Report on recommendations for adaptation and mitigation strategies.

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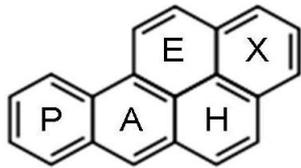
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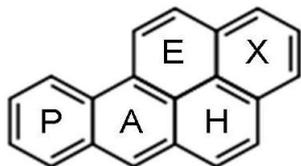
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Summary

Introduction

The present report summarizes the main conclusions and recommendations for adaptation and mitigation strategies identified by the LIFE+ EXPAH project to reduce the population exposure to Polycyclic Aromatic Hydrocarbons (PAHs). After a brief description of the state of art of PAHs, in terms of regulation, sources, known exposure, health effects and recent results from literature, evidence from the EXPAH project are presented. Then recommendations for EU policy on PAHs and possible adaptation and mitigation strategies at different levels are given.

1. State of art on Polycyclic Aromatic Hydrocarbons (PAHs): policy and regulations

1.1. Regulation

Polycyclic Aromatic Hydrocarbons (PAHs are carcinogenic and mutagenic pollutants, typically affecting urban areas, produced by incomplete combustion of organic substances (Kameda et al., 2005). PAH heavy congeners are air contaminants bond to fine particulate matter for their prevailing mass fraction.

The national policies concerning PAHs are regulated by the Directive 50 released in 2008 (Directive 2008/50/EC of the European Council and Parliament of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe. Official Journal of the European Union L152/1, 11.6.2008). In particular, Italy adopted the Directive in 2010, through the Legislative Decree no. 155 (Decreto Legislativo 13 agosto 2010, n. 155. Attuazione della direttiva 2008/50/CE relative alla qualità dell'aria ambiente e per un'aria più pulita in Europa. Gazzetta Ufficiale della Repubblica Italiana, 15 September 2010, Suppl. no. 217L). For PAHs, the air quality must be estimated through benzo[a]pyrene, which is overall associated to fine and ultrafine particles and is recognized as certain carcinogen (it is listed in Group 1 according to IARC classification). This approach, although affected by some uncertainty, is commonly accepted because B[a]P is the most potent carcinogenic component of the group (except for dibenz[a,h]anthacene and dibenzopyrenes that occur at much lower extents), and the percentage distribution of PAHs is expected fairly constant with time and space. The concentration limit is equal to 1.0 ng/m^3 of B[a]P, calculated as mean annual concentration at a set of sites representing as a whole the real exposure experienced by population. The sites and time schedule of PAH measurements are established by European Countries according to distribution of population over the territory, and taking in account the influence of weather and seasonality. In Italy, ten sites have been chosen in nine cities (two in Milan), where the measurements will cover at least 126 days per year, and three sites in rural areas (51 days); there, six other "carcinogenic" PAHs must be investigated, to check for possible modulations of the PAH signature in the airborne particulates, regulated by year time.

In highly urbanized areas, mobile sources and domestic heating are usually regarded as the largest contributors of PAHs, with diesel fuelled vehicles emitting much more particulate than
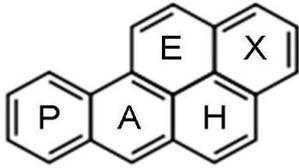
gasoline fuelled cars (Zhang et al., 2009; Ravindra et al., 2008). At this regard, according to monitoring campaigns performed in many European countries including Italy, the PAH concentrations show a negative trend over the last decades, due to availability of new technologies that have abated the emissions from industries, power and heating plants and vehicles; moreover, new regulations have promoted the recycling of materials and the heat recovery. Nonetheless, nowadays this trend seems to show a reverse direction as a consequence of the increase of emissions released by burning devices fuelled with biogenic or low-cost matter (wood and its derivatives). B[a]P is still considered a problem in Europe, even increasing nowadays in areas where wood or coal are used for house heating (EEA, 2013). This trend has been further emphasized by the effects of the ongoing economy crisis. The impact of the increased non-industrial emission sources turned out to have major relevance and their impact is far to be reliably accounted for.

As regards the assessment of PAH toxicity on the basis of the sole B[a]P, it must underlined that: i) different PAH emissions show different fingerprints all comprising B[a]P, thus this latter as alone is insufficient recognize the pollution source nature ; ii) the choice of the only B[a]P to index the PAH-associated toxicity highlights the carcinogenicity, but omits other adverse effects are associated with PAHs overall, e.g. mutagenicity; and iii) synergistic or antagonistic effects of the individual PAHs and the particulate substrate are neglected.

1.2. Sources

The sources of air pollution affecting the cities are known since long time; they are private and public transport (vehicles), house heating and cooking, waste burning and, at minor extent, industry and small enterprises. Nonetheless, the relative importance of these sources changes as technology and society habits change. In addition, the impact of external sources (e.g., biomass burning and forest fires, agricultural activities) grows as soon as control and abatement of toxic emissions are imposed by European Normative to other sectors of production.

Thus, the understanding of the air pollution sources in the urban domains is crucial to promote efficient policies and actions aimed at preserving the human health and the whole environment of life. At this regard, a major approach followed by scientists is the source apportionment of pollution. The source apportionment is comprised of the analysis of measured concentrations of air contaminants and of the application of receptor modeling techniques. Receptor models are usually based on the application of Chemical Mass Balance; the sources emission profiles must be known a-priori, or identified a-posteriori using Positive Matrix Factorization techniques. In particular with regards to PAHs, the distinct molecular fingerprints of sources can be used to characterize emissions if measurements of sufficient congeners are available. The source apportionment can be alternatively realized using deterministic modeling techniques, when provided reliable emission inventories are available with regard to the targeted territory.
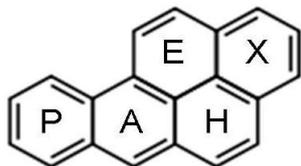
The use of molecular fingerprints to recognize the PAH sources has been applied since '80s of the last century. Unfortunately, specific PAH congeners have not been still identified for any source, and each combustion process releases into environment tens of PAH compounds. Thus, two different approaches have been attempted, the former based on examining the whole profile of the group (percentages vs. total PAHs or relative abundances normalized vs. a reference compound), and the latter consisting of a selection of concentration ratios (DRPAHs), typical and "diagnostic" for both the source nature and operating conditions.

Two problems are typically encountered when the PAH concentrations are investigated in the urban air. First, the wide difference between the concentrations detected in the winter and in the other seasons, with higher levels in winter. The difference covers about one order of magnitude, and is even higher considering the coldest period of the year, when heating plants run at 100% rate. This pattern is only in minor part induced by the meteo-climatic conditions prevailing in the two seasons, since other contaminants (e.g. suspended particulates) are only two to three times more abundant in the winter. Second, the technical literature about this topic is quite old, lacking investigations on molecular signatures of biomass burning and new vehicles, boilers and waste treatment plants, so that the DRPAHs values known seem unable to assign unequivocally PAHs to specific sources; this is especially true for domestic heating. The misinterpretation of the results can be induced also by the overlapping of ranges observed for DRPAHs, atmospheric oxidants that can attack the reactive compounds (e.g., B[a]P), and the change of source profiles with time.

To solve this problem, the study of PAH fingerprints for several emission sources should be conducted with two objectives: i) chose persistent and low-volatile PAH compounds; ii) revise the values or ranges proposed by literature for the classical DRPAHs; and iii) improve the list of monitored PAHs, identifying new DRs specific for any source.

1.3. Known exposure at EU level

According to Jedynska et al. (2014), who conducted a PAHs monitoring study in ten areas across Europe, PAH concentrations exhibited similar concentrations in southern and northern regions. Higher concentrations were measured at street locations in comparison to urban background and regional background locations. Yearly averaged values range from 0.1 to 0.2 ng/m^3 for B[a]P and from 1.0 to 2.0 ng/m^3 for PAHs. Strong seasonality was revealed in all regions. A highest cold to warm ratio was found for PAH with median of 4.46 (2.80 – 17.8). Furthermore, PAHs concentrations showed for all study areas higher variation within area than between study areas. According to analysis of the ratios between concentrations of selected pairs of PAHs compounds (see DRPAHs in &1.2), the main PAH sources are traffic emissions (diesel vehicles and gasoline fuelled cars), and an important contribution is associated to wood burning, overall in regional background stations. The identification of PAHs sources seems to indicate that PAH sources other than traffic including domestic heating activities act seasonally.
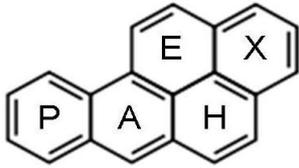
The above results confirm those presented in "The Air quality in Europe — 2012 report" (Guerreiro et al. 2012) where the annual average of B[a]P in Europe are presented. They found that B[a]P did not exceed concentration of 1 ng/m^3 in the same studied areas. There was also no north to south trend in B[a]P concentrations, but there was a trend from west to east with the highest B[a]P concentrations in central and eastern Europe.

1.4. Known Health effects

Benzo[a]pyrene (B[a]P) has been classified as carcinogen for humans (group 1) by IARC in 2012. Some other PAHs have been identified as probable (Dibenz[a,h]anthracene and Dibenz[a]pyrene, in 2010) or possible (Benz[a]antracene, benzo[bjk]fluoranthene, benzo[c]phenanthrene and indeno[1,2,3-cd]pyrene, nel 2010) carcinogens for humans. Among the evidences supporting this assessment there are experimental and human toxicology studies which identified PAHs as the active components (mutagenic, genotoxic, embriotoxic) of air particles (Farmer Mutagenesis 1996; Binkovà MutatRes 2003; Rossner MutatRes 2007; Sevastyanova MutatRes 2008) as well as studies of molecular and occupational epidemiology which identified both the PAH biomarkers of exposure via air pollution (Farmers, MutatRes 2003; Sørensen MutatRes 2003; Pedersen MutatRes 2006; Singh MutatRes 2007; Taioli MutatRes 2007; Rossner MutatRes 2008) and the PAHs effects on respiratory and urinary tract cancers in occupationally exposed subjects (Nadon et al AmJIndMed-1995; Porru et al. G Ital Med Lav Ergon. 1997, Rota et al. Arch Toxicol. 2014).

Since the carcinogenic potentials of PAH in humans are known and the PAH fraction is trapped in fine and ultrafine particles as the most active component, the scientific research is focused on the PAH effects at low-to moderate exposure levels and health effects other than cancer. The most relevant evidences can be summarize as follows: Lewtas et al. (Lewtas J, 2007) identified PAHs as the cause of oxidative DNA damage, leading in turn, to reproductive and cardiovascular effects of $PM_{2.5}$. A non-linearity with decreasing DNA adducts in people exposed via air particles at high PAH levels was reported since 1997 (Lewtas Mutat Res. 1997). A similar relationship between PAH and lung cancer was confirmed more recently (Armstrong, OEM, 2009), despite the difficulties to identify PAH exposure biomarkers in people exposed to moderate-to-low levels in outdoor air pollution (Kyrtoupoulos, MutatRes, 2001; Vineis, Carcinogenesis, 2005). Temporal variations with much higher "in vitro" biological effects (DNA adducts) have been reported in cold seasons (Binkovà MutRes,2003; Sevastyanova MutatRes 2008;).

Among other possible health effects, the more important are intrauterine growth restriction, bronchitis, asthma and asthma-like symptoms, fatal ischemic diseases, neurodevelopmental problems (WHO GL sected poll 2010). Nonmalignant mortality has been reported to PAH exposure in workers (Burstyn Epidemiology 2005; Merlo OEM 2004; Romundstad ScandJWEH, 2000; Moulin IArchOccupEnvHealth 2000). Increases of infant mortality, intrauterin growth retardation, difficulties of neurocognitive development in early child (Jedrychowski
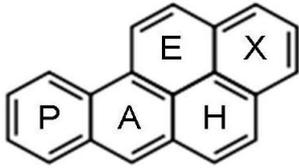
IJOccupMedEnvHealth 2003; Sram, IJHEH, 2013) were found to be associated with prenatal exposure to PAH, while early childhood respiratory diseases were found to be associated with early exposure to PAH (Hertz-Picciotto, EHP 2007; Le HEI-RR-2012).

## 1.5. Recent results from research activities

The recent literature about PAHs exposure and its health effects highlights the importance of biomass combustion for heating and cooking (Ozgen et al., 2014; Fuller et al., 2014;Shen et al., 2013, 2013b; Pizzalunga et al., 2013; Giannelle et al., 2013). Various authors have analyzed different aspects of biomass combustion from domestic appliances. It has been estimated that residential wood combustion contributes nearly 10% of the total PAH (12 PAHs) at background monitoring stations in Greece and Croatia and about 50% of total PAH in Sweden (Mandalakis 2005). In Turin and Susa in Italy, the contribution of wood combustion to B[a]P levels was about 60% during winter time (Piazzalunga 2013). Fuller et al. (2014) show how the amount of PM_{10} pollution emitted by wood burning was greater than the reductions achieved through the first two phases of London's Low Emission Zone programme. The impact of economic crisis on air quality in Thessaloniki, Greece, was found by Saffari et al. (2013) to be related with an increase of biomass burning. They found the total concentration of the 13 PAHs in 2013 increased 5-fold compared with 2012, underscoring a significant increase in combustion-related sources during the current year (2013), most likely driven by increased wood combustion for residential heating purposes. In addition to wood-burning emissions from households there is also a more global contribution from biomass fires (likely from agricultural and wild fires) to be seen even at distant background stations and over the oceans (Hu 2013).

Indoor PAHs exposure is another field of studies (Sangiorgi et al., 2013, Romagnoli et al., 2014). The authors highlighted the PAH exposure in different working and living environments, presenting peculiarities and differences. Wood combustion was found to be responsible for high indoor PAHs concentrations. The levels of B[a]P and several other PAHs were found to be significantly higher (3 to 5-fold) in homes with wood combustion appliances compared to homes without (Gustafson 2008).

Other recent papers address local air quality problems mainly related to local emission sources. An example is the contribution of a large steel facility located close to an urban area (Amodia et al., 2013).

Recent studies on health effects of PAH address cardiovascular damages related to PAH exposure. Increase in cardiac mortality related to PAH in heavy exposed workers (Costello AmJIndMed 2013; Friesen AmJEpidemiol 2010) and cardiac autonomic dysfunctions from occupational exposure to PAH have been reported (Lee, OEM 2011).
Reproductive effects, related to both perinatal outcomes and life-course effects in children, continue to be addressed with particular interest on maternal exposure during pregnancy. The most important results, though the evidence is only prelimanary, can be summarize as follows. Anthropometric measures, such as placental weight and cord length (Al-Saleh SciTotEnviron 2013) as well as small for gestational age offspring (Langlois Occup Environ Med. 2014) are influenced by PAH exposure. In the National Birth Defects Prevention Study, a large
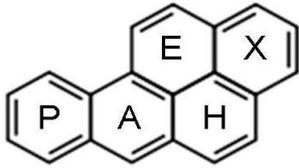
population-based prevention study carried-out in the USA, maternal occupational exposure to PAHs increased the risk of congenital heart defects (Lupo Birth Defect Res A Clin Mol Teratol 2012), neural tube defects (Langlois Birth Defect Res A Clin Mol Teratol 2012) and gastroschisis (Lupo EHP 2012) among offspring. Neurobehavioral impairments emerged in children of exposed mothers, specifically symptoms of anxiety/depression and attention/intelligence problems at age of 5-7 years were reported (Perera EHP 2012; Edwards EHP 2010).

2. Evidence from EXPAH project

2.1. PAHs concentration results Indoor and outdoor

Citizens are exposed to PAHs during the whole day. PAHs are released both indoors and outdoors by a list of sources. They penetrate indoors due to air exchange. Exogenous PAHs are driven inside by fine airborne particles and add to those generated by indoor activities. Living environment such as houses, schools, offices and public and private transportation vehicles are affected by an indoor air contamination of PAHs, like benz(a)anthracene (BaA); benzo(b)fluoranthene (BbF), benzo(j)fluoranthene (BjF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (B[a]P), indeno(1,2,3-cd)pyrene (IP); dibenz(a,h)anthracene (DBahA), benzo(g,h,i)perylene (BPE), the magnitude of which depends mainly on outdoor pollution, but also by indoor resuspension and generation by fireplace, cooking and smoking. The heating sources, in general, are also responsible of a seasonal variation of PAHs environmental pollution. Other variables affect the entity of PAHs indoor contamination: indoor temperature, pressure, air exchange capacity. The presence of cooking sources and/or smokers contribute to the indoor emission of PAHs. The EXPAH results show that the indoor PAHs levels are about one order of magnitude higher in winter than in spring/summer period; but indoor levels were lower than the outdoor ones in all seasons, as showed in Figure 1.
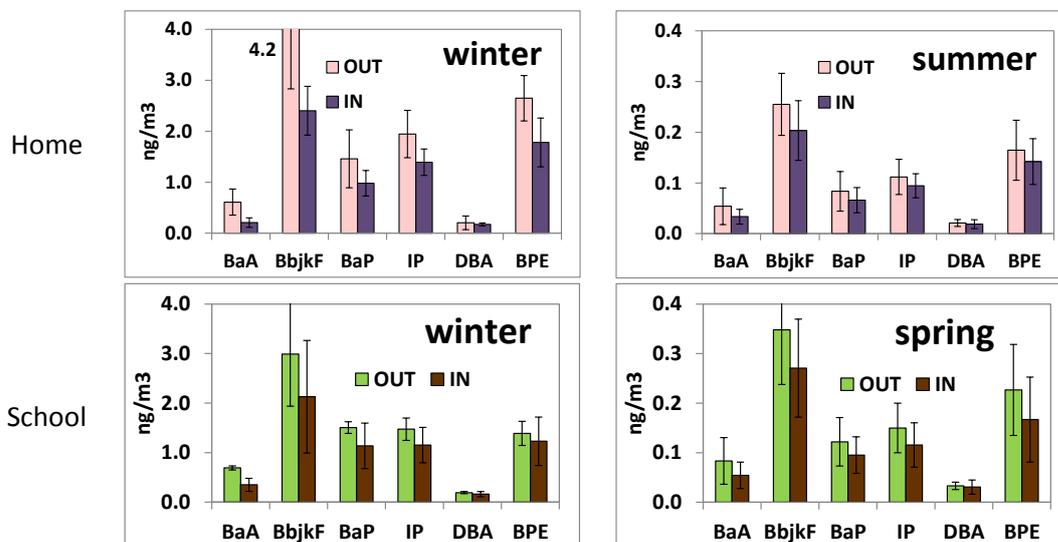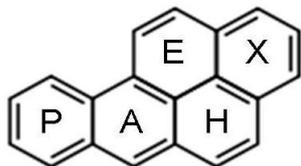

Figure 1. Average airborne PAHs observed at homes and schools.

For the indoor environment, on average, the sum of eight carcinogenic PAHs, BaA, BbF, BjF, BkF, B[a]P, IP, DBahA, plus the mutagenic BPE, reached the values shown in Table 1.

Table 1. Total PAHs average concentrations (ng/m^3) measured in indoor living environments.

	Home	school	Office
winter	5.2	6.1	5.0
spring/summer	0.62/ 0.39	0.58/ 0.46	0.43

The most toxic PAH, benzo(a)pyrene, (B[a]P), is usually well below the European guideline (1 ng/m^3) in the warm season whilst during winter 1.0 ng/m^3 is exceeded even indoors.

In other living environments such as vehicles (Figure 2), the average total concentration of target PAHs was 4.11 ng/m^3 inside buses during winter, and 0.67 ng/m^3 in summer. Cars showed 4.67 ng/m^3 of PAHs inside during winter, and 0.64 ng/m^3 during summer. During the winter the in-vehicle B[a]P level can exceed the guideline value of EU Air Quality.
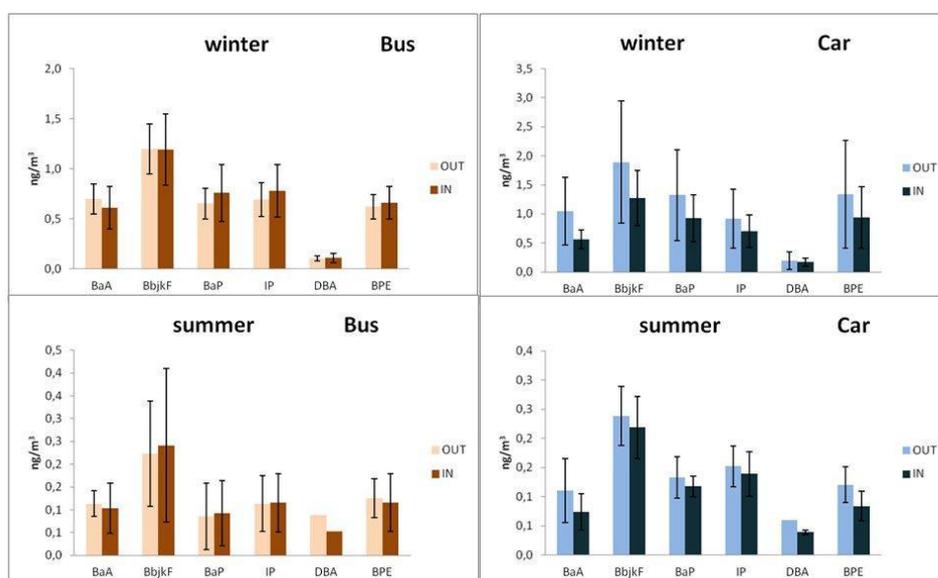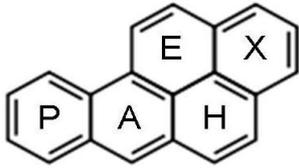

Figure 2. Average airborne PAHs observed on buses (D) and cars (E).

According to our study at schools, offices and homes the PAHs concentrations are lower indoors compared to outdoor, but they never approach zero: so, even in indoor environments

without direct sources of PAHs (i.e. cooking and smokers), like schools and offices, building barriers do not protect from pollution. The citizen resulted exposed to particle-bound PAHs in indoor transport vehicles too. Moreover, in the EXPAH study the PAHs levels resulted about one order of magnitude higher in winter than in spring/summer both in indoor and outdoor environments.

2.2 Analysis of PAH exposures and sources

A PAHs emission inventory, including four compounds (B[b]F, B[k]F, B[a]P and I[123-cd]P), has been built for Lazio Region. Emissions from road transport have been estimated from traffic fluxes and from the circulating fleet on the regional road network, while the other sources emissions have been derived from the Italian national emission inventory.

Domestic heating was estimated to be responsible for 96% and 32% of PAHs and PM2.5 emissions, respectively. Within the domestic heating systems the main source of both components is biomass combustion (99% and 91% of PAHs and PM2.5, respectively).

Emission inventory was used as an input in an advanced air quality model (FARM), including PAHs chemistry, to estimate spatial and temporal variability of outdoor concentrations at 1 km resolution. Yearly averaged PM2.5 concentration field shows that the European limit value of 20 µg m-3 is exceeded over a large fraction of Rome conurbation, while annual average B[a]P concentration does not exceed the 1 ng m-3 limit value. However, daily concentrations during the winter exceeded the limit value.

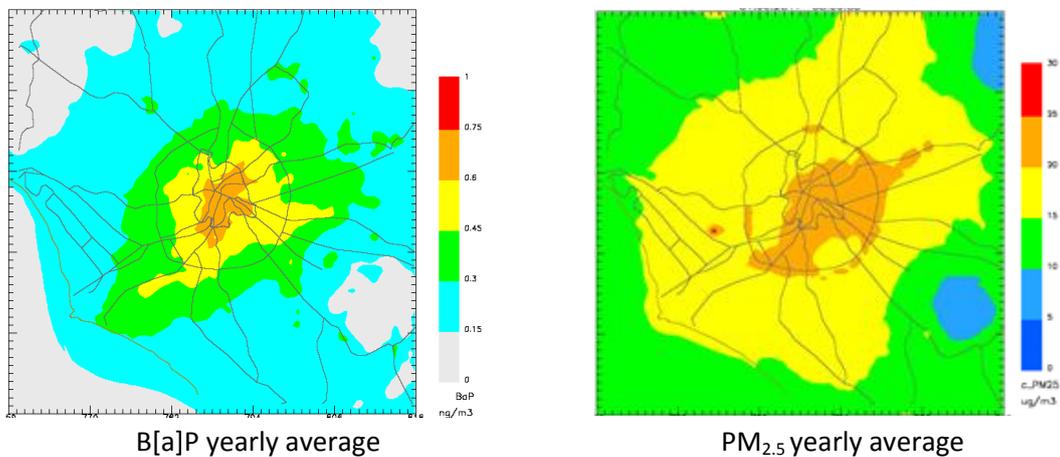| B[a]P yearly average | PM$_{2.5}$ yearly average |

Figure 3. Spatial patterns of benzo[a]pyrene and fine particle concentrations in 2011 in Rome.

Exposure levels were measured in the main indoor and traffic environments of school children and the elderly. Results show a strong seasonality of exposure to PAHs which is higher during colder seasons. This occurrence is attributed to high emissions coming from domestic heating. Less relevant seasonality has been found in exposure to PM$_{2.5}$.
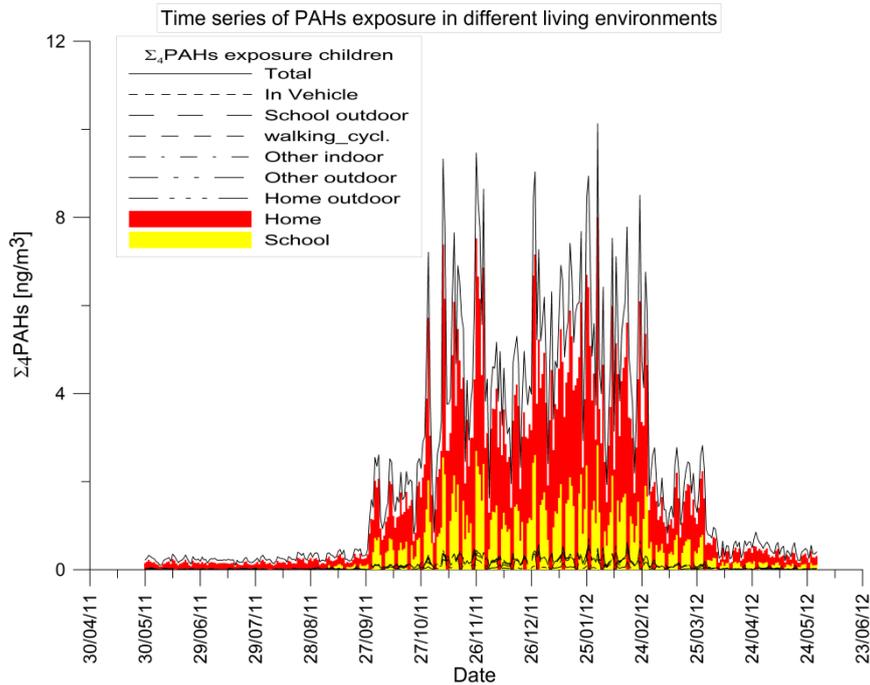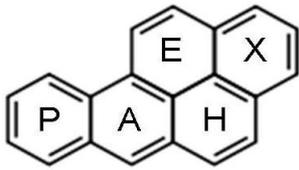
Figure 4. Time series of PAHs exposure in different living environments

Most important microenvironments were homes for the elderly and homes and schools for the children. Exposure levels in different microenvironments, including traffic, were comparable and the most striking difference was between indoor and outdoor levels: in indoor environment 20-50% of the outdoor particles and PAH compounds are filtered by the buildings.
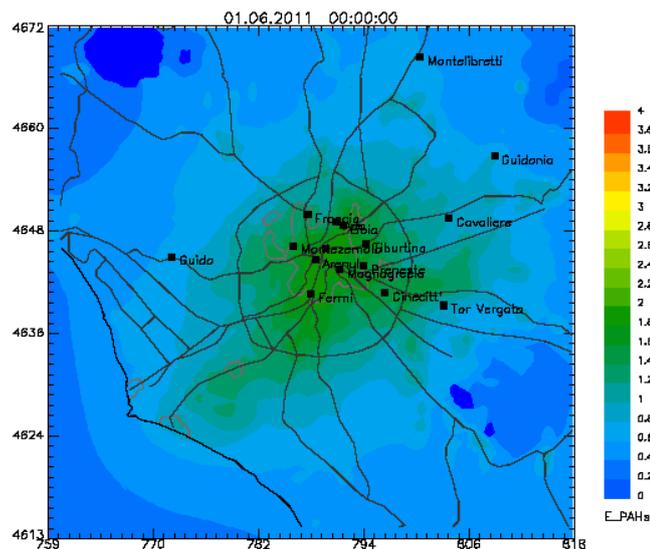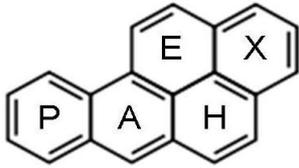

Figure 5. Map of annual children PAHs exposure in the city of Rome

Spatial distribution of exposures were calculated by combining microenvironment data and ambient air quality models results (Figure 5). Annual mean exposure of the children was lower

than 2±1ng/m^3 and 0.5 ±0.2 ng/m^3 for PAHs and B[a]P, respectively. The legal limit of 1 ng/m^3 for B[a]P is not exceeded. Annual mean exposure to PM$_{2.5}$ shows values lower than 20 μg/m^3. A significant portion of population (90%) is exposed to concentrations higher than WHO guideline limit set on 10 μg/m^3. This result demands for implementation of mitigation strategies.

B[a]P exposure profile of children living in Rome

PAHs exposure profile of children living in Rome
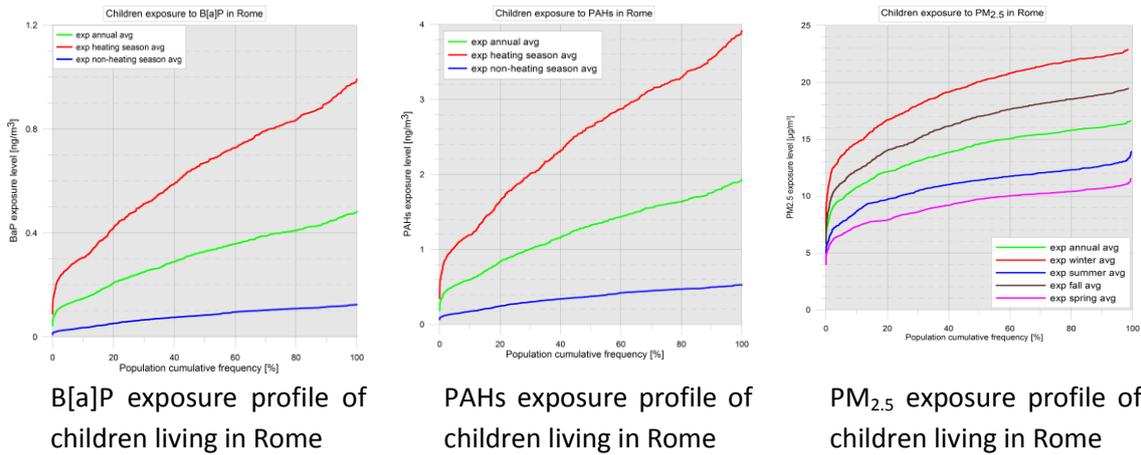
PM$_{2.5}$ exposure profile of children living in Rome

Figure 6. Population B[a]P, PAHs and PM$_{2.5}$ exposure profiles for children living in Rome.

In order to evaluate the effects on air quality and health of the expectable future variation of pollutants emission, two different scenarios for year 2020 have been considered: a Current Legislation (CLE) scenario based on GAINS-Italy project results and an Additional Measures (AME) scenario adding to CLE the substitution of biomass with natural gas for domestic heating as a possible effective action. The CLE scenario includes the implementation of all the abatement measures expected by legislation already in force.

A general reduction of 2020 emissions with respect to 2009 reference values was obtained for all pollutants but PAHs, which shows an increase of 38%. The growth of PAHs emission is largely influenced by domestic heating and mainly due to the expected increase of wood combustion contribution. As for AME scenario, a reduction of PM2.5 emissions of about 45% and PAHs emissions of more than 90% was found.
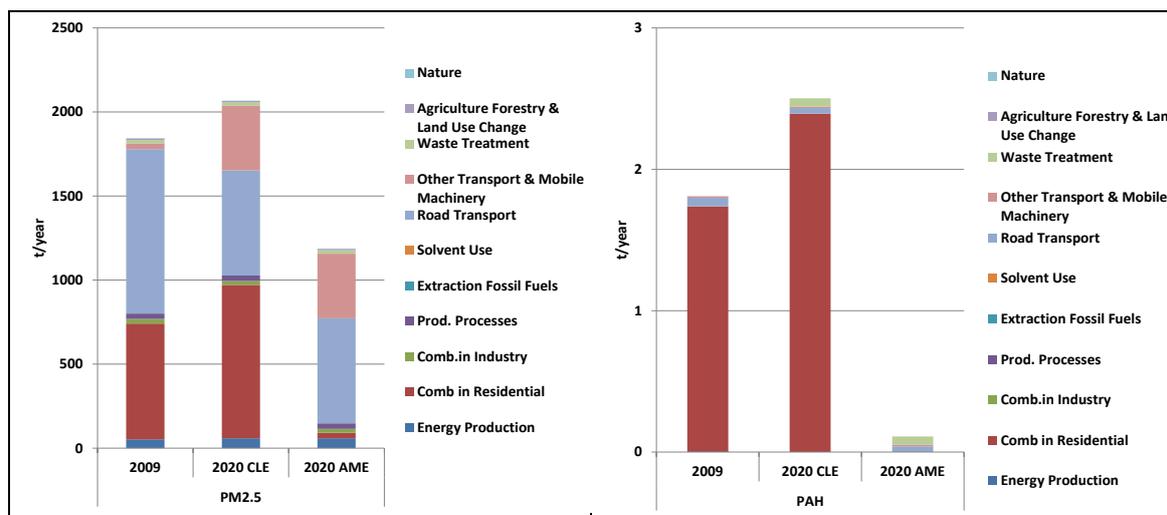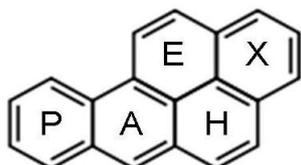
Figure 7. Emission Scenarios: reference (2009); current legislation (2020 CLE); additional measures (2020 AME).

The following table summarizes the results obtained when the above mentioned emission scenarios are used to evaluate their effects on ambient concentrations through air quality simulations:

Table 2. Expected variation of the average concentrations in the future scenarios with respect to year 2011-2012.

	2020 CLE scenario	2020 AME scenario
NO_x	-26%	-26%
$PM_{2.5}$	-7%	-17%
B[a]P	+24%	-66%

A relevant reduction of NO_x concentrations is expected due to the emission reduction from the transport sector. The $PM_{2.5}$ reduction in the CLE scenario is limited by the growth of the heating sector emissions that partially counterbalances the transport sector reduction, as confirmed by the relevant improvement obtained by the AME scenario. B[a]P would grow in CLE scenario, while a strong reduction is foreseen in the AME scenario.

Consequently, in absence of additional interventions, the impact on ambient air of future emissions are expected to exacerbates the PAHs concentrations. Only the substitution of biomass with natural gas would produce a significant reduction of PAHs levels.

2.3 Health effects

The association between exposure to PAHs and human health in Rome was investigated. The short term effects were studied by relating daily deaths and hospitalizations to daily variations in PAHs. We also studied the long-term effects by considering the geographic distribution of PAHs in Rome, and relating it to the addresses of adults residents in the Rome Longitudinal Study from 2008 to 2012. In both cases, we found clear evidence of association between PAHs exposure and mortality.
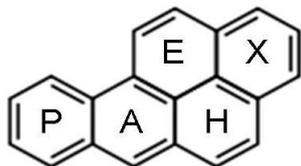
We estimated a 3.1% increased mortality for 1ng/m^3 variation in PAHs exposure occurring 2 to 5 days before deaths, with evidence of linearity in the dose-response association. Results on cardio-respiratory mortality or hospital admissions were less clear.

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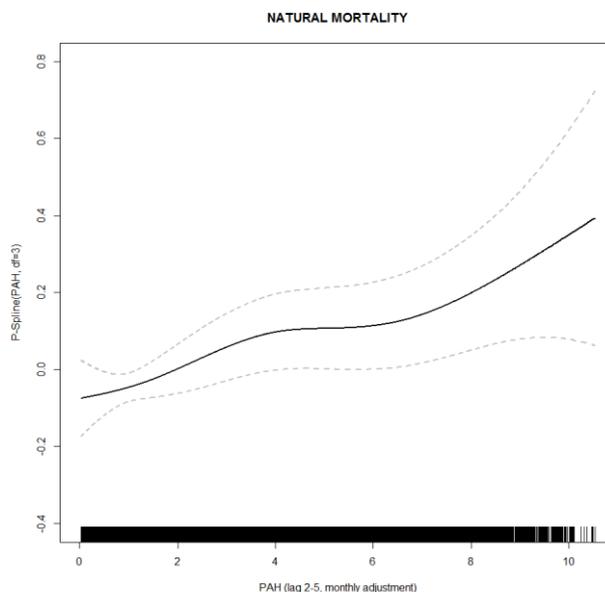
For each increase of 1ng/m3 in PAHs exposure there was a 4% higher risk of dying for non-accidental causes and for cardiovascular causes, and a 8% higher risk of lung cancer. There was some evidence of an association between long term exposure to air pollution and stroke.

3. Proposal for EU policy on PAHs, national and regional implications and recommendations

3.1 Modification of EU regulation on B[a]P limits and PAHs monitoring

The observed PAHs levels in urban areas have been found to be characterized by high seasonality with large differences between heating and non-heating seasons. During cold seasons, high concentration of PAHs were both observed and modeled. The current EC air quality standard for B[a]P, based on annual mean value, seems to be unable to represent a safe limit for health protection, as high winter PAHs concentrations are compensated by the one order of magnitude lower values occurring during the summer.

Consequently a shorter time average period would better represent the actual exposure level of population. A monthly value of B[a}P concentration is recommended. A revision of the EC directive 2008/50/EC is consequently suggested.

Furthermore, the prescribed minimum temporal coverage of PAHs sampling and analysis adopted by environmental authorities (33%) seems to be unable to monitor the high temporal variability observed in PAHs levels. High peak of PAHs concentrations can be lost by this sampling frequency, underestimating the actual exposure of population. Consequently, an extended period of PAHs sampling is recommended for PAHs monitoring.
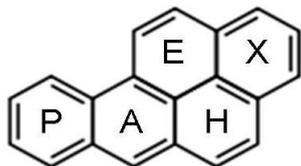
3.2 Emission policy and biomass regulation at national and regional level

Evidences from the EXPAH project indicate biomass combustion as the most important PAHs emission sources in the metropolitan area of Rome. When used as domestic heating system, wood produces large $PM_{2.5}$ and PAHs emissions with a low heat production efficiency, especially if traditional stoves are employed. The increase of selling domestic heating systems based on pellets, together with the use of traditional stoves and fireplaces as secondary heating systems, has increased the problem. Consequently, the use of biomass for domestic heating should be regulated and possibly reduced at regional and National levels. In principle, for environmental and efficiency reasons, it should be substituted with natural gas. Revision of the regional air quality intervention plan (D.C.R. n. 66/2009) is suggested. Alternatively, low emission high quality biomass burning system should be used in addition to recommendations on their proper use and maintenance. Research in the field of ultra low dust technologies, high efficiency and clean combustion system is needed.

An important aspect to be highlighted is the large uncertainty affecting the estimation of PAHs emissions, particularly for biomass combustion used in domestic heating. An effort is needed to reduce this uncertainty. National, Regional or local environmental agencies should improve this estimation by collecting raw data or identifying proper proxy variables.

### 3.3 Short term and long term plans, transport and heating system plans at local level

The major air quality problem affecting Rome conurbation is connected to particulate matter concentration in both its fine and coarse component. It is therefore advisable to address local measures to the possible reduction of PM emissions. Transport and residential heating are the sectors accounted for the larger contribution to PM emissions in Rome. Improving Rome public transport and regulation of diesel vehicle can be identified as the most promising measures. The knowledge of the transport system and of its pollutant emissions in Rome is up to date, being based on traffic modeling and bottom-up emission estimate.

Improvements are possible for residential heating emissions. A large number of public and private building are heated by gasoil fired boilers that could be substituted by more efficient and less polluting gas fired heating systems. The increase of use of biomass for house heating should be estimated to detect the areas more affected. Information campaigns and regulations could be promoted to reduce this fuel inside Rome metropolitan area. The promotion of economic incentives to substitute biomass with greener fuels could be considered.

Measures concerning residential heating are expected to be the most effective to reduce PAHs concentrations in Rome area.

3.4 Recommendation for reduction of indoor concentrations and exposure

Findings of the EXPAH project highlight the presence of PAHs in the normal living environments. They are mainly caused by infiltration from outdoor air. Main risk reduction should therefore target improvement of outdoor air quality, especially consideration for cleaner biomass combustion technologies and use of alternative energy sources.
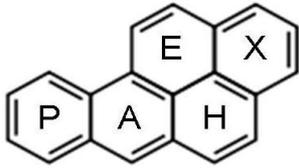
Substantial indoor sources were not identified in the study, although it is well known that perfumed candle and wood ovens (cooking), fireplace are possible indoor sources. Re-suspension of indoor particles with a likely outdoor origin represents another possible indoor source.

Northern Europe experiences highlight the possible use of filtered ventilation systems to reduce the impact of infiltration from outdoor air. Interventions on building structures to reduce the penetration efficiency and increase the air exchange and deposition rates might produce improvements in indoor air quality. Furthermore, the use of domestic facilities able to produce indoor emissions (e.g., fireplaces, candles) should be limited or properly used.

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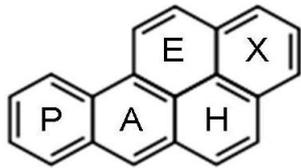
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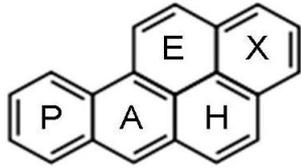
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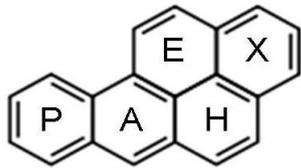
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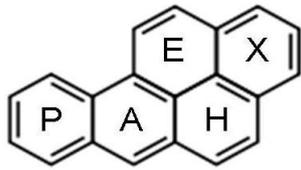
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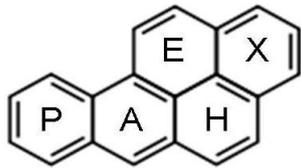
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