant concentrations at a characteristic location within the urban conurbation of Athens (Mavroidis and Chaloulakou, 2011).

The spatial distribution of the greater Athens area air pollution monitoring network is presented in **Fig. 7.1**. Therefore, in 2009, 15 AQMS were operating in total in the GAA (region of Attica). **Table 7.1** presents the detailed AQMSs specifications.

According to HMEECC (Direction of Air Pollution and Noise Control, 2010) these stations are classified as follows: (a) six urban-traffic, (b) two urban-background, (c) four suburban-background, (d) two suburban-industrial, and (e) one suburban. In the present study, air pollutant variables are investigated using data sets obtained from thirteen AQMS in the Athens conurbation, corresponding to the three main monitoring station categories, i.e. urban-traffic, urban-background and suburban background. Although urban-traffic and urban background stations are located within urban areas of major cities such as Athens, they are distinguished from each other in the basic allocation strategy (Nguyen and Kim, 2006).

Urban-traffic stations are located very close to major traffic arteries (roadside or kerbside stations) in order to monitor the direct influence of traffic to air pollution, while urban-background stations aim to monitor the background concentrations of pollutants in urban areas, outside the direct influence of major roads. Suburban-background stations are set to be representative of the pollution levels observed in the respective suburban background areas. Pollutant concentrations determined from all three types of monitoring stations can therefore be used to explore the spatial and temporal distribution patterns of different pollutants, both primary (e.g. NO) and secondary (e.g. O_3) as well as their interrelation, under varying environmental conditions.

7.1.1. AQMN description

Long data time-series are available at all thirteen stations, providing the opportunity for an investigation and comparison of the long-term pollutant concentration trends, while on the same time allowing an evaluation of the type/classification of all AQMSs.

1. **"Patission" station** is located on a busy street near the Athens city-center, where the traffic load is very high. Its classification is Urban – Traffic as expected and usually the site is a benchmark for traffic-volume and air pollution status for the entire city of Athens. Traffic intensity (24-h) at Patission Street during a typical, busy, weekday in November 2009 was approximately 67,000 vehicles (Ministry of Development, Competitiveness, Infrastructures, Transportation and Networks, 2012).
   The AQMS is among the oldest included in the AQMN of Athens. It is operating since 1984 and it's the only one that detects C_6H_6. The proximity of the site with the two of the same class monitoring stations, ("**Aristotelous**" and "**Athinas**") is something that has to be re-considered regarding its representativeness. The distance between "Patission" and "Aristotelous" station is about 1.3km and between "Patission" and "Athinas", 2.4km. Those three AQMSs are almost on a straight line and **probably there is an overlap** between the three of them. The expected concentration measurements during a normal (non-episode) day are highly correlated. Only 1000m are separating the "Patission" and "**Aristotelous**" AQMSs and although the latter is also located in an area with a heavy load of traffic primary pollutants, there is a high possibility to be the **"least informative"** station between the three of the same class. This indication comes from long-time NO_2 time-series and other traffic related pollutants, by applying a single linear regression for these sites.
   Athinas' AQMS is near Acropolis, Thisseio and Ancient Agora archaeological sites and thus the protection from high pollutant concentrations, of those sites is a primary target. Several other cultural properties are close to those three AQMSs and as mentioned in Chapter 4.7.2, this is a micro-scale siting criteria issue that has to be taken in high priority in a possible network optimization or redesign.

2. **"Liossia" station** is located within a suburban area at the north/north-west part of the Athens conurbation. It operates since 2000 at a location 2 km southwest of its original location (while for two years between 1997 and 1999 it operated at a different, third, location 3 km north of the original one). The exact characteristics of the Liossia station could be also influenced to some extent from changes in the distribution of traffic loads in its greater vicinity, associated with the construction and operation (in the beginning of the 00's) of a new traffic network, including the new toll motorway of Athens ("Attiki Odos"). **Liossia and Patission** stations are operating since 1984, from the beginning of operation of the network of the Athens monitoring stations.

3. **"Peristeri" station** is located within the Athens urban-area, but away from the city-center and it is in operation since 1990. (Further description of the AQMS at chapter 7.2)

4. **"Geoponiki" station** is located in the western side of Athens, in the suburb called "Votanikos", inside the territory of the **Agricultural University of Athens,** next to "Iera

Odos" avenue, only a few minutes from the center of Athens. Nearby there is a wooded area of about three hundred acres. The station is operating since 1984 and is **classified as suburban-industrial**. Although it is close to the urban area of Athens, the time the station was first sited; the area was industrialized and considered as a suburb. The site is not representative for its current classification. Further changes in the vicinity of the station such as the urban deployment of Athens and the declining of the industrial activities, **makes necessary the re-classification of the AQMS**. The industrial characterized area has no permanent emissions from nearby industries. The major source of the emissions nearby (western) the station are the road transport agencies which they deliver stuff, using heavy trucks mostly during weekdays and working hours. The wind direction is critical for the site's representativeness. Winds with west or south-west direction are transferring traffic pollutants from the center of Athens and the site is highly correlated with the three Urban-Traffic AQMS (Patission, Aristotelous, and Athinas). The site is also between two major traffic sources: Iera Odos (westerly) and Leoforos Athinon (easterly) with tens of thousands of vehicles every day. According to siting criteria described in chapter 4, the AQMS has to be relocated otherwise its **contribution to Network's reliability** shall remain poor.

5. **"Nea Smirni" station** is located in the southern side of Athens, in Nea Smirni suburb. It is a typical Urban-background site and the station is next to a park, sports facilities and the municipality's cemetery. The streets that surrounding the site are mainly of low traffic, not exceeding the ADT of 500vehicles/day, but there are also major streets at a distance of about 200m with traffic volume more than 500vehicles/day. It is dominated by traffic pollutants from the center of Athens when the winds blowing from the north. Most of the siting criteria discussed in chapter 4 are covered regarding the representativeness of the current classification, although when the initial siting of the station was done back in 1984, there must have been consideration for the "Elliniko" Airport which was operating until March of 2001. The airport is located southern of the AQMS less than 3.5km away in **a straight line with** its runway, which is NNW oriented. As for most of the AQMS included in the metropolitan network, later infrastructure development affected the site's representativeness. The site covers a major area and its contribution to the AQMN is important, while the closest AQMS is more than 5km distance.

6. **"Agia Paraskevi" station** is a typical suburban-background site which is not influenced by any major pollution sources, located southern of the suburban area of Agia Paraskevi at the foot of the mountain Ymittos, more than 500 m from any street with low traffic. The site is **fully representative for its classification**.

7. **"Koropi" station** is operating since 2008 and is classified as suburban-background. The nearest AQMS of the same class is "Agia Paraskevi", with a great distance between them. Located in the eastern side of Attica where in the mid 00's there has been a rapid residential building deployment. Additional, great public works including the "Attiki Odos" highway road, the new international airport of Athens and the simultaneous expansion of public transport means, made the necessity to monitor the pollutants which produced from the aforementioned activities an urgent issue. The site is inside the territory of the town Koropi, in an "open" space site which is not influenced by any

major pollution sources. The AQMS Koropi is considered as a **strong contribution to GAA's network coverage.**

8. **"Lykovrisi" AQMS** is a classified as **suburban** and it's the only one of its class. Located in the suburban area of Lykovrisi at the northern side of Athens, with a distance more than 100 meters from any street with low traffic. This is a residential not so densely built area and in the station's vicinity there are several parks. It could have been classified as suburban-background site.

Ozone concentrations are also reported at an hourly basis, using an Ultra-Violet Absorption ozone analyzer. Concentrations of NO, NO_2 and O_3 in the troposphere are in general dominated by the main reactions (Mavroidis and Chaloulakou, 2011):

(a) $NO + O_3 \rightarrow NO_2 + O_2$
(b) $NO_2 + h_\upsilon + O_2 \rightarrow NO + O_3$, in which h_υ is light, with wavelength shorter than 424 nm.

In the present study, we investigated photochemical episodes using concentration time series (covering a monthly period from 15 July to 15 August 2013). We have chosen the most intense episode which was at 30/31 of July 2013 using hourly measured O_3 concentrations from ten/eight/six AQMSs in a simple multiple regression model.

Air Quality Monitoring Station (AQMS)						Sampled Pollutants						
	Site											
	Name	Longitude	Latitude	Elevation(m)	Classification	SO_2	NO_X	CO	O_3	PM_{10}	$PM_{2.5}$	C_6H_6
1.	Athinas	23° 43′ 36′′,63	37° 58′ 41′′,53	100	Urban-traffic	✓	✓	✓	✓			
2.	Aristotelous	23° 43′ 39′′,46	37° 59′ 16′′,90	95	Urban-traffic		✓			✓		
3.	Geoponiki	23° 42′ 24′′,44	37° 59′ 01′′,05	40	Suburban-Industrial		✓	✓	✓			
4.	Liossia	23° 41′ 52′′,23	38° 04′ 36′′,53	165	Suburban-Background		✓		✓			
5.	Lykovrisi	23° 47′ 19′′,71	38° 04′ 04′′,35	234	Suburban		✓		✓	✓	✓	
6.	Marousi	23° 47′ 14′′,49	38° 01′ 51′′,02	170	Urban-traffic		✓	✓	✓	✓		
7.	N.Smirni	23° 42′ 46′′,83	37° 55′ 55′′,18	50	Urban-Background		✓	✓	✓			
8.	Patission	23° 43′ 58′′,97	37° 59′ 58′′,05	105	Urban-traffic	✓	✓	✓	✓			✓
9.	Peiraias 1	23° 38′ 42′′,81	37° 56′ 40′′,75	4	Urban-traffic	✓	✓	✓	✓	✓	✓	
10.	Peristeri	23° 41′ 18′′,08	38° 01′ 14′′,91	80	Urban-Background	✓	✓	✓	✓			
11.	Ag. Paraskevi	23° 49′ 09′′,90	37° 59′ 42′′,39	290	Suburban-Background		✓	✓	✓	✓	✓	
12.	Elefsina	23° 32′ 18′′,41	38° 03′ 04′′,86	20	Suburban-Industrial	✓	✓		✓	✓		
13.	Thrakomak	23° 45′ 29′′,46	38° 08′ 36′′,68	550	Suburban-Background		✓		✓	✓		
14.	Koropi	23° 52′ 44′′,48	37° 54′ 04′′,70	140	Suburban-Background		✓		✓	✓		
15.	Oinofita	23° 38′ 20′′,09	38° 18′ 22′′,39	100	Suburban-Industrial	✓	✓		✓	✓		
16.	Aliartos	23° 06′ 36′′,96	38° 22′ 30′′,89	110	Background	✓	✓		✓	✓		

Table 7.1: Specifications of the AQMSs included in the Athens AQMN

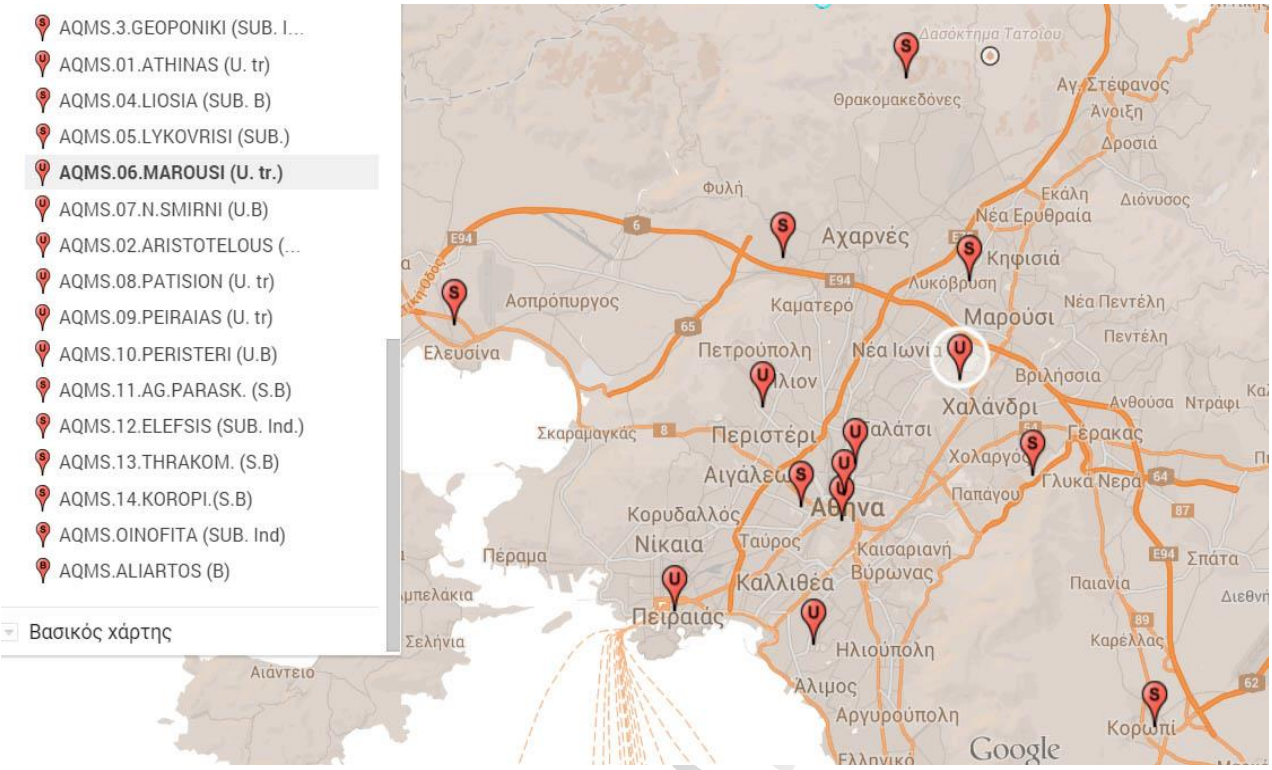
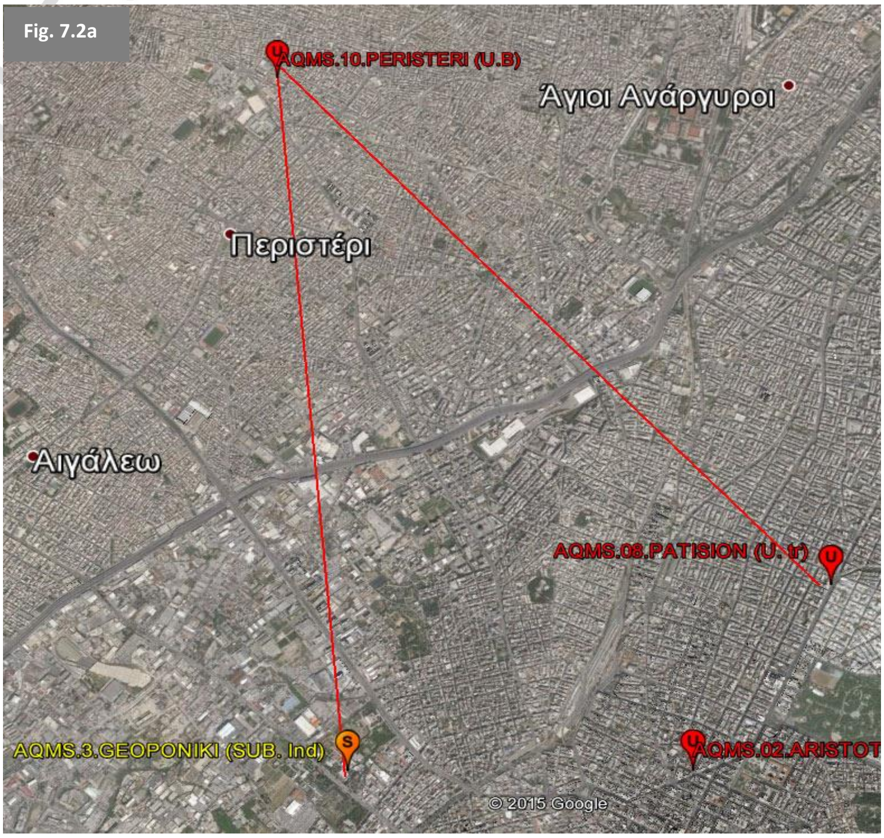


Fig.7.1: Map of the GAA and the location of each AQMS

7.2. Athens - Application of Multiple Regression Model – First Part

The AQMSs selected in the present study at the **first part of the multiple linear regression model** (the numbers are corresponding to sites on the map of Fig. 7.1) are: **(10) Peristeri (urban-background)** as the primary dependent variable and as the independent variables of the multiple linear regression:

- (4) Liossia (suburban-background),
- (3) Geoponiki (Suburban-Industrial)
- (7) Nea Smirni (Urban-Background)
- (11) Agia Paraskevi (Suburban-Background) and
- (14) Koropi (Suburban-Background).



At the second part of the regression, the model includes: (5)

Lykovrisi (Suburban) as the dependent variable and:

- (6) Marousi (Urban-traffic)
- (12) Elefsina (Suburban-Industrial)
- (11) Agia Paraskevi (Suburban-Background)
- (13) Thrakomakedones (Suburban-Background)
- (4) Liossia (Suburban-Background), as the independent variables of the multiple linear regression model.

The AQMS "Peristeri" is selected as our primary dependent variable. The classification of the site is Urban-Background (U.B) and it is located at the western side of the center of Athens, in a suburb inhabited by **low income population**, where high ozone concentrations are also expected. The station installed in 1990 and except from the later building development mainly from mid-90s until mid-00s, there is no other activity that could affect the site's original representativeness, as it was initially planned. The closest AQMS sites to the last mentioned are "Patission" and "Geoponiki, both of them in a straight distance of about 4,5km and "Peristeri" is on the top angle of an isosceles triangle between the three of them as seen in fig 7.2a. Clearly in the satellite image, the "triangle" is cut in the middle by the national Highway road which is the physical border between the municipality of Athens and the western suburbs. (**All images/maps are North oriented**)

As described above **the classification of the site as U.B, is justified** according to literature criteria which mentioned in chapter 2.2. **There aren't nearby emitters or any other source stream**. The **AQMS covers the macro scale siting criteria** as discussed in Chapter 4, like "site logistics" or representativeness according to population coverage and social criteria. The station is about at 3m height in the roof of a primary school. Mostly it is surrounded by an open space with buildings (from northeast to northwest) of low height (2-3 floors).

Fig.7.2c: Location of AQMS Peristeri

Southwest of the station, there is an average traffic street, more than 130m away (cyan line in **fig 7.2c**) and about 300m (southeast) from another average traffic street (red distance line). In the vicinity of the AQMS there are soccer fields, a park (southwest), a high school (northwest) and low traffic streets with ADT<100 vehicles/day. There is also the municipality's parking and laundry for garbage trucks at a distance of 330m southwest of the station. During the summer months with high average temperatures and blowing from SSW prevailing winds, it might be a potentially confounding air pollutant source.

<u>The weather conditions during the episode (Table 7.2b)</u>:

Wind Speed: At daylight the maximum wind speed that observed was about 20km/h at noon, with no wind gusts. Generally wind speed was between calm and at about 10km/h. **Wind direction**: Mostly south or SSW during daylight hours and calm or from variable directions early in the morning, in the evening and late at night. T**emperature**: The temperature was between 25^{o}C and 37^{o}C. The highest temperature was observed from 11:00 until 14:00; the sky was partly cloudy during early noon hours until 15:00 and the next couple of hours the temperature dropped by one Celsius degree because of that. **Humidity**: The conditions were "dry" with average daily relative humidity approximately 30%. At noon hours the lowest value was 18%.

Date	Time	Wind Direction	Wind Speed	PERISTERI
			Km/h	μg/m^3
				Ozone
30/7/2015	1:00	NNW	9.3	94
30/7/2015	2:00	Calm	Calm	86
30/7/2015	3:00	Calm	Calm	66
30/7/2015	4:00	Calm	Calm	87
30/7/2015	5:00	North	7.4	75
30/7/2015	6:00	NNW	9.3	92
30/7/2015	7:00	Calm	Calm	48
30/7/2015	8:00	South	11.1	26
30/7/2015	9:00	South	11.1	50
30/7/2015	10:00	South	14.8	91
30/7/2015	11:00	SSW	18.5	134
30/7/2015	12:00	South	16.7	138
30/7/2015	13:00	South	16.7	150
30/7/2015	14:00	South	20.4	165
30/7/2015	15:00	South	14.8	187
30/7/2015	16:00	SSW	11.1	197
30/7/2015	17:00	South	9.3	183
30/7/2015	18:00	Calm	Calm	166
30/7/2015	19:00	Calm	Calm	145
30/7/2015	20:00	Calm	Calm	86
30/7/2015	21:00	NNW	7.4	85
30/7/2015	22:00	Calm	Calm	73
30/7/2015	23:00	Calm	Calm	56
31/7/2015	0:00	NNW	7.4	45

Table 7.2b

Initially on the first "run" of the model, we included nine independent variables in our regression model. The selected sites were: (4) Liossia, (3) Geoponiki, (7) Nea Smirni, (11) Agia Paraskevi, (14) Koropi, (5) Lykovrisi, (6) Marousi, (12) Elefsina and (13) Thrakomakedones. Our model gave us satisfied results with a good significance F-value, although the p-values of Lykovrisi, Marousi, Elefsina and Thrakomakedones were very poor. Table 7.2c presents the correlation properties between the selected ten AQMSs, during the episode-day.

	Lykovrisi	Peristeri	Marousi	Liossia	Geoponiki	n.smirni	thrakom	ag parask	Elefsina	Koropi
Lykovrisi	1									
Peristeri	0,885251	1								
Marousi	0,869226	0,883752	1							
Liossia	0,817284	0,930159	0,895969	1						
Geoponiki	0,840924	0,93884	0,93431	0,96338	1					
n.smirni	0,828282	0,932858	0,90548	0,883051	0,923972	1				
thrakom	0,600364	0,684412	0,496998	0,702183	0,660037	0,606632	1			
ag parask	0,857274	0,796448	0,649592	0,655022	0,669532	0,657756	0,505547	1		
Elefsina	0,87554	0,902877	0,892904	0,921764	0,941556	0,903707	0,591385	0,687401	1	
Koropi	0,850188	0,848209	0,841258	0,821238	0,870298	0,838516	0,498894	0,837237	0,871935	1

Table 7.2c: Correlation Coefficients for all sites – 30 July 2013

In the second "run" we excluded those sites with p-value>.05 in our ANOVA table results: (5) Lykovrisi, (6) Marousi, (12) Elefsina and (13) Thrakomakedones. **"Liossia" station** kept as a variable inside our model although its p-value was approximately 9% on the first "run". This was crucial for the consistency of the experimental network model we decided to implement because this AQMS is very close to city's landfill and its location is the only one left northern of "Peristeri" site. Finally, on **the second "run"** of our multiple regression model we included the AQMSs with the following hourly ozone concentrations as seen on **diagram 7.2a** and the chosen sites as seen in **fig 7.2d:** (10) Peristeri (U.B) as the dependent variable and as independent variables: (4) Liossia (S.B), (3) Geoponiki (S.I), (7) Nea Smirni, (11) Agia Paraskevi and (14) Koropi.

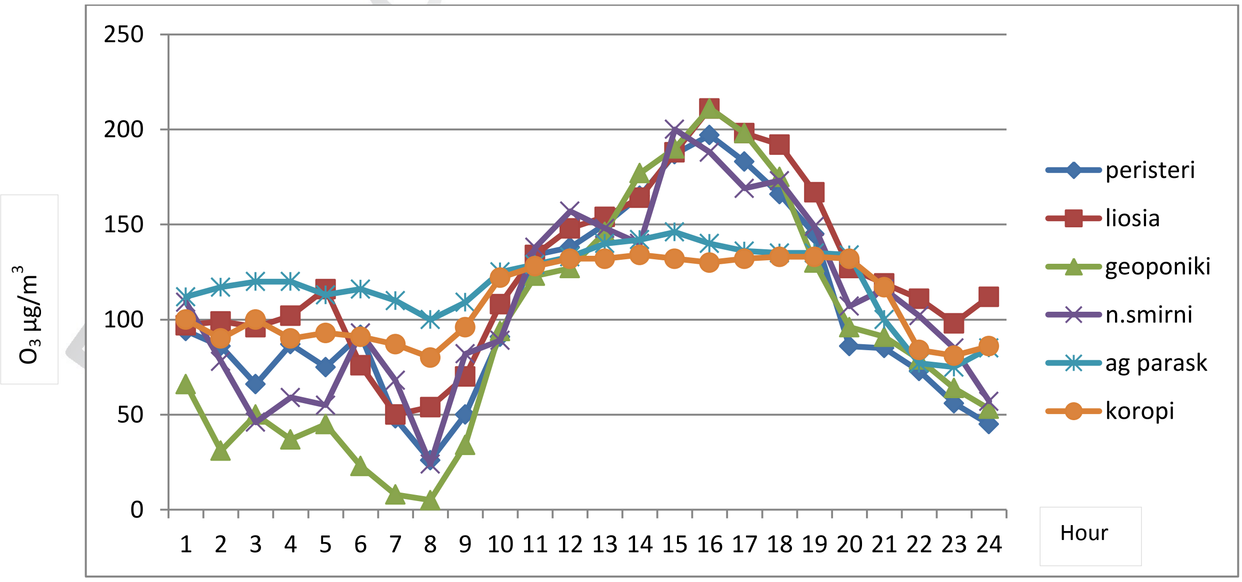


Diagram 7.2a: 30 July 2013, Hourly O_3 concentration variance of selected AQMS for second "run"

The S.B classified stations of Agia Paraskevi and Koropi have less concentration fluctuation compared to other AQMSs of those who participate on the model and this is something we expected to happen. There is no significant pollutant transportation during the episode from the center of the city (wind direction was opposite) to the direction that the aforementioned AQMSs are located. The correlation coefficient of Agia Paraskevi station is low, compared to all other sites.

All others stations showed a rapid increment of ozone concentration simultaneously at noon hours. It seems that only the general local pollutant sources contributed to this and not a spatial dispersion of the ozone related pollutants as further discussed in next chapter 7.2.1

Fig.7.2d: The AQMSs included in the second run of the model

The results of our **ANOVA table,** gave us an excellent **F-value** and all of our independent variables **were statistical significant regarding the p-value**. The decision to keep the variable of "Liossia" site, improved our model results although its p-value was .078 slightly higher than .05. Nevertheless the adjusted R-squared has improved and the predicted values versus actual values of "Peristeri" station can be seen in **diagram 7.2b**. It seems that during a day with hot and dry meteorological conditions the model works well for the specific sites and there is no sufficient spatial distribution of ozone related pollutants between the sites.

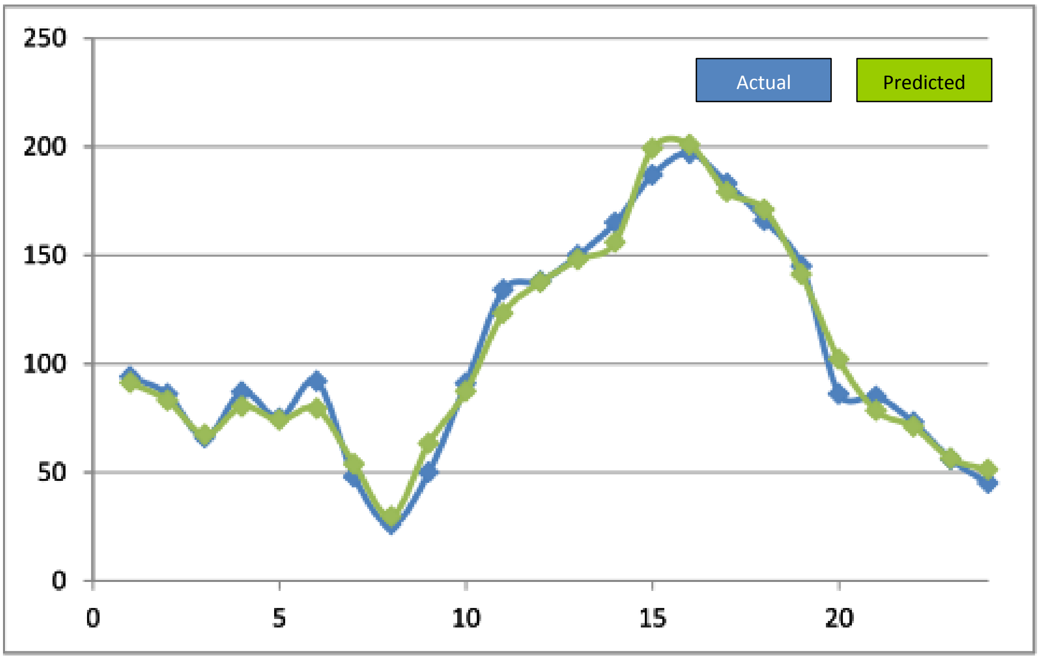


Diagram 7.2b: 30 July 2013, Actual and predicted values of AQMS "Peristeri"

7.2.1. **Determination of correlation and local source contributions**

The relationships between temporal trends of different measuring stations were analyzed in terms of the Pearson correlation coefficient. This approach, tests the linear correlation between two variables. The episode's correlation coefficients between them[15] in **table 7.2c**, as they were in 30th July 2013, with the meteorological conditions as seen in **table 7.2b. "Peristeri" as the selected dependent variable seems to has the better degree in correlation with the other selected AQMS. The Suburban Background classified AQMS of Agia Paraskevi is the least correlated site and this is a strong indication that during the episode conditions, the AQMS's is representative for its location.** The data that generated from this site reflects the O_3 concentrations and their variations in the area.

	Peristeri	Liossia	Geoponiki	n.smirni	ag parask	Koropi
Peristeri	1					
Liossia	0,930159	1				
Geoponiki	0,93884	0,96338	1			
n.smirni	0,932858	0,883051	0,923972	1		
ag parask	0,796448	0,655022	0,669532	0,657756	1	
Koropi	0,848209	0,821238	0,870298	0,838516	0,837237	1

Table 7.2c: Model Correlation Coefficients – 30 July 2013

[15] In Regression theory, we need a high degree correlation coefficient between the Y-dependent variable and the X's independent variables and in opposite a low degree between X's independent variables

As all in the Mediterranean countries in summer there are reduced human activities in urban areas due to vacation season resulting to lower primary pollutant emissions which are related to ozone. At a glance we can see in urban-traffic sites the reduced ADT volume between 20th July until 15th August and data time-series from all sites classified as “Urban-Traffic” of Athens’ AQMN prove this claim.

Liossia, Peristeri, Geoponiki and Smirni are almost in a straight line (from north to south) and this explains the observed **high correlation coefficients between them**, considering the prevailing winds during that day, which they were from north to south direction. In Athens, north northeasterly winds are synoptic and usually stronger as compared to south - southwesterly winds, assisting the increased dispersion of primary pollutants (Direction of Air Pollution and Noise Control, 2010).

Considering the physical distance between the sites and although there is a high correlation coefficient among some of them, we concluded that the ozone concentrations in the selected sites, **simultaneously increased** during the day, with the present meteorological conditions. This indicates that there is a low contribution from specific local sources and it consists mainly of background pollution inventory or **general local sources**. **The affection** of ozone related pollutants can be examined here.

We also used the **Durbin-Watson test** for our test conditions, to detect **the presence of autocorrelation**. The test resulted a value of **2.36** (close to 2) which is a very good prove of no autocorrelation between the chosen independent variables.

The lowest ozone concentrations in all included sites were observed in the morning between 07:00am and 09:00am. That was when the wind changed direction from north-NNW to South-SSW. There wasn’t any primary pollutant transfer from the central urban areas of Athens.

At noon the observed ozone concentrations were the highest of the samples as expected. Usually in GAA, **the highest ozone concentrations** are observed when the winds are blowing from the south-easterly and south directions, since these winds bring primary pollutants from the more polluted central parts of Athens towards the north, where pollutants are trapped at the mountainous ranges and are converted to secondary pollutants, such as ozone, through photochemical reactions in the atmosphere (I. Mavroidis, 2012). This effect is captured by the ozone concentrations observed at Peristeri and Liossia stations, since these stations are located at the north to north-west of Athens.

Non episode Correlation Conditions

In similar meteorological “dry” conditions the correlation coefficients were at the same level, more or less. Wind direction was mostly East and ESE during the noon hours that day, thus higher correlation values for ozone concentrations observed between “Agia Paraskevi” station, “Geoponiki” and “N.Smirni”. As seen, the meteorological conditions are a critical factor, for correlation properties between sites.

	Peristeri	*Liossia*	*Geoponiki*	*N.Smirni*	*ag parask*	*Koropi*	*Lykovrisi*
Peristeri	1						
Liossia	0.861730341	1					
Geoponiki	0.924300339	0.916135506	1				
N.Smirni	0.927978031	0.849676665	0.964034	1			
ag parask	0.863828528	0.867158623	0.970617	0.934861	1		
Koropi	0.927969559	0.850864876	0.933081	0.924594	0.92144	1	
Lykovrisi	0.872140358	0.950526075	0.964581	0.886664	0.9309	0.882481	1

Table 7.2d: Correlation Coefficients – 28 August 2013

7.2.2. **Third "Run" of the Regression Model A**

On the **third "run"** an additional **site is included to test our predictability**. The station "Lykovrisi" is the **sixth independent variable (Fig. 7.2e)** which initially was already included in our model and then excluded due to low p-value following the procedure of excluding the least significant variables from the model equation.

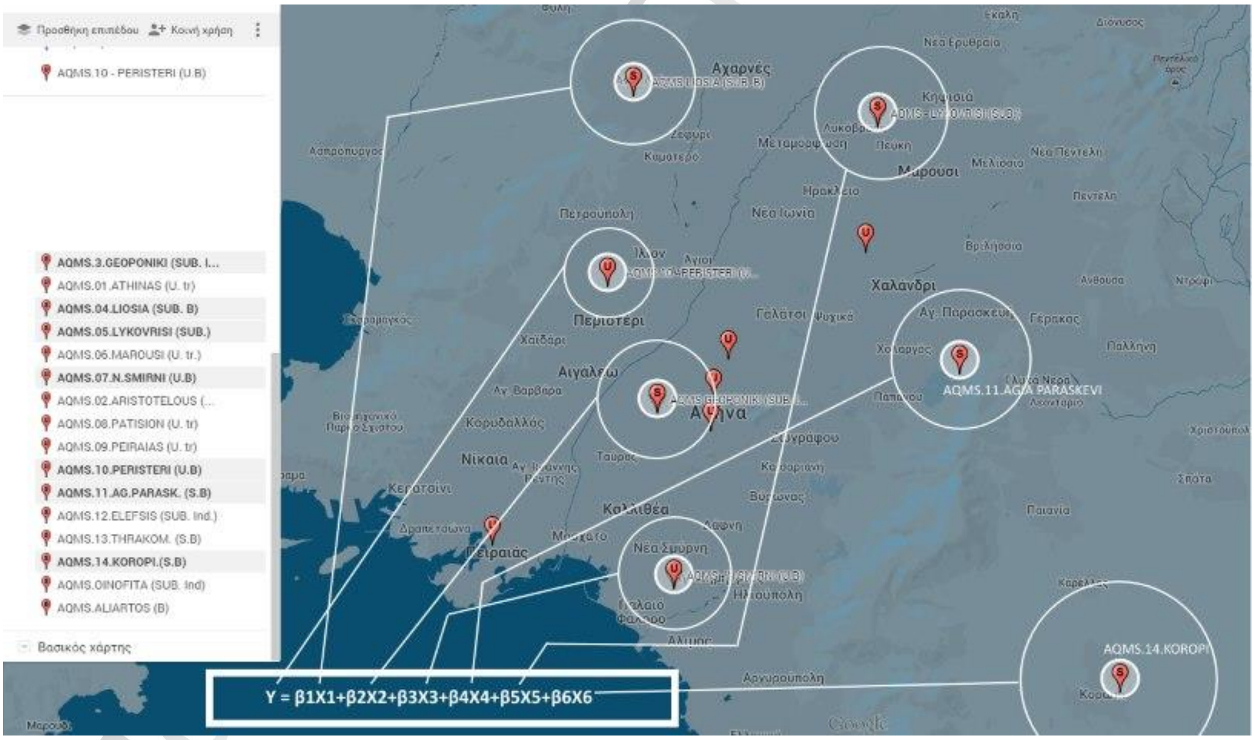


Fig.7.2e: Map of the GAA and the location of each AQMS of the third "run" of the multiple regression.

The addition of a new independent (or explanatory) variable did not affect the **adjusted R-squared**[16] value (actually it was slightly improved) and the results in our ANOVA table regarding the p-values of the X variables **were improved** in comparison with the second "run" of the model.

[16] The use of an adjusted R^2 (often written as $\bar{R}^2$ and pronounced "R bar squared") is an attempt to take account of the phenomenon of the R^2 automatically and spuriously increasing when extra explanatory variables are added to the model. Unlike R^2, the **adjusted R^2** increases when a new explanatory is included only if the new explanatory improves the R^2 more than would be expected by chance. If a set of explanatory variables with a predetermined hierarchy of importance are introduced into a regression one at a time, with the adjusted R^2 computed each time, the level at which adjusted R^2 reaches a maximum, and decreases afterward, would be the regression with the ideal combination of having the best fit without excess/unnecessary terms.

Although the p-value (0.26) of Lykovrisi site is statistically insignificant, the addition of this specific site improved all the other p-values. The **R-squared[17] value** is also improved on the third "run" of the model and **this demonstrates that our data are fitted better in the regression line**. A further addition of an independent variable to the model is not necessary, as this might be a negative influence considering the limit value of adjusted-R^2. **Table 7.2e** presents these results and the Durbin – Watson test. The Durbin Watson test (2.377) result proves no presence of autocorrelation (no relationship between values for the given time lag).

	First «Run"	Second "Run"	Third "Run"
Multiple R	0.9905	0.9893	0.9901
R-squared	0.9811	0.9788	0.9803
Adjusted R-squared	0.9690	0.9729	0.9734
Durbin-Watson test	2.431	2.357	2.377
Explanatory Variables	9	5	6
Statistically significant variables (p-value<0.05)	4/9	4/5	5/6
Observations	24	24	24

Table 7.2e: Model General Statistic Coefficients with AQMS Peristeri as dependent variable

When the number of explanatory variables is large (1st Run), it often happens that not all variables are needed to accurately predict the response, and model selection is an issue. The problem consists of choosing the best subset of p explanatory variables among q candidate variables (sites), where p is not specified (i.e. $0 \le p \le q$).

Ideally, one has to select the best model among 2q possible models. In practice, when q is large, one cannot calculate all possible models but only some of them (using e.g. stepwise procedures such as **forward** selection or backward elimination). Then, one may select the best model among the models calculated according to some appropriate criterion.

Obviously, one cannot use only **coefficient R^2 as a criterion for model selection** since this coefficient systematically increases when new variables are included in the model **(Table 7.2e)**, such that one would select the model which includes all q candidate variables. A common strategy for model selection consists in looking for the model which **maximizes R^2-adj**. It turns out that this procedure often selects models with too many variables, and hence still leads to overfitting (V. Rousson, 2006). As seen on table 7.2e the "best" of the three "Runs" of the model was that with the most balanced R^2, R^2-adj and the most statistically significant variables.

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17 **R-squared** is a statistical measure of **how close the data are to the fitted regression line**. It is also known as the **coefficient of determination**, or the coefficient of multiple determination for multiple regression. The definition of R-squared is fairly straight-forward; it is the percentage of the response variable variation that is explained by a linear model. **R-squared = Explained variation / Total variation**
R-squared is always between 0 and 100%:

- 0% indicates that the model explains none of the variability of the response data around its mean.
- 100% indicates that the model explains all the variability of the response data around its mean.

In general, the higher the R-squared, the better the model fits your data.

By alternating the dependent variable (Table 7.2f) in our model, we've tried to investigate which AQMS's concentration values are more predictable for the given model. AQMS "Peristeri" has given the best value for the Pearson correlation coefficient, followed by AQMS "Geoponiki". This indicates that "Peristeri" has a **better linear relationship compared to others as a dependent variable** and considering the results of the model, the station could be characterized as "predictable" and thus it is a candidate site for a possible exclusion from the network.

Y	Multiple R	R-squared
Peristeri	0.990127	0.980351
Lykovrisi	0.939826	0.883273
Liossia	0.971568	0.943945
Geoponiki	0.985425	0.971063
N.Smirni	0.971938	0.944663
ag parask	0.974447	0.949546
Koropi	0.970127	0.941147

Table 7.2f: Alternation of dependent variable on the third "Run"

7.2.3. Second part - Alternative evaluation of the model

Our Linear regression model, run mean air pollutant concentration at the **AQMS Lykovrisi** as the **dependent variable** and Thrakomakedones, Elefsina, Marousi, Liossia and Ag.Paraskevi AQMS as the independent variables**(Fig.7.2f)**. Our independent variables **were all statistically significant (p < .05).**

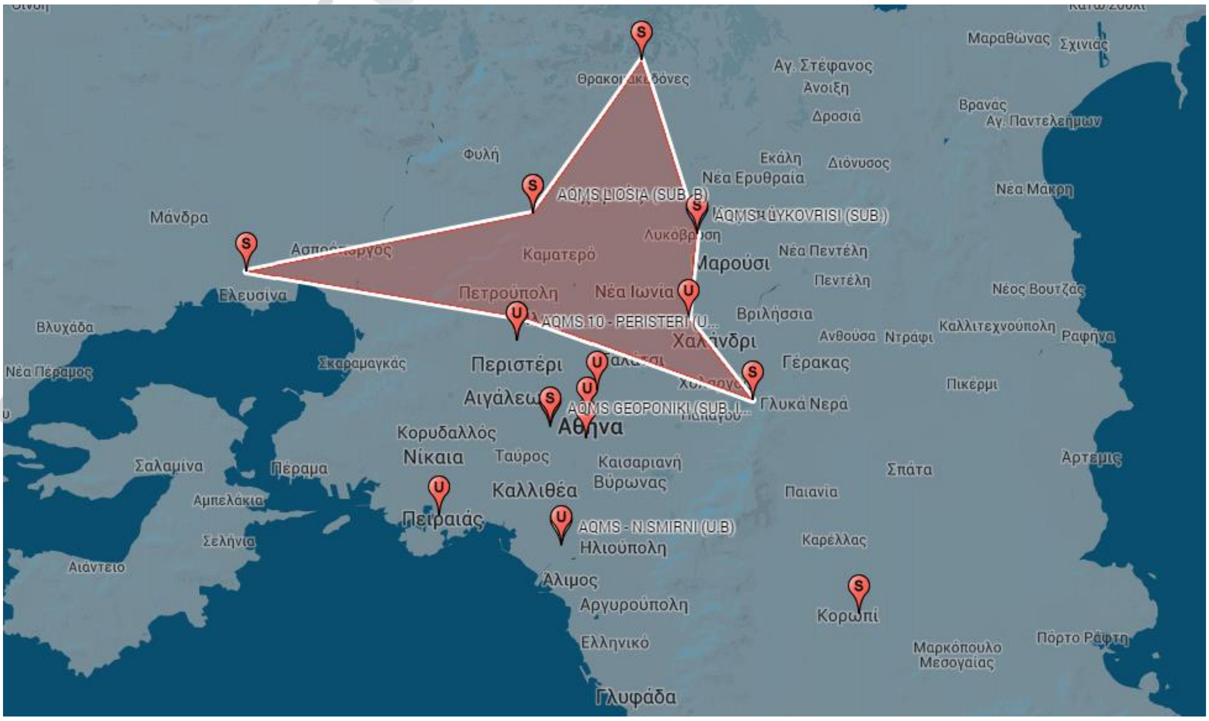


Fig 7.2f: Map showing the station of the second part

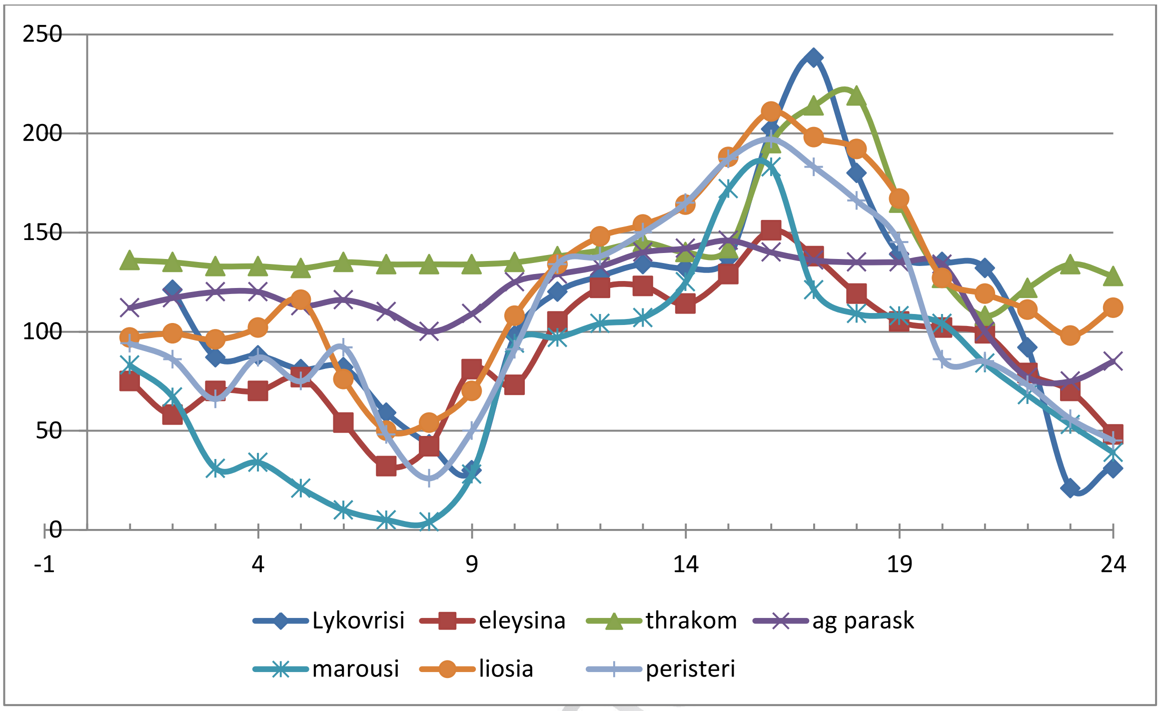


Diagram 7.2c: 30 July 2013, O3 μg/m3, concentrations

The presence of precursors, solar radiation, increased sunlight and high temperatures, contribute to form ozone through photochemical reactions in the lower atmosphere. As a result concentrations of O3 increase rapidly in all AQMSs after 15:00 (**diagram 7.2c**). O_3 concentrations at the background stations of **Liossia, Thrakomakedones and Peristeri** are much higher than at the Urban-traffic station of **Marousi**, where the primary pollutants prevail and O_3 is depleted through equation presented in (a) 7.1.1. During the summer months the reduced traffic activity, reduces also the concentrations of NO and NO_2 traffic primary pollutants and this explains the lower observed concentrations in urban areas of Athens related to background stations. Further away from the road-traffic emissions, i.e. the primary pollutant source, O_3 production is assisted by increased solar radiation through equation (b). **The "suburban" classified site of Lykovrisi appears the highest ozone concentration related to all other stations.**

The **Suburban Background site of Thrakomakedones** during the summer months (1st June- 31st Aug) of 2013 gave an average value of ozone concentration more than 120μg/m3. The value dropped below 100μg/m3 only for a few case that summer during the night hours. This indicates that independently from blowing winds the background concentration is constantly high in that area. It might be said that the production and persistence of ozone is much more evident in suburban-background sites and there is a stronger correlation with meteorological parameters; ozone has a positive correlation with solar radiation and temperature, since ozone is produced through photochemical processes in the atmosphere. Similarly but with much lower average concentration, the phenomenon is observer at Lykovrisi AQMS.

The regression statistics can be seen on below table, as well as the Durbin-Watson statistic. The latter is inconclusive and cannot detect the presence of autocorrelation between the variables.

Regression Statistics	
Multiple R	0.9677
R-squared	0.9365
Adjusted R-squared	0.9188
D/W test	1.454

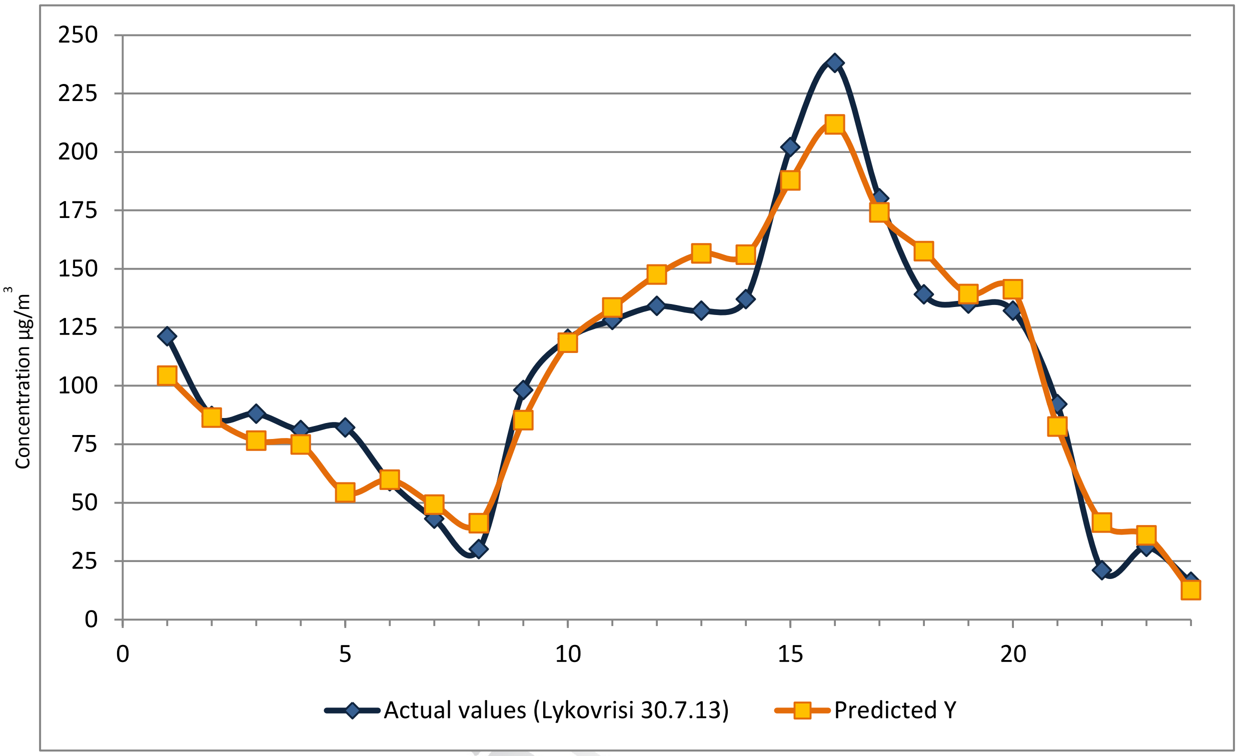


Diagram 7.2d: 30 July 2013, Actual and predicted values of AQMS "Lykovrisi"

Lykovrisi is the only one AQMS of the network **classified as suburban**. A **classification update should be considered for this site** and/or a **possible exclusion** from the network, too. The site cannot fulfill the macro and micro-scale siting criteria, regarding also the representativeness of the measurements of the area. Other sites nearby might be more representative as "suburban" class sites. **The relocation of the station easterly or north-easterly of its current position** might be a better choice for improved network coverage of the area.

7.3. Istanbul – PM_{10} Smog Episode

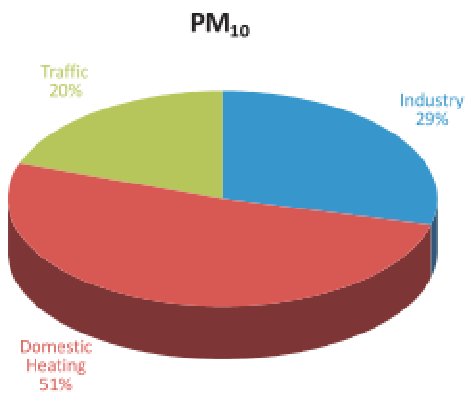
Air pollution is one of the most important environmental problems in metropolitan cities like Istanbul. The spatial and temporal variations in emissions of air pollutants and the accompanying variability in meteorological conditions can lead to occurrences of pollutant levels, which can cause adverse short-term and chronic human health impacts (Künzli et al., 2005). Urban air quality management and information systems are required to predict of next day's air pollution levels and for providing proper actions and controlling strategies. Air quality warning systems are therefore needed in order to obtain accurate advance notice that ambient air concentration levels might exceed air quality guideline or limit values. Warnings can be utilized to alert health care as well as traffic and environmental management so that the adverse effects can be minimized. Such warning systems must be sufficiently reliable and understandable by the majority of people.

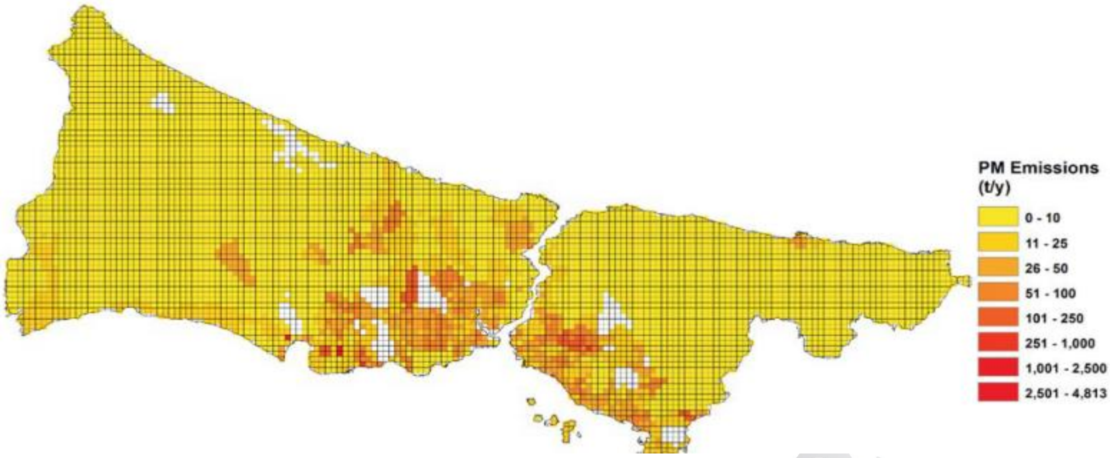
Istanbul covers land and water of about 5343km^2 and the city forms the largest urban agglomeration in Europe. As being one of the biggest cities in the world Istanbul, with extremely fast development and population growth during the second half of the 20th century, it also emerged important environmental problems due to poor quality fuel, poor quality burning devices, buildings without the heat insulation, problems associated with urbanization, application of ineffective burning technologies in industry and insufficient efforts on reducing traffic emissions (Istanbul Air Quality Strategy, 2009). Road traffic emissions are the major source of particulate matter with additional contribution of air pollutants via long range transport mainly from Eastern Europe (Markakis et al., 2009; Kindap et al., 2006; Karaca and Camci, 2010). The air pollution problem experienced in İstanbul has reached to a significant level since 1980's. Similarly, the pollutant concentrations have exceeded the air quality standards for several times.

The climate in Istanbul is dominated by the Black Sea and the Mediterranean climates. Winter is cold and wet while summer is hot and humid. Average annual wind speeds in the city are only 3.0 m/s, 8% calm hours. Prevailing synoptic wind arriving Istanbul are from the north and northeast and southeast in winter, northeast and southeast during the summer months. Daily mean temperatures are 6.3 ^{o}C for winter and 22.4 ^{o}C for summer (Topcu et al, 1995). During the summer, the effect of the Persian Gulf low-pressure system was a key parameter in the meteorology of the region. The system produced north-easterly winds through the Black Sea toward İstanbul. When the system weakened, the so called "relatively" high-pressure system starts to develop over the region exerting its own characteristics of circulation.

7.3.1. PM10 - Pollution Inventory

The area is one **of the most industrialized in Europe and domestic heating is the most polluting sector for PM contributing to 51% of total emissions**. Traffic is also the most polluting sector for NO_X, and CO emissions with the contributions of 89% and 68%, respectively, in our study area (İstanbul Air Quality Strategy, 2009)





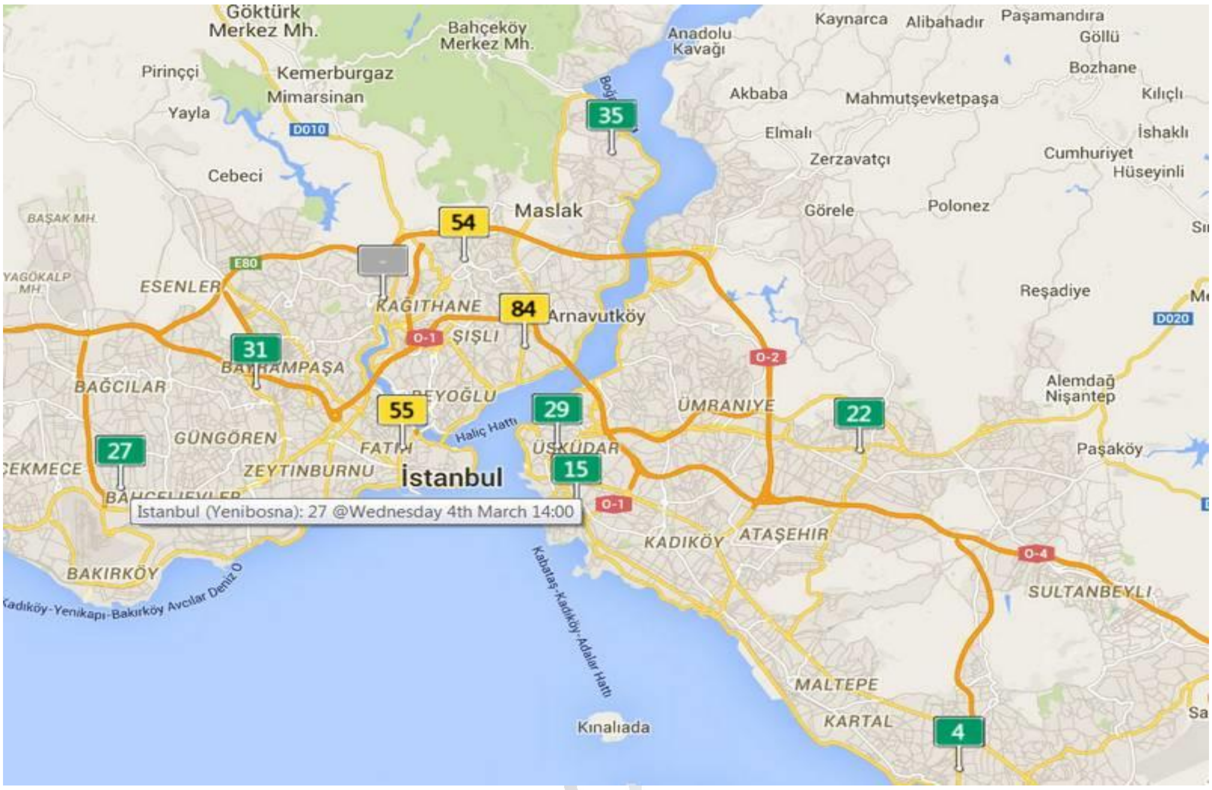
Distribution of annual PM10 emissions from all sources in 2007. Source: İstanbul Air Quality Strategy, 2009

7.3.2. Istanbul's AQMN

Marmara Region is one of the major residential areas of Turkey, where industrialization resulted in an increase in population and road links. Due to its facilities, geographical situation, and ecological characteristics, it has been the focus of constant attention regarding industrialization, transportation and residential development. One of the environmental problems in the region is the pollutant emissions from industry, residential areas and traffic into the atmosphere. How the quantities and properties of these emissions are vary according to time, distance, and the influence of meteorological conditions must be followed significantly. Therefore a total of 39 air quality monitoring stations have been established in 11 provinces in the Marmara Region by the Ministry of Environment and Urbanization creating an air quality monitoring network (MEU, 2013). These stations have been established in 4 different categories, urban, traffic, industrial, and rural. There are differences in the measured parameters between different categories of monitoring stations. At the stations, the measured pollutants are: PM_{10}, SO_2, NO, NO_2, NO_X, O_3. Air pollution has been monitored since 1995 in İstanbul and **metropolitan network includes fourteen AQMS** with ten of them being active or **PM_{10} certified** and most of them **classified** as urban-traffic/urban/suburban, covering an area of approximately 2040 Km^2, and their characteristics appeared below at **Table 7.3a**. Data from the regional monitoring network from the year 2014 were used and came from a total of 14 stations located in the urban areas of the regional territory[18]. Only the monitoring stations with a sampling efficiency of more than 75% have been considered in this analysis **(Fig7.3a).** The method used for the measurement of PM10 concentrations is ß–ray attenuation.

[18] It is possible to reach İstanbul's air quality data from website (http://www.ibb.gov.tr).

Figure 7.3a: Istanbul's AQMN (PM_{10} certified)



Station	Height above sea level (m)	Approximate distance to major roadways (m)	Approximate distance to residential areas (m)	Approximate distance to industries (m)
Istanbul–Aksaray	41	40	190	
Istanbul–Alibeykoy	6	30	100	
Istanbul–Besiktas	98	10	120	
Istanbul–Esenler	55	30	210	
Istanbul–Kadikoy	13	100	10	
Istanbul–Kartal	31	25	150	276
Istanbul–Sariyer	105	42	75	
Istanbul–Umraniye	154	170	250	
Istanbul–Uskudar	70	45	50	
Istanbul–Yenibosna	30	47	70	

Table 7.3a: AQMS characteristics

7.3.3. Application of the model

The PM_{10} smog episode (**11-12, Jan 2014**) was evaluated and hourly measured PM_{10} concentrations[19] from **eight AQMS used in a simple multiple regression model**. Initially performing a multiple linear regression model is running mean PM_{10} concentration at Aksaray's AQMS **location** as the **dependent variable** and seven other AQMSs as independent variables. Four of them were statistically significant ($p << .05$) while correlation coefficient (Pearson) was the highest observed.

[19] Data source online: http://www.havaizleme.gov.tr/Default.ltr.aspx

The F-test performed, resulted a very low significance F value. The confidence level of the regression is 95%

Date	Time	Wind Direction	Wind Speed (km/h)	Aksaray PM10 (μg/m³)
11/1/2014	1:00	SSW	11.1	**83**
11/1/2014	2:00	SSW	11.1	**78**
11/1/2014	3:00	West	7.4	**74**
11/1/2014	4:00	West	11.1	**66**
11/1/2014	5:00	West	9.3	**61**
11/1/2014	6:00	Variable	3.7	**60**
11/1/2014	7:00	West	9.3	**59**
11/1/2014	8:00	West	7.4	**64**
11/1/2014	9:00	West	7.4	**67**
11/1/2014	10:00	WSW	11.1	**66**
11/1/2014	11:00	WSW	13.0	**64**
11/1/2014	12:00	WSW	11.1	**61**
11/1/2014	13:00	WSW	14.8	**62**
11/1/2014	14:00	SW	13.0	**65**
11/1/2014	15:00	WSW	13.0	**68**
11/1/2014	16:00	WSW	11.1	**73**
11/1/2014	17:00	WSW	7.4	**80**
11/1/2014	18:00	SSW	5.6	**84**
11/1/2014	19:00	Calm	Calm	**87**
11/1/2014	20:00	Variable	3.7	**89**
11/1/2014	21:00	SW	5.6	**86**
11/1/2014	22:00	Variable	3.7	**83**
11/1/2014	23:00	Calm	Calm	**88**
12/1/2014	0:00	Calm	Calm	**101**
12/1/2014	1:00	Variable	1.9	**115**
12/1/2014	2:00	SE	5.6	**123**
12/1/2014	3:00	Variable	1.9	**127**
12/1/2014	4:00	Variable	1.9	**127**
12/1/2014	5:00	Calm	Calm	**121**
12/1/2014	6:00	Variable	1.9	**114**
12/1/2014	7:00	WSW	5.6	**106**
12/1/2014	8:00	SW	18.5	**96**

Table 7.3b. PM_{10} Concentration values and wind data

As long as the incident lasted the **dominated winds** were mainly from southwest and south-southwest direction and average 24h **wind speed** 6.5 km/h. There weren't wind gusts or dust transfer from outside territories as long as the episode lasted. The **humidity** was between 67% and 97% with an average value at 85%. The temperature was between 6-11 ^oC with an average approximately at 8 ^oC.

Aksaray's AQMS **location** is at the southwest of the Istanbul city in the European part of the city (**Fig.7.3b**) and as mentioned above, the prevailing wind direction prevent the quick transferring of pollutants from other areas of the city. Although **the episode began** earlier at about 16:00 of 11/01/2014 simultaneously in most of other areas, Aksaray site affected a few hours later. The higher peak concentration was at midnight to 01:00 of 12/01/2014. Winds at that time were calm with variable direction. **Diagram 7.3a** presents the PM_{10} concentrations of the Istanbul's network during the episode day.

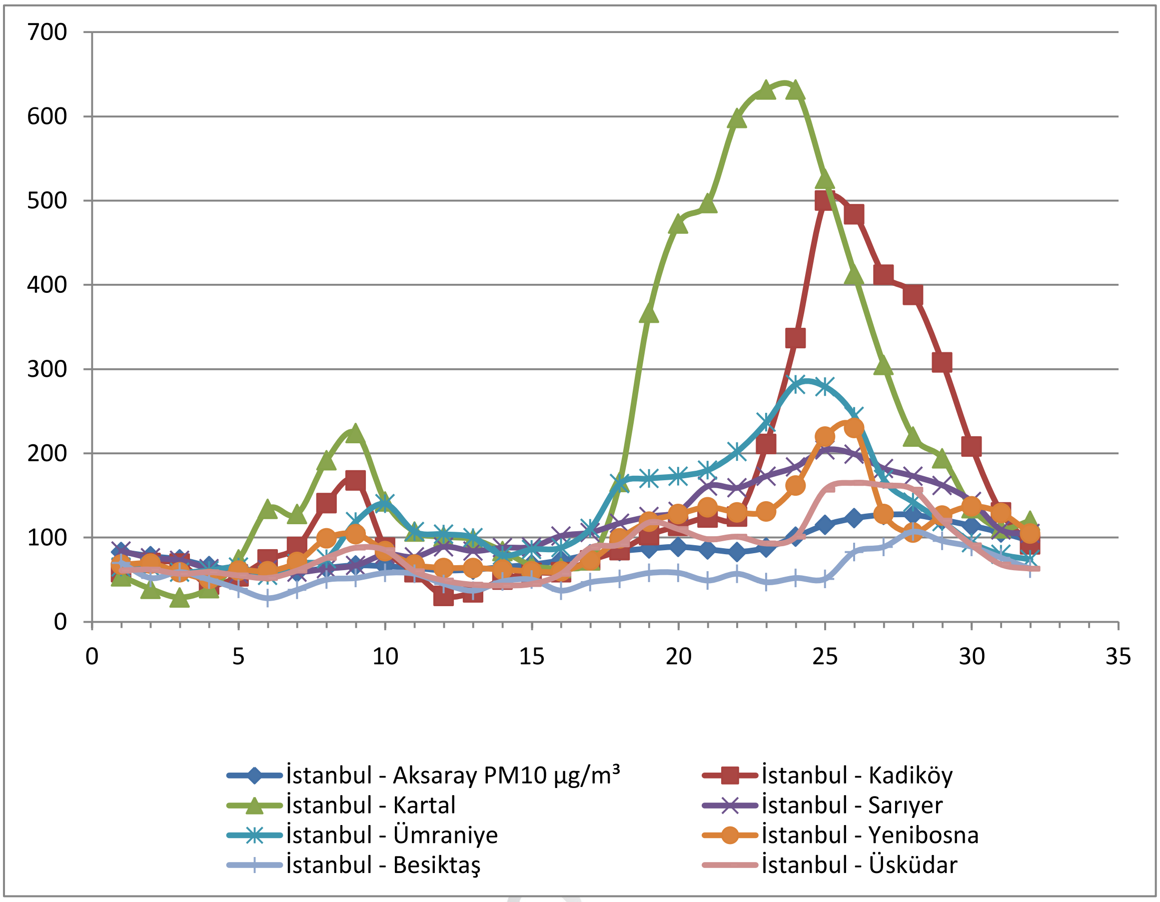


Diagram 7.3a: PM_{10} concentrations of the Istanbul's network during the episode day

The industrial area of **Kartal** showed a rapidly increment of PM_{10} concentration after 17:00 of 11th January, which cannot be explained for the specific hour. Real-time measurements shows a severe smog episode (PM_{10} mass>400µg/m3) which **indicates a stable concentration of black carbon** in the aerosol. It might be exclusively by **local stream** sources and the same happened to **Kadikoy,** which affected a few hours later, due to pollutant dispersion from variable and WSW wind directions. Kadikoy site is distanced less than 5km, northwest from Kartal's industrial area, in a straight line with no physical obstacles between them. **The AQMS of Kadikoy contributes to the network for the protection of the population in that area and covers the macro and micro-scale siting criteria discussed in chapter 4**. The correlation coefficients for PM_{10} are quite high except from those AQMSs which they are at the eastern side of the city. It seems that initially the local emission sources contributed only, so the average concentration to be constantly above 50µg/m^3. The emission sources from the European side of the city (domestic heating), later affected the Aksaray territory and thus the average concentration increased dramatically during the first morning hours from 01:00 up to 07:00 of 12/1/2014. Later that day the episode faded out. The model worked well for the specific incident and the prediction values are closed to the actual values and it is obvious that the areas of Sariyer, Umraniye, Yenibosna and Besiktas are highly correlated with Aksaray area.

(Fig.7.3b) AQMS's "Aksaray" location, SW of the city

AQMS	Aksaray	Kadiköy	Kartal	Sarıyer	Ümraniye	Yenibosna	Besiktaş	Üsküdar
Aksaray	1							
Kadiköy	0,838375773	1						
Kartal	0,428541342	0,570784475	1					
Sarıyer	0,852526602	0,832365154	0,768160157	1				
Ümraniye	0,531178006	0,700813978	0,906318879	0,848955	1			
Yenibosna	0,754868334	0,840844741	0,760126687	0,853305	0,825602	1		
Besiktaş	0,82845333	0,597683037	0,084984833	0,534588	0,167003	0,430512	1	
Üsküdar	0,828925889	0,890999655	0,625896921	0,841082	0,733964	0,809837	0,63159818	1

During a "normal" day with the same meteorological conditions the correlation coefficients (Table 7.3d) between the AQMNs were generally lower than they were during the episode. The contribution of specific local sources mainly consists of the coarse part of PM_{10}. This reveals that mostly mechanical processes emit dust, such as windblown dust, re-suspension by traffic and handling of dry bulk goods.

	İstanbul - Aksaray	İstanbul - Alibeyköy	İstanbul - Besiktaş	İstanbul - Esenler	İstanbul - Kadiköy	İstanbul - Kartal	İstanbul - Sarıyer	İstanbul - Ümraniye	İstanbul - Üsküdar	İstanbul - Yenibosna
İstanbul - Aksaray	1									
İstanbul - Alibeyköy	0,2974	1								
İstanbul - Besiktaş	0,079633	0,718301	1							
İstanbul - Esenler	0,675128	0,644295	0,479809	1						
İstanbul - Kadiköy	0,424679	0,78285	0,688799	0,829194	1					
İstanbul - Kartal	0,203481	0,631658	0,401681	0,431818	0,567672	1				
İstanbul - Sarıyer	0,507591	0,724316	0,636382	0,676582	0,756978	0,635487	1			
İstanbul - Ümraniye	0,2974	1	0,718301	0,644295	0,78285	0,631658	0,724316	1		
İstanbul - Üsküdar	0,380772	0,749874	0,734904	0,759294	0,811542	0,617544	0,685432	0,749874	1	
İstanbul - Yenibosna	0,751229	0,289594	0,18187	0,636128	0,62352	0,326102	0,489459	0,289594	0,522078	1

Table 7.3d: Non episode Correlation Conditions

Alternation of dependent variable: By alternating the dependent variable (**Table 7.3e**) (as we previous did in Athens' AQMN O_3 episode, in our model), we've investigated which AQMS's concentration values are more predictable for the given model. AQMS "Aksaray" has given the best value for the Pearson correlation coefficient, followed by AQMS "Sariyer". **This indicates that "Aksaray" has a better linear relationship compared to others as a dependent variable and it is a candidate site for a possible exclusion considering also the social-economic purposes and siting criteria of the station**. **Diagram 7.3b** presents the actual and predicted values for the **first "run"** of the model with AQMS "Aksaray" as dependent variable.

Y	Multiple R	R squared
İstanbul - Aksaray	0,980542027	0,961462666
İstanbul - Sarıyer	0,979802686	0,960013304
İstanbul - Ümraniye	0,966502209	0,934126521
İstanbul - Yenibosna	0,932762134	0,870045198
İstanbul - Üsküdar	0,932254518	0,869098486
İstanbul - Kartal	0,928616415	0,862328446
İstanbul - Kadiköy	0,928528143	0,862164513
İstanbul - Besiktaş	0,907162154	0,822943173

Table 7.3e: Alternation of Dependent variable

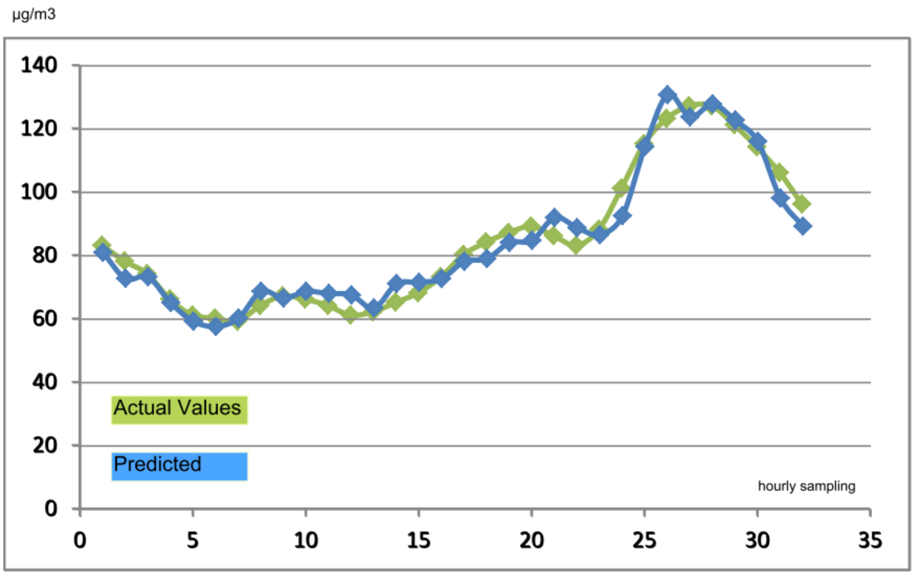


Diagram 7.3b actual and predicted values for the first "run of the model with AQMS "Aksaray" as dependent variable.

The next step was to reduce our independent variables by excluding the least significant sites considering the **p-value** of the ANOVA table of the regression. **We excluded Kartal, Kadikoy and Uskudar sites** (considering also that they are at the Asian side of the city) and we run the regression again with "Aksaray" as dependent variable and the rest sites as they were on the first run. **Table 7.3f** presents the regression statistics for the first and second run.

Regression statistics	First Run	Second Run
Multiple R	0.980542027	0.975393943
R-squared	0.961462666	0.951393343
Adjusted R-squared	0.95022261	0.944192357
D/W test	1.341	1.31
Explanatory Variables	7	4
Statistically significant variables (p-value<0.05)	4/7	4/4
Observations	32	32

Table 7.3f

All the independent variables were statistically significant with p-values far below 0.1%. F-test and T-test gave as expected fine results and although the correlation coefficient and the coefficient of determination were slightly decreased after the exclusion of three independent variables, their values are already high. **The combination of R-squared, adj-R-squared and p-values of the explanatory variables indicates a good fit and validity of the model**

The **modification of the model** by exclusion of Kadikoy, Kartal and Uskudar AQMSs, which they gave us the least correlated data during the incident, improved our model with more accurate predictions. These sites are in the **Asian territory** of the city. Although the initial model performed adequate predictions, additional assistance of the specific meteorological conditions helped for valid measurements during the episode. The increment of PM_{10} concentration at all locations during the evening hours (Saturday night) indicates a contribution of traffic and the whole residential area due to poor quality of domestic fuels. The contribution of wind speed and wind direction is very significant. During morning hours the PM_{10} concentrations are generally in a stable (but already above the European alert threshold of 51-75μg/m^3) condition with minor exceptions in industrial areas (Diagram 7.3c).

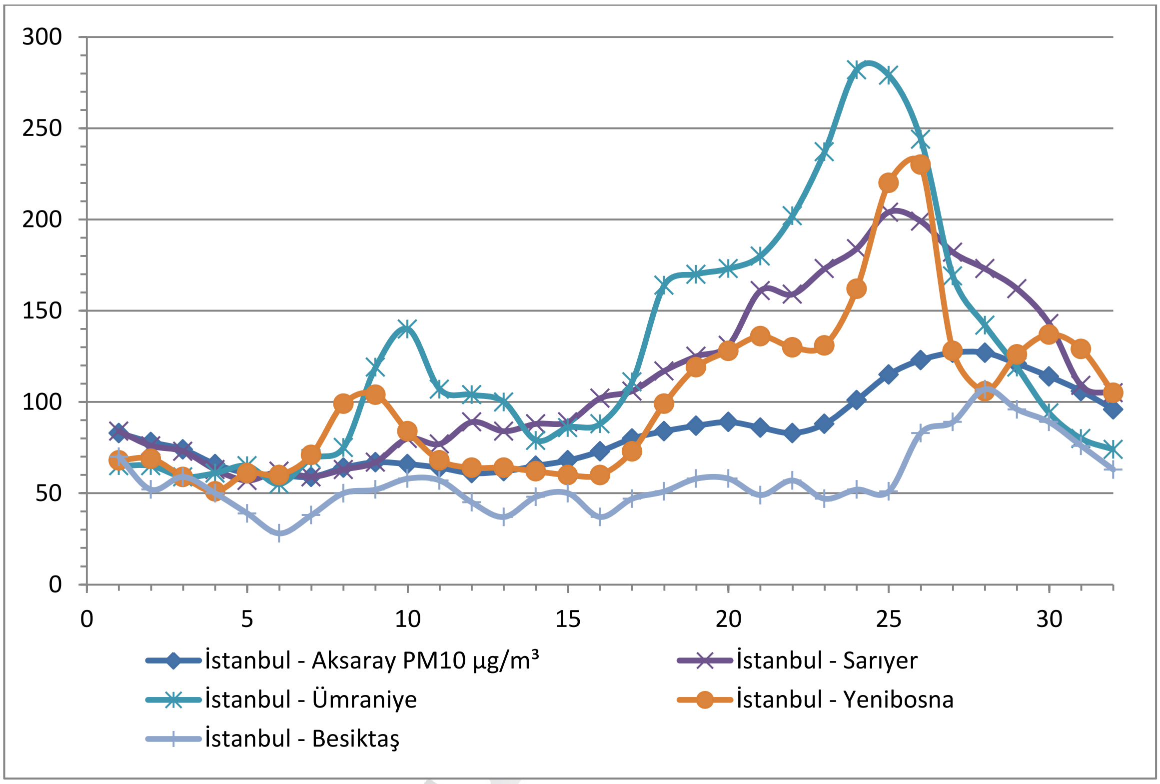


Diagram 7.3c: Second "run" of the model and relative PM10 concentration values

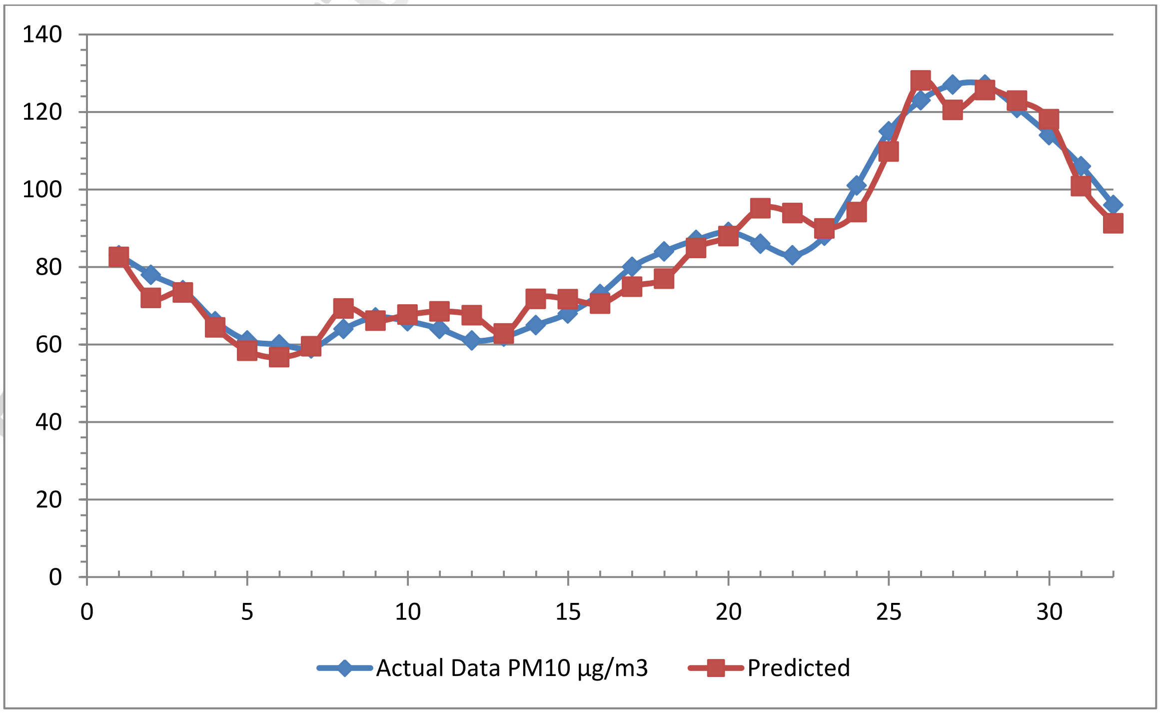


Diagram 7.3d: Aksaray's predicted and actual data.

When PM_{10} concentrations obtained from 10 monitoring stations in the Istanbul Region are compared to the national and international limit values, at **all monitoring stations are above the limit**[20]. Therefore, measures are needed to reduce the emissions at those residential areas that have monitoring stations with pollutant concentrations above the limit values. **Some AQMSs should be used as "pilots" for an early warning system of a possible pollution episode.** In such cases, with an automated process, the sampling frequency of the measured pollutants should be changed in such a rate that the trend of the concentrations should be predictable compared to historical data for the specific site with the assistance of continuous meteorological forecasts. **We propose the AQMS "Kartal" as pilot station for an early warning system** because the site is constantly providing data with intense increment rates in similar episodes and meteorological conditions, compared to other AQMSs of the network. The Turkish authorities and the Istanbul's Municipality are already participating in various public informative platforms[21], providing real-time data and information for all the ambient measurable pollutants. However there are not future predictions of air pollution situation of the city.

It is proposed, in a possible optimization of the AQMN considering the already heavy polluted inventory of the area, that **no AQMS should be excluded**. Instead a repositioning and re-classification of some AQMSs is necessary. **The siting criteria for redesigning the Istanbul's metropolitan network should be enhanced with these specific local particularities (low income population areas/near industry)** which affect the decision making process as already mentioned (ch.4.7.2) for the protection of Antiquities in Athenian region.

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[20] The limit value of 50 μg/m3 set by U.S. EPA, was also exceeded at most of the stations. In Turkey, for the evaluation of the air quality data within the scope of the EU accession process, the procedures given in Air Quality Assessment and Management Regulation (AQEMR), which was published in the Official Gazette No. 26898 dated 06.06.2008, are in effect. In this regulation, it is aimed to progressively reduce the national air pollution until 2014, and to ensure full compliance with EU limit values by then. So, when comparing the results with the national limit values, the target limit values given in AQEMR were taken into account instead of the limit values that are valid during the current transition period (S. Dogruparmak, 2014)

21 http://aqicn.org/map/europe/

8. Discussion and Literature Review

In the present study **we applied a simple multiple linear regression model** for a possible exclusion of the least useful monitoring station from Athens' and Istanbul's AQMNs. The same procedure was followed for both AQMNs. In chapter 4, it was mentioned macro and micro scale criteria regarding the siting of monitoring stations. Those siting criteria together with the evaluation model were under consideration in our study for the areas of Athens and Istanbul. A recent ozone photochemical episode has been chosen for the city of Athens with hourly concentration time series and a PM_{10} smog episode for the city of Istanbul. The examination of concentrations from other pollutants during the episodes was not an objective of this study. A detailed description was given for those AQMSs that included in the multiple linear regression model as either dependent or independent variables in the city of Athens. The validity of the classification of the monitoring sites was also evaluated. The absence of official records, maps and documentation regarding the procedures and the criteria used for the initial siting of the AQMN of Athens, was something that brought difficulties in our effort for a more attentive evaluation of the network.

We have also found that there are no sufficient records from the Greek competent authorities regarding the followed process in order to classify the chosen AQMS sites. Thus, there is missing information regarding the topology and the characteristics of the area, in the vicinity of the AQMS. In order to overcome this lack of information, we searched for published maps and aerial photographs, in which buildings and infrastructures appear through the time. Major public works and later industrialization affected several square kilometers in urban or suburban areas changing the characteristics of those areas rapidly.

The application of the simple multiple regression model of this study was implemented in steps in both cities. In each step of the model selection procedure what is gained when adding a variable in, or lost when removing a variable from the model, could be quantified. This strategy facilitates the comprehension of proper model selection. It needed three "runs" up to the final shape of the most **suitable model for Athens**. At the **first step** we removed from the model those AQMSs which were the least statistically significant. But we kept in mind that it is preferable to include in our model AQMSs with various classifications and to preserve additionally:

a. minimum overlapping between the stations
b. maximum network coverage of the GAA
c. particular area protection (from landfills or industry)

We re-included in the model some AQMSs that had been removed in previous steps. This proved to be very helpful for the evaluation of the network. Finally at the **third step** the model worked very well with no presence of autocorrelation between the variables. Then, we applied the model with **alternative dependent variable** and a **new selection of monitoring sites** as explanatory variables**.** By alternating the dependent variable in our model, we have investigated which AQMS's concentration values are more predictable for the given model. The increment or decrement of the number of explanatory variables **in balance with R^2 and R^2_{adj} values** is the strategy that we followed for the most suitable model for the specific meteorological conditions.

The same methodology was followed, in the city of Istanbul. The application of the model in the selected sites of Istanbul had a good functionality. After the conclusion of which sites' PM_{10} concentrations are best predictable from the given model, an assessment had to be done for each AQMS in case of a possible:

a) Exclusion from the network

b) Classification update (in order to be more representative for the area)

c) Re-siting in a different location.

An operating metropolitan AQMN covers the objectives and necessities of the selected area. The objectives are different weighed for each area and in cases of a new AQMN design or network reallocation, this is a difficult task that it cannot be fulfilled, as mentioned in the introduction of chapter 1. For example, in case of optimization of Athens' AQMN a significant objective is the protection of the valuable antiquities. This has to be carefully estimated but at the same time in the center of Athens there is an obvious overlapping issue between AQMSs classified as "Urban-traffic". On the other side in Istanbul, daily mean PM_{10} concentrations are varying rapidly and unpredictably.

In the same direction as we have done but with a different approach, (Dogruparmak et al, 2014) in her study in the city of Istanbul determined whether **a reduction can be made in the total number of monitoring stations** within the AQMN. She claims that in case of necessity, the devices at one group of stations having similar air pollution characteristics can be transferred to another zone. She grouped the monitoring stations that share similar air pollution characteristics by using the methods of Principal Component Analysis (PCA) and fuzzy c–means (FCM). This would significantly decrease the capital investment and operational cost. In addition, the study also enables determining the emission sources, evaluating the performances of the methods and examining the zone in terms of pollution. In the classification of monitoring stations, different groups were formed depending on both the method of analysis and the type of pollutants. As a result of PCA, 5 and 3 classes have been determined for SO_2 and PM_{10} respectively. This shows that the number of monitoring stations can be decreased. When reduced classes were analyzed, it was observed that a clear distinction cannot be made considering the affected source type. However, the number of monitoring stations in a zone should depend on the air quality of that zone. If it exceeds the requirements, the expenditures will increase.

The meteorological conditions during the episodes are critical for the **correlation conditions for the specific pollutants between the selected sites** and the consistency of our predictions. It is observed that **wind speed and direction can change rapidly the correlation** between fixed site stations. Unspecified reasons also resulted in severe concentrations changes and differences between nearby sites in the city of Istanbul. In the case of Athens there must be also a primary pollutant concerning for the ozone related time-series. "Background" classified sites in Athens seem to keep a constant high mean ozone concentration during the summer months in contrast with "urban-traffic" classified stations. Thus **trends of NOx and NO_2 have to be examined furtherly in those sites, from historical data of these pollutants' time-series**. Mavroidis and Ilia (2012) **used the same time series source as we have done in the present work and among others present the spatial distribution of the greater Athens area air pollution monitoring network**. Hourly, daily, monthly, seasonal and annual pollutant variations(NO_2, O_3 and NO) are examined and compared, using the results of concentration time series from three different stations of the national network for air pollution monitoring, one urban-traffic, one urban-background and one suburban-background (Patission, Peristeri, Ano Liossia). Meteorological parameters from the three years for which concentration data are used (i.e.2007-2009) are presented and analyzed. To derive mean annual concentrations the original concentration data sets are analyzed by HMEECC(ΥΠΕΚΑ) using the following data quality criteria: initially only the days containing at least 75% of validated hourly values are selected and then, based also on this validation, the years containing at least 65% of validated daily values are selected. Finally **they recommend a further investigation of the representativeness of the station at "Ano Liossia" due to a relocation** which changed the behavior of the station.

An application of a simple regression model for AQMSs in pairs and also conclusions regarding the **correlation between AQMSs** on an urban scale presented by Sajani, Scotto and Lauriola,(2004). The rich regional AQMN of the Emilia-Romagna region of Italy has been also used to quantify the spatial variability of the main pollutants within urban environments. The **spatial variability of the concentrations** of the majority of pollutants within the city was very high, making it difficult to differentiate and characterize the urban environments and to apply legal limits with uniform criteria. The analysis showed generally high correlation values between the daily data of different measuring sites for the primary traffic-related pollutants. Analysis of the **correlation level between the temporal trends of the measuring sites** highlighted the strong relationship between the concentrations measured by different stations. The work also shows the results of the performance of the **regression procedure between different sites to estimate pollution levels** in a site with short time measurements. They conclude that if two monitoring stations are well correlated, it is possible to highlight the potentially incorrect measurements by analysis of the standardized residuals with respect to the regression line between the stations. This procedure seems very effective and quick, especially for analysis of quite long-term series (annual). It could provide the **basis for an automatic system for identification of possible anomalous data**. The large spatial variability of the main traffic-related pollutants implies the impossibility of obtaining from the data of the fixed-site stations a complete picture of the atmospheric pollution in the urban areas and the mean population exposure. This is because the range of the experimental data is poorly representative. Especially in urban environments that have deep street canyons, high traffic densities, and very low ventilation.

Although, Athens has street canyons near the historical center, in the present work this is something that it was not evaluated due to lack of information and availability of precise designs of the building infrastructures. Enhanced attention was given to t**he accuracy of our model predictions. Valid predictions could be used as an assistant criterion to those criteria proposed in chapter 4, in case of candidacy exclusion of a monitoring site from the network.** Other works that **attempt to optimize existing networks by excluding redundant stations** and/or least informative ones (Pires et al., 2009; Silva and Quiroz, 2003) or by including new measuring sites (Haas, 1992) **are not considering macro/micro-scale siting criteria for the specific network coverage**. However, most of these approaches deal with dense air pollution monitoring networks and a more complicated methodology is followed by Silva and Quiroz who they attempt to optimize Santiago's AQMN by **excluding the least informative stations** with respect to the variables under study: (CO), (PM_{10}), (O_3) and (SO_2) and, if possible, to find out an optimal configuration of stations, meaning a smaller set of stations that provides adequate information for administrative purposes. To accomplish this, an index of multivariate effectiveness, based on **Shannon information index**, is applied to that network. From the computation of Shannon's index of information they calculated the losses of information, with respect to the optimal configuration, for all the other configurations and for each variable. In short, the idea is to find out a configuration of stations adequate to monitor all the variables of interest with minimal loss of information excluding one station, two, etc.

Different approaches for **planning or siting of an AQMN and proposals for environmental protection authorities** to plan and set up AQMN effectively and systematically are found in several studies. Locating and installing monitoring sites in large cities is a complex task to solve and usually **a multi-criteria analysis** is implemented. In general, their aim is to detect the maximum spatial variability of the concentrations or "hot spots". Kanaroglou et al. (2005) has developed a methodology to optimally locate a dense network of air pollution monitoring stations **based on the location—allocation approach**, which offers the flexibility to integrate an assortment of variables into the "demand surface". In particular, their methodology seeks both to identify the areas with the highest spatial variability and to carry out measurements in areas of specific sociodemographic interest. To estimate the initial pollution surface for determining the spatial variability, they utilize **Land Use Regression (LUR)**. LUR uses **pollution concentrations as the dependent variable and proximate land use, traffic, and physical environmental variables as independent predictors**. This methodology thus seeks to predict pollution concentrations at a given site based on surrounding land use and traffic characteristics. Specifically, this method uses measured pollution concentrations (y) at locations (s) as the response variable and land use types (x) within circular areas around s (called buffers) as predictors of the measured concentrations. A similar approach to the **development of sustainable air quality monitoring networks** has been proposed by Chen et al. (2006). Their procedure, which responds to **multi-objective planning**, simultaneously considers environmental, social and economic objectives, including their sub-objectives and weights. The methodology described by Cocheo et al. (2008) involves obtaining a large database of high-resolution measurements by means of passive sampler measuring campaigns. Using **geostatistics, they estimate environmental data in order to increase the resolution of the monitoring network** and obtain representative isoconcentration maps and, finally, they identify a subsized subnetwork with the most informative sites to minimize costs without losing information. Mazzeo and Venegas (2008) have described an approach, which uses **atmospheric dispersion models** to identify the areas where the concentrations are higher than a reference value and sets up the monitoring stations in these areas. Using the described ‘‘system’’, they are able to identify the areas in the city where high background concentration of CO and NOx and where high concentrations are expected to be found in Buenos Aires City with reasonable accuracy. In future work, these results can be combined with the information of population density distribution to evaluate the population that might be exposed to high concentration levels.

Among the studies on AQMN design and optimization, Mei-Kao Liu (1987) presented a methodology which uses an objective technique to **determine the locations of a minimal number of monitoring stations** giving a prescribed level of efficiency. Design priorities other than efficiency are factored in by a ‘figure of merit’ ranking procedure. **The first step, the so-called figure of merit (FOM) procedure**, defines the locations of the monitoring stations that best characterize the peaks and troughs of the concentration field, so that the concentration field could be reconstructed from data obtained at these monitoring stations. **The second step, the so-called sphere of influence (SOI) methodology**, defines the extent of the area around each station in which the station’s measurements can be regarded as representative. This procedure is based on an analysis of the correlation of air quality at the stations and at points in the vicinity of the station. A threshold correlation value defines the boundaries of the area around each station that can be considered represented by that station; clearly, the lower the threshold correlation, the larger the area. This procedure determines the minimum number of sites required to achieve the desired spatial coverage.

On the other hand A.Mofarrah, T.Husain (2009) suggested an objective methodology for **determining the optimum number of ambient air quality stations in a monitoring network**. The methodology integrates the multiple-criteria method with the spatial correlation technique. In the first stage, this methodology uses Fuzzy Analytic Hierarchy Process (FAHP) for identification of the potential monitoring sites using Environmental, Social and Cost criteria. The special area coverage of the monitoring station is determined on the basis of the concept of a sphere of influence (SOI) suggested by Liu et al. (1987). **SOI is defined as the zone** over which the air quality data for a given monitoring location can be considered representative. The **spatial correlation coefficient (r)** can be used to represent the SOI. This coefficient gives an indication of the relationship among the monitoring locations to be selected in the designed optimal monitoring network (Elkamelet al., 2008). The methodology was implemented for different cutoff values (rc) in the correlation coefficient matrix to test the robustness of the AQMN design. The cutoff value (rc) was varied from 0.45 to 0.75 in order to study the effect of cutoff values (rc) on the coverage effectiveness of the monitoring networks. The data uncertainties were minimized by using fuzzy triangular number in the criteria data. The assigning weights are critical for a multi-criteria problem; uncertainties may involve in this stage. The **Triangle Fuzzy Numbers** was used to minimize those uncertainties. The results show that there is a significant effect of cutoff values on the final ranking. The optimal numbers of monitoring stations required is then determined by the combined utility scores gained from first and second steps**.**

As written above Chen et al. 2006 developed a methodology and a computer system for planning air quality monitoring networks. In detail, t**he environmental, social and economic objectives including their sub-objectives and weights** would be simultaneously considered for assisting the competent authorities to generate the plans for sustainable air quality monitoring networks. The chosen region which the AQMN is intending to operate is divided into grid squares as subsystems. **The components of each subsystem** include the air quality monitoring stations, air pollutants, air pollution sources (including the industry, mobile, and area sources) and human society (including the quantity of population, traffic volume, and sensitive receptors). **Four classes of monitoring stations**, general, traffic, background, and industrial stations, could be installed in each grid square. **The environmental objective** for choice of air quality monitoring station site included seven sub-objectives, as follows: (1) highest pollutant concentration, (2) highest average concentration, (3) largest range of the concentration exceeding the regulation standard, (4) largest variation range of pollutant concentration, (5) largest total emission quantity, (6) largest emission quantity of the industry sources, and (7) largest emission quantity of the mobile sources. **The social objective included four sub-objectives**, as follows: (1) largest population, (2) largest number of sensitive receptors, (3) largest traffic volume, and (4) largest number of air pollution petitions. The objective value was identified as the sum of each sub-objective value multiplied by the weight. The weight value was determined by the class of the selected monitoring station in each grid square. Finally an algorithm (optimization model) is applied in each grid square which can be considered as one stage and can be figured in six options: **no station, general station only, traffic station only, background station only, industry station only, and general station plus traffic station**.

Optimizing of existing monitoring networks in compliance with the latest EU Directive 2008/50/EC is discussed in several studies. Directive 2008/50/EC on ambient air quality and cleaner air for Europe dictates the minimum number of fixed measuring points and provides basic guidelines for the location of monitoring sites in built-up areas. However, some of the indications are imprecise. For example, the directive states that the highest concentrations to which the population is directly or indirectly exposed should be registered, while at the same time demanding concentrations that are "representative of the exposure of the general population" without specifying what these concentrations are. The situation is especially confusing in cases for which only one sampling point is necessary, since the directive does not state which of the two criteria should prevail — the maximum concentrations or the most "representative" concentrations. A method for towns in which only one fixed measuring point is required by legislation (Directive 2008/50/EC) developed by E. González Ferradás, M. Miñarro, I. Terrés, F. Martínez(2010). In order to identify the best sites for fixed measuring station, six campaigns for sampling of a specific pollutant were undertaken during different periods of the year. The method followed was also applied in other pollutants which exhibit similar distribution patterns in cities. The annual mean value of the pollutant and **the percentage of population who lives in areas under the**

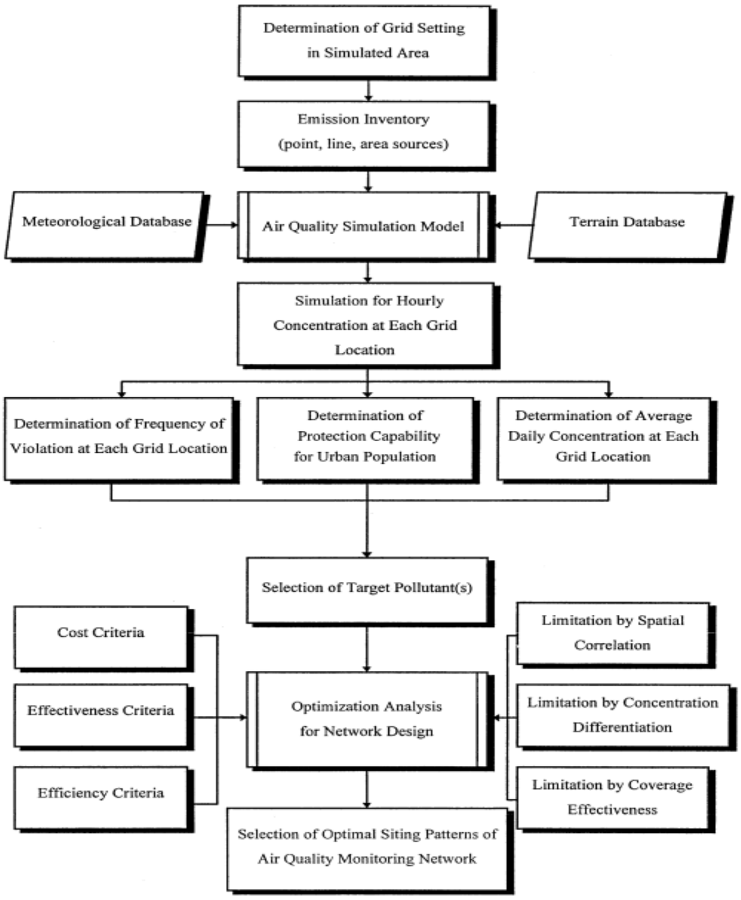
mean value is the basic criterion. Approximately 65% of the population lives in areas where the concentrations are below the annual mean value. The maximum results occur in areas with <0.5% of the population. So **they propose this mean value as a criterion** for **siting monitoring stations**, since the mean value is representative of a high percentage of the population. The most suitable sites were selected on the basis of the mean of isoconcentrations maps. They also noticed imprecise guidelines by the legislation for siting monitoring stations in built-up areas, especially in cases where one station is necessary: **The legislation does not state which of the two proposed criteria should prevail: the maximum concentrations or the most "representative" concentrations.**

In compliance with the legislation 2008/50/EC, J.Usero, A.Lozano, (2010) described **a method in four steps to design or optimize air quality networks, particularly detecting nitrogen dioxide and ozone**. The first step in the optimization process is to establish the minimum number and characteristics of the stations needed in each zone by evaluating air quality, based on historical data. The location of the monitoring station depends on the distribution of the contamination levels of pollutants, as the stations need to record representative levels for the entire zone. Second step of the method consists of sampling campaigns to determine the spatial distribution of the concentrations thus defining the best location in each zone for continuous monitoring of air quality. Third step: The concentration values obtained were spatially interpolated to assign contamination value to every point of the study area. The result map obtained by GIS is used to define the best locations for placing the AQMS. Fourth Step: After the selection of the best locations for the sampling station is made, they obtain a spatial distribution that ensures compliance with the micro- and macroscale location criteria established in the legislation. Every few years, new sampling campaigns are carried out to verify the improvement of the optimized network and the representativeness of the measurements.

Assessment on siting criteria, classification and representativeness of air quality monitoring stations and analysis of shortcomings in the up to date air quality legislation (EU directives 2004/107/EC, 2008/50/EC, 2011/850/EU) provided by EEA/Joint Research Centre/AQUILA in collaboration with the working group on "Siting criteria, classification and representativeness of air quality monitoring stations" (SCREAM). The assessment was carried out by a group of national experts with a long standing experience in the field of air quality assessment and amongst others active in AQUILA, FAIRMODE, the Time Extension Notification assessments, the EU Ambient Air Quality Expert Group, the Implementing Decision Pilot Group. They suggested modifications based on technical and scientifically considerations and also proposed to extend the requirements of present Annex III (D) with a requirement for Member States to provide an assessment strategy for all zones and agglomerations. This strategy should provide documentation of the site-selection procedures and information that supports the monitoring network design where complementary methods (modelling, indicative measurement) are used. Assessment strategies should include details of these methods, along with information on how the criteria for using supplementary information (provided in Article 7 (3)) are met.

A two stage analytical procedure which uses both simulation and optimization models for achieving the siting goals and objectives developed by C.C Tseng, Ni-Bin Chang (2001):

- In the simulation process they trace the pollutants dispersion, transport and transformation in the study area, based on the existing databases of meteorological emission inventory and terrain information and they define the target pollutants
- In the optimization analysis process they consider the simulation results, efficiency /effectiveness and cost criteria, together with, limitation by spatial correlation, limitation by concentration differentiation, limitation by coverage effectiveness.



The above procedures conclude in the Selection of optimal siting patterns of AQMN.

A simplified approach for classifying monitoring stations into six different siting categories, based on a review of research data on the spatial variation of CO concentration in urban areas, proposed to the Governmental authorities by Wayne R. Ott (1977) in his study “Development of Criteria for Siting Air Monitoring Stations”:

TYPE A: Downtown Pedestrian Exposure Station. Locate station in the central business district (CBD) of the urban area on a congested, downtown street surrounded by buildings [i.e., a "canyon" type street] and having many pedestrians. Average daily travel (ADT) on the street must exceed 10,000vehicles/day, with average speeds less than 15 miles/hour

TYPE B: Downtown Background Exposure Station. Locate station in the central business district (CBD) of the urban area but not close to any major streets. Specifically no street of average daily travel (ADT) exceeding 500vehicles/day can be less than 100 meters from the monitoring station. Typical locations are parks, malls, or landscaped areas having no traffic

TYPE C: Residential Population Exposure Station. Locate station in the midst of a residential or suburban area but not in the central business district (CBD). Station must not be less than 100 meters from any street having a traffic volume in excess of 500vehicles/day

TYPE D: Mesoscale Meteorological Station. Locate station in the urban area at appropriate height to gather meteorological data and air quality data at upper elevations. The purpose of this station is not to monitor human exposure but to gather trend data and meteorological data at various heights. Typical locations are tall buildings and broadcasting towers

TYPE E: Nonurban Background Station. Locate station in a remote, nonurban area having no traffic and no industrial activity. The purpose of this station is to monitor for trend analyses, for non-degradation assessments, and for large-scale geographical surveys. The location or height must not be changed during the period over which the trend is examined

TYPE F: Specialized Source Survey Station. Locate station very near a particular air pollution source under scrutiny. The purpose of the station is to determine the impact on air quality, at specified locations, of a particular emission source of interest.

A **number of factors criteria** referenced to the guidelines adopted by EPA of the United States, so as to ensure the representativeness of the data suggested by the Environmental Protection Department (EPD) of the Government of Hong Kong. They had planned to establish a general AQMS in "Tseung Kwan O" area. The members of Housing and Environmental Hygiene Committee of the Sai Kung District Council had briefed for the site selection. The main considerations included:

- The AQMS should be established in the more densely populated location, so the data collected can represent the air quality being exposed by the majority of people in the district
- The location of the AQMS should not be influenced by local pollution sources (e.g. cooking fume, exhaust outlets), or obstructed by buildings, trees or any other objects; otherwise, the representativeness of the AQMS may be affected
- In foreseeable future, there should not be any planned large development or re-development in the vicinity of the AQMS as that may produce local pollution sources or masking effects to the AQMS and hence affect its representativeness. In general speaking, the roof of a government or public building of several floors is more suitable for such establishment
- Other technical factors such as sufficiency in areas for the installation and operation of the instruments, easiness in access and instruments transportation, etc., would also be considered.

The existing Air Quality Monitoring Network in Hong Kong comprises 14 fixed stations: 11 General AQMSs and three roadside AQMSs. The main purposes of setting up the AQMN are to collect data to assess the impact of air pollution on the public, to formulate air quality management policies, and to determine their effectiveness. Based on the real time data collected, the EPD also provide the hourly Air Pollution Index to the public for reference.

Other Governmental Authorities such as the **Indian Ministry of Environment** & Forests suggest Guidelines for Ambient Air Quality Monitoring (2003). They proposed guidelines for siting a monitoring network and they suggest recommended criteria as described in "Development of Criteria for Siting Air Monitoring Stations" - Wayne R. Ott**.** They also highlight that for setting up of any ambient air quality monitoring station, the most important thing to be considered prior to commencement of actual monitoring is to collect its background information. The background information that needs to be collected includes details of sources and emissions, health status, demography, population growth, land-use pattern, epidemiological studies. Such prior information will provide immense help to identify the likely effects and in particular health impacts resulting from population exposure to air pollutants. Knowledge of existing air pollutants levels and pattern within the area are essential for deciding number and distribution of stations. **The no. of sampling sites depends on:**

- Size of the area to be covered
- The variability of pollutant concentration over the area to be covered
- The data requirements, which are related to the monitoring
- Pollutant to be monitored and
- Population figures which can be used as indicators of criticality both from view of likely air quality deterioration as also health implications.

EPA with its directive EPA-454/D-07-001 (February 2007) provides information on the regulatory requirements for **the discontinuation of a monitor used in National Ambient Air Quality Standards (NAAQS) compliance.** The section also provides procedures that can be used to determine if a monitor meets the requirements. In addition to the requirement for state or local monitoring agencies to conduct a network assessment every 5 years, the October 17, 2006 amendments to the national monitoring regulations added a requirement that a state or local agency seek the Regional Administrator's approval prior to shutting down a State or Local Air Monitoring Site (SLAMS). **The criteria described are the following:**

1. A monitor can be removed (after Regional Administrator approval) if it is currently in attainment with the applicable NAAQS standard and if four tests can be met which are described analytically.
2. Consistently low concentrations relative to other monitors
3. A monitor can be removed that has not measured violations of the NAAQS
4. A monitor that has been determined by EPA not to be comparable to the relevant NAAQS because of monitor siting (FR Section 58.30) may be recommended for removal.
5. For a monitor that is designed to measure concentrations upwind of an urban area to characterize transport into the area, the following two sub-criteria should be met for removal:
    a. The monitor has not recorded violations of the relevant NAAQS in the previous five years.
    b. The monitor discontinuation is tied to start-up of another station also characterizing transport.
6. A monitor not eligible for removal under any of the above criteria may be moved to a nearby location with the same scale of representation if logistical problems beyond the State's control make it impossible to continue operation at its current site.

There is also a section that provides guidance to the user for identifying monitoring needs **and introduces existing network assessment analyses**. Such works that incorporate the EPA guidelines and criteria are two studies of selecting near-road monitoring sites presented by Sue Kimbrough, Daniel A. Vallero (2008 &2011) **based on multi-criteria decision analysis**. In their first study the site selection criteria were applied mainly by EPA meeting the FHWA Monitoring protocol requirements including: AADT, Sound wall presence, Topology, road elevation, Meteorology, Presence of confounding air pollutant sources, site access, administrative and physical impending construction activity, Vegetated embankments, site logistics, security, electrical supply, costs, insurance, financial issues and private property permissions. **On the second study**, they adapting previous site selection criteria and modified to the new candidate site considering topology and social-economic conditions. The selection criteria had been developed by Federal Highways Administration (2006) and candidate sites had been chosen using GIS data and annual statistics including average Daily Traffic (AADT) and annually wind direction proportion. The site selection criteria were applied as a set of filters to eliminate candidate sites including:

- AADT >150000
- Restricted downwind sampling, placement <250- 300m
- Presence of confounding air pollutant sources
- Site access, administrative and physical
- Impending construction activity
- Vegetated embankments
- ARCGIS, Google earth pro used, in order to support site selection, considering vicinity of wells, airports, landfills, soil permeability
- Site logistics, security, electrical supply, costs, insurance, financial issues and private property permissions.

- Relevant data layers and maps created based on site selection criteria and advantages and disadvantages of each site were "weighed"…

The prediction of air pollution levels is critical to enable proper precautions to be taken before and during certain events. The **Forecasting Models** consider the prediction of daily concentrations of various ground-level air pollutants, namely CO, PM_{10}, NO, NO_2, NOx , SO_2 , H_2S, and O_3, which were measured by an AQMS. The results from those studies conclude and showing also the importance of temperature in the daily variations of O_3, SO_2, and NOx, whilst the wind speed and wind direction play significant roles in the daily variations of NO, CO, NO_2, and H_2S. PM_{10} concentrations are influenced by almost all the measured meteorological parameters. I.Kapageridis, V.Evagelopoulos, A.Triantafyllou (2007) presented **a PM_{10} concentration prediction method** based on a modular neural network (MNN). The neural network is integrated with an online air quality monitoring system and the results of current versus predicted air quality are available to the public through the internet. The MNN system is based on Radial Basis Function (RBF) networks. The networks are arranged in two levels. The first level consists of three networks, each receiving different inputs and each producing a forecast of next day 24h average PM_{10} concentration. The first receives the eight PM_{10} hourly measurements, the second network receives meteorological inputs (observed values) regarding the last 24 hours, and the third network receives meteorological inputs (forecasts) regarding the following 24 hours. The outputs from the three networks of the first level are directed as inputs to the single RBF network of the second level. This network combines the outputs from the three previous networks into one forecast of next day's average PM_{10} concentration.

The application of localized linear models for **forecasting hourly PM_{10} concentration values** using data from the monitoring stations of Athens, Helsinki and London, introduced by A.Sfetsos, D. Vlachogiannis (2010). **Time series analysis** is used for the examination of a data set organized in sequential order so that its predominant characteristics are uncovered. The idea behind the application of clustering algorithms in time series analysis is to identify groups of data that share some common characteristics. **The described forecasting methodologies** were applied to eight different data sets both univariate and multivariate. The data sets were **hourly PM10 concentration values from the monitoring network in the Greater Athens Area** and in the cities of Helsinki and London, spanning over different seasons. In order to evaluate the ambient air concentrations of particulate matter, a deterministic urban air quality model should include modelling of turbulent diffusion, deposition, re-suspension, chemical reactions and aerosol processes. In recent years, an emerging trend is the application of Machine Learning Algorithms (MLA), and particularly, that of the Artificial Neural Networks (ANN) as a means to generate predictions from observations in a location of interest. The strength of these methodologies lies in their ability to capture the underlying characteristics of the governing process in a non-linear manner, without making any predefined assumptions about its properties and distributions. Once the final models have been determined, it is then a straight-forward and exceedingly fast process to generate predictions.

8.1. Conclusions

The AQMN represents an essential tool to monitor and control atmospheric pollution. The use of some specific criteria in conjunction with the mathematical models provides a general approach to determine the optimal number and location of monitoring stations. In Greece, air quality is determined by a limited number of AQMSs such as the Athens and Thessaloniki's AQMNs and in cities without an AQMN such as Volos, Larissa, Ioannina, Heraklion, Patra, a few other independent monitoring stations are operating. Due to the limited amount of data from air pollution measurements, additional calculations are taken from the application of air quality models. According to the real time measurements from the AQMSs and the gathered information from model calculations, the European air quality requirements for O_3, PM_{10} and other primary pollutants are exceeded in many locations in urban areas. As a result, spatial planning of new houses or schools near PM_{10} sources should be in consideration for redesign. However, in some situations, for several reasons, the results of the modeling might not be accurate enough for describing the local conditions. Models in the EU are accepted to be adequate for screening of potential exceedance situations and large scale, time trend monitoring, but are probably not always accurate enough for determination of the occurring local ambient PM_{10} concentrations. Also the contribution of local sources to local ambient concentrations relative to background concentrations might be different from the modeled situation. Therefore, the municipalities need to get better insight in the contributions of local sources to ambient PM_{10} concentrations, next to model calculations. In this direction the latest EU Directive 2008/50/EC, although with deficiencies, dictates the minimum number of fixed measuring points and provides basic guidelines for optimizing existing monitoring networks in build-up areas in Europe. In parallel, the designing or optimization of an AQMN is not simple or straightforward problem and depends on many site-specific issues and purposes. Good upfront planning is therefore crucial in properly assessing the problem and designing an optimal AQMN.

In chapter 7 we have presented an evaluation model of O_3/PM_{10} concentrations and thus a possible candidacy for elimination/relocation/reallocation of an AQMS from/of a network. The model incorporates the simple multiple linear regression method for evaluating data time-series for hourly generated O_3 concentrations from the AQMN of Athens[22] and hourly PM_{10} concentrations from Istanbul's AQMN[23] during a photochemical and a particulate matter smog episode respectively. Both in Athens and Istanbul**, it proved that the applicable method** of multiple linear regression can give us strong indications of how the existing networks could be more efficient and reliable. The model worked well as an **assistant AQMS evaluation criterion** to the aforementioned siting criteria of Chapter 4 and as an **assessment tool** for validation of the representativeness and the classification of monitoring sites.

For example, in the city of Athens we saw that the AQMS of "**Agia Paraskevi**" (classified as Suburban-Background) is the least correlated site among all the others of the network and this is an evidence that during the episode conditions (low relative humidity, high temperatures, variable wind directions and average wind speed below 7km/h) the AQMS is representative for its location. On the other side, the AQMS "**Lykovrisi**" which was the dependent variable on the second attempt to apply the model in Athens' AQMN seems to be less representative as "suburban" class site

[22] The data from Athens AQMN online at: http://www.ypeka.gr/Default.aspx?tabid=495&language=el-GR
[23] The Turkish data are available online at: http://www.havaizleme.gov.tr/Default.ltr.aspx

compared to nearby AQMSs. We've **recommended the relocation of the station in less predictable areas**, easterly or north-easterly of its current position, as a better choice for **improved network coverage of the area**, although a possible update to its classification as an "urban-background" site should be another potential decision for the local authorities.

In **real conditions our evaluation model could be useful**, such as in the case of overlaps between stations. The proximity of three of the same class(Urban-traffic) monitoring stations, ("Patission", "Aristotelous" and "Athinas") in the center of Athens kept are attention. The distance between "Patission" and "Aristotelous" station is about 1.3km, between "Patission" and "Athinas", 2.4km and only 1000m are separating the "Patission" and "Aristotelous" AQMSs. As mentioned in chapter 7, we have found that there is an overlap between the three of them and the expected concentration measurements during a non-(photochemical)-episode day are already highly correlated and "Aristotelous" AQMS is the "least informative" station between the three of the same class. This indication comes from long-time NO_2 time-series and other traffic related pollutants, **by applying a single linear regression for these sites**[24]. The model verified that the range between urban traffic stations has to be such that should also satisfy a threshold value for the correlation coefficient. The latter has to be less than 0.65 if the covering area is more than $10km^2$ (Liu and Langstaff, 1987). As we saw the three Urban-traffic AQMSs and "Geoponiki" AQMS are the stations that cover the Historical center of Athens and major traffic avenues with approximately $12km^2$ of surface area. A partial reallocation that will include these AQMSs should be in a possible future optimization plan of the network but the authorities should also have in mind the protection of Antiquities in the influence range of those AQMSs.

The method that we have followed has also functionality in cases that although the site is representative for some measured pollutants and for its classification, too, but due to high predictability it is an easier choice for elimination from the network and as an aftermath, a decline in operational costs. The first part of the evaluation model used AQMS "Peristeri" as dependent variable. The final shape (part I) of the evaluation model came from various changes of the explanatory variables. AQMS "Peristeri" together with "Liossia", "Geoponiki" and "N.Smirni" are almost in a straight line (from north to south) and we have found high correlation coefficients between them. Considering the physical distance between the sites and although there is a high correlation coefficient among some of them, we concluded that the ozone concentrations in the selected sites, simultaneously increased during the day, with the present meteorological conditions. The model gave us results with strong indication that there is a low contribution in concentrations from specific local sources and it consists mainly of background pollution inventory or general local sources. Thus we've concluded that "Peristeri" station is highly predictable and it could not be necessary in the AQMN.

The application of the evaluation model in the metropolitan network of Istanbul except from similar conclusions as mentioned above**,** it proved that **some AQMSs should be used as "alarm signals"** of an early warning system for potentially evolving air pollution episodes**.** The Suburban-Industrial AQMS "Kartal" proposed **as pilot station for an early warning system** because the site is located in a distance less than 300m from industrial facilities and is constantly providing data with intense increment rates (and also hourly mean concentrations above $300μg/m^3$) in similar episodes and meteorological conditions, compared to other AQMSs of the network. Many low income population areas or near industry which are found in the city should be protected and the siting

[24] A S.M.L.R applied with NO_2 time series data in order to inspect that the AQMS "Aristotelous" is the least informative for other pollutants, too

criteria for the metropolitan network's redesign should be enhanced by consistent estimates of the relationship between daily variations in PM and health effects provided by epidemiological studies.

The Istanbul's Municipality provides real-time data to various public informative platforms[25] for all the ambient measurable pollutants as most of the European countries do internationally[26]. However although there is the technological background and the amount of data is fair enough for such applications, there are not future predictions of air pollution situation of the city. The city has already a heavy polluted inventory enhanced by industrial sources and anthropogenic activities. By applying the same method, we've reached some useful conclusions regarding the necessary relocation/reallocation and classification update of some AQMSs.

The Greek Ministry of Productive Reconstruction, Environment and Energy, responsible for the operation and maintenance of the Athens Metropolitan AQMN **is not participating to an early warning system or AQI for the public**. Additionally, the technological obsolescence of the current operating AQMN is obviously an issue that has to be considered regarding the reliability of the provided measurement reports to EEA[27]. Major changes over the last three decades in the Athenian urban and suburban areas, regarding the industry, the residential development, the public works etc. changed rapidly and in many cases violently the topology of those areas. An optimization of the Athens Metropolitan AQMN should be decided for the above reasons. Most of the AQMSs of the network should be re-classified, or reallocated in parallel with a procurement of new and modern equipment. The Ministry should establish short time measurements with mobile instrumentation which can track increased particulate matter concentrations, in cases like the later smog episodes, in Athenian suburbs over the last years and traffic load on major streets and sites when no AQMS is installed nearby. Thus, an increased representativeness should be expected with reliable and precise measurements.

25 http://aqicn.org/map/europe/

26 See Annex II section C

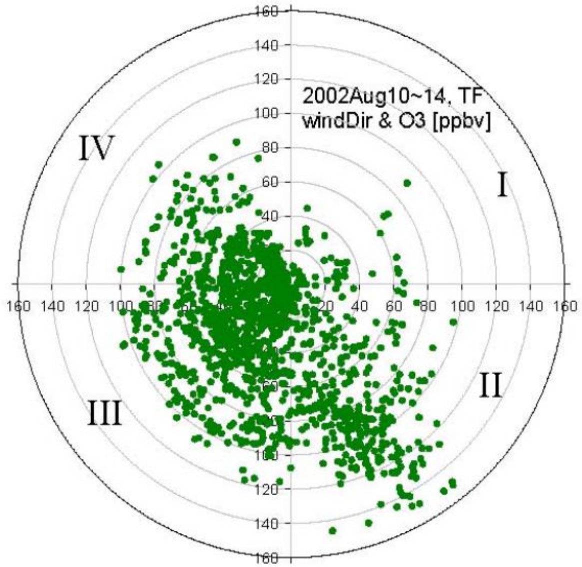
27 European Commission Implementing Decision 2011/850/EU of 12 December 2011 (laying down rules for the air quality directive in force as regards the reciprocal exchange of information and reporting on ambient air quality)

ANNEX I

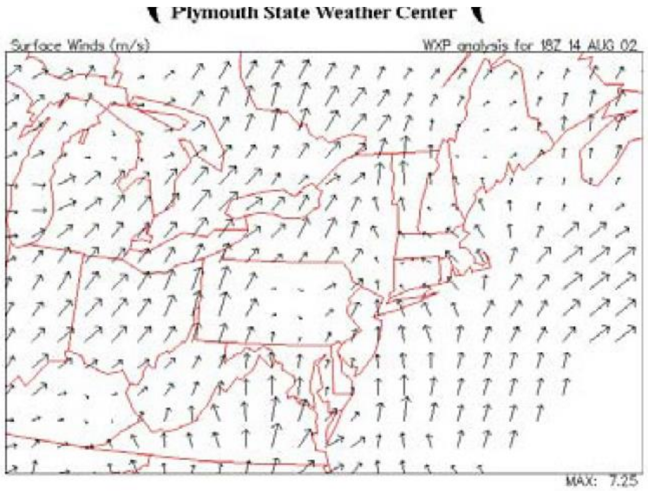
Episode Case studies

City	Year	Incident	Actions Taken	Bibliography
Paris	2003	**February 2003 Episode & March 2003**. The influence of neighboring countries over the Paris Basin concentrations is assessed. Influences of Belgium, Netherlands, Germany and Italy are studied. Because of their location, these countries are likely to have an influence over the PM concentrations on the North part of France during such episodes. On 21 February and 21 March episodes, the outside contribution reaches 50%, while during non-episode situations the contribution drops down to 20%.	The CHIMERE model has been used over Europe with a zoom on the Paris Basin. Although model results are quite good for PARTISOL PM10, ammonium and nitrates concentrations, model deficiencies are observed for sulfate. Indeed, sulfate in winter is produced in clouds, involving modeling parameters, which are sometimes difficult to obtain from meteorological outputs. Error statistic show large differences between the continental and local simulations due to the resolution and the two different inventories used.	Origin of particulate matter pollution episodes in wintertime over the Paris Basin
Baltimore US	1993	The forecast problem for Baltimore is to identify weather patterns characteristic of strong ozone events and associate these patterns with standard meteorological variables.	A pilot program was undertaken to forecast episodes of high ozone concentrations for 24-72 h in the Baltimore metropolitan area. This program utilized Classification and Regression Tree (CART) algorithms as well as standard regression analysis and expert forecasts. All approaches tend to under predict peak 03 concentrations at 24 h. The "key" is accuracy in temperature forecasts for both models	FORECASTING SEVERE OZONE EPISODES IN THE BALTIMORE METROPOLITAN AREA
Delhi, India	2012	Delhi. The hour-by-hour analysis of past data pattern at different monitoring stations suggest that the haze hours were occurred approximately 48% of the total observed hours in the year, 2012 over Delhi urban area. The haze hour forecasting models in terms of PM2.5 concentrations (more than 50 m g/m3) and relative humidity (less than 90%) have been developed through artificial intelligence based Neuro-Fuzzy (NF) techniques and compared with the other modeling techniques e.g., multiple linear regression (MLR), and artificial neural network (ANN).	Neural network and fuzzy logic are combined for forecasting of PM 2.5 during haze conditions. The haze occurs when the level of PM 2.5 is more than 50 m g/m3 and relative humidity is less than 90%.	Artificial intelligence based approach to forecast PM2.5 during haze episodes: A case study of Delhi, India

Lisbon, Portugal	2010	From all the available data only cases with hourly concentrations of ozone above 180 µg·m3 were kept. This value is the threshold over which a brief exposure is a risk to human health, particularly for the sensitive sections of the population for which immediate and appropriate information is necessary (Directive 2008/50/EC).	ANN can classify the origin of an O3 episode with a mean error around 2-7%. • The best classification is obtained when a simpler input combination is used. • ANN can help authorities to foster O3 action plans to control exceedances.	Can artificial neural networks (ANN) be used to predict the origin of ozone episodes?
UK, Mainland	1989-1999	The geographical origins of such episodes are determined from an analysis of the trajectories associated with elevated ozone levels at 14 rural sites and six urban sites in the UK over the period 1992–1999. The analysis shows that the highest levels of ozone occur under summertime anticyclonic conditions, when the back trajectories have 'looped' over mainland Europe and arrive in the UK from a broadly easterly or southeasterly direction. Monitoring data from the same sites over the period 1989–1999 clearly demonstrate that ozone episodes are more prevalent at the end of the week, with the greatest numbers of hours >=90 ppbv occurring on Fridays.	Analysis of monitoring data from the same sites over the period 1989–1999 demonstrate that ozone episodes are more prevalent at the end of the week, with the greatest numbers of hours X 90 ppbv occurring on Fridays. Relative to Fridays, the number of hours exceedance on the other days are: Sundays 51%, Mon 50%, Tue 54%, Wed 39%, Thur 70% and Sat 82%. The observed day-of-week dependence is believed to result from the temporal dependence in the emissions of the precursor VOC and NO x (which are greater on weekdays) and the multi-day timescale required for chemical processing and transport to lead to elevated ozone levels under photochemical episode conditions in the UK. This hypothesis is broadly supported by the results of a case study using a **photochemical trajectory model**, which includes a full representation of seasonal, day-of-week and hour-of-day variations in precursor emissions, based on a recent appraisal (Jenkin et al., 2000).	The origin and day-of-week dependence of photochemical ozone episodes in the UK
Izmir, Turkey	2000	This paper presents a comparison of the predicted and measured concentrations of sulfur dioxide in the Izmir metropolitan area for the year 2000. Both the measured and predicted data includes daily SO2 concentrations for 1 year. The comparison included data from four air quality monitoring stations in the metropolitan area.	The CALMET (Scire et al., 2000) meteorological model and its puff dispersion model CALPUFF were used to predict ambient SO2 concentrations. Statistical analyses were carried out to evaluate the model performance by comparing the predicted and measured time series of sulfur dioxide	Comparison of model predictions with the data of an urban air quality monitoring network in Izmir, Turkey

		concentrations at four monitoring stations using two main methods: root of the mean square error (RMSE) and an index of agreement (d).	
New Hampshire (NH), USA.	**The August 2002 high O3 event** at Thompson Farm (TF) occurred under stagnant synoptic high-pressure conditions that prevailed over the entire eastern USA for an unusually extended time period. The clear skies and stable meteorological conditions resulted in accumulation of pollutants in the boundary layer. Local land-sea-breeze circulations also added to the impact of this event. **The unprecedented high levels of O3 on 22 July 2004** at CS was driven by two mechanisms, stratospheric intrusion and the Appalachian lee trough (APLT), which was not found during other O3 episodes at the site in the decade long data record. • On the synoptic scale, studies have demonstrated that a common characteristic of many elevated O 3 events in the eastern USA was the presence of a slow moving high-pressure system • The weather under high-pressure systems is typically clear skies, high temperatures, and the stable meteorological conditions, which promotes O 3 formation and also tends to trap pollutants within the boundary layer • Another synoptic mechanism potentially affecting surface O3 mixing ratios is stratospheric subsidence. Some studies have found that several high O3 events during summertime were dramatically influenced by injection of O3 -rich stratospheric air. Winds 1. Strong southwesterly winds on **August 10 of 10~14 m/s**	The observations of O3 and wind directions at TF from 10–14 August. Radial scales present O3 mixing ratios from 0 to 160 ppbv, in 10 ppbv interval. Angular degrees in clockwise present wind directions. In degrees of 0°–90° are northerly-to-  easterly winds (I); 90°–180° are easterly-to-southerly winds (II); 180°–270° are southerly-to-westerly winds (III); and 270°–360° are westerly-to-northerly winds (IV).	An Investigation of Two Highest Ozone Episodes During the Last Decade in New England

2. and on **11–13 August up to ~14 m/s** at late night and early morning hours at altitudes below 500 m. These meteorological patterns are characteristic of the nocturnal low-level jet (LLJ), sea breeze circulation



Bor (Serbia)	2013	During 2011, extremely high concentrations of SO 2 were registered in the urban area of the town Bor (Serbia). This was the case on 112 days or 46.1% out of the total time. Episodes of ultra-high PM concentrations occurred simultaneously with the episodes of ultra-high concentrations of SO 2 . Ultra-high concentrations of SO 2 and PM synergically present a risk to human health and the ecosystems in the area.	Since May 2011, frequent episodes of extreme concentrations of SO 2 , PM 10 and PM 2.5 have occurred because (1) of the construction of new smelter and sulphuric acid plants implementing modern technologies was officially commenced in late June 2011, (2) during the three-year construction period of these new plants, the old smelter and the sulphuric acid plant will continue in operations at the current capacities, (3) the worn-out equipment for gas dedusting has not been repaired because the new plants are under construction, (4) the production of sulphuric acid is limited and all gases are frequently released into the atmosphere.	Episodes of extremely high concentrations of SO 2 and particulate matter in the urban environment of Bor, Serbia
Krakow Poland	2005	Stable weather conditions together with extensive use of coal combustion often lead to severe smog episodes in certain urban environments, especially in Eastern Europe. In order to identify the specific sources that cause the smog episodes in such environments, and to better understand the mixing state and atmospheric processing of aerosols, both single particle and bulk chemical characterization analysis of aerosols were performed in Krakow, Poland, during winter 2005. Real-time measurements of the bulk PM10 aerosol during a severe smog episode (PM10>400 µg/m3) showed a stable concentration of black carbon in the aerosol, and an increase in the sulphate and chlorine mass contributions towards the end of the episode. Chemical characterization of single particles further helped to identify residential coal burning as the main source that caused this severe smog episode, consisting of single particles with major signals for carbon with simultaneous absence of sulphate, chlorine and calcium. Particles from industrial coal combustion gained importance towards the end of that		Source attribution of urban smog episodes caused by coal combustion

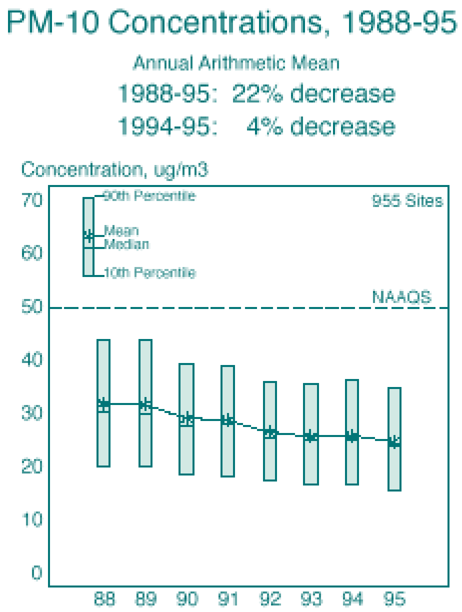
episode, after residential coal combustion was switched off, indicated by an increase of the percentage of sulphate and chlorine containing particles. Traffic was not a significant source during the severe smog episode. During a lighter smog episode, residential and industrial coal combustion was still predominant, with an increased contribution of traffic and processed/aged aerosols. On a clean day, particle classes containing nitrate were the most abundant. In addition, the aerosol was more internally mixed showing that there were more sources contributing to the total aerosol population.

ANNEX II
International Case Response – Contingency Plans - Rules

Section A

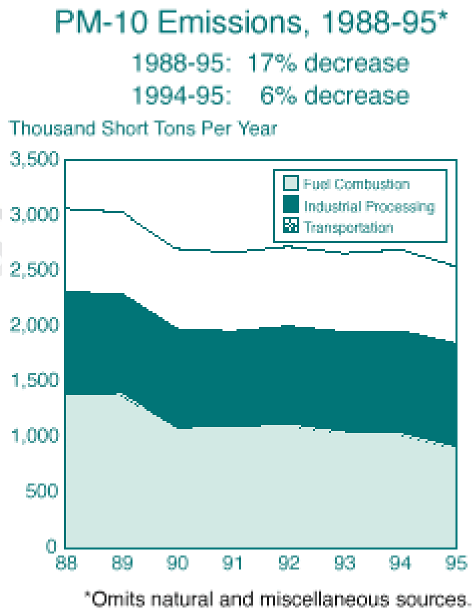
International Case Response – Contigency Plans - Rules

	Ozone	PM
EPA (USA)	**2008 Eight-Hour Ozone Standard (2008 to Present)** On March 27, 2008, the United States Environmental Protection Agency (EPA) strengthened the primary and secondary eight-hour ozone standard to 0.075 ppm (73 FR 16436). On March 10, 2009, the governor recommended to the EPA that Collin, Dallas, Denton, Ellis, Hood, Johnson, Kaufman, Parker, Rockwell, and Tarrant counties be designated nonattainment for the 2008 eight-hour ozone standard (see the governor's letter to EPA region 6). All of the counties except Hood were previously designated nonattainment under the 1997 eight-hour ozone standard (0.08 ppm). In September 2009, the EPA announced it would reconsider the 2008 NAAQS and on January 19, 2010, proposed **to lower the primary ozone standard to a range of 0.060–0.070 ppm**, and proposed a separate secondary standard based on cumulative seasonal average ozone concentrations. On September 2, 2011, President Obama announced that he had requested the EPA withdraw the proposed reconsidered ozone standard. In a memo dated September 22, 2011 from EPA Assistant Administrator Gina McCarthy, the EPA announced that it would proceed with initial area designations under the 2008 eight-hour ozone standard, starting with the recommendations states made in 2009 and updating them with the most current, certified air quality data (2008 through 2010). On October 31, 2011, the governor sent a revised recommendation to the EPA that Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, and Tarrant Counties be designated nonattainment for the 2008 eight-hour ozone standard based on 2008 through 2010 air quality data. The EPA sent a letter to the governor on December 9, 2011, responding to the state's recommendations for area designations under the 2008 eight-hour ozone standard. In that letter, the EPA indicated that it intended to modify the state's recommended DFW nonattainment area designation to include Hood and Wise Counties. On May 21, 2012, the EPA published in the *Federal Register* final designations for the 2008 eight-hour ozone standard (77 FR 30088) . A ten-county DFW area including Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise Counties was designated nonattainment and classified moderate under the 2008 eight-hour ozone standard, effective July 20, 2012. The DFW area includes the nine counties that were designated nonattainment under the 1997 eight-hour ozone standard in addition to Wise County. Hood County was designated attainment/unclassifiable. The attainment deadline for the DFW moderate nonattainment area is December 31, 2018.	In **1987,** EPA replaced the earlier **Total Suspended Particulate (TSP)** air quality standard with a **PM-10 standard**. The new standard focuses on smaller particles that are likely responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. The PM-10 standard includes particles with a diameter of 10 micrometers or less (0.0004 inches or one-seventh the width of a human hair). EPA's health-based national air quality standard for PM-10 is 50 µg/m^3 (measured as an annual mean) and 150 µg/m3 (measured as a daily concentration). Major concerns for human health from exposure to PM-10 include: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children, and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. Acidic PM-10 can also damage human-made materials and is a major cause of reduced visibility in many parts of the U.S. New scientific studies suggest that fine particles (smaller than 2.5 micrometers in diameter) may cause serious adverse health effects. As a result, EPA is considering setting a new standard for PM-2.5. In addition, EPA is reviewing whether revisions to the current PM-10 standards are warranted. **Trends in PM-10 Levels**: Air monitoring networks were changed in 1987 to measure PM-10 (replacing the earlier TSP monitors). Between 1988 and 1995, average PM-10 concentrations decreased 22 percent. Short-term trends between 1994 and 1995 showed a decrease of 4 percent in monitored PM-10 concentration levels.



Emissions of PM-10 shown in the chart are based on estimates from fuel combustion sources, industrial processes, and transportation sources, which account for only 6 percent of the total PM-10 emissions nationwide. Between 1988 and 1995, PM-10 emissions for these sources decreased 17 percent. Short-term emissions trends between 1994 and 1995 showed a 6 percent decrease.

The emissions estimates presented below do not include emissions from natural and miscellaneous sources which are fugitive dust (unpaved and paved roads), agricultural and forestry activities, wind erosion, wildfires and managed burning. These emissions estimates also do not account for particulate matter that is secondarily formed in the atmosphere from gaseous pollutants (e.g., SO_2 and NO_x).



EPA (USA)

1997 Eight-Hour Ozone Standard (1997 to Present)

In July 1997, the EPA announced a revised NAAQS for ground-level ozone. The EPA phased out and replaced the previous one-hour standard with an eight-hour standard set at 0.08 ppm to protect the public health against longer exposure to this air pollutant. The eight-hour ozone standard became effective on September 16, 1997.

Effective June 15, 2004, Collin, Dallas, Denton, Tarrant, Ellis, Johnson, Kaufman, Parker, and Rockwall Counties were designated nonattainment for the 1997 eight-hour ozone standard. The area was classified moderate nonattainment for the standard, with an attainment deadline of June 15, 2010.

To satisfy the requirements of Phase I of the 1997 **eight-hour ozone standard implementation rule** (69 FR 23951), the TCEQ adopted the DFW Eight-Hour Ozone Five Percent Increment of Progress SIP Revision on April 27, 2005 and submitted it to the EPA. The revision used a 5% increment of progress from the area's 2002 emissions baseline beyond the reductions from federal and state measures already approved by the EPA, and was the first DFW SIP revision submitted under the 1997 eight-hour ozone standard.

In May 2007, the TCEQ submitted attainment demonstration and reasonable further progress (RFP) SIP revisions for the DFW area to the EPA. The **May 2007 DFW Attainment Demonstration SIP** included a plan for DFW compliance with the 1997 eight-hour ozone standard by June 15, 2010 (based on 2009 ozone season monitoring). The RFP SIP revision demonstrated 15% total NO_X and volatile organic compound (VOC) emissions reductions between 2002 and 2008, as required. The attainment demonstration and RFP SIP revisions relied on photochemical modeling and weight of evidence (WoE) analyses that examined qualitative and other factors that could not be directly included in the models, but that nevertheless supported the projected attainment by 2010. On March 21, 2008, the EPA found the on-road motor vehicle emissions budget (MVEB) contained in the DFW attainment demonstration adequate for transportation conformity purposes (**73 FR 15152**).

The TCEQ provided supplemental information pertaining to the attainment demonstration to the EPA on April 23, 2008. After the attainment demonstration was supplemented, it was revised in November 2008 (contingency plan revisions), and again revised in December 2008 (DERC program revisions).

The EPA approved the May 2007 DFW RFP SIP revision (which included an updated MVEB and emissions inventory) on October 7, 2008 (**73 FR 58475**) .

On January 14, 2009, the EPA published final conditional approval (**74 FR 1903**) of components of the attainment demonstration, including the original May 2007 DFW 1997 Eight-Hour Ozone Attainment Demonstration SIP Revision, the April 23, 2008 supplement, and the November 2008 DFW Attainment Demonstration Contingency Plan SIP Revision. This was the first attainment demonstration SIP revision in the U.S. for the 1997 eight-hour ozone standard to receive approval from the EPA. The DERC Program SIP revision component submitted in December 2008 was not included in the EPA's conditional approval, and remains under review. The EPA approval included:

- Conditional approval of the 2009 attainment MVEBs, Reasonably Available Control Measures (RACM) demonstration, and failure-to-attain contingency plan.
- Full approval of local Voluntary Mobile Source Emission Reduction Plan (VMEP) and Transportation Control Measures (TCM).
- Full approval of the VOC Reasonably Available Control Technology (RACT) demonstrations for the one-hour and 1997 eight-hour ozone standards.
- A statement that all control measures and reductions relied upon to demonstrate attainment has been approved by the EPA.

On March 10, 2010, the TCEQ adopted the **DFW RACT, Chapter 117 Rule, and Contingency Plan SIP Revision** to: (1) address several CTGs issued by the EPA between 2006 and 2008, (2) expand a specific exemption from NO_X control requirements and demonstrate that the expansion would not interfere with attainment, and (3) revise the contingency measure plan to reflect the two rule changes included with the 2007 DFW attainment demonstration SIP revision. Based on the revised RACT analysis, the offset lithographic rules that had been contingency measures for the area were made full control measures and were removed from the contingency plan. Emissions reductions from fleet turnover that were not already used for the contingency plan were used to replace the reductions removed from the contingency plan from adoption of offset lithographic controls and expansion of the NO_X control exemption.

On August 10, 2010, the TCEQ adopted the **Environmental Speed Limit (ESL) Control Strategy Conversion to a TCM SIP Revision**. Conversion of the DFW-area ESL strategy to a TCM was made to allow increased flexibility for local air quality planners to change ESLs in the area. With adoption of this SIP revision, future changes to ESLs may be accomplished through a TCM substitution process, which is the responsibility of local air quality planners, instead of through a formal revision of the DFW SIP. The conversion of the ESL strategy to a TCM is consistent with the MVEB submitted in the 2007 DFW attainment demonstration SIP revision.

Effective January 19, 2011, the EPA published a final determination of failure to attain and reclassification of the DFW area from a moderate to a serious nonattainment area for the 1997 eight-hour ozone standard (**75 FR 79302**). The EPA set January 19, 2012 as the deadline for Texas to submit attainment demonstration and RFP SIP revisions addressing the serious ozone nonattainment area requirements of the Federal Clean Air Act.

On December 7, 2011, the TCEQ adopted the **2011 DFW 1997 Eight-Hour Ozone Attainment Demonstration SIP Revision** and the **2011 DFW 1997 Eight-Hour Ozone RFP SIP Revision**. The 2011 attainment demonstration SIP revision demonstrated that the state's control strategy would result in the area's attainment of the 1997 eight-hour ozone standard by 2012, the attainment year for serious nonattainment areas. As required by the EPA, the 2011 attainment demonstration SIP revision included an MVEB, a VOC and NO_X RACT analysis, a RACM analysis, and a contingency plan. The 2011 attainment demonstration SIP revision also described revisions to **30 TAC Chapter 115, Subchapter E** and **30 TAC Chapter 115, Subchapter B, Division 1**. The 2011 attainment demonstration SIP revision used the EPA's Motor Vehicle Emissions Simulator (MOVES) model to develop the on-road mobile emissions inventory and attainment year MVEB.

The 2011 RFP SIP revision demonstrated that an emissions reduction of at least 3% per year would occur between milestone years 2011 and 2012. The 2011 RFP SIP revision established baseline emission levels, calculated reduction targets, identified control strategies to meet emission target levels, and tracked actual emission reductions against established emissions growth. The 2011 RFP SIP revision also included an MVEB for each milestone year as well as a contingency plan. As with the 2011 attainment demonstration SIP revision, the 2011 RFP SIP revision used the EPA's MOVES model to develop the base year and milestone year on-road mobile emissions inventories and the milestone year MVEBs.

EPA (USA)	**One-Hour Ozone Standard (1990 to 2008)** *Note:* In 1997, **the one-hour ozone standard was replaced by the more protective eight-hour ozone standard**. The one-hour standard has been revoked in all areas, although some former one-hour ozone nonattainment areas have continuing obligations to comply with the anti-backsliding requirements described in 40 CFR §51.905(a). The 1990 Federal Clean Air Act Amendments authorized the EPA to designate areas failing to meet the NAAQS for ozone as nonattainment and to classify them according to severity. The EPA designated four DFW area counties (Dallas, Denton, Collin, and Tarrant) moderate nonattainment of the one-hour standard of 0.12 ppm. In September 1994, the TCEQ submitted to the EPA an attainment demonstration SIP revision focused on controlling VOC emissions. The DFW area did not attain the one-hour ozone standard by the November 15, 1996 attainment deadline. On February 18, 1998, the EPA reclassified the four-county area to serious nonattainment, with a new attainment deadline of November 15, 1999. The TCEQ submitted a 9% rate-of-progress SIP revision to the EPA, but there was not enough time to implement rules to achieve necessary reductions by the attainment deadline. In April 2000, the TCEQ adopted a full attainment demonstration including rules to attain the one-hour standard. That **attainment demonstration SIP revision** took into account the importance of local reductions in emissions of NO_X and the transport of ozone and its precursors (NO_X and VOC) from the Houston-Galveston-Brazoria (HGB) area. Based on photochemical modeling demonstrating that ozone and precursors transported from HGB were impacting DFW area ozone concentrations, the TCEQ requested an extension of the DFW area's attainment date to November 15, 2007. In July 1997, the EPA announced a revised NAAQS for ground-level ozone. The EPA phased out and replaced the previous one-hour standard with an eight-hour standard to protect public health against longer exposure to this air pollutant. EPA rules (Phase I) implementing the new eight-hour standard and revoking the one-hour standard (**69 FR 23951**) were issued in April 2004. Designated nonattainment area classifications determined what one-hour ozone requirements remained in effect. Areas not attaining the one-hour standard, including DFW, were required to comply with the one-hour standard until attained. The four DFW area counties remained subject to the one-hour standard. The EPA no longer redesignates areas under the one-hour standard, but may issue determinations of attainment, which allow areas to suspend requirements for additional SIP-submission requirements under the one-hour standard. On October 16, 2008, the EPA issued a determination that the DFW four-county one-hour ozone area had attained the one-hour

	NAAQS based on verified 2004 through 2006 monitoring data, further supported by data from 2007 and 2008 (73 FR 61357). Requirements for this area to submit an attainment demonstration or 5% increment-of-progress plan, an RFP plan, contingency measures, and other planning SIP revisions related to one-hour ozone NAAQS attainment are suspended as long as the area continues to meet the standard.	
EPA	**Contingency Implementation**	**Contingency Measures**
	The Section 175A maintenance plan requirements include contingency measures to promptly address any violation of the NAAQS that occurs. The **contingency plan ensures that the contingency measures are adopted expeditiously once they are triggered**. The contingency plan for the ozone maintenance area is triggered upon monitoring a violation of the 8-hour ozone standard. A violation occurs when the design value for the area exceeds 0.084 ppm on one or more monitors in the network over the 3 year data collection period. Implementation of contingency measures will occur within 24 months of the triggering event. Implementation of the contingency plan involves analysis of data to determine the cause of the violation. If, after this analysis is complete, the state determines that the violation was caused by events that can be controlled within the state's jurisdiction through regulatory actions, the state will determine the appropriate measures for implementation in the area and implement such measures within the 24 month period suggested by EPA guidance. Determination of the appropriate contingency measure(s) for implementation will involve the following actions: • Identification of potential sources for emission reductions; • Identification/evaluation of prospective control measures; • Initiation of stakeholder process; and • Implementation of contingency measures through promulgation of appropriate control rules adhering to public notice and comment requirements.	Contingency measures to be considered for implementation will include, but will not be limited to extending the applicability of the state's NOx control rule LAC 33:III.2202 to include the months of April and October each year. Currently, the provisions of Chapter 22 apply during the ozone season (May 1 to September 30) of each year. Reducing NOx emissions during April and October will further reduce high ozone days in the Baton Rouge Ozone Maintenance Area. The state will also consider other measures deemed appropriate at the time as a result of advances in control technologies. These measures may include lowering of the NOx emission factors of LAC 33:III.2205.D and/or requiring more stringent monitoring of elevated flares. Other possibly contingency measures that may be considered include: • Diesel retrofit/replacement initiatives • Programs or incentives to decrease motor vehicle use • Implementation of fuel programs, including incentives for alternative fuels • Employer-based transportation management plans • Anti-backsliding ordinances • Programs to limit or restrict vehicle use in areas of high emissions concentration during periods of peak use.
New York State dptm of Environmental	**Ozone Contingency Measures**	Under the CAA, 8-hour ozone areas subject only to subpart 1, as well as those classified under subpart 2 as moderate, serious, severe and extreme must include in their SIPs contingency measures consistent with Sections 172(c)(9) and 182(c)(9), as applicable. Contingency measures are additional controls to be

conservation	implemented in the event the area fails to meet an RFP milestone or fails to attain by its attainment date. Such measures shall take effect in any such case without further action by the state or the Administrator. EPA requires that contingency measures identified by the state must be sufficient to secure an additional 3 percent reduction in ozone precursor emissions in the year following the year in which the failure has been identified. For a non- attainment area that fails to meet RFP percent reduction requirements, and where it has been demonstrated that NO_x controls are needed to attain the primary NAAQS for ozone, measures that produce a combination of NO_x and VOC reductions may serve as 15 percent contingency measures. EPA requires at least 0.3 percent out of every reduction of 3 percent be attributable to a reduction in VOC measures. The New York State portion of the New York-N. New Jersey-Long Island, NY- NJ-CT non-attainment area meets RFP percent reduction requirements as demonstrated in Chapter 10. In order to demonstrate compliance with the contingency measures provision applicable to the attainment demonstration, the Department has opted to include measures that have been or will be adopted for its contingency measures for the New York State portion of the New York-N. New Jersey-Long Island, NY-NJ-CT non-attainment area. http://www.dec.ny.gov/chemical/37101.html
National Ambient Air Quality Standards (NAAQS)	
İstanbul Metropolitan Municipality **Environmental Protection and Control Department** Action Plans	
Vehicle Emission Reduction	**Industrial Emission Reduction**
• **Raising awareness about the environmentally friendly driving techniques.** As well as fuel characteristics, exhaust emissions also originated from	**Industrial site selection considering wind direction.** Site selection for industries should be out of residential areas

improper driving techniques. Green driving tips such as; planning and consolidating trips, keeping cars well maintained, avoiding topping-off the gas when refueling, keeping ties properly inflated, repairing air conditioning, accelerating smoothly, avoiding excess idling in non-traffic situations and maintaining steady speed will be promoted for emission reduction.

- **Using filter and catalytic converter systems for exhaust emission control on vehicles.** Convenient filter systems substantially contribute to the reduction of exhaust emissions. Especially for vehicles which are in traffic all day long, (e.g. public transportation busses, taxis) filter appliance is crucial for emission reduction.

- **Reducing pollution through the use of environmentally acceptable vehicles and fuels in public transportation.** More efficient use of energy, use of less-polluting fossil fuels, increased use of non- fossil energy sources, use of newer and environmentally more benign combustion technologies will led to emission reduction from vehicles and will be promoted especially to achieve national air quality objective for NO2.

- **Promoting alternative and more sustainable modes of transport to the cars.**

- **Improving and popularizing the marine transportation.**

- **Promoting the implementation of Park and Ride applications.**

and made by considering the pre dominant wind directions and the location of residential areas.

Using environment friendly fuels. Maximize the fuel efficiency and the use of eco-friendly fuels to conserve energy and reduce emissions.

Industrial source contribution to air quality. Contribution of each industrial source to local and regional air quality must be quantified and the required control equipment should be selected.

The effects of neighbouring regions on air quality. Transport of air pollutants (including air toxics) from neighbouring regions such as Dilovasi and Corlu to İstanbul should be quantified using the required air quality models.

Promoting new technologies in industries. Although, investment costs of new technologies are higher than the old ones, they are economic and eco-friendly technologies by the means of operation.

Online monitoring of emissions from industrial stacks. Continuous online monitoring of emissions from large industrial stacks is essential to ensure compliance with limit values.

Section B

Emergency episode criteria requirements for Air Pollution Alert and Emergency Plan

1. "**AIR POLLUTION FORECAST**": An Internal watch by the Division of Air Pollution Control shall be actuated by a National Weather Service advisory that Atmospheric Stagnation Advisory is in effect or the equivalent local forecast of stagnant atmospheric conditions.
2. "**AIR POLLUTION ALERT**": The Alert level is that concentration of pollutants at which emissions reductions must begin. An Alert will be declared when any one of the following levels is reached at any monitoring site: (a) SO2-800 μg/m3 (0.3 ppm), 24-hr. average. (b) PM10-350 μg/m3, 24-hour average. (c) Reserved (d) CO--17 mg/m3 (15 ppm), 8-hour average. (e) Ozone (O3) -- 400μg/m3 (0.2 ppm) -- 1 hr. average. (f) NO2--1130 μg/m3 (0.6 ppm), 1-hr. average; 282μg/m3 (0.15 ppm), 24-hour average. And meteorological conditions are such that pollutant concentrations can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken, or in the case of ozone, the situation is likely to reoccur within the next 24 hours unless control actions are taken.
3. **"AIR POLLUTION WARNING**": The warning level indicates that air quality is continuing to degrade and that additional control actions are necessary. A warning will be declared when any one of the following levels is reached at the monitoring site: (a) SO2 - 1600 μg/m3 (0.6 ppm), 24-hr average. (b) PM10 - 420 μg/m3, 24-hour average. (c) Reserved (d) CO-34 mg/m3 (30 ppm), 8-hr. average. (e) Ozone (O3) - 800 μg/m3 (0.4 ppm), 1-hr. average. (f) NO - 2,260 μg/m3 (1.2 ppm)--1-hr. average; 565 μg/m3 (0.3 ppm), 24-hr. average And meteorological conditions are such that pollutant concentrations can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken, or in the case of ozone, the situation is likely to reoccur within the next 24 hours unless control actions are taken.
4. "**AIR POLLUTION EMERGENCY**": The emergency level indicates that air quality is continuing to degrade to a level which could cause an unreasonable risk to public health and that the most stringent control actions are necessary. An emergency will be declared when any one of the following levels is reached at any monitoring site: (a) SO2-2, 100 μg/m3 (018 ppm), 24-hr. average. (b) PM10 - 500 μg/m3, 24-hour average. (c) Reserved (d) CO-46 mg/m3 (40 ppm), 8-hr. average. (e) Ozone (O3) - 1,000 μg/m3 (0.5 ppm), 1-hr. average. (f) NO2--3,000 μg/m3 (1.6 ppm) 1-hr. average; 750 μg/m3 (0.4 ppm), 24-hr. average. And meteorological conditions are such that this condition can be expected to continue for twelve (12) or more hours, or in the case of ozone, the situation is likely to reoccur within the next 24 hours unless control actions are taken.
5. "**TERMINATION**": Once declared, any status reached by application of these criteria will remain in effect until the criteria for that level are no longer met. At such time, the next lower status will be assumed.

REQUIRED EMISSIONS REDUCTIONS

(1) When the Technical Secretary has declared that an air pollution alert, an air pollution warning, or an air pollution emergency exists, all persons must follow the requirements **for that episode level as outlined in Tables 1, 2, or 3 or the air pollution episode emissions reduction plan approved in accordance with paragraphs (2), (3), (4), (5) or (6) of this rule. If a plan has been approved, emissions must be reduced at that level or lower.**

(2) Major sources **in or significantly impacting a nonattainment area** must submit to the Technical Secretary an acceptable air pollution episode emissions reduction plan to be followed during the alert**, warning, and emergency levels of an air pollution episode. The term "Major source" as used above means any of the following types of stationary sources of air pollutants which emit, or have the potential to emit,** one hundred tons per year or more of any air pollutant **from the following types of stationary sources: fossil fuel fired steam electric plants of more than two hundred fifty million British thermal units per hour heat input,** coal cleaning plants (thermal dryers), draft pulp mills**,** Cement plants, primary zinc smelters, iron and steel mill plants, primary copper smelters, municipal incinerators capable of charging more than two hundred and fifty tons of refuse per day, hydrofluoric, sulfuric, and nitric acid plants, petroleum refineries, lime plants, coke oven batteries, sulfur plants, phosphate rock processing plants, sulfur recovery plants, carbon black plants, (furniture process) primary lead smelters, fuel conversion plants, sintering plants, secondary metal production facilities, chemical process plants, fossil-fuel boilers of more than two hundred and fifty million British thermal units per hour heat input, petroleum storage and transfer facilities with a capacity exceeding three hundred thousand barrels, taconite ore processing facilities, glass fiber processing plants, charcoal production facilities. Such term also includes any other sources with the potential to emit two hundred and fifty tons per year or more of any air pollutant**. Only the pollutants for which the area is nonattainment are considered in determining whether a source is a major source.**

(3) Any source subject to paragraph (2) above must submit a revised air pollution episode emissions reduction plan at the request of the Technical Secretary should the nature and quantity of the source's emissions change or the original plan be deemed inadequate.

(4) The owners and operators of other air contaminant sources, having a smaller potential for emissions than one hundred tons per year, may file an acceptable air pollution episode emissions reduction plan for use during an air pollution episode if they feel they can contribute through other measures as much or more benefit to the reduction of the health hazard in the area at a much lower cost to themselves.

(5) Where specific actions may be necessary to relieve a health hazard by sources emitting at lower levels than that indicated in paragraph (2) above the Technical Secretary may require the submittal of an acceptable plan from the owners or operators of that source. The owner or operator will have thirty (30) days to submit the plan, once it has been required.

(6) If the owners or operators of any source required to have an approved air pollution episode emissions reduction plan on file with the Technical Secretary by paragraphs (2), (3), or (5) above, fails to submit an approvable plan to the Technical Secretary, the Technical Secretary may schedule an Administrative Hearing to set an approved air pollution episode emissions reduction plan for that air pollution source.

TABLE 1 - EMISSION REDUCTION PLANS ALERT LEVEL

Part A. GENERAL

1. There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form.

2. The use of incinerators for the disposal of any form of solid waste shall be limited to the hours between 12:00 noon and 4:00 p.m.

3. Persons operating fuel-burning equipment which requires boiler lancing or soot blowing shall perform such operations only between the hours of 12:00 noon and 4:00 p.m.

4. The Tennessee Air Pollution Control Division encourages persons operating motor vehicles to eliminate all unnecessary operation.

Part B. SOURCE CURTAILMENT

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Warning Level.

	Source of Air Pollution		Control Action
1.	Coal or oil-fired electric power reduction by generating facilities	a.	Substantial utilization of fuels having low ash and sulfur content.
		b.	Maximum utilization of mid-day (12:00 p.m. to 4:00 p.m.) atmospheric turbulence for boiler lancing and soot blowing.
		c.	Substantial reduction by diverting electric power generation to facilities outside of Alert Area.
2.	Coal and oil-fired process steam generating facilities	a.	Substantial reduction by utilization of fuels having low ash and sulfur content.
		b.	Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing and soot blowing.
		c.	Substantial reduction of steam load demands consistent with continuing plant operations.
3.	Manufacturing industries of the following classifications: Primary Metals Industry; Petroleum Refining Operations; Chemical Industries; Paper and Allied Products; Grain Industry	a.	Substantial reduction of air contaminants from contaminants from manufacturing operations by curtailing, postponing, or deferring production and all operations.
		b.	Maximum reduction by deferring trace waste disposal operations which emit solid particles, gases, vapors. or malodorous substance.
		c.	Maximum reduction of heat load demands for processing.
		d.	Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing or soot blowing.

TABLE 2

EMISSION REDUCTION PLANS

WARNING LEVEL

Part A. GENERAL

1. There shall be no open burning by any persons of tree waste, vegetation, refuse or debris in any form.

2. The use of incinerators for the disposal of any form of solid waste or liquid waste shall be prohibited.

3. Persons operating fuel-burning equipment which requires boiler lancing or soot blowing shall perform such operations only between the hours of 12:00 noon and 4:00 p.m.

4. The Tennessee Air Pollution Control Division encourages persons operating motor vehicles to reduce operations by the use of car pools and increase use of public transportation and the elimination of unnecessary operation.

Part B. SOURCE CURTAILMENT

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Warning Level.

Source of Air Pollution	Control Level
1. Coal or oil-fired electric power generating facilities	a. Maximum reduction by utilization of fuels having lowest ash and sulfur content.
	b. Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing and soot blowing.
	c. Maximum reduction by diverting electric power generation to facilities outside of Warning Area.

2.	Coal and oil-fired process steam generating facilities	a.	Maximum reduction by utilization of fuels having the lowest ash and sulfur content.
		b.	Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing and soot blowing.
		c.	Making ready for use a plan of action to be taken if an emergency develops.
3.	Manufacturing industries which require considerable lead time for shut-down including the following classifications:	a.	Maximum reduction if air contaminants from manufacturing operations if necessary, assuming reasonable economic hardship by postponing production and allied operation.
	Petroleum Refining		
	Chemical Industries	b.	Maximum reduction by deferring which emit solid particles, gases, vapors, or malodorous substances.
	Primary Metal Industries	c.	Maximum reduction of heat load demands for processing.
	Glass Industry		
	Paper and Allied Products	d.	Maximum utilization of mid-day (12:00 noon to 4:00 pm) atmospheric turbulence for boiler lancing and soot blowing.
4.	Manufacturing industries which require relatively short lead time for shut-down including the following classifications:	a.	Elimination of air contaminants from manufacturing operations by ceasing, curtailing, postponing, or deferring production and allied operations to the extent possible without causing injury to persons or damage.
	Primary Metal Industries		
	Chemical Industries	b.	Elimination of air contaminants from trade waste disposal processes which emit solid particulates, gases, vapors, or malodorous substances.
	Mineral Processing Industries	c.	Maximum reduction of heat load demands for processing.
	Grain Industry	d.	Maximum utilization of mid-day (12:00 noon to 4:00 pm) atmospheric turbulence for boiler lancing and soot blowing.

TABLE 3

EMISSION REDUCTION PLANS

EMERGENCY LEVELS

Part A. GENERAL

1. There shall be no open burning by any persons of tree waste, vegetation, refuse or debris in any form.

2. The use of incinerators for the disposal of any form of solid or liquid waste shall be prohibited.

3. All places of employment described below shall immediately cease operations.

   a. Mining and quarrying of non-metallic minerals

   b. All construction work except that which must proceed to avoid emergent physical harm.

   c. All air contaminant sources except those required to have in force an air pollution emergency plan.

4. Any commercial and manufacturing establishments not included in this order will institute such actions as will result in maximum reduction of air pollutants from their operations by ceasing, curtailing, or postponing operations which emit air pollutants to the extent possible without causing injury to persons or damage to equipment.

5. The Tennessee Air Pollution Control Division encourages the users of motor vehicles to cease usage except in emergencies.

Part B. SOURCE CURTAILMENT

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Emergency Level.

Source of Air Pollution	Control Action
1. Coal or oil-fired electric power generating facilities.	a. Maximum reduction by utilization of fuels having lowest sulfur and ash content.
	b. Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing or soot blowing.
	c. Maximum reduction by diverting electric power generation to facilities outside of Emergency Area.
2. Coal and oil-fired process steam generating facilities.	a. Maximum reduction by reducing heat and steam demands to absolute necessities consistent with preventing equipment damage.
	b. Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing and soot blowing.
	c. Taking the action called for in the emergency plan.
3. Manufacturing industries of the following classifications: Primary Metals Industries Petroleum Refining Chemical Industries Grain Industry Paper and Allied Products	a. Elimination of air contaminants from manufacturing operations by ceasing, curtailing, postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment.
	b. Elimination of air contaminants from trade waste disposal processes which emit solid particles, gases, vapors, or malodorous substances.
	c. Maximum reduction of heat load demands for processing.
	d. Maximum utilization of mid-day (12:00 noon to 4:00 p.m.) atmospheric turbulence for boiler lancing or soot blowing.

Section C

International Real Time Air Quality Index/Maps

Type of event	Source	Geographic Coverage	Output	Website	Description
Air Pollution					
	European Space Agency (ESA)	Global	Daily Maps of total ozone column, global ozone field, erythemal UV index, NO_2 column, absorbing aerosol index and 8-days forecasts	http://www.temis.nl/index.html	ESA provides daily maps of air quality: Ozone column from SCIAMACHY, GOME or OMI; UV information is from SCIAMACHY and other sources, NO_2 from OMI and GOME-2 and SCIAMACHY. Is also available a 8-day forecast of total ozone column and UV index at a global scale. *Comments:* Information on ground-level ozone is not provided thus the use of these products for local scale air pollution assessment is limited.
	NASA	Global	Daily maps of total ozone column and Aerosol index	Maps of total ozone column from OMI: http://toms.gsfc.nasa.gov/teacher/ozone_overhead_v8.html?96,56 Maps of total ozone from OMI: http://toms.gsfc.nasa.gov/ozone/ozone_v8.html Maps of aerosol index: http://toms.gsfc.nasa.gov/aerosols/aerosols_v8.html	NASA provides daily maps of total ozone column and aerosol index from OMI instrument that also provides information on aerosol type and cloud coverage. Using these data it is possible to monitor a wide range of phenomena such as desert dust storms, forest fires and biomass burning. *Comments:* Information on ground-level ozone is not provided thus the use of these products for local scale air assessment pollution is limited.
	Europe				
	European Environment Agency-EEA	Europe	Real-time Maps of ground-level ozone	http://www.eea.europa.eu/maps/ozone/welcome/	Data is collected by EEA from several European organizations which provide ground-level ozone measurements to EEA. Data is then made available on the EEA website through real-time interactive maps, which are updated an hourly basis. Air quality maps are color coded according to threshold values in EU legislation. *Comments*: The air quality data used on EEA website are preliminary. They are received immediately —within an hour of the measurement being made –from measurement stations. Particulate matter information will be provided in the future. Forecasts of ground-level ozone are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Air Quality Network	U.K.	Real-time maps of air quality index	For London: http://www.londonair.org.uk/ london/asp/ PublicBulletin.asp? bulletindate= 03%2F05%2F2006& region=0&bulletin= daily&site=&la_id= &postcode=&Submit =Go For the whole U.K. http://www.airquality.co.uk/archive/ index.php	The London Air Quality Network measures air quality parameters as $N0_2$, C0, $S0_2$, ozone, PM2.5 and PM10 in and around greater London. Measurements are collected either hourly or twice daily from continuous monitoring sites, processed and checked then placed on the web site with an hourly update. The air quality index displayed on the map is color coded. *Comments*: Air quality information is not complete for all the monitoring sites. Forecasts of air quality index are not available.
	Leeds City Council	Leeds, U.K.	Real-time maps of fPM10, $S0_2$, $N0_2$, $C0_2$, ozone.	http://www.airviro.smhi.se/leeds/	Leeds City Council Air Pollution Monitoring site operates a monitoring network to gather information used to review and assess air quality within the Leeds area. The maps gives access to the PM10, $S0_2$, $N0_2$, $C0_2$, ozone current values and results for the last 7 days are also available. It is also possible to download data in Excel format. *Comments:* Forecasts of PM10, $S0_2$, $N0_2$, $C0_2$, ozone are not available.
	National Environmental Research Institute of Denmark	Denmark	Real-time maps of air quality index	http://www2.dmu.dk /1_Viden/2_miljoe -tilstand/3_luft/ 4_maalinger/ default_en.asp	Air quality in Denmark is monitored with a network of measuring stations. Data are usually updated every hour during daytime and updated in real-time. *Comment*: The webpage is only available in Danish.
	PREV'Air (Ministere de L'Ecologie et du development durable, INERIS, CNRS, Meteo France and Institute Pierre Simon Laplace)	Europe	Real-time maps of ozone, $N0_2$, and PM10 (only for France) and 3-day forecasts	http://prevair.ineris.fr /fr/index.php http://www.notre-planete.info/ environnement/ picsactus.php	Real-time maps of ozone, $N0_2$, and PM10 are available for France from Associations Agrees de Surveillance de la Qualite de l'Air (AASQA) updated every hour. PREV'Air uses a predictive model to produce 2-days prediction maps ozone, $N0_2$, and PM2.5, PM10 for Europe and for ozone the product is available also at a global scale. *Comments:* The website is available only in French.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Interregional Cell for the Environment	Belgium	Daily values and forecast maps of ozone, N02, C0, S02, PM10, PM2.5 and C6H6	0bservations: http://www.irceline.be/-celinair/english/homeen_java.html Home page: http://www.irceline.be/	This effort is a collaborative effort Interregional Cell for the Environment and the European Agency for the Environment EEA.
	AirParif	Ile de France	Real-time and forecast maps of NO2, PM10, ozone and SO2	http://www.airparif.asso.fr/	AIRPARIF provides air quality information for the region and 1 day forecast. It also displays an interactive map on air quality for major European cities.*Comments*: The website is available only in French.
	Federal Environmental Agency	Germany	Real-time maps of NO2,ozone, PM10, $C0_2$ and SO2. Forecast maps of ozone	http://www.env-it.de/luftdaten/start.fwd?setLanguage=en	Federal Environmental Agency (FEA) and the German Laender collect air quality data from measuring stations in Germany on air quality. *Comments:* Some of the website's pages are available only in German.
	Environmental Protection Agency	Ireland	Daily values of $N0_2$, $S0_2$, PM, benzene	http://www.epa.ie/whatwedo/monitoring/air/data/	The Environmental Protection Agency (EPA) for Ireland provide an interactive map of air quality and daily values of $N0_2$, $S0_2$, PM, benzene. *Comments:* Daily values are not available for all monitoring sites. Forecasts are not available.
	Asia				
	Ministry of Environmental Protection Administration of China	China-84 major cities in China	Daily values of air quality index and prominent pollutant (PM or $S0_2$)	Main website in English: http://english.mep.gov.cn/ Air Quality Daily: http://datacenter.mep.gov.cn/report/air_daily/air_dairy_en.jsp Air Quality Forecast: http://datacenter.mep.gov.cn/report/air_forecast/dairy_forecast_en.jsp	Ministry of Environmental Protection Administration of China provides daily air quality index and prominent pollutant (PM or $S0_2$) associated with a level grade for 120 cities in China on their website. Forecasts are also available. *Comments:* Daily values are not available for all monitoring sites.
	Environmental Protection Department-Government of Hong Kong	Hong Kong	Daily values of air quality index and prominent pollutant (PM or $N0_2$).	http://www.epd-asg.gov.hk/	The Environmental Protection Department (EPD) provides daily air quality index and prominent pollutant (PM or $N0_2$) associated with a level grade. Graphs are also available to show data of the past days. *Comments:* Forecasts are not provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Environmental Protection Administration	Taiwan	Real-time air quality index map. For each monitoring site is provided a detailed table of $S0_2$, C0, ozone, PM10, 0_2.	http://210.69.101.141/taqm/en/default.aspx	The EPA of Taiwan aims at preventing pollution, and supporting international environmental initiatives in order to achieve sustainable development. EPA provides a daily map of air quality level for Taiwan. *Comments:* Forecasts are also provided.
	AIRK0REA	Korea	Real-time map of air quality index and $N0_2$, C0, PM10, ozone, 0_2, $S0_2$.	http://www.airkorea.or.kr/airkorea/eng/realtime/main.jsp	Since 2005, AIRK0REA provides a public access to air quality information collected hourly in more than 16 areas in South Korea. 0n the website, an interactive map shows air quality index and pollutant values for major cities. *Comments:* Forecasts are not provided.
	Pollution Control Department–Ministry of Natural Resources and Environment	Thailand	Daily map of air quality index and values of PM10, $S0_2$, $N0_2$, C0, ozone are provided in a table.	Daily air quality map: http://www.pcd.go.th/AirQuality/Regional/Graph/createaqi2.cfm Values of $S0_2$, $N0_2$, C0, ozone: http://www.pcd.go.th/AirQuality/Regional/Default.cfm	Pollution Control Department provides access to air quality information for 30 locations in Thailand. A color coded air quality map is available on the website. For each location is also provided a table with pollutants values. *Comments:* Forecasts are not provided.
	Australia				
	Environment Protection Authority–Department of Environment and Conservation	New South Wales	Values of ozone, $N0_2$, PM10, C0, $S0_2$.	http://www.environment.nsw.gov.au/AQMS/aqi.htm.	The EPA is involved in programs on pollution, coastal management, and water quality. The EPA website provides daily values of pollutants for the Sydney area, Illawarra, Hunter, Tablelands and Slopes areas. *Comments:* Forecasts are not provided.
	Environment Protection Authority–Victoria	Victoria, Australia	Map of air quality index and forecasts of C0, $N0_2$, 0_3 and hydrocarbons concentrations. (only for Victoria and Melbourne). Also wind condition and temperature are provided.	Map of air quality index: http://www.epa.vic.gov.au/Air/AQ4Kids/station_map.asp Forecasts: http://www.epa.vic.gov.au/Air/AAQFS/AAQFS_VIC_Forecast.asp http://www.epa.vic.gov.au/Air/AAQFS/AAQFS_Melb_Forecast.asp	EPA Victoria provides public access to values of several air pollutants selected C0, $N0_2$, 0_3 and hydrocarbons concentrations. In addition to it, prevailing temperature and wind conditions, are also provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	North and South America				
	Environment Canada	Canada	Real-time maps of air quality index and forecasts (only in summer)	http://www.ec.gc.ca/cas-aqhi/	Environment Canada website provides access to real-time maps of air quality index for British Columbia, Alberta, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Labrador and Newfoundland. From May to September forecasts are also available. Air Quality advisories are issued when the air pollution levels exceed national standards. They are issued in partnership with provincial and municipal environment and health authorities and contain advice on action that can be taken to protect the health of Canadians and the environment. *Comments:* Forecasts are available only in summer.
	Alberta Government	Alberta, Canada	Maps of air quality index	http://environment.alberta.ca/0977.html http://www.environment. alberta.ca/apps/aqhi/aqhi.aspx	Alberta Government website provides access to air quality information through interactive Google maps, which also provides forecasts.
	Ministry of Environment, Government of British Columbia	British Columbia, Canada	Real-time values air quality	http://www.bcairquality.ca/	The Water, Air and Climate Change Branch Ministry of Environment provides information on air quality for various locations in British Columbia, together with forecasts.
	Ministry of Environment, Ontario	Ontario	Real-time and forecast maps of air quality index and information on O_3, PM, NO_2, SO. E-mail alerts	http://www.airqualityontario.com/	Ministry of Environment provides a detailed and comprehensive service to air quality information with daily updated air quality index maps and 3-day forecast; email alerts for several locations in Ontario are also available.
	Ministry of Environment, Quebec	Quebec	Daily map of air quality index	http://www.iqa.mddep.gouv.qc.ca/contenu/index_en.asp#carte	Ministry of Environment, Quebec provides daily air quality and past days values. This information is accessible on the website through an interactive map. *Comments:* Forecasts are not available

Type of event	Source	Geographic Coverage	Output	Website	Description
	Ville de Montreal	Montreal	Maps of air quality index and values of PM, C0, $N0_2$, 0_3 (shown on a graph). Forecast report	http://ville.montreal.ca/portal/page?pageid=7237,74495616&&_dad=portal&schema=P0RTAL	The City of Montreal operates its own Air Quality Monitoring Network. For each station, air quality levels are provided *Comments:* Website is only in French.
	Bay area air quality management district	Bay Area, u.s.	Daily and forecast maps of air quality index and value of PM2.5. Bulletins on air quality incidents	Air quality forecast: http://www.sparetheair.org/stay-Informed/Todays-Air-Quality/Five-Day-Forecast.aspx Bulletins: http://www.baaqmd.gov PM2.5: http://gate1.baaqmd.gov/aqmet/aq.aspx	The Bay Area Air Quality Management provides daily information on air quality and 5-days forecasts.
	u.s. Environmental Protection Agency	u.s. and Canada	Real-time and forecast maps of air quality index and values of 0_3 and PM2.5	u.s.: http://airnow.gov/ Canada: http://airnow.gov/index.cfm?action=airnow.canada	EPA AirNow provides real- time air quality index for the major cities of u.s. and parts of Canada. Maps are provided via AirNow website and the website offers daily forecasts as well as real-time air quality conditions for over 300 cities across the us, and provides links to more detailed state and local air quality web sites. The Enviroflash notification service provides air quality information in real-time to subscribers by e-mail, cellphone, pager, allowing them to take steps to protect their health in critical situations.
	CAMNET Real-time pollution and visibility camera network	North East Coast, u.s.	Live pictures from webcams, 0_3 and PM levels, wind speed	http://www.hazecam.net/	CAMNET provides webcam live pictures and corresponding air quality conditions from scenic urban and rural vistas in the Northeast. CAMNET, brings to the attention the effects of air pollution on visibility. *Comments:* Values of pollutants are not available.
	Virginia Department of Air Quality	Virginia, u.s.	Current and forecasts of air quality index	http://www.deq.state.va.us/airquality/	Virginia Department of Air Quality monitors levels of ozone and particle pollution from stations around Virginia and provides air quality index for each town. *Comments:* Values of pollutants are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Georgia Department of Natural Resources	Georgia, u.s.	Daily Values of 0_3, $s0_2$, C0, $N0_2$, PM10, PM2.5 and air quality index (also forecasts).	http://www.air.dnr.state.ga.us/amp/	The Ambient Monitoring Program measures levels of air pollutants throughout the state. The data are used to calculate the Air Quality Index and to compare it with air standards established. *Comments:* Forecasts are available only for air quality index.
	Delaware Air Quality Monitoring Network	Delaware, u.s.	Daily maps of air quality index and values of 03, PM, wind speed and direction.	http://www.dnrec.state.de.us/air/aqm_page/airmont/Air.asp	Data are collected by air quality monitoring stations distributed in the region. A map shows the air quality index and for each station location are provided values of 0_3, PM, wind speed and direction.*Comments:* Forecasts are not provided.
	Department of Conservation and Natural Resources	Nevada, u.s.	Air quality information and values of 0_3, PM10 and PM2.5 and others	Website: http://ndep.nv.gov/admin/monitoring.htm	The department provides air quality status and trends for the state's monitoring jurisdiction. Graphs of the monitoring data for each station can be found by navigating through the Monitoring Data menu item. *Comments:* Forecasts are not provided.
	Arizona Department of Environmental Quality	Arizona, u.s.	Daily and forecast values of 0_3, C0, PM10, PM2.5 and air quality index. Live images from webcams in the Phoenix area.	Live webcam pictures: http://www.phoenixvis.net/ http://www.azdeq.gov/environ/air/monitoring/links.html http://www.azdeq.gov/environ/air/index.html	Arizona Department of Environmental Quality informs on air quality by providing daily values of pollutants and live webcam images. Forecasts are provided through a report. *Comments:* Daily values are provided by us EPA.
	Department of Environmental Quality, Montana	Montana, u.s.	Maps of air quality index	http://todaysair.mt.gov/	Air quality of Montana is provided through an interactive color coded maps. For each station a graph of hourly air quality variations is shown on the website. Thresholds are also set for unhealthy, very unhealthy, and hazardous conditions. *Comments:* Values of pollutants are not provided.
	Idaho Department of Environmental Quality	Idaho, u.s.	Daily maps and values of air quality index, 0_3 C0, $s0_2$, $N0_2$, PM	http://airquality.deq.idaho.gov/	For each monitored site, the Idaho Department of Environmental Quality provides air quality index maps and the values of pollutant of concern. *Comments:* Information is not complete for all monitoring sites

Type of event	Source	Geographic Coverage	Output	Website	Description
	Florida Department of Environmental Protection	Florida, u.S.	Real-time and forecast maps of air quality index, 0_3 and PM.	http://www.dep.state.fl.us/air/air_quality/airdata.htm	Through a Java/GIS application map air quality information is provided, in particular hourly ozone, particulate matter and air quality index. *Comments:* Values of pollutants are not available.
	Wisconsin Department of Natural Resources	Wisconsin, u.S.	Real-time map of air quality index and values of S0, $N0_2$, C0, PM10 and PM2.5.	http://dnr.wi.gov/air/aq/health/status.asp http://prodoasjava.dnr.wi.gov/wisards/webreports/previousDaysData.do	The map provided by the Wisconsin Department of Natural Resources shows air quality index derived from ozone and PM2.5 values. The Air Quality Index is calculated from real time data. Additional pollutants are available as S0, $N0_2$, C0, PM10, provided for each monitoring site in a table. *Comments:* Forecasts are not provided.
	Pima County Department of Environmental Quality	Tucson, Arizona, u.S.	Values of 0_3, wind speed, wind direction.	http://www.airinfonow.org/monsites/map_site.asp	The Pima County Department of Environmental Quality Air Info Now web site, provides current air quality information for the metropolitan Tucson area. The information can be accessed from an interactive map, clicking on each monitoring site a table opens providing ozone concentration and wind and temperature recordings. *Comments:* Air quality index and other relevant pollutants are not provided, neither forecasts.
	Greater Vancouver Regional District-GVRD	Canada	Air quality index and forecasts	http://www.metrovancouver.org/services/air/monitoring/Pages/airqualityindex.aspx	Real-time information on air quality for several locations is provided by GVRD. An interactive map shows the monitoring stations aroundthe Vancouver area. For each site are provided graphs of air quality index and forecasts. *Comments:* Values of relevant pollutants are not provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Inter Agency Real-Time Smoke Particulate Monitoring	U.S.	Graphs of air quality index, Real-time smoke monitoring.	http://www.satguard.com/USFS/realtime/fleet.asp	This web site provides real-time smoke concentration data (along with some other meteorological information) from portable smoke monitors. Historical data from past monitoring efforts are also available. The data is updated hourly with S-minute averages from the operating site. An interactive map is available on the website from which users can access detailed tables of air quality index. *Comments:* Note only 9 sites are monitored throughout the US.
	Washington Department of Ecology	Washington area, U.S.	Daily maps of air quality index and values of pollutant of concern.	https://fortress.wa.gov/ecy/enviwa/Default.htm	An interactive map is available on the website of the Washington Department of Ecology. For each site is provided a graph of the recording of the pollutant of concern (0_3, PM, C0). *Comments:* Not all pollutants are available for all monitoring stations. In addition, forecasts are not available.
	USDA, Forest Service Real-time air quality	U.S.	Live webcam images and values of air quality index, 0_3 and PM10 and PM2.S.	http://www.fsvisimages.com/descriptions.aspx	Forest Service Real-time air quality provides live pictures from webcams and corresponding air quality conditions in the Northeast. Real-time display panel for visibility data show the air pollution and meteorological conditions associated with each image. These data are collected at the site of the camera or at another location within the scene of the photograph. *Comments:* Forecasts are not available.
	Ministry of Defense, National Meteorological Service	Argentina	Daily values of 0_3	http://www.meteofa.mil.ar/?mod=ozono&id=1	Ministry of Defense, National Meteorological Service website provides a table with daily values of ozone for Base Vicecomodoro Marambio, Ushuaia, Comodoro Rivadavia, Buenos Aires. *Comments:* Forecasts are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	INPE, Brazil	Brazil	Maps of CO, O_3, NOx, PM, and Volatil Organic Compounds	http://meioambiente.cptec.inpe.br/	INPE produces real-time maps of air quality for Brazil, from satellite observations. Maps are produced for fine particles from fires, carbon monoxide and industrial and urban emissions and are updated every 2 hours. *Comments:* The website is available only in Portuguese.
	Secretaria del Medio Ambiente	Mexico City	Hourly maps of air quality index	http://www.sma.df.gob.mx/simat/	Secretaria del Medio Ambiente monitors hourly the air quality of Mexico City. For each monitoring location is provided a table of major pollutants and the related air [illegible] n.
	Direccion de Ecologia	Baja California	Daily maps of air quality index	http://aire.bajacalifornia.gob.mx/eng/aqmaps.cfm	Direccion de Ecologia provides daily information on air quality for different locations in Baja California. Information on air quality and related health effects is provided for each location. *Comments:* Values of pollutants are not provided, neither forecasts.
	Africa				
	City of Cape Town air quality network	Cape Town, South Africa	Data provided by request	http://www.capetown.gov.za/airqual/	Reports are available and data can be requested by email.

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