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Current Status of Particulate Matter Pollution in Europe and Future Perspectives: a Review

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Abstract

Particulate matter (PM) pollution is currently one of the main concerns at a global scale for its adverse effects on the human health, environment and climate. In spite of the considerable improvements achieved in the last decades in many industrialized countries, PM pollution is still responsible of thousands premature deaths and of the increase of many pathologies each year in Europe. After a brief description of particulate matter properties and its health effects, we summarize the present status of PM (both PM_{10} and $PM_{2.5}$, where the subscript refers to the maximum size of the particle) pollution in Europe and the current EU legislation. Finally, we discuss on the recent developments and perspectives on PM monitoring with focus on the emerging low-cost participatory sensing technologies.

1. Introduction

Air is a fundamental ingredient for life on Earth and several studies have clearly demonstrated the correlation between poor air quality and human health risks [1-6]. Air pollution is indeed a complex issue involving a large number of substances emitted by multiple sources (e.g., PM_{10}, $PM_{2.5}$, CO, CO_2, NO_2, Pb, SO_2) and characterized by a wide spatial and temporal variability [7-9]. According to the World Health Organization (WHO), it represents a global health emergency for the present and future generations. However, historical documents show that the air pollution problem began much earlier than the Industrial Revolution due to agriculture, domestic livestock, mining, and metallurgical activities [10,11]. In the 13th century, England's *KingEdward I* promoted official actions to reduce the free use of coal that included harsh penalties for transgressors [12]. Along with amazing technological advances, the Industrial Revolution introduced additional sources of air pollution between the late 18th and first part of the 19th century. The large-scale combustion of coal and other fossil fuels produced serious health impacts on the citizens of urban areas. The first observations of acid rain started in 1850s in the forests located downwind of industrial areas, however it was not considered a serious issue for the environment until 1970s.

In 1948, a poisoned mixture of carbon monoxide, sulfur dioxide, and metal dust killed 20 people and sickened 7000 more in Donora, Pennsylvania [13]. The disaster was caused by a temperature inversion that led to the accumulation over the city of pollutants emitted by local factories. The "Great Smog" event that affected London in 1952 killed at least 4000 people in few days; this event was due to emissions both from factories and home fireplaces, mixed with unfavorable weather conditions [12]. Starting from 1960s, citizens became increasingly more aware of environmental issues such as air pollution; this process led to new actions and policies on air quality and to the adoption, by the United Nations in 1972 of the Stockholm Declaration and, the Rio Declaration on Environment and Development in 1992 [14]. Tighter controls and policies produced a significant reduction of air pollution in many European and US urban areas during the second half of the 20th century. Ground-based in situ measurements from ~200 background sites in Europe and North America show downward trends in $PM_{2.5}$ and SO_4^{2-} concentrations since mid-1980s [15]. The measurements indicate downward trends of $PM_{2.5}$ in Europe of 2-6 %/yr and in USA of 1-2.5 %/yr; a reduction trend of SO_4^{2-} of 2-5 %/yr was also observed [15]. However, the air quality is still not acceptable and harmful for many days of the years in many European urban areas [16].

The literature on this topic is huge, however it is dispersed in a large number of scientific or official reports and in newspapers/books for non-professional people [1, 2, 3, 5, 6]. Therefore, it is not easy for a reader to focus on the main problems involved. In this paper, we briefly report on the properties of PM and its effects on the human health. We then focus on the current state of PM pollution in Europe, and discuss the recent developments and the future perspectives for PM monitoring.

2. Particulate matter properties and effects on human health

Particulate matter is constituted by liquid, droplets, and solid particles suspended in the air. PM can be emitted by both natural (e.g., volcanic ash, dust storms, products of forest fires, sea spray, biogenic particles, etc.) and anthropogenic sources (e.g., industrial processes, fossil fuel combustion, quarrying activities, etc.). The major sources of the natural airborne particles are the large desert areas: Sahara, Kalahari, Gobi, Arabian Peninsula, Australian Desert, Death Valley, Patagonian Steppe [17]. In the urban areas, the main source of PM is vehicular traffic (i.e., engine emission, brake wear, tires wear, clutch and road surface wear) and burning of fossil fuels for heating and cooking (i.e., coal, oil, wood). In particular, the majority of PM emissions related to vehicular traffic are from diesel exhaust. It has been calculated that in the largest urban areas particles derived by diesel exhaust can account for up to 90 % of PM [18].

On the basis of their origin, airborne particles are classified into two categories: primary and secondary particles. The first are released directly into the atmosphere from their sources primarily by combustion processes, and are mainly constituted by wind-carried soil, sea spray, emissions by industrial activities and road transportation [7, 17,]. The secondary particles are the result of chemical reactions that produce low volatility substances, which successively condense into solid and liquid particles [7, 17,]. Typical examples are: oxidation of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) to acids which are then neutralized by ammonia, and oxidation of volatile organic compounds (VOCs) to form secondary organic aerosol (SOA) in carbonaceous particles. Secondary particles include ammonium sulfate, gypsum, nitrates, chloride salts, and carbon related to SO_2 emissions [19].

A widespread distinction classifies airborne particles on the basis of their aerodynamic diameter in a coarse fraction (i.e., PM_{10}, particles with an aerodynamic diameter smaller or equal to 10 μm) and a fine fraction (i.e., $PM_{2.5}$, particles with aerodynamic diameter smaller or equal to 2.5 μm). The coarse fraction (PM_{10}) includes mechanically generated particles (e.g., wind-blown dust, sea spray, volcanic particles, desert dust, soil), biological particles (e.g., pollens, fungal spores), and some secondary particles. $PM_{2.5}$ is constituted by primary combustion particles and secondary particles grown by coagulation and condensation processes [7, 17]. However, a large number of airborne particles is constituted by the ultrafine particles (UFPs) with a diameter smaller or equal to 0.1 μm. UFPs are mainly constituted by OC (organic carbon), EC (elemental carbon), sulfates, and nitrates derived by primary combustion emissions and secondary particles by gas-to-particles conversion processes [20].

PM presents a highly variable chemical composition related to the pollution sources, long-range transport, chemical reactions, and meteorological conditions. The components of PM include water soluble substances (e.g., ammonium sulfate, ammonium nitrate, and sodium chloride), insoluble minerals, and sooty particles made up largely elemental carbon (EC) coated in organic compounds. The bulk chemical composition of PM includes secondary sulfate, nitrate and ammonium particles, sea salt, mineral dust, biological particles, and carbonaceous compounds [21].

Sulfate is present in the fine fraction as ammonium sulfate. It is formed mainly by oxidation of SO_2 in the atmosphere [21]. Sulfate can be also present as Na_2SO_4 of marine origin. Over the sea, sulfate is also produced by reaction of dimethyl sulfide derived from phytoplankton.

Nitrate is present mainly as ammonium nitrate produced by the reaction of gaseous nitric acid and ammonia [21]. It shows larger spatial variation than sulfate and may be predominant in the coastal areas. Nitrate can be also present as sodium nitrate, generated by the reaction between gaseous nitric acid and sea salt.

Ammonium is produced by neutralization of nitric and sulphuric acids by atmospheric ammonia, whereas chloride is formed mainly from primary emissions of sea salt [21]. Elemental carbon (also termed as black carbon, BC) and organic carbon are produced by incomplete combustion processes of biomass and fossil fuel [21]. Elemental carbon has very good adsorptive properties, which allow it to retain organic and inorganic pollutants. Organic carbon is produced mainly by combustion processes as semi-volatile compounds or formed by gas-to-particle conversion of gaseous precursors. Mineral dusts represent mainly the coarse fraction and are formed by soil, windblown materials and degradation of building materials. The composition of mineral dust varies greatly due to the geology of the source areas, meteorology, and surface processes. Biological particles

also vary widely in size and morphology and include fungal spores, pollens, bacteria cells, viruses, as well as fragments and products of organisms [8, 9].

2.1 PM effects on human health

Particulate matter is considered one of the most serious hazards for human health, environment, and climate at a global scale [7, 17]. PM deposition causes severe harmful effects on terrestrial and aquatic environments such as soil acidification with a significant negative impact on the agriculture and the economy, and the eutrophication of aquatic ecosystems that is strongly harmful for the aquatic life [22]. Depending on their size, morphology and composition, airborne particles exhibit different abilities to interact with solar radiation. They impact on the regional and global climate through scattering and adsorption processes and may affect the properties of clouds. In particular, high levels of fine particles ($PM_{2.5}$) may cause reduction in the atmospheric visibility.

The scientific evidences of the effects of PM pollution on the human health are validated by numerous epidemiological, biological, and pathological studies [1, 7, 23, 24, 25, 26]. The epidemiological studies have been mainly focused on the adverse effects associated with the exposure to PM [27, 28]. In particular, toxicological studies have shown that PM causes inflammatory and oxidative stress-related processes that have consequences on the respiratory and cardiovascular system [29].

The effects of PM exposure on the human health depend on size and chemistry of the particles [3, 28] as well as the individual sensitivity and characteristic of a person (e.g., allergies, breathing mode, rate, and volume). Physical considerations point out that the risk and severity of respiratory diseases are inversely related to the aerodynamic diameter of the particles. Particles between 5 and 10 μm are deposited in the tracheobronchial tree. Particles between 1 and 5 μm are mainly deposited in the respiratory bronchioles while those smaller than one micron can penetrate into the alveoli and enter into the circulation system [30]. In ref. [31] authors showed a correlation between exposure to fine particles with the increase in mortality and hospitalizations for respiratory and cardiovascular diseases. Studies of a cultured human lung tissue have shown that the finest particles react with the organic tissues by releasing chemical compounds that may induce cell damages [32]. Experimental studies on animals have shown that mass-equivalent doses of insoluble UFP are more effective in inducing lung inflammation, tissue damage, and lung cancer than larger particles with similar composition [33, 34].Other more recent studies pointed out the ability of nanoparticles to access to intracellular organs (i.e., organelles, DNA) by diffusion and adhesive mechanisms [34, 35]. Moreover, it was also reported that metals act as possible mediators of PM induced disease and inflammation [36]. In particular, transition metals induce the production of reactive oxygen species (e.g., O_2^-, H_2O_2, OH) resulting in an oxidative damage of cells [29]. Also the exposure to metals such as Zi, V, Pb and Ni has been associated to adverse health effects even at low concentrations [37]. Ref. [38] highlighted that risk of hospitalization is higher in communities exposed to $PM_{2.5}$ containing Ni, V, and elemental carbon (EC).

The World Health Organization (WHO) estimated that ambient air pollution contributes to ~ 6.7 % of all deaths [39]. Moreover, 3 % of cardiopulmonary and 5 % of lung cancer deaths are related to $PM_{2.5}$ exposure. Several studies focused on the concentration limits at which statistical increased in mortality is expected. For example, an increase of 10 $\mu g/m^3$ of $PM_{2.5}$ is correlated to an increase of the daily mortality of 6 % for all-cause mortality and 11 % for cardiovascular mortality.

Studies conducted in numerous European cities showed that an increase of 10 $\mu g/m^3$of $PM_{2.5}$ is associated with an increase between 1.4 % and 2.7 % of all causes of mortality [40, 41, 42]. In particular, Ref. [2] reported that 10 $\mu g/m^3$ increases in PM_{10} and $PM_{2.5}$ in London resulted in an increment of 0.5 % in all-cause mortality and 2.1 % in respiratory mortality.

Other studies highlighted that a short-term exposure to particulate matter causes adverse effects on mortality (e.g., cardiovascular and respiratory mortality) and morbidity (e.g., hospital admissions, asthma attacks) both in developed and developing countries [6, 30]. The risk for total and cause-specific mortality shows a clear correlation with PM concentration. Moreover, chronic adverse effects on human health have been associated with long-term exposure to PM. The Cancer Prevention Study II by the US American Cancer Society (ACS) followed 500,000 adults linked with air pollution exposure from 1982 to 1998 [6]. The study reports that an increase of 10 $\mu g/m^3$ in $PM_{2.5}$ concentration leads to an increase in risk of mortality of 4, 6, and 8% for all-cause, cardiopulmonary and lung cancer, respectively. The Harvard Six-City cohort study reports that the long-term exposure to $PM_{2.5}$ is related to an increase of cardiovascular diseases and mortality among 65,893 postmenopausal women [30]. An increase in $PM_{2.5}$ exposure of 10 $\mu g/m^3$ is also associated with an increase of 24 % and 76 % of cardiovascular event and death from cardiovascular disease, respectively. The increase in $PM_{2.5}$ exposure is also associated with an enhanced risk of cerebrovascular events.

3. PM pollution in Europe: current status and legislation

3.1 EU legislation on PM pollution

The most recent EU policy document on air pollution is the Thematic Strategy on Air Pollution, dated 2005 [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Al28159]. It aimed to established measures and legislation to attain levels of air quality that *do not give rise to significant negative impacts on, and risks to human health and the environment*. To achieve the objectives of the Thematic Strategy on Air Pollution, the EU legislation on air pollution has been implemented both on air quality standards and emission mitigation.

The main instruments of the EU policy on air pollution are the New Air Quality Directive (2008/50/EC) and the National Emission Ceilings Directive (2001/81/EC). Moreover, other legal instruments have been used to minimize air pollution (e.g., Council Directive 96/62/EC, Directive 2004/107/EC, Commission Decision 2004/461/EC). The New Air Quality Directive is aimed to merge the existing legislation into a single directive. The latter also introduces new objectives for $PM_{2.5}$ as the limit value objective, the exposure related objective, the exposure concentration obligation, and the exposure reduction target (Tab. 1). The Directive sets both a short-term limit for PM_{10}, i.e., not more than 35 days per year with a daily average concentration exceeding 50 $\mu g/m^3$, and an annual average limit for PM_{10} at 40 $\mu g/m^3$. The target value for $PM_{2.5}$ was set at 25 $\mu g/m^3$ and the exposure concentration obligation (AEI) for $PM_{2.5}$ at 20 $\mu g/m^3$. Moreover, EU States are required to reduce the $PM_{2.5}$ exposure of the population to an annual average limit of 20 $\mu g/m^3$ by 2020.

Actually, the Air Quality Guidelines (AQGs) set by the World Health Organization [71] are stricter than the EU air quality standards (Tab. 1). The AQGs set the limit value for $PM_{2.5}$ at 10 $\mu g/m^3$ annual mean and 25 $\mu g/m^3$ 24-h mean, while the limit values for PM_{10} is 20 $\mu g/m^3$ annual mean and 50 $\mu g/m^3$ 24-h mean [43]. These values are considered acceptable and achievable objectives to minimize adverse effects on human health. However, in 2013, a new Clean Air Policy Package has been introduced by the European Commission [http://ec.europa.eu/environment/air/clean_air_policy.htm]. The package updated the existing legislation aiming to reduce harmful emissions from industry, traffic, energy plants and agriculture. The package includes a new clean air framework, with measures to meet existing air quality targets in the short term, and sets new objectives to be met by 2030. A revision of the National Emissions Ceilings Directive [Directive 2001/81/EC] has been also proposed to reduce national emission limits for nitrogen oxides, volatile organic compounds, ammonia, fine particulate matter ($PM_{2.5}$), and methane. The package also introduced a new directive regarding combustion installations of medium size, i.e., between 1 and 50 MWth. If full implemented, the impact on health by the Clean Air Policy Package has been estimated in 58,000 less premature deaths within 2030. It is expected to have a positive net impact also on the economic growth in Europe, e.g., increasing in competitiveness, higher productivity and employment, and lower healthcare costs. Its economic benefit is estimated to reach 3.4 billion EUR per year.

Despite the increasing concern on the health risk related also to exposure to indoor pollutants, including microbial pollution, many countries do not have a harmonized legislation and regulations on indoor air pollution; the indoor air quality of public spaces, e.g., offices, homes, schools, stations, is still unregulated although several studies already pointed out how most of these sites indeed may present significant adverse effects for human health [18, 44, 45].

Table 1. Air quality standards for $PM_{2.5}$ and PM_{10} set by the European Union (EU) and the WHO Air Quality Guidelines (AQG).

Pollutant	WHO AQG	EU standard	Averaging period	Permitted exceedences each year
$PM_{2.5}$	10	25	1 year	n/a
	25	n/a	24 hours	
PM_{10}	50	50	24 hours	35
	20	40	1 year	n/a
$PM_{2.5}$exposure concentration obligation	n/a	20 (AEI)	3 year	n/a
$PM_{2.5}$ exposure reduction target	n/a	Percentage reduction* + all measures to reach 18 $\mu g/m^3$(AEI)	3 year	n/a

* Depending on the value of AEI in 2010, a percentage reduction requirement is set in the Directive. AEI (average exposure indicator) is determined as a 3-year running annual mean concentration averaged over the selected monitoring stations in agglomerations and larger urban areas, set in urban background locations to best assess the exposure to the general population.

3.2 Current status of PM pollution in EU

In Europe, air pollution has significant impacts on the human health (i.e., reduce of life expectancy) and the economy (i.e., increase of medical costs and reduction of productivity). The 2015 Report on Air Quality in Europe emitted by the European Environmental Agency (EEA) updated with 2013 data, presents a detailed analysis of the European status [16]. The EEA document highlights that in large European regions the limit values for PM_{10} are still exceeded in 2013 (Fig. 1). In particular, the PM_{10} daily limit value was usually exceeded in Italy, Poland, Bulgaria, Slovakia and the Balkan region (Fig. 1).

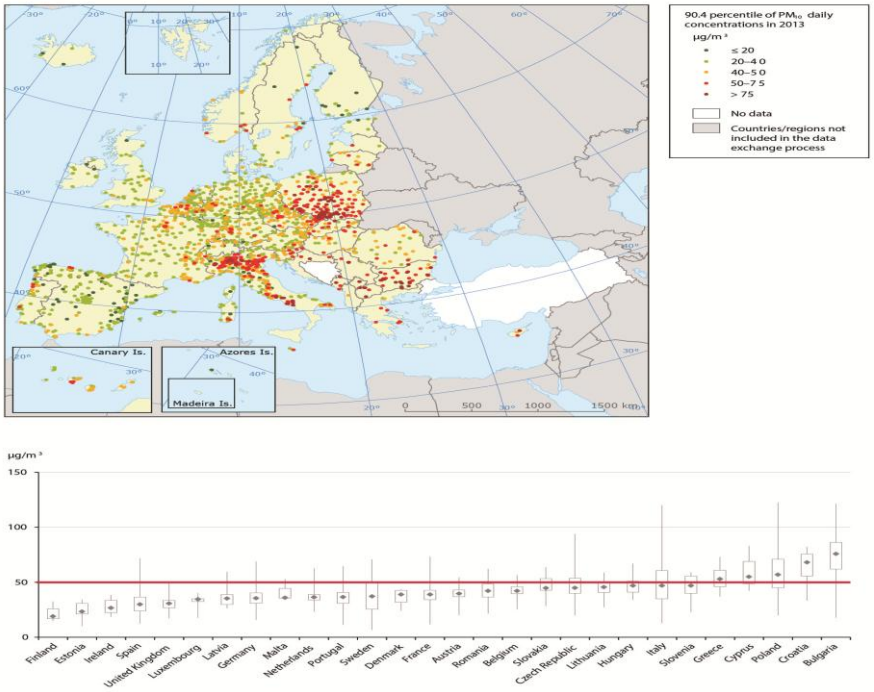

Fig. 1. a) Concentration of PM_{10} in Europe in 2013 showed as the 90.4 percentile of the data records in one year; b) attainment scenario for PM_{10} in 2013 in the EU-28 based on the 90.4 percentile of the daily mean concentration values. The lowest, highest, and median percentile 90.4 values at the stations are showed for each country in $\mu g/m^3$; the rectangles mark the 25 and 75 percentiles. The EU recognized daily limit value is indicated by the red line; (modified after [16]; source: EEA Air Quality e-reporting database).

The exceedances of the daily limit value at least at one station was observed in 2013 in most of the EU States with exception of Denmark, Estonia, Finland, Ireland, Luxembourg and the United Kingdom; the exceedances occurred in 95% of the urban or suburban areas. Regarding $PM_{2.5}$, Bulgaria, Czech Republic, Italy and Poland, ex-Yugoslav Republic of Macedonia, Romania, Kosovo, and Slovakia show concentrations higher than the target value (i.e., 25 $\mu g/m^3$ annual mean, which is the limit value from 2015) at several stations already in 2013. In the same year the exceedances $PM_{2.5}$ target value was observed at least in one station in seven EU States, mostly in urban and suburban areas of Eastern Europe (Fig. 2); while the PM_{10} limit value of the WHO AQG (i.e., 20 $\mu g/m^3$ annual mean) was exceeded in 27 EU States and 67% of the stations. The limit value for $PM_{2.5}$ of the WHO AQG (i.e., 10 $\mu g/m^3$ annual mean) was exceeded at 81% of the stations and 28 of the EEA-33 countries.

It is worth to note that the PM levels in rural areas without direct influence from anthropogenic sources (i.e., background concentrations) also exceeded the limit values in some countries in 2013. In particular, the daily PM_{10} limit value was exceeded in 2013 at several rural background stations in the Czech Republic, Italy, Poland, as well one station in Slovenia. The same occurred for $PM_{2.5}$ target value in 2013 at several rural background stations in Czech Republic, Italy, as well as on station in Romania. Between 2004 and 2013, a general reduction in emission of primary PM by transport and industry was observed, whereas commercial, institutional, and household sectors still are the most important emission sources of primary PM_{10} and $PM_{2.5}$, contributing to 43 % and 58 % of the total EU-28 emissions in 2013. In the EU-28, always in the same period, there was a reduction in emissions of the PM precursors (e.g., NO_x, SO_x, VOCs) much larger than the reductions in emissions of primary PM. Despite these reductions, an equivalent reduction in PM concentrations has not yet been observed due to the uncertainties in PM emissions data as well as to the contribution of the intercontinental transport of pollutants from outside Europe.

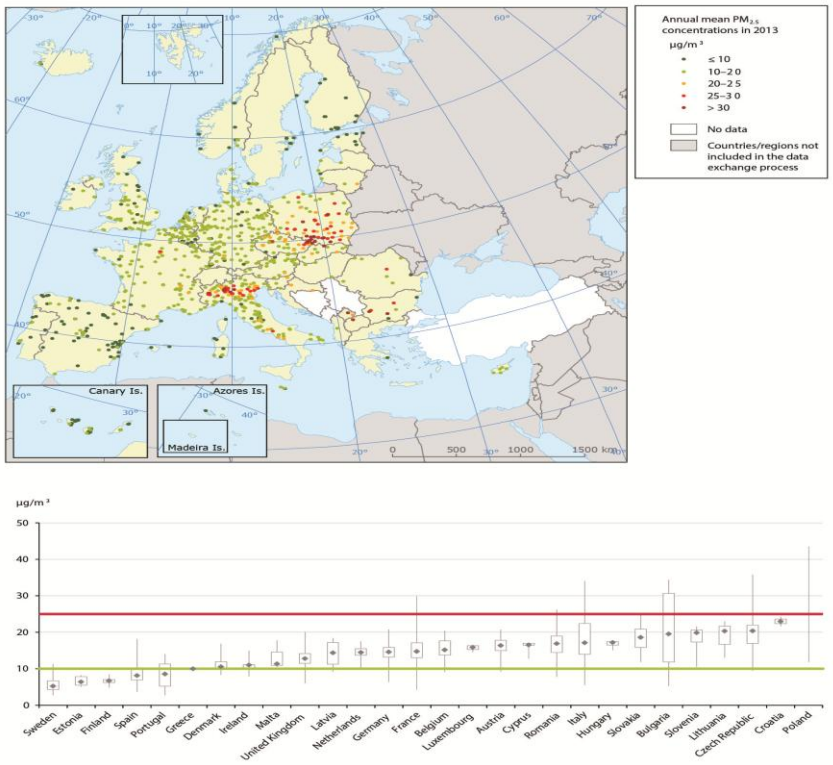

Fig. 2. a) Annual mean $PM_{2.5}$ concentrations in 2013 in Europe. The red dots indicate exceedances of the EU annual target value (25 µg/m^3).

The dark red dots indicated exceedances of the EU annual target value plus at least 5 µg/m^3. The orange dots indicate exceedances of the EU target value for 2020 (20 µg/m^3). The light-green and dark-green dots, respectively indicate values above and below of the WHO AQG for $PM_{2.5}$ (10 µg/m^3); b) attainment scenario for $PM_{2.5}$ in the EU-28 in 2013 based on the annual mean concentration values. The lowest, highest and median percentile 90.4 values at the stations are showed for each country in µg/m^3; the rectangles mark the 25 and 75 percentiles. The target values set by EU and WHO AQG are marked by a red and a green line, respectively; (modified after [16]; source: EEA Air Quality e-reporting database).

Always in 2013, about 17 % of the EU28 urban population was exposed to level of PM_{10} above the EU daily limit values. This percentage ranged between 17 % and 30 % in 2011-2013 and the 61 % of the same population has been exposed to PM_{10} concentrations above the WHO AQG annual limit (i.e., 20 µg/m^3).

About 9 % of the EU28 urban population was exposed to $PM_{2.5}$ level above the EU target value (25 µg/m^3 annual mean) in 2013, while the percentage ranged between 9 % and 14 % in 2011-2013. At the same time, between 87 % and 93 % of urban population was exposed to levels of $PM_{2.5}$ exceeding the WHO AQG limit (10 µg/m^3, annual mean) from 2011 to 2013.

At present an issue of great relevance is represented by long-range trans boundary air pollution, i.e., the transport over long distances of airborne pollutants by the atmospheric circulation [7,16]. In this framework, at present any country may simultaneously be producer and receiver. Actually, Europe is strongly affected by oceanic transport of PM. Studies performed in the last 25 years in the continent have shown that more than 50% of $PM_{2.5}$ originated outside the European boundaries [16]. Moreover, in the last century, the trans-continental transport of brown clouds becomes increasingly important [46].

4. Recent development and perspectives on PM monitoring

Despite the improved understanding and the development of innovative monitoring technologies, air pollution remains a relevant issue for the society and many aspects associated to airborne pollutants are far to be understood. Actually, air pollution is a dynamic phenomenon and pollutants concentrations are highly variable in space and time, especially in urban areas due to many concurrent phenomena. In addition, it is also evident that the operating monitoring networks based on static, gravimetric (and costly) devices are reliable but absolutely insufficient to assess the spatial and temporal distribution of PM in urban and sub-urban areas [20]. Static stations are also unsuitable to respond to environmental crisis also of natural origin (e.g., volcanic

eruptions, dust storm, etc.), among the most critical events that many countries are experiencing [47]. Moreover, the information provided by the available stations limit the resolution of the air pollution models and the reliability of air pollution forecast maps.

For these reasons, in the last decade we assisted to the development of the mobile monitoring concept based on compact devices with improved performance, reduced sizes, and portability with the goal to improve the spatial and temporal resolution of PM measurements [20,48,49,50]. At present, a wide typology of professional instruments is available for real-time monitoring of PM [37] and many cities worldwide are considering these mobile devices to monitor air quality for specific purposes, e.g., traffic management plan, feasibility studies. Moreover, thanks to the recent advancements of technology, a great number of small low-cost sensors with minimum power consumption have been made available. Their reduced cost and dimension allow collecting large datasets with high temporal and spatial resolution through the deployment of low-cost air sensor networks [51,52]. The majority of these low-cost sensors whose price ranges from tens to hundreds euro, are based on the principle of light scattering [53] and can detect particles down to 0.5 mm. The cheapest ones (e.g., Sharp GP2Y1010; Samyoung DSM501) need interfacing with an external microcontroller, whereas the medium-cost (few hundreds euros) sensors typically integrate microcontrollers (e.g., Shinyei PPD 20V and PPD 60 V; Alphasense OPC-N2)~~,~~ and are provided with dedicated softwares (e.g., Alphasense OPC-N2). Some of these sensors are also provided with a screen display (e.g., Dylos DC110; Dylos DC 1700). Recent tests have shown that low-cost sensors generally exhibits a rough agreement with expensive reference instruments [22, 54], whereas the most advanced ones, after an adequate calibration, may provide reliable PM concentration data [27].

In the last decade, the growth of the high-density urban areas in particular in Asia increased the demand of efficient and sustainable solutions in term of energy, transport systems, water consumption, law enforcement, and obviously of air quality monitoring. In this framework, the possibility to combine the information and communication technologies (ICT) with the Internet of Things (IoT) networking philosophy, is playing a key role in the transition of the European cities in *Smart Cities* [55]. In a *Smart City*, the urban infrastructures combine digital technologies and ICT-based solutions for a real-time assessment of several issues inside an urban infrastructure. As an example, the new technologies can be used to build wireless air quality networks providing real-time data on atmospheric pollution [56]. Data can be also easily made understandable to citizens through awareness systems. In principle, citizens could access to air quality information by smartphones and tablets receiving recommendations in order to reduce the exposure, e.g., by selecting less polluted routes [57]. At present, several research projects are devoted to developing new devices to monitor and visualize air quality data (e.g., Every Aware, Opensense, City sense MOB). In this scenario each citizen may become a potential source of data using a smartphone or a tablet: for example, small add-ons can be used to turn the mobile-device into an optical sensor to measure aerosol particles (http://ispex-eu.org/). Nowadays data are easily shared in cloud-services and/or social media platforms due to the existing capabilities. In summary, the unavoidable future target of air quality monitoring is certainly associated to the possibility to share high-density information in real-time within a social-like network frame based on low-cost sensors and small portable devices [58]. However, the openness of participatory monitoring has also risks such as the distribution of erroneous or inexact information, which may generate alarm and/or panic or corrupted data. Missing or poor quality data may also affect the retrieved information that – speaking about pollution - has to be considered sensitive. Models and algorithms are continuously developed to identify, manipulate and recover missing data [59-61].

In addition to the benefit to make available the PM concentration in the air in real-time, it is mandatory monitoring the morpho-chemical properties of single particles to assess the effects of the different components of PM on the human health. Most of the toxicological and epidemiological studies focus on a single fraction of PM (e.g., PM_{10}, $PM_{2.5}$) rather than on dependence of health effects of the particles size and its chemistry concurrently. This issue is still debated in the case of asbestos and other fibers although many studies have shown that dimension, durability and dose of fibrous particles are key parameters with respect to their pathogenicity [62,63]. With this respect, it is worth to underline that the most recent industrial developments are releasing in the environment large amounts of a new class of UFP (nanoparticles, carbon nanotubes etc.) whose effect on the human health is still largely unknown [64, 65]. Moreover, the nanostructure-dependent biological activity differs from, and is not always directly related to, the bulk properties of the constituent chemicals and compounds. Therefore, the future EU policies on air quality have to consider and include also the monitoring of UFPs to assess role and their contribution to the air quality. Accordingly, besides the monitoring of the concentration of the different fractions of PM, morphology and chemical characterization of the particles is crucial for evaluating the potential health risks [61,66,67]. The chemical characterization of airborne particles, e.g., major and trace elements, isotopic analysis, spectroscopic analysis, may eventually allow the identification

of the natural and anthropogenic sources of particulates as well as PM tracing in the environment [68, 21, 69, 26, 70]. At present, neither the chemistry nor the morphology of PM is adequately monitored by national environmental authorities because of difficulty, high cost and long time required for the analysis. However, the chemistry and morphology of PM are crucial information for a careful assessment of the health risks for the population. The development of monitoring devices able to carry out chemical analysis in near real-time is foreseen [71]. Actually, it will allow to achieve a better assessment of the health risks associate to the air quality in particular areas as well as to identify both the natural and the anthropic sources of pollution.
Another further requirement is represented by the improvement of the present emission inventories that may foster more effective solutions to many of the existing and future air quality issues and respond also to the transnational issue of the air pollution monitoring. To this purpose, the emission inventories should include species so far ignored such as heavy metals, isotopes, and intermediate volatility organic compounds (IVOCs), which are an important class of secondary organic aerosol precursors, which greatly contribute to many chemical processes involving PMs [12].

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