Atmospheric Pollution in Urban Areas of Greece and Economic Crisis.

Trends in air quality and atmospheric pollution data, research and adverse health effects

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Abstract. Ambient air pollution in urban and industrial areas in Greece was a serious environmental problem which was connected with rapid urbanization of cities, anarchic housing development without basic infrastructures and increases of motor vehicle fleet in urban regions. Especially Athens, witnessed severe air pollution problems in the decades 1960s'-1970s' and the formation of the infamous brown-yellow "nephos" in Athens. But in recent years the air quality in Greece has greatly improved in most urban areas because of the better fuels and replacement of the polluting vehicles of old technology. In Athens and Thessaloniki, the ambient levels of coarse smoke, CO, SO_2, NO_x (NO_2, NO), O_3 and Pb were reduced substantially below air quality limits. In Athens and Thessaloniki air pollution was characterized by high concentrations of airborne particulate matter (PM) of carbonaceous particles and photochemical smog –which was linked to an excess of nitrogen oxides, hydrocarbons, carbon monoxide (primary pollutants), ozone, and organic nitrates (secondary pollutant) as a result from a series of chemical reactions driven by sunlight. The primary pollution sources were vehicular traffic, central heating, industrial facilities and small enterprises.

In the past decades several environmental legislations were undertaken in an effort to improve the existing air quality conditions in urban areas. Replacement of old vehicles (1991), new cars equipped with catalytic converters, replacement of the old buses equipped with anti-pollution devices and natural gas for heating and energy generation was introduced. Environmental legislation was enacted for the abatement of industrial pollution and smoke and energy efficiency measures. Abatement practices reduced substantially primary pollutants (SO2, NOx, CO, smoke) and secondary (O3). The economic crisis of the last five years (2010-2015) affected the prices of heating oil and forced some families to use low-cost wood and biomass as fuel for fire places and stoves (the later dropped in international prices of petrol reduced financial constrains in the use of oil for heating, while the 2014-2015 winter months were mild and air pollution episodes were limited).The result was smoke haze and high levels of airborne particulates (fine and superfine) during the evenings and morning hours of the day in Athens, Thessaloniki and other cities. Airborne particular matter (PM) from burned wood are dangerous because of their toxic organic constituents (polycyclic aromatic hydrocarbons, PAH), free radicals and metals. This review collected some of the most important studies on air pollution in urban areas and the consequences of economic crisis in Athens and other cities. Also, studies on air pollution in areas with lignite-fired power stations were included. Air pollution causes adverse health effects, respiratory diseases (hospitalization), and increased mortality in the last decade (in the years before after the economic crisis). Adverse health effects on urban dwellers in major cities of Europe cities were investigated by multicenter panes of researchers. The results showed that Athens and Thessaloniki have some of the highest levels of air pollutants and PM (PM10, PM2.5). Epidemiological studies in European cities have documented associations between outdoor exposure to air pollutants biomass combustion products and a range of adverse health effects. The present review covers the most important research papers on the air pollution trends in major urban areas, the results of economic crisis in the use of biomass fuel. Also, this review includes studies and investigations for the association of air pollutants (especially PM) with adverse health effects, in particular respiratory diseases, and increased mortality in urban areas.

Introduction: Air Pollution in Urban Areas in Greece

After 1974 Greece concentrated its major economic and developmental efforts towards public investment in basic infrastructure and building economic convergence with other countries of the European Union. But these efforts have been only partially matched by environmental plans aimed at improving the quality of life in urban and industrial areas. As a result, Greece in the 21st century continues to face many environmental problems and challenges. The main problems are in controlling air emissions from vehicular transport, industrial enterprises and from large lignite-fired power (electricity) and industrial plants. Greece encountered problems with water resource's supply and demand, reduction of effluents to water from municipal and agricultural sources. Major problems were caused by increasing municipal and industrial wastes accumulated in landfills (some of them illegal) while recycling has not been resolved effectively to protect land and coastal areas. Greece is lacking clear objectives for conserving biodiversity of terrestrial and marine ecosystems. Natural parks and areas of environmental interest remained unprotected for many decades until Greek authorities were forced to take action by international and European legislation. Economic growth (mostly with foreign loans) and rising income levels without measures for sustainable development and planning generated increased pressure on the environmental quality of urban and rural areas. Environmental policies were postponed or overturned by economic interests and local resistance to protect natural resources and co-operate with environmental legislation.[1,2]

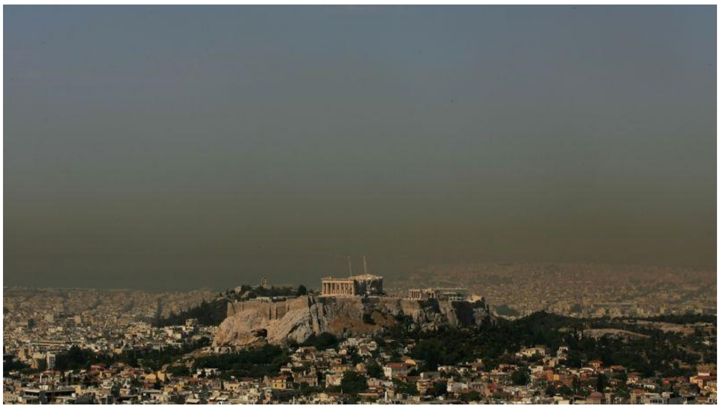

Figure 1. Air pollution in Athens and other urban areas of Greece was the resulted from high concentrations of air pollutants, photochemical smog and airborne particulates (PM) mainly from exhausts of diesel vehicles and central heating.

In Greek urban areas, like in the cities of Athens, Thessaloniki, Patras, Volos, Heraklion, etc, there are mainly two types of air pollution that were recognized over many years: High concentrations of airborne particular matter (PM) and photochemical smog which was linked to an excess of nitrogen oxides (NOx), sulphur dioxide (SO_2), smoke, hydrocarbons (HCs), carbon monoxide (CO) (which are primary pollutants), and various secondary pollutant s (ozone, O_3) as a result from a series of chemical reactions driven by sunlight.[3]

From the 1990s the air quality in Greece has greatly improved in most urban areas because of the odd-even traffic regulation system in the Athens city centre, better fuels and replacement of the polluting vehicles of old technology. Especially in the Attica basin the ambient levels of SO_2, NO_2, CO and Pb were reduced substantially below air quality limits. A number of significant measures for the improvement of air quality were introduced in 1994: The content of sulphur (S) in heavy fuels was reduced from 0.3% per weight to 0.2% per weight and from 1995, the content of S in unleaded gasoline was reduced from 0.10% per weight to 0.05% per weight. The content of benzene in gasoline was reduced from 5% per volume to 4% per volume. The introduction of natural gas at around 15% of the energy balance in Athens by the year 2000 (households and industrial units) was another important change. As a result of abatement practices the concentrations of primary air pollutants were reduced and the quality of air in urban areas improved substantially. However, the exceeding of the levels of the WHO is still recognized for fine and superfine particles (PM) in the city centre and of photochemical ozone (secondary pollutant) in the periphery of urban areas.[3,4]

Restrictions and relocations of industrial activities from urban areas in designed industrial regions reduced substantially air pollution. In big cities there were restriction of road traffic (alternate days of license plate system in Athens), extensive pedestrian areas, promotion of public transport (subway train lines, tram and bus fleet improvements). A great improvement in air pollution in Greece in the last decades was achieved from fuel quality improvement (clean diesel) for industry and households. In Athens the construction of two additional subway lines and the relocation of the airport strengthen this success. Since the mid-1990s, measures in Greece have been launched to improve energy efficiency in power generation and industry. Energy reform generally integrates air quality management concerns effectively, and the resulting environmental benefits should gradually become evident. In particular, the supply of natural gas to power generation (industry and households). In the last decade use of renewable energy sources is also progressing. Flue gas desulphurisation equipment has been installed at two refineries and at the largest unit of the Megalopolis lignite-fired power plant. Major improvements to public transport are under way in Thessaloniki, Patras, Heraklion, Volos, Rhodes and other cities. A programme in the early 1990s resulted in the scrapping of many old cars. However, the intensity of air pollution emissions is very high, overall; emissions of SOx, NOx and CO_2 (per unit of GDP) exceed the OECD Europe averages by 100%, 42% and 38%, respectively. SOx emissions from large combustion plants somewhat exceed the ceiling established by EU directive. Ozone air pollution in the periphery of urban areas increased substantially. Air pollution in urban and industrial areas increased especially for particulate matter (PM_{10}, $PM_{2.5}$). Also, Volatile Organic Compounds (VOC) emissions increased substantially, a signal for the need to control emissions from refineries and two-stroke engines, and to deal with photochemical ozone formation. The OECD investigators in Greece (2010) noticed that systems for ambient air quality monitoring and emission inventorying were insufficient.[3,4]

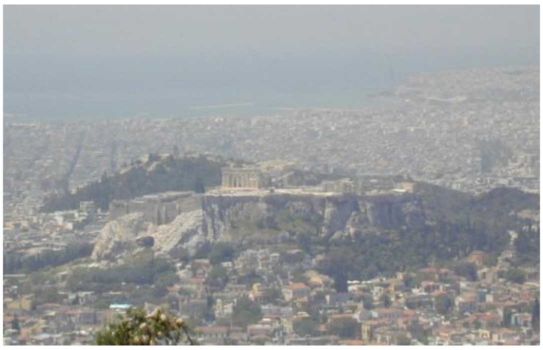

Figure2. Air pollution in Athens in the 1970s and the “nephos” in the atmosphere was the result of vehicular exhaust gases and central heating in houses and offices using poor qualtiy fuels.

Athens is a city of 4,5 million inhabitants and in the 1960s and 1970s had high levels of air photochemical pollutants, especially smoke, SO_2, NO_x and ozone (O_3). From the 1990s, these air pollutants decreased substantially with the use of cleaner fuels, alternate vehicle numbers in the centre of the city, restriction of diesel cars, replacement of old technology private vehicles and buses. By 2000 the introduction of natural gas (households and industrial units) for the 15% of energy reduced substantially air pollution in cities.[5]

Although there were improvements in gaseous air pollution levels the airborne particulate matter (PM) in cities increased substantially above international standard because of increases in the vehicular traffic. The new investigations focused on the chemical composition of PM fractions (trace elements, coarse smoke particles and Polycyclic Aromatic Hydrocarbons, PAHs, fine and superfine carbonaceous particles) because of their adverse health effects to urban inhabitants. Measurements in Athens were compared with seasonal distribution of PM fractions in selected cities in Europe.[9-14]

Epidemiologic investigations in Athens and other European cities showed that PM and other air pollutants (including airborne desert dust and smoke from forest fires) is a very important air quality parameter contributing to increases of mortality and morbidity in the Athens area for short-term and long-term effects.[15-22]

Air Pollution in the Greater Athens Area in the Years of the Economic Crisis

In the last decade many studies of atmospheric pollution in urban areas, especially Athens and Thessaloniki, were performed by environmental scientists with the purpose to measure air quality trends before and after the economic crisis of the last five (2010-2014) years. These studies focused on energy prices for heating oil, the use of wood and biomass waste for heating, the formation of smoke haze in winter months in Athens and Thessaloniki and the effects of air pollution on the respiratory health of urban dwellers. Fuel oil prices for central heating were influenced by the international prices and fuel taxes: 2010, 1,25-1,3 euro/l, 2011, 1, 2012, 1,35 (tax), 2013, 1,3 , 2014, 1, 2015 0,8-0,85. The coldest winter months in Greece were in 2011, 2012 and 2013, whereas in 2014 and 2015 temperatures in winter months were mild. Inevitably, poor households use wood and biomass (pieces of wood from doors and furniture and other waste). Also, the economic crisis restricted the use of private cars for transport. A study investigated the energy consumption in the years of the evolving economic crisis in Greece. It was concluded that energy consumption of the households of Greece during the harsh winter 2011–12 was 37% less than expected. The energy consumption of 598 Greek households in 2010–12 was investigated. Poorer households had less income and lived in less energy efficient dwellings. Households were found to consume less energy despite harsher weather conditions. 2% of high-income households and 14% of low-income households were fuel poor.[23] The austerity policies and other conditions imposed by the Memoranda of Understanding in Greece by the troika of international lenders undermined the progress made in the pre-crisis years in the framework of EU environmental policy. Examples include the air pollution caused by fuel substitution following a vast increase in heating fuel tax.[24] Other scientists focused on the health effects of air pollution (respiratory diseases) on urban dwellers in Greece. According to Dr. Karamanoli the problem was especially bad in Athens, where people were burning anything they can find in fireplaces to avoid paying for highly taxed heating oil, and where many immigrants were crowded into small, poorly ventilated apartments. For civilians, the priority was making enough money to support themselves and their families, whereas the government the priority was to collect taxes in order to pay the country's debt to the EU and the IMF.[25]

A comprehensive study on the atmospheric pollution sources, transport, transformation and levels in three representative capitals (Cairo, Athens and Istanbul), with very high density of urban areas and traffic in the East Mediterranean, was published in 2011. The study focuses both on the background atmosphere and on the similarities and differences between the three urban areas. Ground-based observations were combined with satellite data and atmospheric modeling. The overall evaluation pointed out that long and regional range transport of natural and anthropogenic pollution sources had similar importance with local sources for the background air pollution levels in the cities. For Athens, the researchers noticed that the massive number of registered vehicles in circulation, growing at a rate of 7% yearly, was allegedly the major cause of air pollution-related problems in the Great Athens Area because of severe congestion phenomena during rush hours. Although the use of natural gas for domestic heating purposes has increased lately, combustion of fuel oil is still primarily used for central heating contributing to air pollution during winter months.[26]

The economic crisis of 2009-2015 that affected Greece and some other Mediterranean countries became the focus of research projects for the impact on air pollution. An interesting environmental study that used both satellite observations of tropospheric nitrogen dioxide (NO_2) columns and a number of economic metrics in order to investigate the impact of the economic crisis (from 2008 onward) on air quality over Greece, and Athens in particular. The multiannual analysis showed that NO_2 columns over Athens have been significantly reduced in the range 30–40%. This decline is further supported by surface measurements of atmospheric NO_2 mixing ratios. The study showed also declining local concentrations of NOx, CO, and SO_2 that are associated with an increase in ozone (O_3). Regression analysis of data revealed that the reduction of NO_2 and SO_2 during the period 2000–2007, significantly accelerated during the economic crisis period (from 2008 onward), reaching 2.3 ± 0.2 ppbv y^{-1} and 0.7 ± 0.1 ppbv y^{-1}, respectively. Scientists concluded that the economic recession of the last years in Greece has resulted in proportionally lower levels of air pollutants over Greece and in the capital in particular.[27]

Airborne particles (car exhausts, desert dusts, resuspended road dusts) of air pollution contain toxic heavy metals that can be deposited on evergreen tree leaves. A study in 2012 investigated air pollution by measuring concentrations of metals from 13 areas of Attica basin and especially from the centre of Athens. Evergreen trees such as *Citrus aurantium*, *Pinus brutia* and *Olea europaea* leaves were collected in various areas since they can act as a pollution screen and particles are absorbed on their surfaces. Cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and lead (Pb) high concentrations were measured near the city centre and in the vicinity of the Attica basin highways. Researchers showed that the geomorphological relief of the Attica basin area plays an important role in the dispersion of airborne particles from pollution sources to the surrounding area. Areas on the NE region are also polluted mainly due to wind directions. The mean heavy metal content in the tree leaves were detected in the descending order of copper>lead>nickel>chromium>cadmium.[28]

The decrease of air pollutants SO_2, NO_x, CO and smoke in the last decade in urban areas from the high concentrations in the period 1960-1990, shifted the research interest to particulate matter (PM), in connection with influence of atmospheric circulation patterns, local transport mechanisms and the influence of Saharan dust outbreaks. A sampling campaign of cold and warm periods of 2008 investigated the PM_{10}, $PM_{2.5}$ and PM_1 aerosols and their temporal distribution in the Greater Athens Area (GAA). Analysis of the measurement data showed that local sources, such as vehicular traffic and industrial installations, dominated over the prevailing PM loads, especially at the 'hot spot' areas. Saharan dust outbreaks appeared to increase the particles' diameter as well as the number of European Union limit value exceedances within the network of sampling stations. A Comprehensive Air Quality Model with extensions was applied for selected sampling dates. Measurements showed that PM_1 always constituted the greatest part of the $PM_{2.5}$ mass, while PM_{10}, especially during the Saharan dust episodes, was mainly constituted by the coarse fraction.[29]

During the economic crisis of the last five years in Greece the air pollution conditions in big cities changed. Decreasing employment (unemployment climbed to 27% in 2013) and rising fuel costs (price increases and fuel tax) compelled residents in Athens and other cities to burn low quality fuel, such as wood and waste materials. Especially during the winter months of the years 2012 and 2013 central heating in many urban areas increased substantially. Some Greek families turned to more traditional ways of residential heating, such as fireplaces with wood and pellet stoves instead of petrol and natural gas. Measurements of air samples supported the evidence that a substantial number of Greek residents in cities burned waste wood in and trash for heating. Taken over two-month stretches in winter 2012 and again in winter 2013, the samples from major Greek cities reveal a dramatic increase in airborne fine particular matter (smoke haze, PM_{10} and smaller).[30]

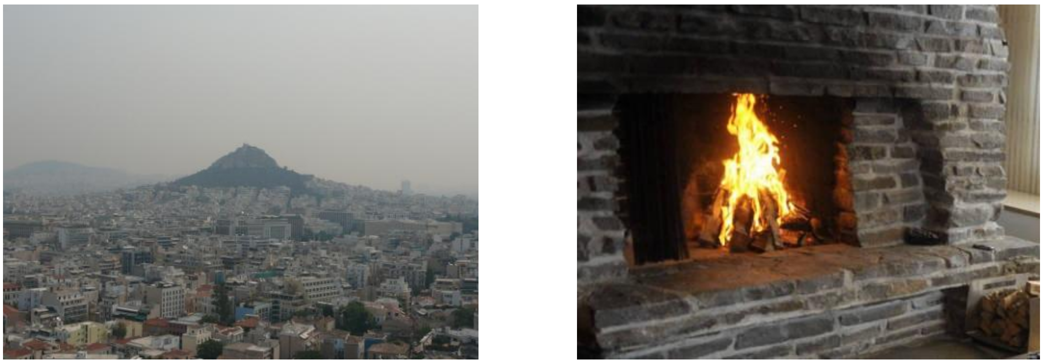

Figure 3. During the winter period the burning of waste wood, pellets in wood stoves and a variety of wooden trash affected the winter air pollution over big urban areas in Greece. A fireplace pollutes the air as much as 1,000 cars 1/3/2013. GRReporter [http://www.grreporter.info/info/en/fireplace_pollutes_air_much_1000_cars/8814].

Wood combustion (biomass) and fossil fuel emissions for domestic heating during the winter months is known from studies as one of the major sources of organic aerosol (particles, volatile organics and air pollutants) in central and northern Europe. Two field campaigns were conducted during the winter of 2012 and 2013 in two of the largest Greek cities (Athens and Patras) in order to quantify the levels of organic aerosols from domestic wood combustion and to characterize the corresponding particulate matter (PM). The instrumentation used included an Aerodyne High-Resolution Time-of-Flight Mass Spectrometer (HR-ToF-AMS) and a selection of on-line aerosol size distribution and concentration instruments (APS, SMPS, TEOM, MAAP) was deployed. In February of 2012, a significant increase of particulate matter less than 1 μm (PM_1) was observed every evening after 6 pm in Patras (population 200,000). Concentrations of PM_1usually exceeded 80 μg m^{-3} (some values were above 150 μg m^{-3}). In Patras increased PM_{10} concentrations were observed during the winter months. Local vehicular traffic was estimated to account for only 12± 4% of the PM_{10} concentration on an annual basis. $PM_{2.5}$ chemical composition was measured at the urban center and biomass burning was identified as a major PM source during the colder months. The transported pollution was found to account for 50% of the $PM_{2.5}$ during winter and for more than 70% during the rest of the year. Organic PM (carbonaceous material) represented more than 90% of the fine particulates during these periods. Black carbon measurements were as high as 10 μg m^{-3} often exceeding the sulfate (SO_3^-) levels in the same area. High potassium (K) and nitrate levels (NO_3^-) were also observed during the night. These concentrations were much higher (double on average) than the concentrations measured in Patras during previous winters. In January 2013, these measurements were repeated both in Athens and Patras and wood burning once more resulted in extremely high nighttime PM levels.[30-34]

Air pollution studies in the last decade across Europe observed significant variability of air pollutants with the lowest concentrations found in Northern Europe countries and the highest in Southern Europe. Within the MED-PARTICLES project the spatial and temporal variations of long-term particulate matter (PM) and gaseous pollutants data were investigated in various cities in Southern

Europe that have high vehicular traffic and high density urban areas. The highest PM levels were observed in populated cities in Greece and Italy (Athens, Thessaloniki, Turin and Rome) while all vehicular traffic sites showed high concentrations of NO_2 frequently exceeding the established limit value. High $PM_{2.5}/PM_{10}$ ratios were calculated indicating that fine particles comprise a large fraction of PM_{10}, with the highest values found in the urban background sites. Traffic sites showed higher $PM_{2.5}$ and PM_{10} than those registered in urban background sites, while the coarse fraction $PM_{2.5\text{-}10}$ is more important at the vehicular traffic sites. Resuspended road dust is affected by traffic, which is particularly relevant for dry and dusty roads of Mediterranean countries. In the other hand air pollution data show that the long-term trends revealed a significant decrease of the concentration levels for PM, SO_2 and CO while for NO_2 no clear trends were observed. Modern technology cars, cleaner fuels, catalytic converters and effectiveness of abatement measures and strategies, as well as meteorological conditions and the economic crisis that affected Southern European countries, play an important part.[35]

Figure 4. Attica basin witnessed many forest wild fires in the last decades during the not summer months that ravage valuable forests and caused increased air pollution in surrounding areas.

The Attica Basin and the urban area of Athens have another problem of air pollution during the summer months from forest wild fires. In August 2009 wild forest fires ravaged the north-eastern fringes of Athens destroying invaluable forests on the mountains around the Greek capital. Every summer in the period 2010-2015 Athens witnessed various types of forest fires (in Mount Hymettus and surrounding areas) which are fuelled by strong winds and high temperatures and produce high amounts of smoke and photochemical pollutants.[36]

A research study examined the impact of forest fires on the air quality of Athens and surface radiation levels. Satellite imagery, smoke dispersion modeling and meteorological data confirm the advection of smoke under cloud-free conditions over the city of Athens. The smoke plume dispersed in the free troposphere and lofted over the city reaching heights between 2 and 4 km. In-situ air quality measurements revealed the impact of the smoke plume down to the surface with a slight delay on both the particulate and gaseous phase. Photochemical processes, studied via NO_x titration of O_3, were also shown to be different compared to typical urban photochemistry.[37]

More than 1500 daily aerosol samples ($PM_{2.5}$) were collected from May 2008 to April 2013 in Athens and were analysed for organic carbon (OC), elemental carbon (EC), water-soluble organic carbon (WSOC) and main ions. The concentrations were compared with samples from Finokalia station as a reference (The sampling station of the University of Crete is situated at Finokalia on the north coast of Crete, 70 km from the urban centre of Heraklion with 150 000 inhabitants). The analysis of measurements estimated that during the warm season in Athens, 67 ± 7% of emitted OC and 53 ± 12% of emitted EC is regional, while, during cold months, the regional contribution of OC is only 33 ± 7% and of EC 29 ± 8%. Furthermore, secondary organic carbon (SOC) was calculated for the warm period of the year (April to October). The estimated SOC constituted about 75 ± 6% of $PM_{2.5}$ organic carbon in Athens, highlighting significant aging processes on a regional scale. In the period 2011–2013 and during wintertime, an increase in OC and EC levels was observed, attributed to an increase in wood burning for domestic heating due to the economic crisis.[38]

The effects on air pollution (smoke haze) from the economic crisis in Greece as a result of the use of fireplaces and wood stoves for domestic heating in densely populated cities in Athens were investigated by another recent study. Sampling of PM_{10} and $PM_{2.5}$ was conducted in an apartment (outdoor and indoor) in suburban Athens (Dec 2012–Febr 2013) for two periods: minimal or no wood burning at fireplaces and another period with intense wood burning. The results highlighted the impact of biomass burning on PM mass concentration in the ambient atmosphere (outdoor) as well as in the indoor air. Organic and elemental carbon ratios and K+ /EC ratios for both (indoor and outdoor) particle fractions revealed their origin from biomass burning. Sulphate and nitrate ions [SO_4^{2-} and NO_3^-] were the most abundant. Iron (Fe) strongly dominated in both indoor and outdoor air while elemental enrichment factors highlighted the anthropogenic origin of trace elements. Indoor to outdoor concentration ratios, especially during the period of extensive fireplace use, showed that carbonaceous particles and some trace species (Cu, K+ , Na+) were released in the indoor air.[39]

Atmospheric Pollution in the City of Thessaloniki, North Greece

Thessaloniki is Greece's second major economic, industrial, commercial and political centre, and a major transportation hub for the rest of southeastern Europe. The population of Thessaloniki in 2011 reached 1,104,460 inhabitants. The commercial port of Thessaloniki is also of great importance for transport and commercial facilities for Greece and the southeastern European hinterland. Thessaloniki has very similar problems of air pollution as Athens. Air pollutant emissions come mainly from traffic, while formation and transportation of pollutants is heavily influenced by the local meteorological and topographic characteristics. Focusing on traffic, it should be noted that recent studies in Thessaloniki have estimated that travel demand has climbed up almost 70% over the period 1988–1998. In addition, the improvement of fuel quality and the renewal of the vehicle fleet during the last decade contributed significantly to the decreasing trend of some primary air pollutants like CO, SO_2 and Pb, but they did not similarly influence the trend of PM_{10}, NO_2 and O_3.[40,41]

Figure 4. Thessaloniki in the morning smoke haze. Airborne PM in the warm and cold months and their organic or elemental carbon were determined. Measurements are indicative of emissions from residential wood burning and biomass combustion in the urban city centre.

The Thessaloniki Greater Area (TGA) is considered as one of the most polluted cities in Europe concerning particulate matter (PM). The Environmental Pollution Control Laboratory of the University of Thessaloniki (AUTH-EPC, http://www.aceptair.prd.uth.gr/AUTH%20description.pdf) has been since several years specialized in air pollution studies. Especially for atmospheric particles since $PM_{10-2.5}$ levels in Thessaloniki exceed systematically the European standards. Vehicular traffic all over the year and residential heating in winter are major urban sources of airborne particles. In addition, particle emissions from the extended industrial area located west/northwest of the city approximate 32,000 tones. The temperate climate with weak prevailing winds (sea breeze) and frequent calms resulting to inefficient dispersion of atmospheric pollutants and short–range transport.[42-45]

Airborne particulate matter (PM) was determined in Thessaloniki during warm and cold months [in 2011 and 2012 (July, Sept, Febr, April)] for PM_{10} and $PM_{2.5}$ particle fractions and analyzed for organic and elemental carbon concentrations. The sampling sites were respectively at two urban sites, one in urban-traffic site and one in an urban-background site. Concentrations ranged at the urban-traffic site [values 11.3 ± 5.0 and 8.44 ± 4.08 14 μg m^{-3} for PM_{10} organic carbon and $PM_{2.5}$ organic carbon, and . 6.56 ± 2.14 and 5.29 ± 1.54 μg m^{-3} forPM_{10} elemental carbon and $PM_{2.5}$ elemental carbon] were among the highest values reported for urban sites in European cities. Significantly lower concentrations were found at the urban-background site for both carbonaceous species. The data of air pollution in the cold months possibly are indicative of emissions from residential wood burning at the urban-background site. At both sites, concentrations of organic carbon (OC) fractions were significantly higher in the cold months, whereas elementary carbon (EC) fractions at the urban-traffic site were prominent in the warm season suggesting some influence from maritime emissions. The secondary contributions to OC (calculated) ranged between 35-59 % (PM_{10} fraction), with higher values, 39-61% ($PM_{2.5}$ fraction).[46]

Is the economic crisis and fuel costs important factors in air pollution of urban areas? A very interesting air pollution study in Thessaloniki, conducted by the University of Southern California's Viterbi School of Engineering and the Laboratory AUTH-EPC of the University of Thessaloniki , found that the energy crisis (as a result of economic crisis of 2010-2015) has increased particulate air pollution (PM_{10}-$PM_{2.5}$) in the economically hardest-hit areas by 30% (winter months 2012-2013). Fuel costs (oil prices, diesel, almost tripled due to tax hikes) and economic hardship forced families in the city to burn low-quality wood and waste materials that produced increasing amounts of fine and superfine particulate matter. Airborne particular matter (PM) from burned wood are dangerous because of their toxic organic constituents (polycyclic aromatic hydrocarbons, PAH), free radicals and metals. Solid particles are trapped inside alveoli of the lungs causing respiratory problems and heart disease. The study found concentrations in the range 26 to 36 μg. m^{-3} in recent years (when the limit is 20 micrograms).[47]

Figure 5. Photograph of Thessaloniki during winter days of high air pollution (2012-2013) by suspended PM (smoke haze). In winter months $PM_{2.5}$ increase by 30%.Tracers of biomass (wood) burning indicated an increased 2-5 fold, whereas fuel oil tracers declined by 20-30%.

This air quality deterioration was mostly due to the increased price of fuel oil, conventionally used as a source of energy for domestic heating, which encouraged the residents to burn the less expensive wood/biomass during the cold season. Sampling in winter months indicated a 30% increase in the $PM_{2.5}$ mass concentration as well as a 2–5-fold increase in the concentration of wood smoke tracers, including potassium, levoglucosan (organic compound, 6 carbon ring structure, formed from the pyrolysis of starch and cellulose), mannosan, and galactosan (all traces of biomass burning). The concentrations of fuel oil tracers (e.g., metals Nickel and Vanadium), on the other hand, declined by 20–30% during 2013 compared with 2012. Also, a distinct diurnal variation was observed by the researchers for wood smoke tracers, with significantly higher concentrations in the evening period compared with the morning.[47]

The problem of particulate matter (PM) air pollution in Thessaloniki is causing great concern among environmental scientists. A new study investigated the coarse particle fraction (PM_c) at two urban sites in the city of Thessaloniki, Greece during the warm and cold months of the year (sampling of PM_{10} and $PM_{2.5}$). The results showed that the levels at the urban-traffic site were among the highest found in literature worldwide exhibiting higher values in the cold period. The urban-background site exhibited significantly lower concentrations of PM_c mass, while the higher levels encountered during the summer months. Minerals oxides (Si, Al, Ca, Mg, Fe, Ti and K) and most trace metals were also higher at the urban-traffic site suggesting a stronger impact from traffic-related sources (road dust resuspension, brake and tire abrasion, road wear). Organic substances and secondary inorganic aerosols (mainly nitrate, NO_3^-) also contribute considerably to the PM_c mass, particularly in the warm period. The scientific study investigated also the influence of wind speed to dilution and/or resuspension of coarse particles.[48]

Suspended particulate matter (PM) evolved as a major atmospheric pollution problem in severa cities in the countries in the Europe. Thessaloniki by comparison is one of the most polluted cities. In addition, the economic crisis in Greece, affected the air quality levels in all big cities. The network of six monitoring stations in Thessaloniki recorded for 20 years the levels of air pollutants to give comprehensive time-trend analysis of measurements. Results have shown that population growth and increase of the vehicular fleet were the main culprits. On top of all these factors the economic crisis and oil fuel prices added another dimension. Numerous studies recorded levels of PM_{10} and $PM_{2.5}$ for the period before the economic crisis (2007-2009) and when the crisis was evolving (2010-2012). The results showed that the overall air quality (especially PM levels) was poor in the city centre, while at the peripheral sites was moderate, during both periods. During the 2010-2012 period and when the domestic heating was on, the mean diurnal variation of PM concentrations has changed and the hourly peak has been shifted to the late night hours while there is a significant increase of PM on weekends and holidays. The overall increase was 13% for PM_{10} and 25% for $PM2_{.5}$. Another interesting finding was that there was a significant decrease of about 20% in the after crisis period and when the domestic heating is off, indicating a cutback on vehicle emissions, which is the primary source of PM in urban Thessaloniki area.[49]

Two recent studies measured the ionic constituents of $PM_{2.5}$ particles and the carbonyl air pollutant in rainwater at the city of Thessaloniki. The $PM_{2.5}$ in urban areas of Thessaloniki, which are the most damaging to health, were investigated for their water-soluble ionic constituents (Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}). Ionic constituents represent 30% (urban-traffic background sites) and 40% (urban background sites) mass fraction of $PM_{2.5}$. Secondary inorganic aerosols represent also a significant fraction of $PM_{2.5}$ mass (27 % and 40% at urban-traffic and urban background sites, respectively).[50] The concentrations of carbonyl compounds (as sum of 14 compounds) ranged from 21.8 to 592 μg/L of rainwater. The dominant carbonyl compounds were formaldehyde, acetaldehyde, hexanal, glyoxal, and methylglyoxal (concentrations in rainwater ranged from 0.46 to 21.3 mg/L).[51]

The basic assumption of expensive fuel during the economic crisis is decrease of traffic activity and increases of biomass burning for residential heating. Thessaloniki was used a test city. Airborne urban PM and gaseous pollutants were measured at the kerbside of a busy road and at a nearby urban background site of Thessaloniki during a winter and a summer period and compared to a study conducted in 2006. The results of the measurements suggested that traffic is less important as an air quality contributor. On the contrary, domestic heating (biomass burning) appeared as a significant contributor to air pollution and affected areas of the city that were earlier not being of environmental concern.[52]

The European Union established atmospheric pollution standards: For PM_{10}: 40 μg.m^{-3} yearly average and 50 μg.m^{-3} daily average, allowed number of exceedances per year 35 (since Jan 2005). For $PM_{2.5}$:25 μg.m^{-3} yearly average, none daily, none number of exceedances (since Jan.2015) . The World Health Organization air quality guidelines for PM_{10}: 20 μg.m^{-3} annual mean, 50 μg.m^{-3} 24-hour mean, $PM_{2.5}$:10 μg.m^{-3} annual mean, 25 μg.m^{-3} 24-hour mean. [WHO . *Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Global Update*. *Summary of Risk Assessment*. WHO publications, Geneva, 2006].[53]

The European cities Barcelona, Marseille, Genoa, Venice and Thessaloniki (one year period, 2011-2012) were used as test sites for the seasonal and spatial characteristics of $PM_{2.5}$ and its chemical composition. The PM_{10} annual mean concentration ranged from 23 to 46 μg.m^{-3}, while the respective $PM_{2.5}$ ranged from 14 to 37 μg.m^{-3}. The results showed that the highest concentrations were observed in Thessaloniki and in Venice. Both cities presented an elevated number of exceedances of the PM_{10} daily limit value, as 32% and 20% of the days exceeded 50 μg.m^{-3}, respectively. Similarly, exceedances of the WHO guidelines for daily $PM_{2.5}$ concentrations (25 μg.m^{-3}) were also more frequent in Thessaloniki with 78% of the days during the period, followed by Venice with 39%. The lowest PM levels were measured in Geneva. $PM_{2.5}$ exhibited significant seasonal variability.[54]

The port of Thessaloniki is one of the largest Greek seaports and one of the largest ports in the Aegean Sea basin, with a total annual traffic capacity of 16 million tones. Thessaloniki port functions as a major gateway for the Balkan hinterland and southeastern Europe and the cargo terminal has a total storage area of 1,000,000 m^2 and specializes in the handling of wide cargo that ranges from metal products, ore and chemical products. The chemical characterization of $PM_{2.5}$ fraction was studied during a 1-year sampling at a site near Thessaloniki's port area. For for polycyclic aromatic hydrocarbons (PAH), minerals, and trace elements (Pb, Ni, Cu, V, Mn, Cr, Zn, etc); water-soluble ions (Cl^-, NO_3^-, SO_4^{2-}, K^+, Na^+, NH_4^+, et al.), and organic and elemental carbon. The average annual $PM_{2.5}$ concentration (66.0 μg.m^{-3}) was at the highest level compared with other studies. The average daily sum of the measured concentration of PAHs was 12.76 ng.m^{-3}, especially benzo[*a*]pyrene during the sampling period was 0.75 ng.m^{-3} (below the EU limit value of 1.0 ng.m^{-3}). The ionic content comprised, on average, 22% of the $PM_{2.5}$ mass, with SO_4^{2-} and NH_4^+ being the most abundant species (31% and 26%, respectively). The organic carbon/elemental carbon ratio ranged from 1.6 to 9.9, suggesting that there is a significant influence of residential wood burning for heating as well as ship and vehicle emissions). The elemental composition of associated $PM_{2.5}$ was dominated by Ca, Fe, and Al.[55]

Air Pollution of Major Provincial Cities in Greece

Atmospheric pollution of major provincial cities in Greece in the last ten years and during the evolving economic crisis changed in comparison to the previous decades. Greek cities like Thessaloniki (population 788 thousands, 2011 census) and Athens (3,089 thousands, 2011) experienced repeated spikes in the levels of PM_{10} exceeding 150 μg.m^{-3}. The deteriorating air quality was the result of burning biomass in winter months. Cities like Patras (168 thousands, 2011), Larisa (144) Ioannina (65), Heraklion (140), Volos (86), Rhodes and Megaloupolis (a small city located close to electricity generating lignite power plants) encountered similar atmospheric pollution problems. Many studies have been carried in the last years in urban areas in Greece focusing on factors such as temperature, humidity, urban climate, traffic, energy behaviour of building and population issues and their combination in air quality changes.[56]

An interesting cooperation of research institutes and university laboratories was carried out in 2013 for measurements of atmospheric pollution by PM in the Greek cities. Sampling took place in the cities of Patras, Ioannina, Heraklion, Athens, Thessaloniki and the new-Navarino Environmental Observatory in Messinia (by the National Observatory of Athens and the Academy of Athens) under the programme "Thales" for measurements of fine and ultrafine particles in winter months of 2013 (10 January-10 February 2013). The concentration of $PM_{2.5}$ was above 50 μg.m^{-3} in the centre of Patras during 12 evenings and nights (for 5 days the concentration reached 100 μg.m^{-3}. Similar measurements in the city of Ioannina (19 evenings and nights) concentration of $PM_{2.5}$ were in the range of 50 μg.m^{-3} but for 5 the level increased in 100 μg.m^{-3}. The lowest levels of pollution by PM were measured in the city **of** Heraklion (Crete). It was established that during the nights with high air pollution, over 90% of the concentration was due to very small particles - with a diameter of less than 2.5 μm. High concentrations of airborne PM were reported between 7 pm and 3 am, the peak being at midnight. According to the researchers the main reason for the increased concentration of PM (90%) was the wood burning during the night hours. Aromatic organic compounds, such as toluene and xylene, were detected among the chemical pollutants during the nights measurements with the highest levels of air pollution (a clear indication that wood and other biomass materials were used for house heating). Sampling in these Greek cities showed that the magnitude of the air pollution problem were created in Athens, as well as other Greek cities, by a combination of the usual polluting sources (traffic, fuel oil central heating) and wood burning under the right conditions (low temperatures and no wind). Fortunately, these conditions were relatively rare in the following winters.[57]

Average daily concentrations of PM_{10} and $PM_{2.5}$ exceeding established standard values appear in many provincial Greek cities, especially during Saharan dust episodes. The air quality in the urban area of Volos (pop. 86,000, 2011) has been studied using the AirQ2.2.3 model, developed by the European Center for Environment and Health (Bonn, Germany, 1991, WHO) during a 5-year period (2007-2011). Air pollution data in Volos were obtained by a fully automated monitoring station located in the centre of the city. The results of measurements indicated the mean annual PM_{10} concentration exceeded the corresponding EU threshold value (50 μg.m^{-3}). The study followed the daily number of hospital admissions in Volos for respiratory disease during the period of 2007-2011. It was estimated an increase of about 2.5% in hospital admissions for respiratory diseases (HARD), compared to the expected annual HARD cases for Volos. A strong correlation was found between the number of days exceeding the EU daily threshold concentration ($PM_{10} \geq 50$ μg m^{-3}) and the annual HARD cases.[58]
The high levels of airborne fine particulates in the Volos city during some days of winter months was established by another study. The study in the city of Volos concerned the levels of PM_{10} pollution. The statistical programme used (probability density function of lognormal distribution) was capable to predict the number of days when the EU air quality standards for PM_{10} concentration are exceeded in Volos area. Also, the programme calculated the minimum reduction in current emission sources of PM_{10} required in order to meet the air quality regulations that are established by the EU and can be utilized as reference for air pollution control strategy in Volos city.[59]

A recent study investigated the elemental composition of water-soluble and acid-soluble fractions of $PM_{2.5}$ samples (some metals are toxic or carcinogenic) from the city of Patras and the town of Megalopolis which represent two different atmospheric environments (Patras an urban environment with a large port, while Megalopolis a small city located close to lignite-fired power plants for electricity production). The concentrations of 14 elements (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Fe, Sr, Ti, V and Zn) were determined in each fraction of $PM_{2.5}$ by ICP-MS (inductively coupled plasma-mass spectrometry). Results showed that Zn (Zinc) has the highest total concentration (273 and186 $ng.m^{-3}$) and Co (Cobalt) the lowest (0.48 and 0.23 $ng.m^{-3}$) for Patras and Megalopolis samples, respectively. Both metals have high toxicity.[60]

Figure 6. Megalopolis is a town (pop. 6,000) in the southwestern part of the regional unit of Arcadia, The large lignite deposits around Megalopoli are being exploited by open-pit mining. The Megalopolis Power Plant, 3 km northwest of the town centre, has produced electricity from this lignite since 1969.

Megalopolis was the subject of another air pollution study. Measurements were performed in two sites (one urban and two rural sites) in Megalopolis area for airborne PM_{10} and associated elemental and ionic species during the cold and the warm months of 2010. The PM_{10} concentrations at the urban site was in the range 44.2 ± 33.6 $\mu g.m^{-3}$, significantly higher than those at the rural sites, 23.7 ± 20.4 and 22.7 ± 26.9 $\mu g.m^{-3}$. All factors contributing to airborne PM pollution were studied (power plant fly ash, wet ash, flue gas desulfurization, opencast mines, road dusts, vehicular traffic, oil combustion, biomass burning, etc). The study found that road and soil dust were major PM_{10} contributors in both the cold and warm periods of the year (32 % at the urban site vs. 22% and 29 % at the two rural sites). Secondary aerosol also appeared to be a significant source (22 % at the urban site in comparison to 30% and 29% at the rural sites). At all sites, the contribution of biomass burning was most significant in winter (28% at the urban site vs. 14% and 24% at the rural sites), whereas vehicular exhaust contribution appeared to be important mostly in the summer. Fly ash contributed to 33 % of PM at the rural site during wintertime, when winds are favorable. Moderate contributions of fly ash were found at the urban sites. The mine field was identified as a minor PM_{10} source.[61]

Electricity generation from fossil fuel-fired power plants (coal, lignite, oil) at national and global level is one of the greatest causes of air pollution and climate change. However, fossil fuels contribute more than 70% in the planet electricity generation during the last 30 years. In Greece, lignite is the only proved significant indigenous fossil fuel source, currently representing about 50% of the national electricity generation, 12% of Greece's electricity comes from hydroelectric power plants and another 20% from natural gas, 5% renewable energy, a situation which is not expected to change dramatically in the near future). Greece at present has the monopoly of electricity generation by the Public Power Corporation (produces 85% of electricity demand, PPC, ΔΕΗ). PPC has 34 major thermal and hydroelectric power plants and the 3 aeolic parks of the interconnected power grid of the mainland, as well as the 61 autonomous power plants located on Crete, Rhodes and other Greek islands (39 thermal, 2 hydroelectric, 15 aeolic and 5 photovoltaic parks). The PPC's industrial corporation constitute the energy basis of all financial activities of the country. The Western Macedonia complex (Florina-Amintaio-

Prolemaida-Kozani) with 5 power stations (lignite-fired) with 4.108 MW represents 1/3 of the power generated in Greece.

Figure 7. The Ptolemaida power stations. The area Florina-Amintaio-Ptolemaida-Kozani wih 1.82 billion tons of lignite has the 57% of exploitable reserves and 79% (2006) of lignite production came from Western Macedonia.

A number of studies in the last decades measured the air pollutants produced in the area of Western Macedonia. The Greek Lignite Thermal Power Stations (LTPSs) were responsible for the production of significant airborne emissions and particulate matter releases (CO_2, SO_2, NO_X, airborne PM). Greece, has accepted special obligations (under the Kyoto Protocol) and has incorporated into its national legislation several air quality Directives (from the EU) concerning the reduction of various harmful pollutant gases and atmospheric particle releases attributed to fossil fuel combustion.[62] The area of Western Macedonia is a very complex in terms of air quality management problem because of large and complex pollution sources operating in the region. The emissions from five lignite power plants, the corresponding opencast lignite mining, as well as the urban activities in the industrial axis, is a complex environmental. A study observed high concentrations of PM_{10} for the period 2007-2010 at various locations in the region.[63] Although lignite is a “cheap” energy source, the environmental impact in Greece associated with its use is high in terms of air pollutants (e.g. 74% of the total CO_2 emissions), something that applies also for petroleum and in a lower extent with natural gas. Greece must followed a radical step in the promotion and production of electricity from renewable sources.[64]

Scientific studies focused on the high levels of suspended particulate PM_{10}. Kozani is a region that is rich in lignite resources and many lignite mines are operating. The large scale mining operations and the burning of the coal at the power plants are highly polluting sources and the levels of PM_{10} often exceeding the air quality legislation standards. The PPC (ΔΕΗ) has developed 9 environmental stations of air monitoring network in the region (Drepano, Kato Komi, Kleitos, Koilada, Kozani, Oikismos, Pentavrisos, Pontokomi, Ptolemaida). Some of the data are covering the period January 2001-December 2003. The statistical analysis showed that the levels of particulate matter (PM_{10}) often exceeded the daily limit of $50 \mu g.m^{-3}$ particularly during the summer months. Specifically most of the exceedances occurred at the station of Oikismos (30% of the available days). Slightly lower are the exceedances for the stations of Kato Komi and the station of Koilada. The airborne PM pollutants are transported by the winds affecting not only the neighbouring area but might also be transported over long distances. It is worth mentioning that, at most stations, PM10 levels are also associated with wind direction.[65] Environmental measurements for PM_{10} in the period 2008-2009 in the most populated cities of Western Macedonia were presented in a conference. Analysis of data found that Kozani had 78 days as “episode days” (10 months period, 27.7-2008—29.5.2009) with concentrations exceeding the 50 μg.m^{-3} (while the yearly mean concentration for Kozani was 44 μg.m^{-3}). In the case of Ptolemaida the study found 90 "episode days" (while the yearly mean concentration was 47 μg.m^{-3}).[66]

Air Pollutants: Ozone, Nitrogen Oxides (NO_x), Volatile Organic Compounds

Although the concentrations of primary and secondary air pollutants decrease substantially in recent years with improvements in fuel quality, regulation of traffic and catalytic vehicular car exhausts, some studies focused in the study of SO_2, NO_x, O_3 and Volatile organic compounds (VOCs). A study analyzed the concentrations of SO_2, NO_2, and O_3 measured by a Differential Optical Absorption Spectroscopy (DOAS) system that was operating at the campus of Technological Education Institute **of** Piraeus (2008 and 2009 warm periods, July to September) in relation to the prevailing meteorological conditions. Also, the DOAS system was measuring levels VOCs (aromatic hydrocarbon substances such as benzene, toluene, and xylene. According to the data, the SO_2 levels were rather high due to the proximity of roadways and local circulation. Also, these factors that can affected levels of NO_2 and O_3. These results provided evidence for the occurrence of an atmospheric phenomenon ("weekend effect") that produces higher O_3 levels during weekends despite lower concentrations of ozone precursors.[67]
Another study investigated the levels of the local and regional oxidants (O_x) concentration at Athens using urban and a rural monitoring stations, during two periods, 2001-2011 and period 2007-2011, respectively. Analysis of data showed a progressive increase of the daytime and nighttime average of ratio $[NO_2]/[O_x]$ versus $[NO_x]$. It was observed a larger proportion of Ox in the form of NO_2 when the level of NOx increased. Similar results were observed when studying the variation of mean values of ratio $[NO_2]/[NO_x]$ versus $[NO_x]$. The results obtained when compared with those that have earlier detected elsewhere, revealed similarities and discrepancies that are discussed in detail in the paper.[68]

Urbanization is a major factor in air pollution and the types of air pollutants. A study in 2012 investigated the potential effects of increased urbanization in the Athens city on the intrinsic features of the temporal fluctuations of the surface ozone concentration (SOC, O_3). Mean monthly values of surface ozone were derived from ground-based observations collected at the centre of Athens basin during 1901–1940 and 1987–2007. The analysis of the data showed a doubling of the present-day surface ozone in respect to historic levels of the first part of the 20th century. The extensive photochemistry enhancement observed in the Athens basin from the beginning of the 20th century until the beginning of the 21st century seems not to have affected the long memory of surface ozone correlations.[69]

Historic and current levels of nitrogen oxides (NO_x= $NO+NO_2$) and ozone (O_3) in Athens and the NO_2/NO_x and NO/NO_2 concentration ratios were analysed in a systematic evaluation. Data from three different stations of the national network for air pollution monitoring were used, one urban-traffic (Patission Street), one urban-background (Peristeri) and one suburban-background (Liossia). Concentration data were also related to meteorological parameters. The results show that the traffic affected station (Patission) presented the higher NO_x values and the lower concentrations of O_3, while it is the station with the highest number of NO_2 limit exceedances. The monitoring data suggested that there was a change in the behaviour of the suburban-background station of Liossia at about year 2000. Comparison of NO_x concentrations in Athens with concentrations in urban areas of other countries reveal that the Patission station recorded very high NO_x concentrations, while remarkably high is the ratio of NO_2 concentrations recorded at the urban-traffic vs. the urban-background (Peristeri) station in Athens, indicating the overarching role of vehicular exhaust gases and traffic congestion on NO_2 formation.[70]

A comprehensive analysis of the most basic features of the air quality (the most important pollutants CO, SO_2, NOx, O_3, PM) of a Mediterranean urban environment area were examined in two measuring stations in Patras. The Weather Research and Forecasting meteorological model was employed to produce a series of surface and upper air data and local circulation and ventilation indices. During the summer period, a significant proportion of the PM is transported from sources away from the measuring sites. The study found that the synoptic setting of winter and summer seasons represented primarily by the local ventilation and recirculation, the wind, the boundary layer height, and the precipitation has a very strong impact in the overall formation of the air quality status.[71]

Air Pollution, Adverse Health Effects, Social Costs: particulate pollution, biomass burning and other pollutants

Atmospheric air pollutants and particulate matter (PM_{10} and $PM_{2.5}$) in urban areas from anthropogenic activities are known from numerous studiers to cause adverse respiratory effects and increased morbidity and mortality from various diseases, including lung cancer. Additionally, PM may settle in the bronchi of the lungs and cause adverse effects via oxidative stress in susceptible individuals, old people with lung diseases and asthmatic children. The atmospheric pollution in Greek cities (Athens in particular) prompted many scientists to investigate the adverse health effects in the last decades.[15-21]

Health effects and the social cost of air pollution in urban areas has been the subject of many studies in European and American cities for many decades. One of the projects was name APHENA (Air Pollution and Health: a European and North American Approach) and its principal purpose was to provide an understanding of the degree of consistency among findings of multicity time-series studies on the effects of air pollution on mortality and hospitalization in several North American and European cities. The project included parallel and combined analyses of existing data. . The APHENA project was based on data collected by three groups of investigators for three earlier studies: (1) Air Pollution and Health: A European Approach (APHEA), which comprised two multicity projects in Europe. (Phase 1 [APHEA1] involving 15 cities, and Phase 2 [APHEA2] involving 32 cities); (2) the National Morbidity, Mortality, and Air Pollution Study (NMMAPS), conducted in the 90 largest U.S. cities; and (3) multicity research on the health effects of air pollution in 12 Canadian cities. . Risks (mortality and hospitalization) were estimated for two pollutants: particulate matter - 10 pm in aerodynamic diameter (PM_{10}) and ozone (O_3). The results of the project showed that APHENA has shown that mortality findings obtained with the new standardized analysis were generally comparable to those obtained in earlier studies, and that they were relatively robust to the data analysis method used. For PM_{10}, the effect-modification patterns observed were not entirely consistent between Europe and the U.S.A. For O_3, there was no indication of strong effect modification in any of the three data sets.[72]

The economic crisis in 2009 and climate change policies (global warming, greenhouse gases) in the developed world, in Europe and especially in Greece stimulated a shift towards renewable energy sources and the use of biomass for household heating. As a result, household biomass combustion has become an important source of air pollutant emissions in the European Union. Recent studies on the contribution of biomass combustion to pollution levels in Europe, provided evidence on the adverse health effects to urban areas of biomass combustion products. A conservative estimate of the current contribution of biomass smoke (and other air pollutants) to premature mortality (from respiratory and cardiovascular diseases) in Europe amounts to at least 40,000 premature deaths per year.[73]

The PM_{10} and $PM_{2.5}$ emissions and the effect of biomass burning in households were studied (chemical analyses and modeling) in Thessaloniki. Measurements included the assessment of outdoor and indoor air quality and the evaluation of biomass use for domestic heating. The outdoor measurements highlighted a significant increase of PM_{10} (from 30.1 to 73.1 μg.m^{-3}) and $PM_{2.5}$ (from 19.4 to 62.7 μg.m^{-3}) concentrations during the transition from the warm to the cold period of the year 2012 compared to 2011.[74] The second part of the study of the same group of researchers assessed the health impact and the respective economic cost attributed to PM emissions from biomass burning for space heating, focusing on the differences between the warm and cold seasons in 2011–2012 and 2012–2013 in Thessaloniki . Health impact was assessed based on estimated exposure levels and the use of established WHO concentration–response functions (CRFs) for all-cause mortality, infant mortality, new chronic bronchitis cases, respiratory and cardiac hospital admissions. Monetary cost was based on the valuation of the willingness-to-pay/accept (WTP/WTA), to avoid or compensate for the loss of welfare associated with illness. Results showed that long term mortality during the 2012–2013 winter increased by 200 excess deaths (premature) in a city of almost 900,000 inhabitants. Estimated health and monetary impacts are more severe during the cold season, despite its smaller duration.[75]

The effects of air pollution emitted by lignite-fired power stations (electricity generation) in the Ptolemaida-Kozani-Florina-Kastoria-Grevena area in the respiratory system of children was recorded in a study by Sichletidis at al. [76] The indoor and outdoor environmental pollution effects on the respiratory system of 3,559 children aged 9-12 were studied (2000-2001 in five cities of Western Macedonia). The study was performed by means of a questionnaire. The study found that environmental pollution had a detrimental effect on the respiratory system of children, mainly attributable to the occurrence of rhinitis and infectious bronchitis. The highest prevalence of rhinitis (40%) and infectious bronchitis (12%) was observed in Ptolemaida, which is a highly polluted region, whereas the lowest (21% and 6.7%, respectively) was seen in Grevena, a town in a non-polluted area.[76]

Childhood asthma is well known that is another respiratory disease that is affected by high levels of airborne particles because they settle in the lung bronchi cause oxidative stress. Daily concentrations of PM_{10} were recorded in greater Athens area and the relationship with childhood asthma admissions (CAA) were investigated with generalized linear models and Poisson distribution. The results showed that there was a statistically significant relationship between childhood asthma admissions and mean daily PM_{10} concentrations on the day of exposure. High mean daily PM_{10} concentration doubled the risk of asthma exacerbations even in younger asthmatic children (0-4 year-old).[77] Acute effects (short-term) of air pollutants and PM on pediatric asthma exacerbation was the continuation of the previous study with emergency admissions in Athens over the period 2001-2004. Short-term effects of PM_{10}, SO_2, NO_2 and O_3 were associated with pediatric asthma emergency admission in hospitals. A 10 μg.m^{-3} increase in PM_{10} was associated with a 2.5% increase (95% confidence interval) in the number of CAA, while the same increase in SO_2 was associated with a 6% increase. The ozone (O_3) levels were associated with a statistically significant increase in CAA among older children in the summer. The findings provided limited evidence of an association between NO_2 exposure and asthma exacerbation. Statistically significant PM_{10} effects were higher during winter and during desert dust days, while SO_2 effects occurred mainly during spring.[78]

Studies of health effects (asthma or chronic obstructive pulmonary disease, COPD) of atmospheric particular matter (PM) were funded by a EU-funded multicentre study (RUPIOH) in four cities: Amsterdam, Athens, Birmingham, Helsinki. Participants in these studies kept a record for respiratory symptoms in a diary for 6 months). Exposure assessment included simultaneous measurements of coarse (>PM_{10}), fine (PM_{10}) and ultrafine particles ($PM_{2.5}$) at a central city site. Data on gaseous pollutants were also collected. A city specific analysis controlling for potential confounders was followed by a meta-analysis to provide overall effect estimates. A 10 μg.m^{-3} increase in previous day coarse particles concentrations was positively associated with most symptoms. Same day, previous day and previous two days ozone (O_3) concentrations were positively associated with cough. No consistent associations were observed between PM_{10} concentrations, NO_2 and respiratory health effects. The magnitude of the associations for $PM_{10-2.5}$ with prevalence of symptoms and restriction of activities remained approximately the same or increased when we applied a two-pollutant model with $PM_{2.5}$. The researchers concluded that results of the study adds to the limited existing evidence of recent epidemiological and toxicological studies that health effects due to the coarse fraction of ambient PM may be substantial. Further studies are needed to clarify possible different effects of PM on COPD and asthmatic patients. The observed associations suggest it is prudent to regulate also coarse particles in addition to fine particles.[79]

Studies on atmospheric pollution have provided evidence that both the long- and the short-term exposures to O_3 and PM are responsible for increased mortality and cardiopulmonary morbidity. A recent paper for the Greater Athens area (in 17 sites) examined the relationship between exposure to ambient PM_{10} and O_3 and public health (quantified for mortality and morbidity through a Life Cycle Impact Assessment). Analysis of data found that mortality due to chronic exposure to PM_{10} has a dominant contribution to years of life lost with values ranging between 6.2×10^{-5} and 1.1×10^{-4}. The mortality caused by short-term exposure to O_3 is weaker. Finally, it was found that 9,000 DALYs (Disability-Adjusted Life Year, quantifying the Burden of Disease from morbidity and mortality) are lost on average in Athens from atmospheric pollution.[80]

A similar study in urban Thessaloniki estimated health damages and social costs from PM_{10} and photochemical pollutants. Thessaloniki is considered one of the most polluted cities within Europe. Social cost of health damages in Thessaloniki turns out to be significant (hospitalization, pharmaceutical therapies, absence from work, etc). The study found that the main contributor is by far premature mortality due to chronic exposure to anthropogenic PM_{10}. The results of this study highlighted the magnitude of the total impacts and costs of urban air pollution (as a percentage of an area's GDP) and can be used for comparison with relevant studies of other cities worldwide. Also the results can be useful to local authorities since they provide an insight on the economic social benefits of emission reductions in the area of urban Thessaloniki.[81]

The association of long-term exposure to traffic-related pollution (PM, NOx, etc) with the incidence of fatal and non-fatal ischemic heart disease (IHD), stroke and total cardiovascular disease (CVD) was investigated by a recent study by Greek scientists for the Athens area. The study followed 2,752 subjects (for 15 years, 1997-2011) in 10 urban municipalities of Athens. Air pollution exposure estimation was based on a spatio-temporal land use regression model linking geo-coded residential addresses to long-term average NO_2 and PM_{10} concentrations. Hazard ratios (HR) above 1 (not all statistically significant) were associated with higher PM_{10} exposure for all outcomes (CVD, IHD). Weaker associations were found with NO_2 exposure. It was concluded that long-term exposure to traffic-related air pollution has an impact on CVD and IHD morbidity, particularly among women and younger subjects.[82]

A scientific investigation estimated the long-term effects of exposure to air pollution on human health (lung cancer) in Europe (project ESCAPE, including 36 European areas, large cities with suburban or rural surroundings) in which air pollution was measured, land-use regression models were developed, and cohort studies were located. The study included 17 cohort studies, located in 12 areas, from Sweden and Greece (EPIC-Athens). The 312, 944 cohort members contributed 4, 013, 131 person-years at risk. The follow-up was 12.8 years and 2,095 incident lung cancer cases were diagnosed. The meta-analyses showed a statistically significant association between risk for lung cancer and PM_{10} (hazard ratio [HR] 1·22 per 10 μg.m^{-3}), while for $PM_{2·5}$ the HR was 1·18 per 5 μg.m^{-3}. The same increments of $PM_{10}$and $PM_{2·5}$ were associated with HRs for adenocarcinomas of the lung of 1·51 and 1·55, respectively. An increase in road traffic of 4,000 vehicle-km per day within 100 m of the residence was associated with an HR for lung cancer of 1·09. The results showed no association between lung cancer and NOx concentration or traffic intensity on the nearest street per 5,000 vehicles per day.[83] The same project was extended for the study of the relationship of long-term exposure to air pollution and nonmalignant respiratory mortality in 16 cohorts with individual level data within the multicenter European Study of Cohorts for Air Pollution Effects (ESCAPE). Data from 16 ongoing cohort studies from Europe were used. The total number of subjects was 307,553. There were 1,559 respiratory deaths during follow-up. Standardized individual cohort analyses were combined using meta analyses. The results found no significant associations between air pollution exposure and nonmalignant respiratory mortality.[84]

It is known that biomass combustion produces particulate air pollution which contain large amounts of carcinogenic polycyclic aromatic hydrocarbons (PAHs). A study investigated the cancer risk attributable to PAH exposure, attributable to the increased use of biomass for space heating in Greece in the cold days of winter of 2012-2013. Fractions of particulates (PM1, PM2.5 and PM10) were measured in two sampling sites (urban/residential and traffic-influenced) followed by chemical analysis of 19 PAHs and (levoglucosan was used as a biomarker tracer). PAH-induced lung cancer risk was estimated by a comprehensive methodology that incorporated human respiratory tract deposition modeling in order to estimate the toxic equivalent concentration (TEQ) at each target tissue. The estimated lung cancer risk was non-negligible for residents close to the urban background monitoring site. Higher risk was estimated for infants and children. Human Respiratory Tract (HRT) structure and physiology in youngsters favor deposition of particles that are smaller and more toxic per unit mass. In all cases, the estimated risk (5.7E-07 and 1.4E-06 for the urban background site and 1.4E-07 to 5.0E-07 for the traffic site) was lower to the one estimated by the conventional methodology. With the methodology proposed herein, the estimated risk presents a 5-7 times difference between the two sampling sites (depending on the age group). [85]

Scientific investigations were carried out for the damaging effects of airborne PM on lung function and nasal airflow among a cohort of children in Ptolemaida and Greven (with . Scientists used questionnaires, spirometry and rhinomanometry and were associated with PM_{10} concentrations from monitoring sites in the area. The participants were 1046 children (10-12 year old) in the heavily polluted town of Ptolemaida and 379 children in the low pollution level town of Grevena (acted as a control group). The study re-evaluated (after 19 years interval) 312 of Ptolemaida and 119 of Grevena. PM_{10} concentrations were above permissible levels in Ptolemaida during all study period. At both visits, nasal flow was significantly lower in the study sample. At the follow-up visit, 34.3% had severe nasal obstruction (< 500 ml/s) and 38.5% reported chronic nasal symptoms. Spirometric parameters did not differ compared to the control group. The conclusion was that PM air pollution had significant and negative effects on nasal but not on lung function development.[86]

The Volos General Hospital was the centre for a time series study (2001-2007) representing a semi-urban tourist Greek city. Data were collected from the computerized database of the hospital on a daily basis all emergency admissions of adults which required hospitalization due to respiratory or cardiovascular problems. Daily concentrations of ambient pollutants [PM_{10}, CO, SO_2, NO, NO_2, NO_X and O_3 were obtained from three air monitoring stations. The impact of air pollutants on morbidity was studied through time series analysis. The results of the study found significant associations between hospitalizations and all indicators of air pollution. Daily elevations in the concentrations of PM_{10}, NO, CO and O_3 increased significantly the number of hospitalizations for respiratory/cardiovascular causes both on the same day and at the next day.[87]

Other investigations were extended to determine the short-term exposures PM_{10}, $PM_{2.5\text{-}10}$ and $PM_{2.5}$ and their association with premature deaths from diabetes, cardiac and cerebrovascular causes (CVC), lower respiratory tract infections (LRTI) and chronic obstructive pulmonary disease (COPD) in 10 European Mediterranean metropolitan areas (during 2001-2010). For a $10 \mu g.m^{-3}$ increase in two days' $PM_{2.5}$ exposure there was a 1.23% increase in diabetes deaths, while six days' exposure statistically significantly increased cardiac deaths by 1.33%, COPD deaths by 2.53% and LRTI deaths by 1.37%. Stronger effects were observed in the warm season. Coarse particles displayed positive, even if not statistically significant, associations with mortality. Scientists concluded that findings provided support for positive associations between $PM_{2.5}$ and mortality due to diabetes, cardiac causes, COPD, and to a lesser degree to CVCs.[88]

A recent study in Thessaloniki calculated the carcinogenic and mutagenic potencies of PAHs in respirable fine and superfine particles and estimated the inhalation cancer risk (ICR) for local population in the city. Measurements were performed for respirable particle fractions of PM_{10} and $PM_{2\cdot5}$ at a heavy-traffic and an urban site in the centre of the city during warm and cold months and 13 particle-phase PAHs (congeners of class 1, 2A and 2B of IARC) were calculated., including nine >4-ring congeners. The quantitative risk was calculated by employing the Chemical Mass Balance modeling for the source apportionment of ambient PAH levels and the estimated lung cancer risk. Results found that the inhalation cancer risk, during winter months, was equivalent in the city center and the urban background area, suggesting that residential wood burning may offset the benefits from minor traffic emissions.[89]

The Long-term exposure to air pollutants in urban areas (PM_{10}, $PM_{2\cdot5}$, NO_x) and mortality have been reported recently for 22 European cohort studies, including Athens (multicentre European Study of Cohorts for Air Pollution Effects , ESCAPE). The total study population consisted of 367, 251 participants who contributed 5, 118, 039 person-years at risk (average follow-up 13·9 years), of whom 29 076 died from a natural cause during follow-up. A significantly increased hazard ratio (HR) for $PM_{2\cdot5}$ of 1·07 per 5 $\mu g.m^{-3}$ was recorded. HRs for $PM_{2\cdot5}$ remained significantly raised even when the study included only participants exposed to pollutant concentrations lower than the European annual mean limit value of 25 $\mu g.m^{-3}$. The interpretation of the results according to researchers is that long-term exposure to fine particulate ($PM_{2.5}$) air pollution was associated with natural-cause mortality, even within concentration ranges well below the present European annual mean limit value.[90]

Finally, in the last decades there were scientific reports investigating the short- term health effects (elevated mortality) of windblown desert dust (Sahara dusts and from North Africa) in Athens and forest fires in the population of Athens. One study investigated the hypothesis of desert dust by using daily air pollution and mortality data for Athens during the period 2001-2006. The study identified 141 dusty days. Exposure to PM10 was correlated to total and cause specific mortality, during days with and without windblown desert dust, for all ages, stratified by age groups and by sex. Researchers used Poisson regression models with penalized splines to control for possible confounding by season, meteorology, day of the week and holiday effect. A $10 \mu g.m^{-3}$ increase in PM_{10} was associated with a 0.71% increase in all deaths. The effects for total and cause specific mortality were greater for those ≥ 75years of age, while for total mortality higher effects were observed among females.

The conclusion from the data of the study indicated that traffic related particles (PM10), which prevail on non-desert dust days, have more toxic effects than the ones originating from long-range transport, such as Sahara dust.[91]

Forest fires also produce vast amounts of smoke and airborne fine particulate matter. Especially in the Athens area smoke from fires can be dangerous to the respiratory system. The climate and vegetation of the Greater Athens area can make forest fires a real threat during the summer. A study investigated the short-term effects of forest fires on non-accidental mortality in the population of Athens during the period 1998-2004. The study used generalised additive models to investigate the effect of forest fires on daily mortality, adjusting for time trend and meteorological variables, taking into account air pollution as measured from fixed monitors. Small fires do not have an effect on mortality. Medium sized fires are associated with an increase of 4.9% in the daily total number of deaths, 6.0% in the number of cardiovascular deaths and 16.2% in the number of respiratory deaths. Cardiovascular effects are larger in those aged <75 years, while respiratory effects are larger in older people. The corresponding effects of the one large fire were: 49.7%, 60.6% and 92.0%. These effects cannot be completely explained by an increase in ambient particle (PM) concentrations.[92]

Conclusions

The rapid urbanization, the increase in traffic, industrial enterprises and low quality fuels in Greece in the 1960s and 1970s increased air pollution in urban areas. Athens has become known for poor air quality during the city's frequent severe incidents of “nephos” (photochemical smog). The same conditions contribute to air pollution in Thessaloniki and other provincial cities. High concentrations of airborne particular matter (PM), CO, SO_2, NO_x and O_3, as well as photochemical smog which was as a result from a series of chemical reactions driven by sunlight. From the 1990s the air quality in Greece has greatly improved in most urban areas because of the substantial environmental improvements, and implementation of legislation. The economic crisis of 2009-2015 reverse this trend and new air pollution problems appeared in urban areas. Airborne fine and superfine particulate matter (PM) increased substantially, especially in winter months. Fuel costs (price increases and fuel tax) compelled residents in Athens and other cities to burn low quality fuel, such as wood and biomass waste materials (especially of the years 2012 and 2013). Measurements of air samples supported the evidence that a substantial proportion of airborne PM is the result of low quality fuel materials. At the same time epidemiological studies investigated the adverse health effects of air pollutants in urban populations and associations of atmospheric air pollutants with respiratory and other diseases. Increased air pollution was correlated with increased morbidity and mortality in urban areas with high density traffic. This review collected the most important air pollution studies in Greece of the last decade and the results which represent an illustration of the air quality problems in urban areas in Greece under the period of economic crisis years and in other European cities.

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