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A COMPARATIVE ANALYSIS OF THE CAUSES OF AIR POLLUTION IN THREE CITIES OF THE DANUBE REGION

IMPLICATIONS FOR THE IMPLEMENTATION OF THE AIR QUALITY DIRECTIVES

Claudio A. Belis, Emilia Georgieva, Osan Janos, Kresimir Sega, Szabina Török, Blagorodka Veleva, Maria Grazia Perrone, Stergios Vratolis, Denise Pernigotti, Kostas Elefhteriadis

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Abstract

The causes of air pollution in three cities of the Danube region (Budapest, Sofia and Zagreb) were studied using datasets of measurements and modelling tools. It was observed that most of the pollutants are emitted locally. However, the medium to long range transport may be also considerable. On the basis of the output of the source identification, a series of measures were proposed to deal with the pollution problem at local, national and international levels.

A comparative analysis of the causes of air pollution in three cities of the Danube region

- *The causes of air pollution in Budapest, Sofia and Zagreb were analysed.*
- *The picture resulting from this study highlights the complexity of the pollution processes*
- *The main sources of gaseous pollutants are large combustion plants and heating systems.*
- *Local sources of particulate matter are biomass burning, re-suspension of dust and traffic exhaust.*
- *Flexible and multilevel measures are needed to improve the air quality in the Danube region's cities*

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Executive summary

Policy context

The Danube region includes one of the air pollution "hot spots" in Europe. Supporting the development of a strategy to achieve the standards laid down in the EU legislation requires appropriate diagnosis with the most suitable tools.

The Danube Air Nexus (DAN) is among the flagship projects of the EU Strategy for the Danube Region (EUSDR). It aims at protecting human health, ecosystems and climate from the impacts of atmospheric pollution. The present study was carried by the EC-JRC in collaboration with local research institutions: the National Institute of Meteorology and Hydrology (Bulgarian Academy of Sciences), the Centre for Energy Research (Hungarian Academy of Sciences), and the Institute for Medical Research and Occupational Health (Croatia). Also N.C.S.R. Demokritos (Greece) contributed to the study.

A set of pilot urban areas, representing different situations within the region, was chosen as case study. The detailed analysis of the causes of pollution in the three studied cities (Zagreb, Budapest and Sofia) was then used to propose measures to be implemented in the air quality plans that local, regional and national authorities are requested to put in place to face the exceedances of limit values (Directives 2008/50/EC and 2004/107/EC) and to comply with the national emission ceilings (NEC) obligations (Directive 2001/81/EC).

The approach adopted in this demonstrative study is suitable to be applied at the local level by regional authorities and could, therefore, be extended to other cities in this and other macroregions.

Key conclusions

At the local level, measures to control diffuse sources from domestic heating and traffic are required (more details in section 8). In these sectors the impact of technological measures (substitution of fleet and use of efficient stoves) is uncertain. Such measures are likely not enough to bring the emissions to acceptable levels and should, therefore, be accompanied by structural and behavioural changes. That means, for example, improving the mobility in the cities by reducing the circulating fleet and promoting centralised efficient heating systems powered with cleaner fuels.

According to the analysis of the abatement potentials, end of pipe measures (high efficiency dedusters and electrostatic precipitators) appear as the most suitable to deal with gaseous pollutants and the consequent secondary aerosol. For the latest category of pollutants, controlling the emissions of ammonia from agriculture is also crucial.

Some of the measures at the national level are already planned by EU member states for the implementation of the directive on national emissions ceiling (NEC).

In this study, long range pollution transport from EU eastern neighbours has been detected in the studied cities. Therefore, action is also needed to control international emissions in the energy production, industrial and shipping sectors in those countries.

Main findings

The main sources of gaseous pollutants (sulphur and nitrogen oxides) in the studied cities are large combustion plants and heating systems, located away from the city centre, using solid or heavy liquid fuels (more details in section 7). The combination of such pollutants with ammonia from agriculture determines the formation of considerable amount of particulate matter (secondary aerosol) which is then transported into the cities. The secondary aerosol, mainly transported, is added to local sources such as biomass burning, re-suspension of dust and traffic exhaust. It has been observed that both biomass burning and secondary aerosol are the most important contributors to particulate matter (PM) during the high pollution episodes.

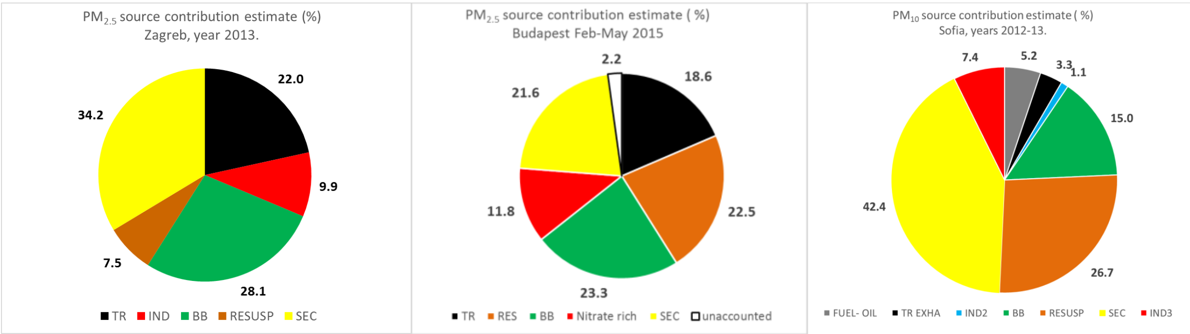


Figure 1. Contribution of sources to particulate matter in Zagreb, Budapest and Sofia. The most important causes of exceedances are biomass burning and transported secondary (aged) aerosol deriving from large combustion plants, heating systems and agriculture. TR: traffic, IND: industry, BB: biomass burning, RESUSP: soil and road dust, SEC: secondary aerosol, TR EXHA (traffic, only exhaust), unaccounted (non apportioned mass).

The picture resulting from this study highlights the complexity of the pollution processes and the need to adopt flexible and multilevel measures to deal with them. Most of the pollutants are emitted locally. However, the medium to long range transport may be also considerable depending on the season and the meteorological conditions. For that reason, there is a need for action at local, national and international scales. The success of the measures mostly depends on the coordination among different levels taking into account the needs/inputs from the relevant sectorial policies.

Related and future JRC work

Further work on the identification of most suitable measures using integrated assessment tools is in progress to support the Pillar 2 of the EUSDR - Quality of Air and Soil (work package ENVIRONMENT-3575, project MARREF-348). In addition, this work is contributing to the evaluation of the impact of bioenergy production on air quality relevant for Pillar 1 of the EUSDR - Bioenergy and Transport multimodality.

Quick guide

In order to protect the human health and the ecosystems, the air quality directives (Directive 2008/50/EC and 2004/107/EC) define limit and target values for legislated pollutants that should not be exceeded. When the levels of pollution pass the established thresholds action is to be taken. To that end, Member States and local authorities are requested to draft air quality plans where measures are implemented to tackle the pollution sources and bring the air quality levels below the limit or target values within a given term. Moreover, according to the Commission implementing decision of 12 December 2011, information about the contribution of sources and scenarios that support the air quality plans are to be reported by Member States to the Commission.

1. Introduction

The EU Strategy for the Danube (EUSDR) aims at tackling the development of key topics that require working across borders and national interests to promote the sustainable development of the region. The identified key issues are mobility, energy, water, biodiversity, socio-economic development, education, culture and safety. The strategy addresses these topics through four pillars divided in 11 priority areas. The pillars are: Connecting the region, Protecting the environment, Building prosperity and Strengthening the region.

The Danube Air Nexus (DAN) is one of the flagship projects of the EUSDR coordinated by the JRC IES Unit "Air and Climate" aiming at protecting human health, ecosystems and climate from the impacts of atmospheric pollution. The project is structured in four work packages: Identifying air pollution sources, Scenarios of future air quality emissions, Climate impact on air quality and health and Assessing impacts of PAH on health.

The present report presents the activity carried out by the EC-JRC in the DAN work package 1 on the identification of pollution sources in collaboration with: the National Institute of Meteorology and Hydrology (Bulgarian Academy of Sciences), the Centre for Energy Research (Hungarian Academy of Sciences), the Institute for Medical Research and Occupational Health (Croatia) and N.C.S.R. Demokritos (Greece).

The Danube region includes one of the air pollution "hot spots" in Europe. Supporting the development of a strategy to achieve the standards laid down in the EU legislation requires appropriate diagnosis with the most suitable tools. From the river sources to the outlet, the watershed spreads out through countries with different emissions, due to the different kind of technologies and fuels used and to different level of implementation of the environmental policies. In addition, within each sub-basin gradients from rural–mountainous areas to flat populated areas impacted by different type of sources can be observed. Also, the impact of shipping is expected to vary according to the distance to main navigation routes both domestic and international.

A selection of pilot urban areas to evaluate the status of the implementation of the air quality legislation was made. Three areas representing different situations within the region were chosen as case study. A thorough evaluation of the emission and the concentration of PM and gaseous pollutants in these areas was accomplished using source apportionment and lagrangian models. The detailed analysis of the causes of pollution in the three studied cities was then used to propose measures to be implemented in the air quality plans that local, regional and national authorities are requested to put in place to face the exceedances of limit values.

The tasks accomplished in this work were:

I. Selection of urban areas in different zones of the region and retrieval of datasets of atmospheric pollutants and meteorological data;

II. Application of receptor models to the datasets with the chemical composition of particulate matter (PM) to quantify the contribution of pollution sources;

III. Execution of statistical analysis on meteorological data and backward trajectories to determine the circulation patterns in the Danube area;

IV. Identification and quantification of the potential geographical source areas for PM and selected pollutants;

V. On the basis of the outcome of the previous steps, the most suitable pollution abatement strategies for the studied areas are discussed.

2. Air quality in Europe

In order to protect the human health and the ecosystems, the air quality directives (Directive 2008/50/EC and 2004/107/EC) define limit and target values for legislated pollutants that should not be exceeded. When the levels of pollution pass the established thresholds action is to be taken. To that end Member States and local authorities are requested to draft air quality plans where measures are implemented to tackle the pollution sources and bring the air quality levels below the limit or target values within a given term. Moreover, according to the Commission implementing decision of 12 December 2011, information about the contribution of sources and scenarios that support the air quality plans are to be reported by Member States to the Commission.

Particulate matter $PM_{2.5}$ and PM_{10} are among the pollutants that most frequently exceed the limit values. The map of the monitoring stations that exceed the PM_{10} daily average shows four major hot spots: The Benelux, the Visegrad, the Po Valley and the Balkan peninsula.

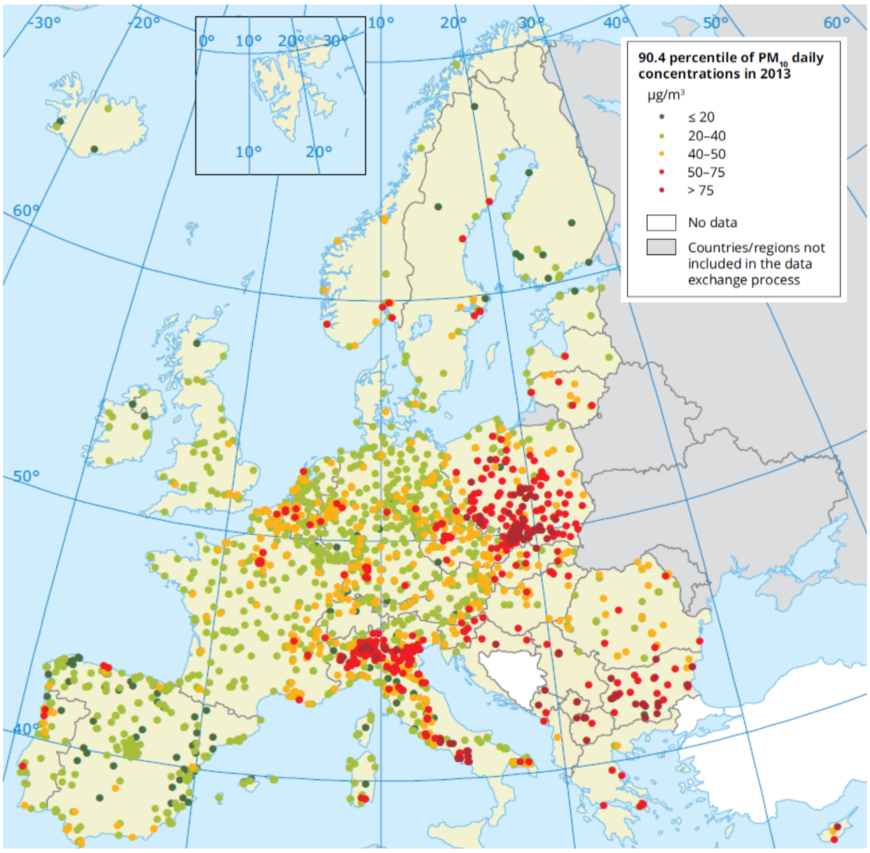


Figure 1. Concentrations of PM_{10} in 2013. The map represents the 36th highest value in a complete series of daily PM_{10}. It is related to the PM_{10} daily limit value, allowing 35 exceedances over one year of the 50 μg/m^3 threshold. Source: Air quality in Europe 2015 report, EEA.

Vehicular traffic is a major source of gaseous pollutants as well as airborne particles of various sizes. Other primary particle sources, such as ships, power plants, industry, small scale combustion for domestic heating contribute as well (Kassomenos et al., 2011). In addition to pollutants directly emitted by the sources (primary) there are atmospheric processes that led to the transformation of pollutants. The pollutants that are the result of physical-chemical transformations in the atmosphere are referred to as secondary. The sources responsible for primary or secondary pollutants may be local or transported from other areas. Long range transported particles often dominate the accumulation mode (particles between 0.1 and 1 µm of diameter) and sometimes even the total number concentration in urban background areas. Given that exposure to particulate matter (PM) is mainly related to urban environments where anthropogenic activities lead to increased concentration levels, natural sources are often underestimated. Nevertheless, their contribution may be significant, especially for certain areas and during specific periods of the year. The main natural sources affecting ambient PM levels are: (i) wind-blown desert dust, (ii) sea salt, (iii) wildfires, (iv) volcanic ash and (v) biogenic aerosol (Viana et al., 2014). It has been estimated that the natural contribution to PM may range from 5% to 50% in different European Countries (Marelli, 2007).

According to a review of source apportionment studies in Europe (Belis et al., 2013), there are six main sources of PM in the cities: traffic, point sources (power plants and industries), resuspension of crustal material, biomass burning, secondary aerosol (mainly ammonium sulphate and ammonium nitrate) and sea salt.

3. The Status of Air Pollution in the Danube Region

Aiming at identifying the most suitable areas for the study, a detailed analysis of the legislated pollutants in the Danube Region was carried out. Figure 2 shows the annual PM_{10} average concentration in 2013 which confirms the high levels in the Balkans pointed out in figure1. More precisely, the highest concentrations are observed in the bigger cities and in the southern rim of the Danube basin. On the basis of the identification of the most critical areas and considering different situations within the Danube Region, three urban background sites were selected for the present study in: Zagreb (Croatia), Budapest (Hungary) and Sofia (Bulgaria).

The three sites represent different geographical situations. Budapest is located in a continental flat area. Zagreb is located in a hilly area close to the Adriatic Sea. Sofia is located at the southern rim of the Danube basin and receives the influence from Eastern non EU countries.

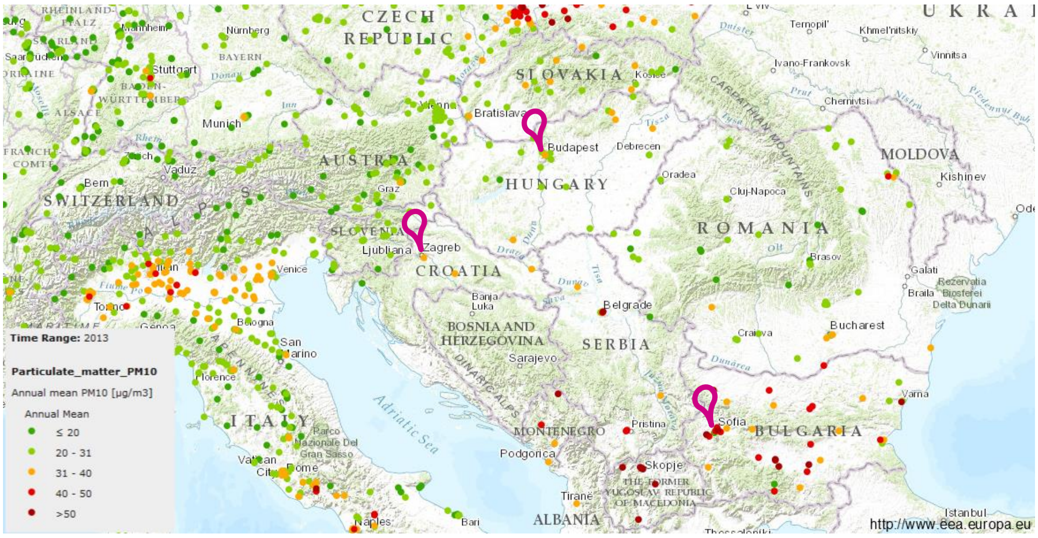


Figure 2. Annual PM_{10} average in the monitoring stations of the Danube Area in 2013. The cities studied in this work are indicated with place marks.
Source: http://www.eea.europa.eu/themes/air/air-quality/map/airbase.

The long–term trends of key pollutants in selected monitoring stations of the three studied cities are shown in Figure 3. The data used for these graphs are those officially reported by the countries to the EEA as part of the mechanism of exchange of information on air quality. The levels of PM_{10} and SO_2 are higher in Sofia than in the other two cities while the levels of nitrogen oxides are the highest in Zagreb.

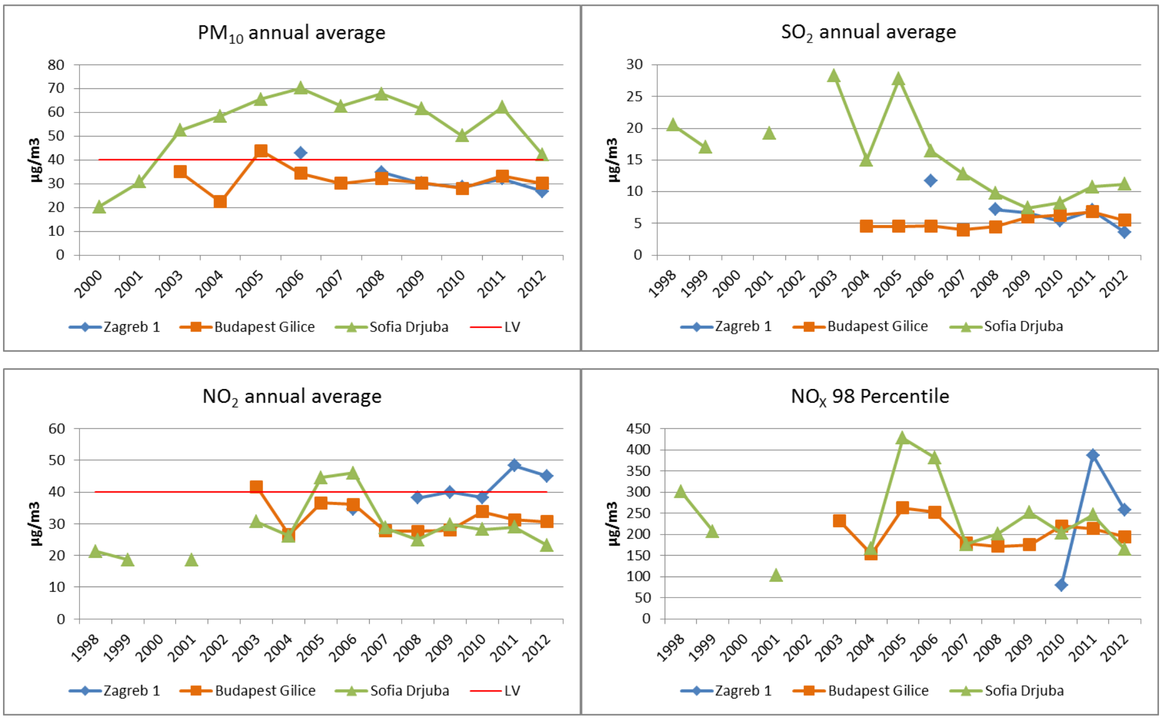


Figure 3. Long–term trends of PM_{10}, SO_2 and NO_2/NO_x in the monitoring stations of the three cities selected for this study: Zagreb, Budapest and Sofia. LV: limit value. Source: Airbase database version 8, EEA.

3.1 Long time trends of air pollution and emissions in the area

This section illustrates the pollution emission long-term trend resulting from the reporting to the Convention on long range transport of pollutants (CLRTAP) available on the EEA website (http://www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap). The data represent the emission estimate on the basis of the sold fuel.

Figure 4 shows total emission trends for the 9 Danube EU member states (Austria, Germany, Croatia, Czech Rep., Slovakia, Hungary, Romania, Bulgaria and Slovenia) compared to each of the three countries studied in this report. The emissions of the whole country are reported.

The most important pollutants show, with few exceptions, a decreasing trend between 1990 and 2013. Nevertheless, the trends vary among pollutants and among countries. The most dramatic decrease in the Danube area, as the rest of Europe, is the one observed in SO_2. The emissions of this pollutant have decreased of 90 % in the considered period. Unlike the other countries, the levels of SO_2 in Bulgaria increased during the early 90s and fell down firstly in the late 90s and again since 2005. In 2013, the SO_2 emissions in this country were still above the average of the Danube countries and between 5 and 10 times higher than Croatia and Hungary. The three studied countries show a steady decrease in NO_x and NH_3 emissions in the early 90s after which the emission remained stable or decreased very little. In 2013 the emissions of NO_x were similar in Hungary and Bulgaria while the NH_3 emissions of the latest were similar to those of Croatia. In the analysed time window the PM_{10} emissions in the Danube countries decreased only by 20%. In the same period the emissions in Hungary decreased by 50% (mainly in 2005) those of Croatia remained stable and those of Bulgaria increased of about a 30%.

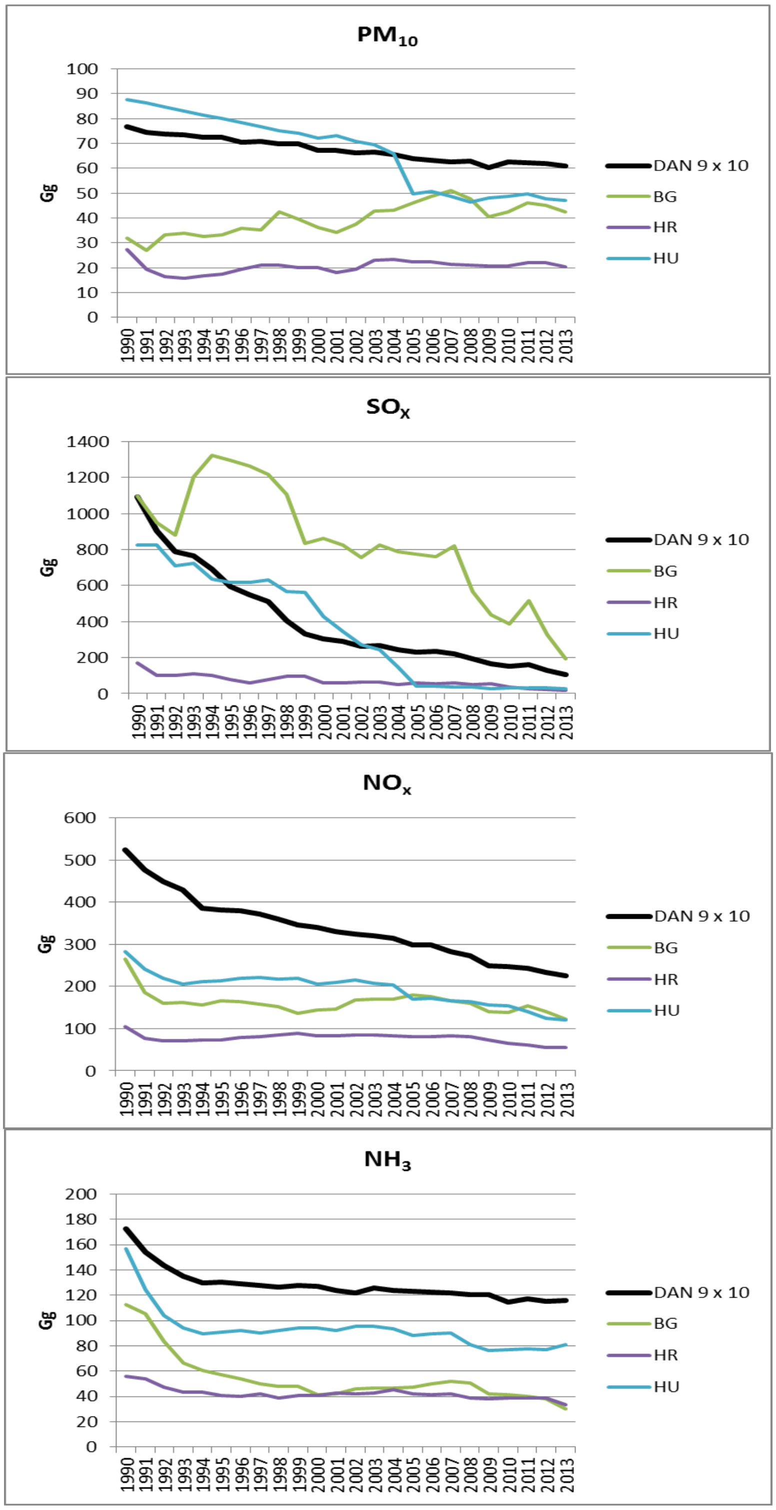


Figure 4. Time series of emission in the nine Danube EU member states compared to the ones of the countries analysed in this study.

4. Methodology for the identification of pollution sources and geographic area sources

The identification of pollution events affecting air quality is a challenging task which requires the combination of different tools: back-trajectory analysis, dispersion and receptor modelling; and data sources such as: observational data on PM concentration and chemical composition, pollution emission maps, etc.

State-of-the-art source apportionment techniques were applied to identify and quantify the contribution of the pollution sources to PM and selected components. Pollution sources in the three areas were compared to identify specific sources and common sources.

The Positive Matrix Factorization (PMF) analysis was carried out according to the European Common Protocol for receptor models (Belis et al., 2014). The methodology includes the statistical description and quality check of the datasets, the selection of species and samples to be included in the analysis and the receptor model runs. The intercomparisons carried out at the European level to test the performance of this methodology conclude that the source contributions estimates obtained with PMF are within 50% target expressed as standard uncertainty (Belis et al., 2015).

PM_{10} and $PM_{2.5}$ samples were analysed for a range of chemical components. The basic set of parameters consisted of the carbonaceous fraction (EC/OC), trace elements and major ions. The number of samples and the analysed components varied among the different sites. In Zagreb chemical data for $PM_{2.5}$ and PM_{10} for 365 samples were available. In addition to the basic set of parameters, polycyclic aromatic hydrocarbons and light absorption coefficient ɑ (useful to determine black carbon) were available. In Budapest and Sofia the basic set of parameters for 100 samples with the exception of EC/OC in Sofia was available.

4.1 PMF analysis

Datasets with the chemical composition of $PM_{2.5}$ and PM_{10} were analysed using PMF (PMF 5.0, EPA) aiming at the identification and quantification of the major PM sources (Norris et al., 2014).

Before running any PMF model, it was necessary to perform some elaborations in the $PM_{2.5}$ and PM_{10} original data set, which included harmonizing unit of measures, handled of missing values, recognition of values below the detection limit and input data uncertainty calculation

In source apportionment, uncertainty values are important since the most commonly used receptor models, like PMF and chemical mass balance (CMB), require the uncertainty of the species concentrations as input data in order to find the solution (Polissar et al., 1998). The analytical uncertainties provided in the original datasets were corrected to take into account the overall measurement uncertainty. Uncertainty data which were entered as input data in the PMF analysis were calculated according to equations reported in EPA PMF 5.0 manual (equation-based uncertainty input data).

Analysis of the changes in the Q value, a goodness of fit parameter, was used to determine the optimal factors. All model runs were monitored by examining the Q values obtained in the robust mode, Q(rob), calculated by excluding outliers. The chemical profiles of the factors were tested against the databases of source profiles: SPECIATE, US EPA (http://www3.epa.gov/ttnchie1/software/speciate/)and SPECIEUROPE, JRC (http://source-apportionment.jrc.ec.europa.eu/Specieurope/index.aspx).

The datasets of Budapest and Sofia were analysed at once while the dataset of Zagreb was used either as a whole and subdivided in warm and cold seasons, considering the high number of available samples (365). This set up was adopted to minimize model errors due to seasonal variations of source profiles and other seasonal differences.

4.2 Transport of pollutants

A number of modelling tools were used to analyse the advection of pollutants to the studied sites.

The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) Model (Draxler & Rolph, 2003; Draxler et al. 2009) provided backward air mass trajectories every hour, going back to 5 days and at a height of 500 m above ground level.

Subsequently, Potential Source Contribution Function (PSCF) analysis (Ashbaugh et al., 1985) was applied to HYSPLIT backtrajectories in order to determine possible source areas for the 90th percentile of higher concentrations for each pollutant. This model can be used for backward trajectories with a maximum duration of 5 days.

The Flexible Particle Dispersion Model (FLEXPART) was also used in order to acquire plumes defined on the basis of their residence time (sensitivity plumes) (Stohl et al., 1998; Stohl et al., 2005). PSCF analysis was applied on the sensitivity plumes in order to increase accuracy in Budapest due to the small number of samples. FLEXPART takes into account not only grid scale wind (as simple trajectory models do) but also turbulent wind fluctuations and mesoscale wind fluctuations. It also incorporates drift correction (to prevent accumulation of computational particles released) and density correction (to account for the decrease of air density with height).

The Conditional Probability Function (CPF) model was applied to concentration and meteorological data from the stations (wind speed and direction) (Ashbaugh et al., 1985). This model can indicate source areas within a few kilometres from the measurement station, or a general wind direction that leads to higher concentration of pollutants. It is influenced by topography, as wind direction measured locally might be altered by nearby mountains.

5. Identification and quantification of source contributions for PM

5.1 Zagreb

The analysed dataset includes measurements performed at an urban site (Ksaverka cesta; 45°50’07.87” N; 15°58’38.86” E) of Zagreb. The site is a background suburban site not directly influenced by traffic (residential area, hills- 200 m asl). PM samples (PM_{10}, $PM_{2.5}$ and PM1) were collected daily (24 hours, noon to noon) during 2013 (01 January 2013- 31 December 2013).

To identify the source categories associated to the factors obtained in the PMF analysis, the chemical composition and time trends were compared with the ones of sources identified in previous studies and with measured source profiles of European sources from the SPECIEUROPE and SPECIATE online databases.

Due to the high number of samples it was possible to make separate runs for the cold (fall- winter) and warm (spring- summer) seasons. This option made it possible to account for possible changes in the source profiles between the two main seasons. PMF factor profiles resolved by PMF for COLD season are displayed in Figure 5 as presented in the PMF output results.

Factor 1, with high concentrations of EC, elements (mainly K, Fe, Pb, Zn) and sulphates, was attributed to industrial sources (IND).

Factor 2, with high concentrations of EC, Cu, Fe, and nitrates, was identified as traffic (TR) source. In summer, this profile presents higher levels of Ca and sulphate than in winter.

Factor 3, with high concentrations of typical biomass burning source markers: OC, K, Rb, Zn, Cl- and PAHs, was ascribed to biomass burning (BB) source.

Factor 4, dominated by sulphates was identified as secondary aerosol (SEC).

Factor 5, with high concentrations of typical crustal source markers, such as Ca, K, Fe, Ti, but also enriched in other species such as OC, EC and sulphates was attributed to resuspension (RES) source.

The same factors with similar profiles were retrieved in the warm and in the cold seasons.

5.1.1 $PM_{2.5}$ source apportionment results for Zagreb (Croatia)

Daily $PM_{2.5}$ source contribution estimations (SCE) are reported as concentrations ($\mu g/m^3$) and percent contribution to $PM_{2.5}$ measured mass concentration (%) in Figure 6 and Figure 7, respectively.

Secondary aerosol (SEC) was found to be the strongest source for $PM_{2.5}$ in Zagreb (Croatia) on an annual basis (34%), together with biomass burning (28%) and traffic (22%), while industry and resuspension accounted for lower contributions, respectively 10% and 7.5%.

However, the contribution from sources to ambient $PM_{2.5}$ concentrations in Zagreb showed some relevant seasonal differences.

Figure 5. Factor profiles for $PM_{2.5}$ of Zagreb, COLD season. The profile graph shows the concentration of each species apportioned to the factor as a bar (left axis) and the percent of each species apportioned to the factor as a point (right axis).

During winter (December, January, February) the SCE of $PM_{2.5}$ for biomass burning was very high (21 μg/m^3), and biomass burning had the maximum contribution (48%) to $PM_{2.5}$ ambient concentrations. The high contribution of biomass burning source during winter can easily explained by the high extent of the use of solid combustible (wood) for residential heating during the coldest winter months in Zagreb particularly in the suburban area.

Conversely, the SCE to $PM_{2.5}$ from resuspension was the highest (1.8 μg/m^3) during spring (March, April, May), when resuspension accounted on average for about 13% of $PM_{2.5}$ ambient concentrations in Zagreb. Resuspension showed the maximum contribution to $PM_{2.5}$ during a specific event which occurred at the end of April- first of May 2013, when resuspension accounted on average 60% of $PM_{2.5}$ (5 consecutive days: 29 April -03 May) (Figures 6 and 7).

The contribution from secondary aerosol source to $PM_{2.5}$ concentrations was the greatest during summer (June, July, August), when it accounted for 50% of $PM_{2.5}$ at Zagreb. The high contribution of secondary aerosol source can be explained as the enhanced secondary formation by oxidation of the gaseous precursor SO_2 (gaseous) with hydroxyl radical (OH) in typical summer conditions.

Although traffic and industry are primary sources not expected to have any specific seasonal trend, due to the low contributions of the dominant sources (biomass burning, resuspension and secondary aerosol) their contributions resulted the highest during fall months (September, October, November). During fall, traffic and industry contributions to $PM_{2.5}$ concentration were 32% and 16%, respectively.

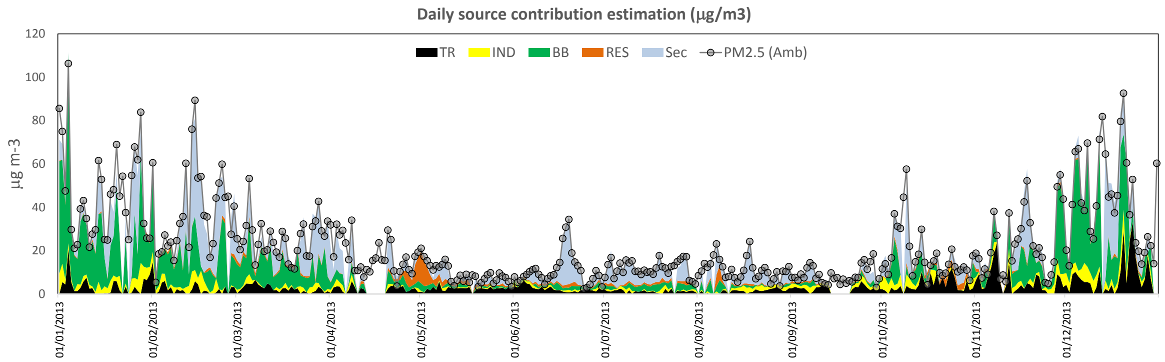


Figure 6. Daily $PM_{2.5}$ source contribution estimation (SCE) (µg/m^3) for Zagreb (Croatia). Dots indicate measured $PM_{2.5}$ concentrations (µg/m^3).

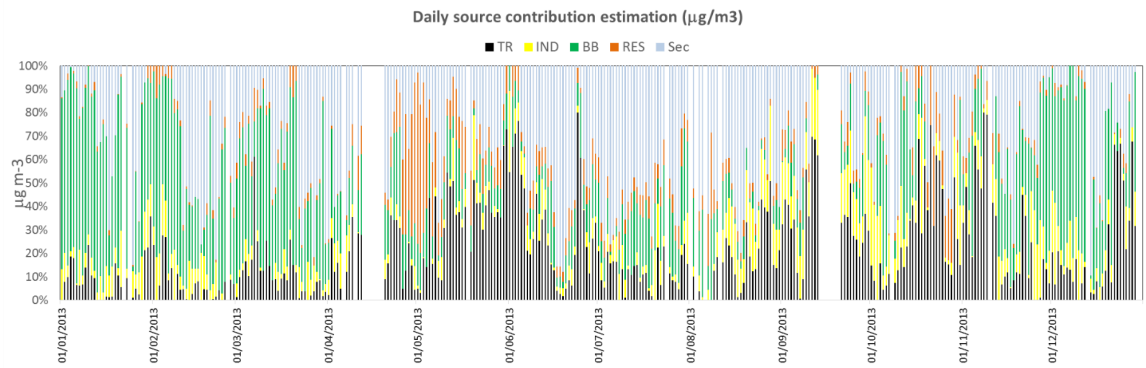


Figure 7 Daily source contribution (%) to measured $PM_{2.5}$ concentrations in Zagreb (Croatia).

5.2 Budapest

The analysed dataset includes measurements performed at an urban site (Gilice ter; 47°25'40.35" N 19°11'11.03" E) in Budapest. The site is a background urban area considered representative of the mixture of sources affecting residential areas of the city. Aerosol samples ($PM_{2.5}$) were collected daily (24 hours, midnight to midnight) during 2015 (09th February to 18th May). The dataset represents the transition between late winter to early summer.

5.2.1 $PM_{2.5}$ source apportionment results for Budapest (Hungary)

Preliminary checks pointed out some inconsistencies between the chemical composition and the gravimetric mass in some episodes of high pollution concentration. Despite this problem the analysis was carried out so that the mass was almost completely apportioned (only 2.2% is on average unaccounted). The chemical profiles of the factors as reported in the PMF output are shown in Figure 8.

Factor 1, dominated by sulphate and nitrate was identified as secondary aerosol (SEC).

Factor 2, with high concentrations of nitrate, EC, elements (K, Cl, Ca) and levoglucosan, was attributed to aged secondary aerosol influenced by biomass burning (NITR).

Factor 3, with high concentrations of typical biomass burning source markers: levoglucosan, OC, EC, K, Cl-, was ascribed to biomass burning (BB) source.

Factor 4, with high concentrations of typical crustal source markers, such as Si, Ca, Fe, Ti, was attributed to resuspension (RESUSP) source.

Factor 5, with high concentrations of OC, EC, Cu, Fe, Ni and nitrates, was identified as traffic (TR) source. The presence of sulphate and V suggest a possible presence of oil fuel emissions.

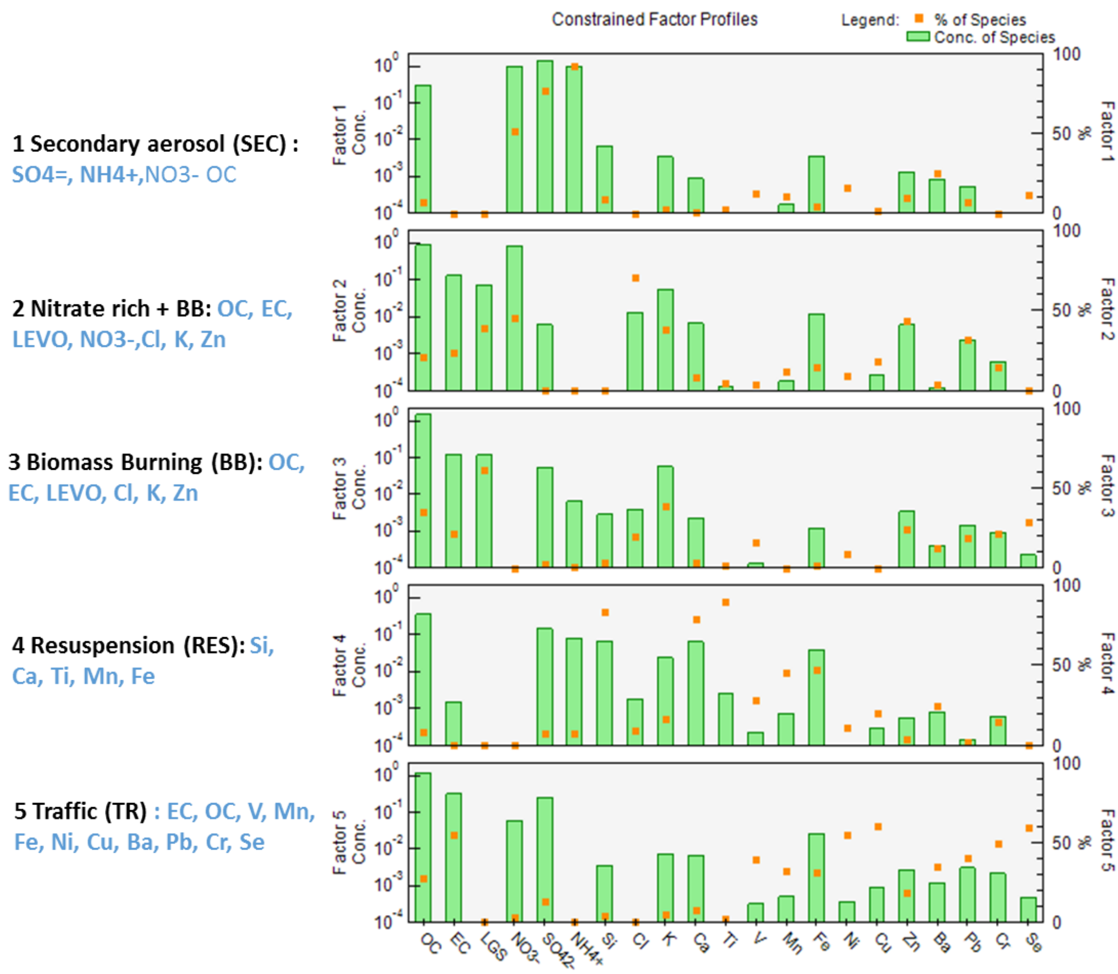


Figure 8. Factor profiles for $PM_{2.5}$ of Budapest. The profile graph shows the concentration of each species apportioned to the factor as a bar (left axis) and the percent of each species apportioned to the factor as a point (right axis).

Daily $PM_{2.5}$ source contribution estimations (SCE) are reported as concentrations (μg/m^3) and percent contribution to $PM_{2.5}$ measured mass concentration (%) in figures 9 and 10, respectively.

Biomass burning (BB), resuspension (RES), secondary aerosol and nitrate (SEC), traffic (TR) and nitrate-rich (Nitrate-rich) were the most significant $PM_{2.5}$ sources in Budapest (Hungary) accounting for 23.3 % (BB), 22.5% (RES), 21.6% (SEC), 18.6% (TR) and 11.8% (Nitrate-rich) of $PM_{2.5}$ ambient concentrations in Budapest for the period Feb-May 2015. The Nitrate-rich source presents sizeable concentrations of levoglucosan, a marker of wood burning, suggesting a possible link of aged aerosol consisting of secondary nitrate with a relatively distant biomass burning source.

The period in question, Feb-May 2015, includes one cold period (Feb-March), during which there were the highest concentrations of PM ($PM_{2.5}$= 24±11 µg/m^3) (Figure 9), and two typical warm months (April-May), during which the PM concentrations were lower ($PM_{2.5}$= 11± 5 µg/m^3). It is worth noting that the source apportionment study of $PM_{2.5}$ in Budapest refers to the period Feb-May 2015 only, and not to the whole year, so average annual values could be somewhat different in relation to the seasonal differences that typically can be observed for PM and its sources.

During cold months (Feb-March), the SCE of $PM_{2.5}$ for secondary aerosol (6.5 µg/m^3), biomass burning (5.7 µg/m^3) and nitrate-rich (4.5 µg/m^3) and was the highest, and they had the maximum contribution (secondary aerosol= 30.7%; biomass burning= 27.9%; nitrate rich= 18.8%) to $PM_{2.5}$ ambient concentrations. The high contribution of biomass burning and to a certain extent of the nitrate-rich source during the cold period can be explained by the combustion of solid combustible (wood) for residential heating during the coldest winter months in Budapest and surrounding areas. The condensation of ammonium nitrate emitted in upwind areas onto the particulate phase is favoured under conditions of low winter temperature. Unlike Zagreb and most western-European sites (Perrone et al., 2012), the highest levels of sulphate are observed in the cold season. The highest contribution of sulphate in Budapest during this period is unlikely due to the enhanced secondary formation of sulphate by photochemistry, while it could be due to S-rich sources during winter in combination with shallow boundary layer.

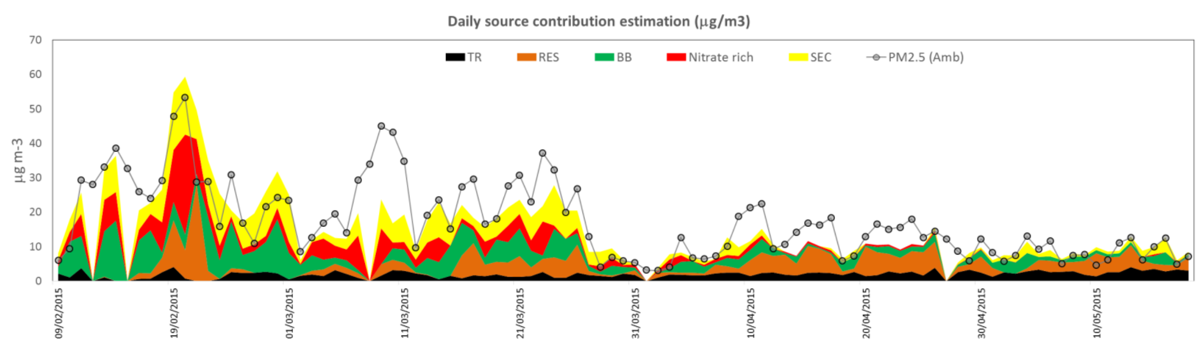


Figure 9. Daily $PM_{2.5}$ source contribution estimation (SCE) (µg/m^3) for Budapest (Hungary). Dots indicate measured $PM_{2.5}$ concentrations (µg/m^3).

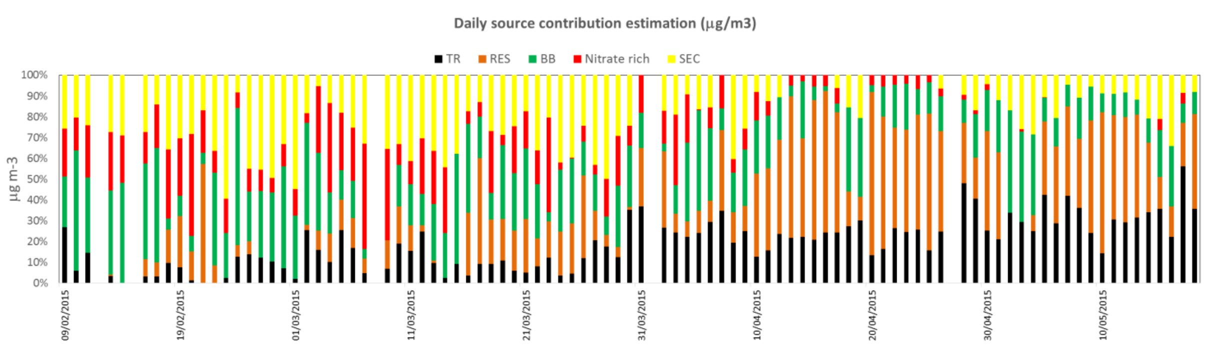


Figure 10. Daily source contribution (%) to measured $PM_{2.5}$ concentrations in Budapest (Hungary)

5.3 Sofia

The analysed dataset includes measurements performed at a monitoring station (42°39'19.08" N, 23°23'04.19" E) in Sofia. The site, located in an urban background area SE of the city centre, is representative of the mixture of sources affecting residential areas of the city. Aerosol samples (PM_{10}) were collected daily (24 hours, 8.30 to 8.30) during 2012 and 2013. The dataset consists of two cold season time windows with samples collected in February 2012 and the period October 2012 - February 2013 and two warm season time window with samples collected in July 2012 and July 2013.The main limitation of this dataset was the lack of total organic carbon and elemental carbon. In general, these two variables explain a considerable amount of the PM mass and are diagnostic for the identification of sources.

5.3.1 PM_{10} source apportionment results for Sofia (Bulgaria)

Factors were assigned to sources by analysing the presence of markers in the factor profiles and their time trends. Moreover, the factor profiles were compared with PM source profiles reported in the SPECIEUROPE and SPECIATE databases. In addition, the list of main point sources in the area deriving from the national emission inventory was also considered. The chemical profiles of the factors as reported in the PMF output are shown in Figure 11.

The seven detected factors were attributed to:

Factor 1 Fuel-oil

Factor 4 Biomass Burning (BB),

Factor 5 Resuspension,

Factor 6 Secondary aerosol (SEC), dominated by ammonium sulphate.

Factor 2 Traffic Exhaust (rich in Cu and Zn) an influence of local metallurgy Cu and Zn alloy production cannot be excluded. In addition, the quantification of traffic exhaust may be affected by the lack of OC/EC among the markers

Factor 6 rich in Pb, Ti, Fe, attributed to lead smelter or glass production (IND2)

Factor 7 rich in Mn, Fe, Ca2+, Mg2+, attributed to waste-incinerator (IND3).

Daily PM_{10} source contribution estimations (SCE) are reported as concentrations (μg/m^3) and percent contribution to PM_{10} measured mass concentration (%) in figures 12 and 13, respectively.

The contribution to PM_{10} concentrations in Sofia (Bulgaria) were calculated for years 2012-2013. The period considered includes different seasons: winter 2012 (06 Feb-25 Feb 2012), summer 2012 (02 July-26 July 2012), fall 2012 (22 Oct-31 Oct 2012), winter 2012-13 (17 Dec 2012- 11 Feb 2013) and summer 2013 (01 July-23 July 2013).

Secondary aerosol (SEC) was found to be the strongest source (42.4%) for PM_{10} in Sofia in 2012-2013 (all samples), followed by resuspension-road dust (RESUSP) (26.7%) and biomass burning (15.0%).

Industry and fuel-oil accounted for lower contributions, 8.5% (the sum of IND2 and IND3) and 5.2% respectively. The traffic exhaust accounted for only 3.3% of the PM_{10}. Among the industrial sources, IND3, likely deriving from incinerator or cement/ lime production plant, had the highest SCE (2.1 μg/m^3) and the highest relative contribution (7.4 %) to PM_{10}.

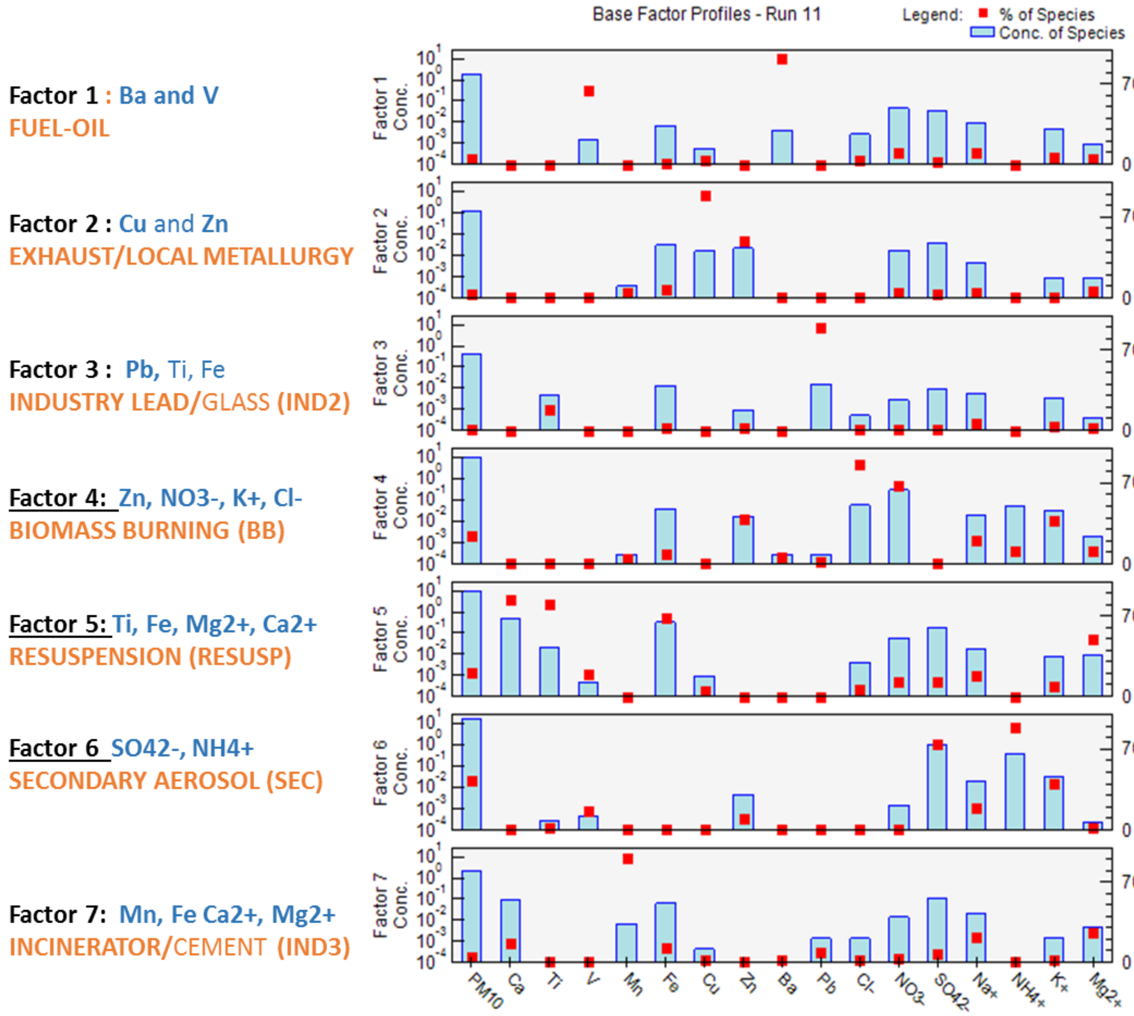


Figure 11. Factor profiles for PM_{10} of Sofia. The profile graph shows the concentration of each species apportioned to the factor as a bar (left axis) and the percent of each species apportioned to the factor as a point (right axis).

The contribution from sources to ambient PM_{10} concentrations in Sofia showed seasonal differences when comparing the COLD season (winter 2012, fall 2012 and winter 2012-13) and the WARM season (summer 2012 and summer 2013).

In particular, biomass burning (BB) source contributed to PM_{10} concentrations in Sofia only during the COLD season (27.4% on average), while BB contribution to PM_{10} concentrations in Sofia during the WARM season was nil (0%). During the COLD season, the SCE to PM_{10} for biomass burning was, on average, 18.2 µg/m^3, and during single days it could reach very high levels (maximum daily SCE was 164.3 µg/m^3) with a maximum contribution of 70.6% of biomass burning to daily PM_{10} ambient concentrations in Sofia. The high contribution of biomass burning source during the COLD season can easily explained by the high extent of the use of solid combustible (wood) for residential heating during the coldest fall-winter months in Sofia and in the surrounding area. Conversely, the SCE to PM_{10} from resuspension was the highest (10.7 µg/m^3) during the warm season, when resuspension accounted on average for about 41.1% of PM_{10} ambient concentrations in Sofia.

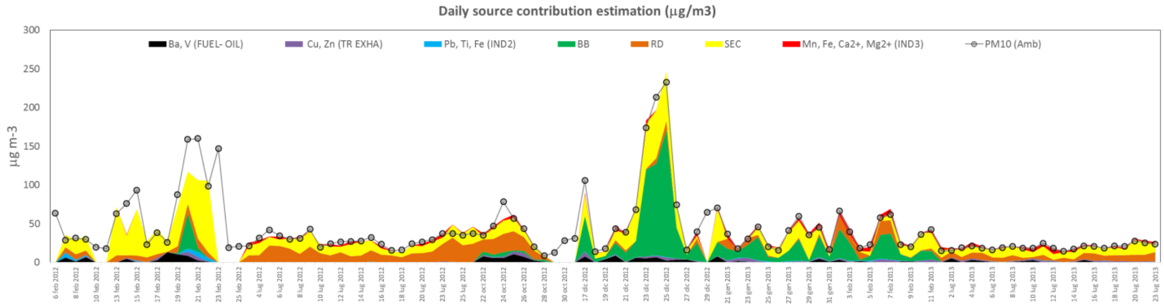


Figure 12. Daily PM_{10} source contribution estimation (SCE) (µg/m^3) in Sofia (Bulgaria). Dots indicate measured $PM_{2.5}$ concentrations (µg/m^3).

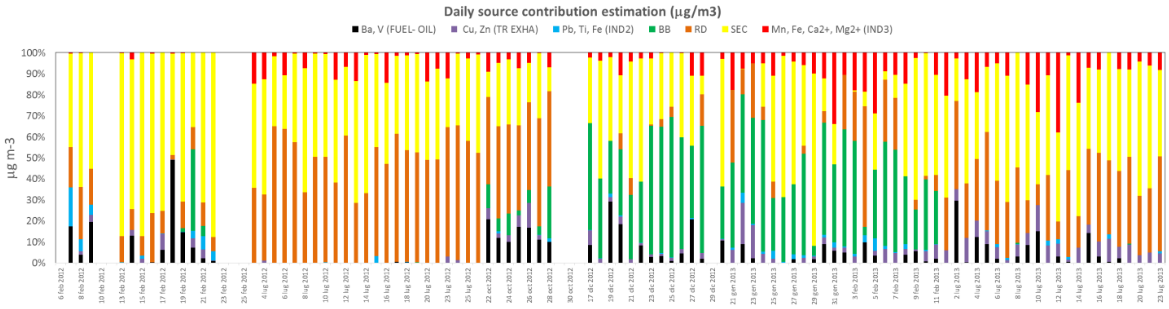


Figure 13 Daily source contribution (%) to measured PM_{10} concentrations in Sofia (Bulgaria)

6. Identification of geographical areas contributing to pollution

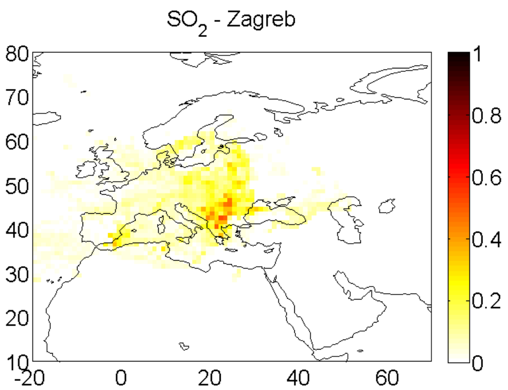
In this section the results of the analysis of trajectories (Potential Source Contribution Function, PSCF) and the analysis of the local wind (Conditional Probability Function, CPF) are presented. The first technique make it possible to identify the geographic origin of the air masses that reach the study site when the concentration of pollutants, or the contribution of a given factor, are high. In the interpretation of the maps it must be considered that high PSCF values are not necessarily indicating a source. The actual contribution of sources to the studied site depends on the emissions that the air masses find on their way. For that reason, the analysis of these maps was made also overlapping them with emission maps (not shown). When sources are locally emitted this may generally result in PSCF maps with no clear patterns. In order to support the interpretation of the maps the CPF plots were also studied. These plots are used to establish to what extent the sources determining high level of pollution are either local or transported from a prevailing direction with a specific wind speed. For the interpretation of the plots it must be taken into account that the colour scale indicates the probability of the wind coming from a given quadrant at a given speed when the concentration of a pollutant or the contribution from a source are high. The higher the wind speed indicated in the plot the longer the advection is expected to have taken. The limitation of the interpretation of the CPF is that local orography may deflect the direction of the air masses. Due to the high amount of presented maps, in this section is provided only a brief comment to each of them. The overall interpretation of the contribution of source categories and geographic areas sources is given in Chapter 7.

6.1 Zagreb

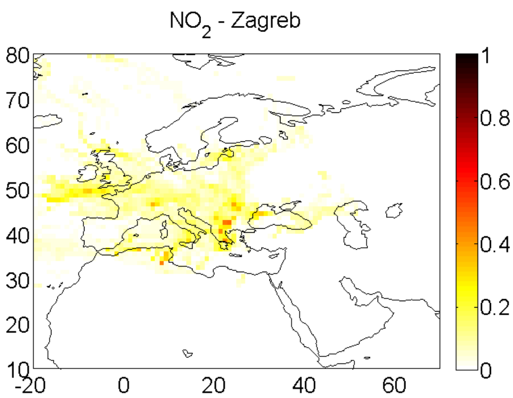
6.1.1 Potential Source Contribution Function results (HYSPLIT):

The PSCF tool allows the identification of the long range transported component with a higher confidence by linking this component with its geographical source areas. This is achieved by using air mass transport information coupled with other parameters like PM mass concentration fractions or chemical tracers.

Figure 14 shows the results of the PSCF analysis for Zagreb for the key gas pollutants and $PM_{2.5}$. Every map in the figure is commented in the caption.

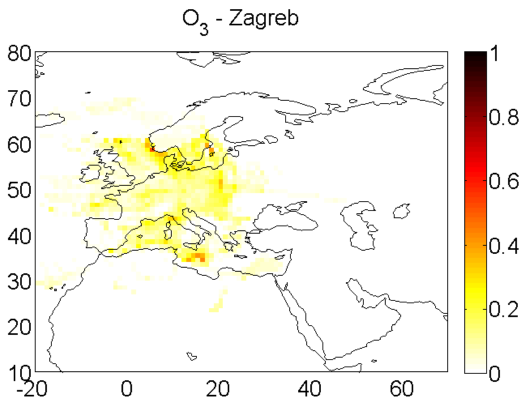


SO_2 has some potential area sources originating from East, North-East and the Balkan area. Possible influence from ship emissions.

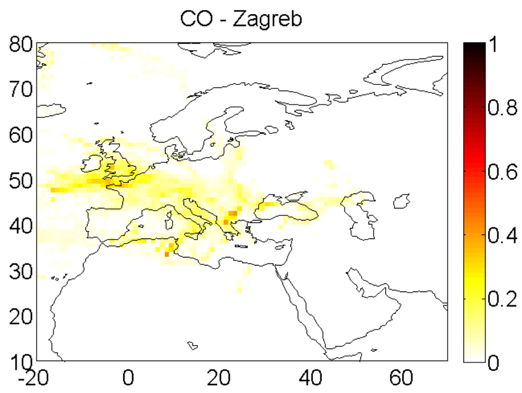


NO_2 potential area sources are the Balkans. The maps suggest a possible influence from shipping.

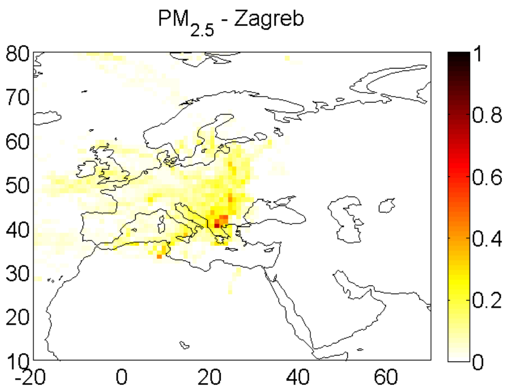
Figure 14: PSCF analysis for gases and $PM_{2.5}$ sources apportioned in Zagreb.



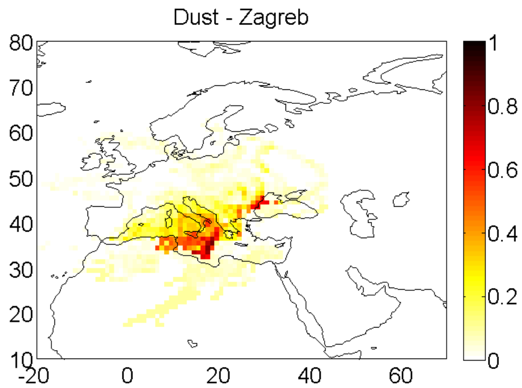
There are no clear potential area sources for **Ozone**.



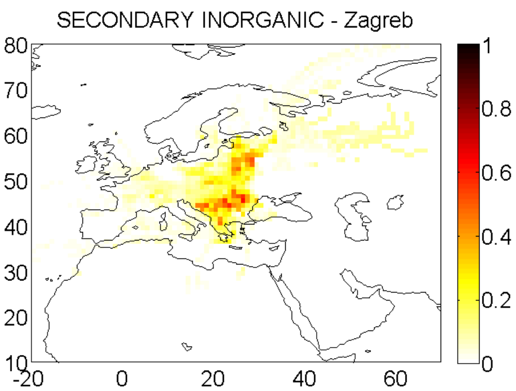
Also **CO** potential area sources are diffuse. Higher probabilities in the Balkan area and Tunisia.



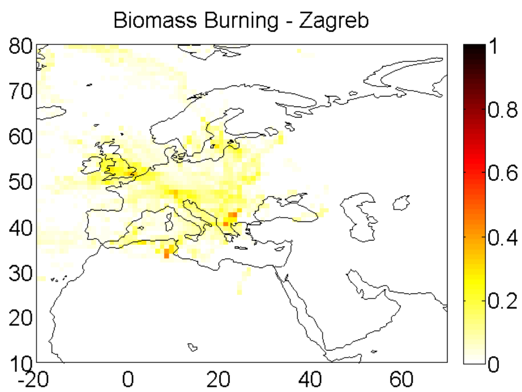
Potential area sources for $\mathbf{PM_{2.5}}$ concentration in Zagreb are from North-East and the Balkan area, Tunisia and probably shipping, but the main contribution must be from local sources.



Dust mainly originates from Libya and Algeria, but there is also a source in the North-East. The hot spot over the Meditteranean sea may indicate transport from Africa.

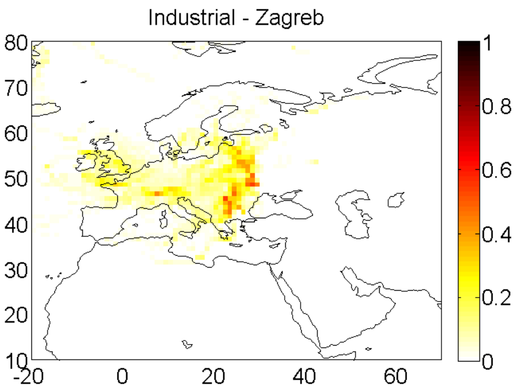


Secondary aerosol has a North-Eastern origin mainly, but there seems to be a large contribution from sources over the Balkans also Belarus.

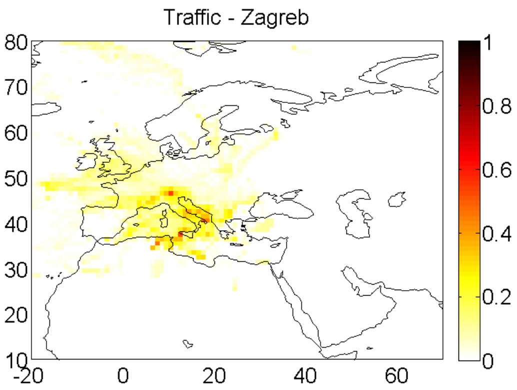


The **biomass burning** potential area sources are not evident. This could be due to local origin of this source.

Figure 14: PSCF analysis for gases and $PM_{2.5}$ sources apportioned in Zagreb (cont.).



Potential area sources for the **industrial** source are from North-East, but there is a hotspot on North Italy.

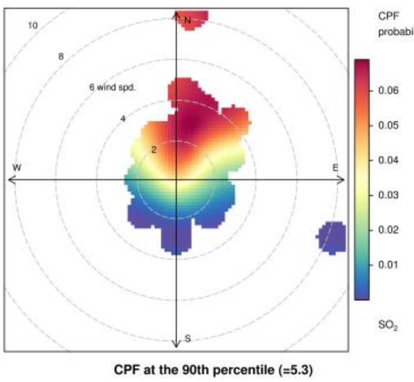


Potential area sources for **traffic** are probably local, but hotspots in Italy and in Tunisia are also visible.

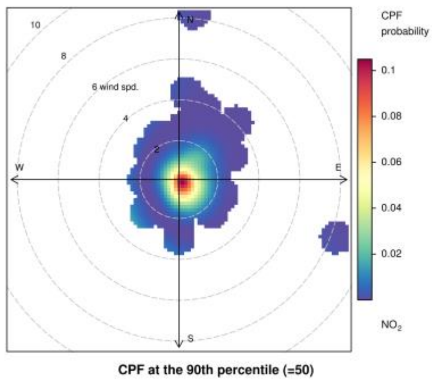
Figure 14: PSCF analysis for gases and $PM_{2.5}$ sources apportioned in Zagreb (cont.).

6.1.2 Conditional Probability Function analysis results

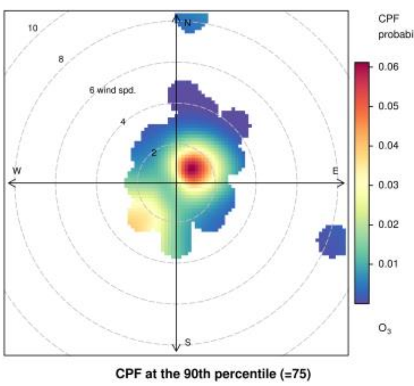
In figure 15 are presented the results of the CPF analysis for Zagreb for the key gas pollutants and $PM_{2.5}$. Every diagram in the figure is commented in the caption.



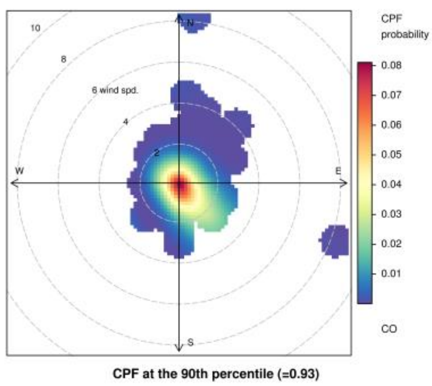
Potential area sources for SO_2 in. Zagreb are in the North, mainly at speeds higher than 2 $m.s^{-1}$.



NO_2 sources are local as are present at low wind speed and no specific direction.

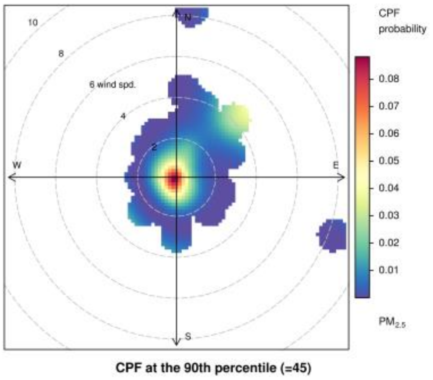


Potential area sources for O_3 are mainly local due to low wind speeds from a North-East direction.

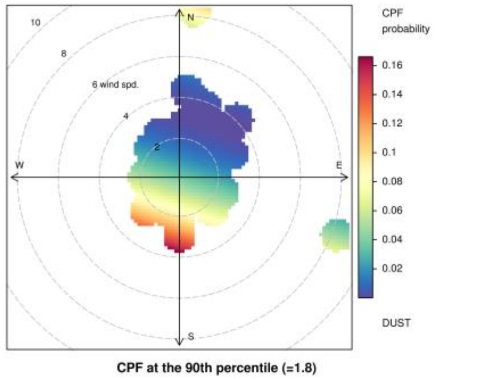


CO sources are local.

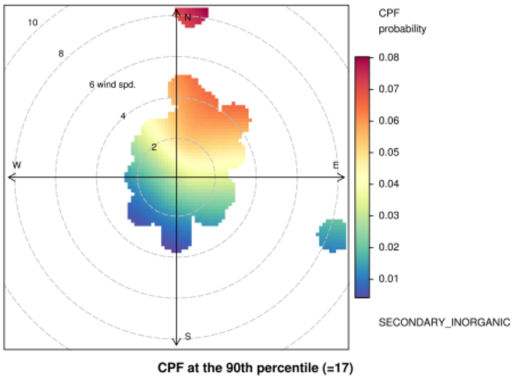
Figure 15: CPF analysis for gases and $PM_{2.5}$ sources apportioned in Zagreb



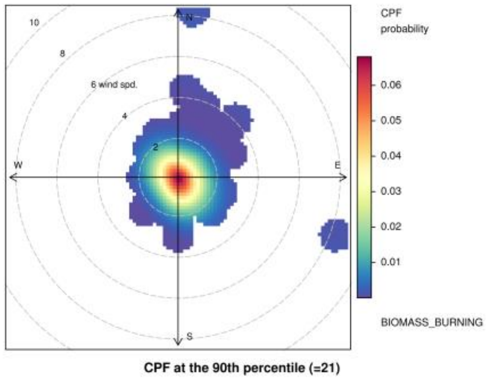
Potential area sources for **$PM_{2.5}$** are local due to low wind speeds.



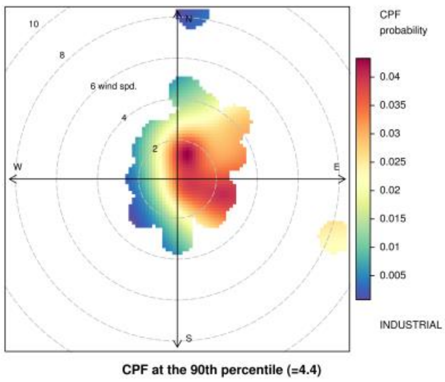
Dust area sources are in the South, at wind speeds higher than 2 $m.s^{-1}$.



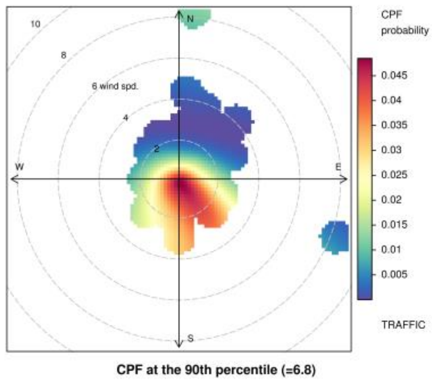
Secondary aerosol have North-Eastern origin mainly.



The **biomass burning** potential area sources are local as indicated by low wind speeds.



Potential area sources for the **industrial** source are from East.



Potential area sources for **traffic** are local and from South-East direction.

Figure 15: CPF analysis for gases and $PM_{2.5}$ sources apportioned in Zagreb (cont.).

PSCF for Zagreb indicates that SO_2 has sources on the North-East and the Balkans. Dust originates from Libya and Algeria and locally. Secondary aerosol originate in the North-East and the region over the Balkans. The industrial source originates mainly from the

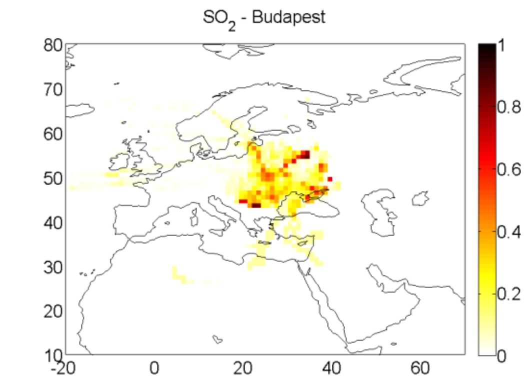
North-East, Northern Italy and Serbia region. Ship emissions might have significant contributions for CO and NO_2.

CPF analysis indicates that NO_2, CO, and Biomass Burning have significant local contribution as they have high probability at very low wind speed for all directions. Therefore, they could be attributed to local traffic and domestic heating. Traffic sources are located to the South and South-East of the monitoring station when wind speeds are low-medium (0 to 4 m/s^{-1}). Dust sources are located southward. The industrial source contributions are high when wind blow easterly and the secondary aerosol when it is northeasterly.

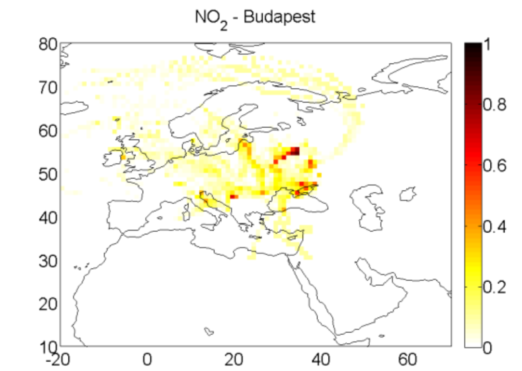
6.2 Budapest

6.2.1 Potential Source Contribution Function results (HYSPLIT)

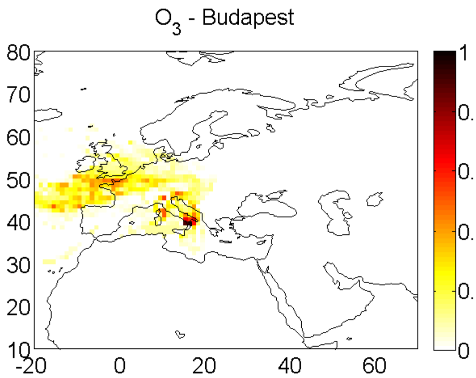
In figure 16 are presented the results of the PSCF analysis for Budapest for the key gas pollutants and $PM_{2.5}$. Every map in the figure is commented in the caption.



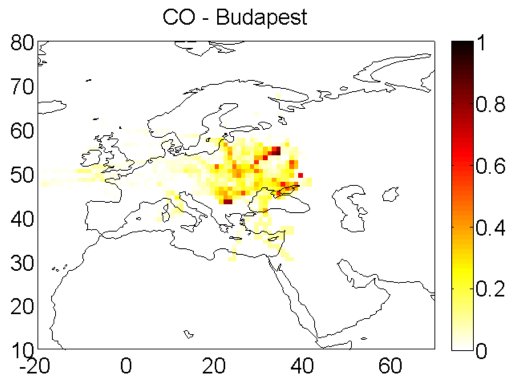
Budapest potential SO_2 area sources originate from East, North-East.



Potential sources for NO_2 are the Moscow – Volga region, Ukraine and Poland.

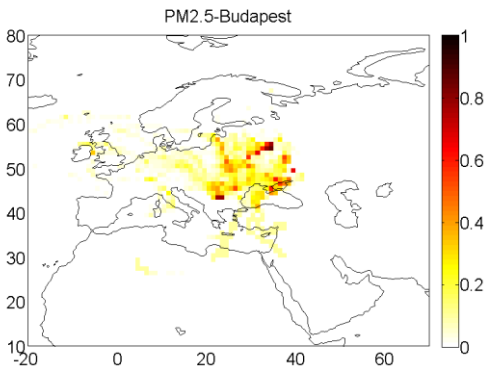


Trajectories circulating over the ocean and western Europe reach the site when O_3 levels are high.

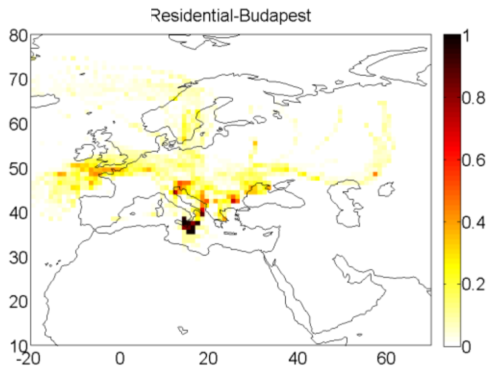


CO relates to sources over the Balkans and North-East. Similar to SO_2 and N oxides

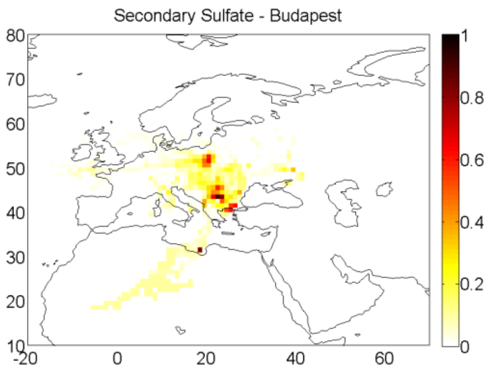
Figure 16: PSCF analysis for gases and $PM_{2.5}$ sources apportioned in Budapest.



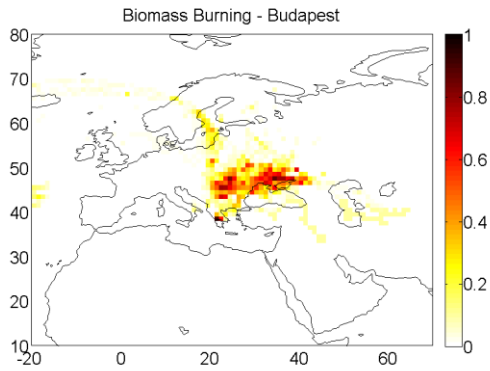
Potential area sources for **$PM_{2.5}$** concentration in Budapest are Moscow region, Ukraine, Poland and Serbia.



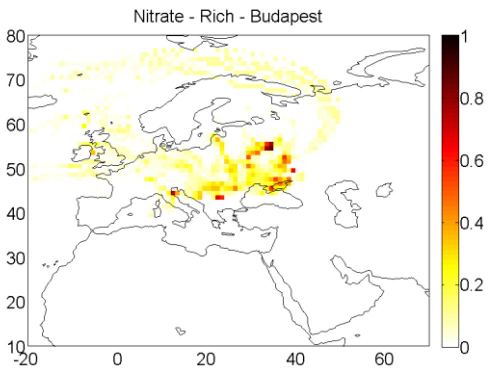
No clear pattern is observed. **Resuspension** hot spot over Sicily is likely due to circulation of African air masses.



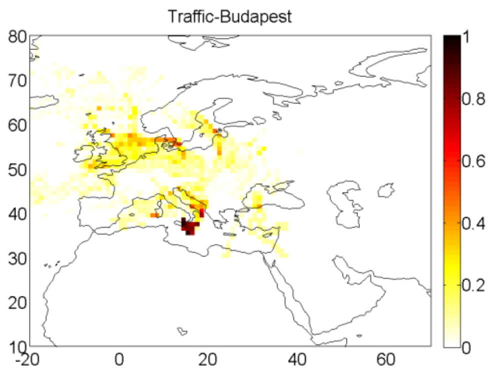
Potential area sources for **secondary aerosol** are in Poland, Serbia and the area close to Istanbul.



The **biomass burning** potential area sources are mainly over Ukraine and further East. A small contribution can be observed originating from Greece.



Potential area sources for **Nitrate rich** (industry/boiler) are Moscow region, the Ukraine, Romania and the Venice area.

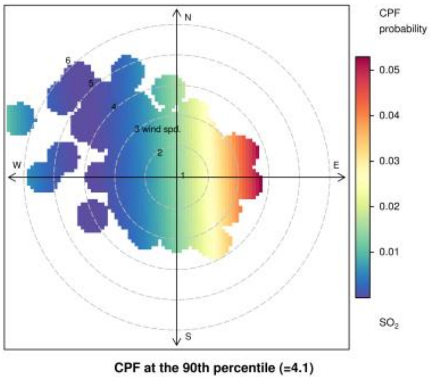


No clear area source for **Traffic,** main contribution from the local area.

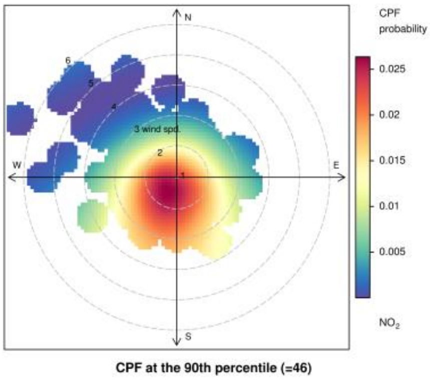
Figure 16: PSCF analysis for gases and $PM_{2.5}$ sources apportioned in Budapest (cont.).

6.2.2 Conditional Probability Function analysis results

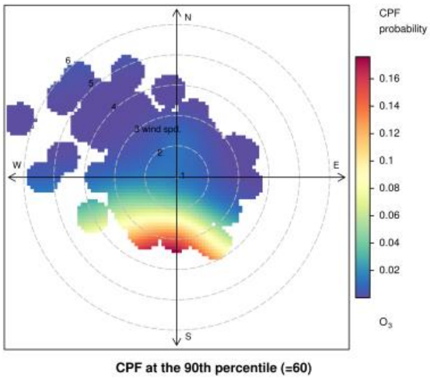
In figure 17 are presented the results of the CPF analysis for Budapest for the key gas pollutants and $PM_{2.5}$. Every diagram in the figure is commented in the caption.



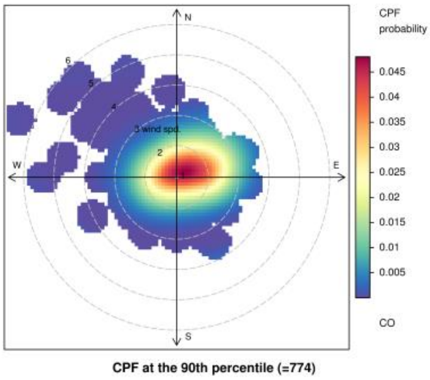
CPF for SO_2 gaseous measurements. We observe that Budapest potential area sources originate from the East.



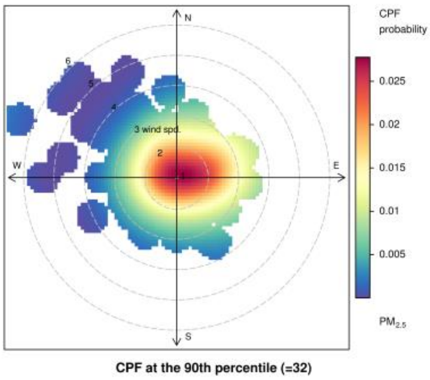
High concentrations for NO_2 are observed at low wind speeds, mainly from the East.



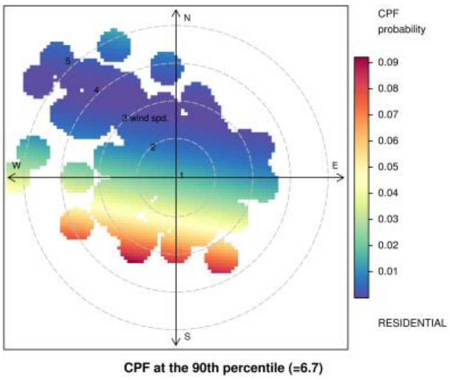
Potential area sources for O_3 high concentrations are from the South at wind speeds higher than 2.5 $m.s^{-1}$.



CO probably relates to local sources at low wind speeds.

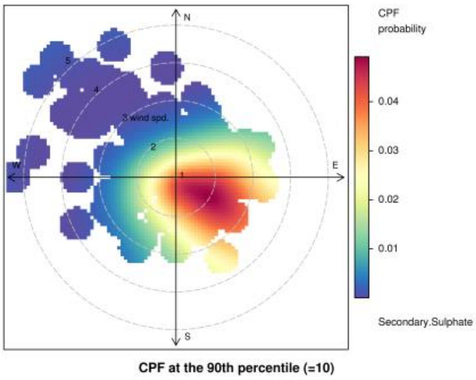


$PM_{2.5}$ concentrations are highest when wind speed is low and local or slightly from East.

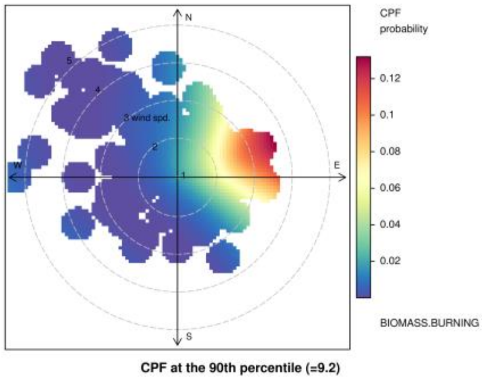


Resuspension aerosol sources are situated on a South direction.

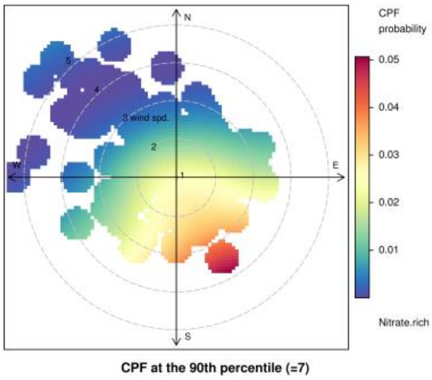
Figure 17: CPF analysis for gases and $PM_{2.5}$ sources apportioned in Budapest.



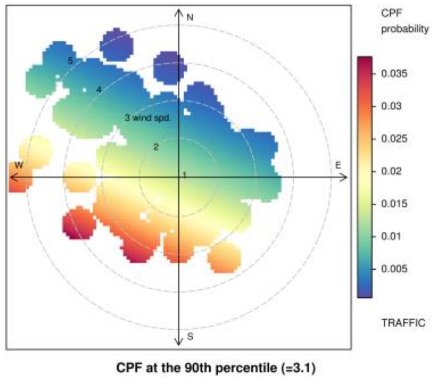
Potential area sources for **secondary aerosol** are from East and South-East at low and high wind speeds.



The **biomass burning** potential area sources are mainly from the East.



Potential sources for **Nitrate rich** are from South-East at high wind speeds.



Traffic potential area sources are situated on the South-West.

Figure 17: CPF analysis for gases and $PM_{2.5}$ sources apportioned in Budapest (cont.).

The PSCF analysis for Budapest indicates that the highest concentrations for SO_2, Nitrate, PM, NO_x and seondary aerosol occur when the air masses originate from the Moscow region, Warsaw region, Ukraine and Serbia. Biomass burning has a source region in the East. Ozone and CO are probably local or not associated to a specific direction. Resuspension and traffic are local (highway). Also local contribution from airport may be considered.

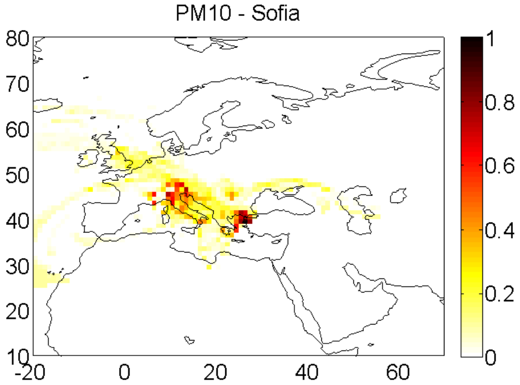
A valdation run of FLEXPART PSCF results indicate source areas with higher statistical accuracy and at longer range. The results of the two models are in good agreement, indicating that the results obatined with HYSPLIT PSCF are suitable for the objectives of this work.

CPF analysis indicates that Ozone, traffic and residential sources originate from the South when wind speeds are higher than 3 m/s^{-1}. SO_2, Biomass Burning, Secondary Sulfates are mainly from the East. CO, NO, NO_2, NO_x, $PM_{2.5}$ have high concentrations at low wind speeds and from all directions, therefore they are mainly local.

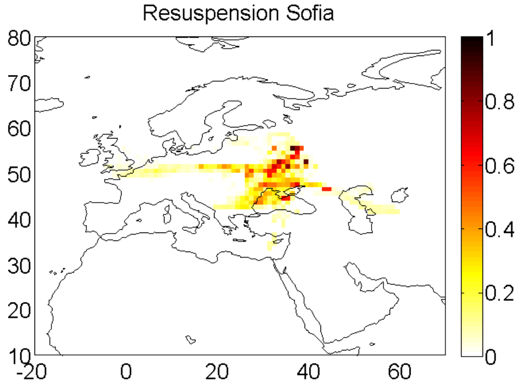
6.3 Sofia

6.3.1 Potential Source Contribution Function results (HYSPLIT):

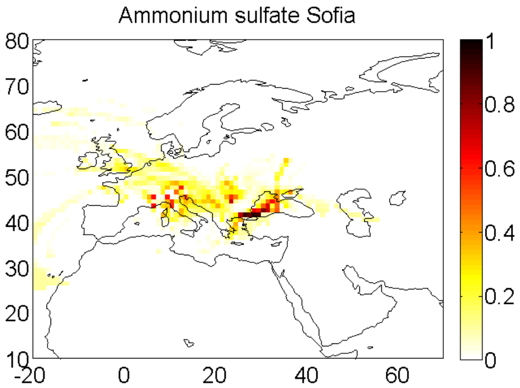
In figure 18 are presented the results of the PSCF analysis for Sofia for the key gas pollutants and PM_{10}. Every map in the figure is commented in the caption.



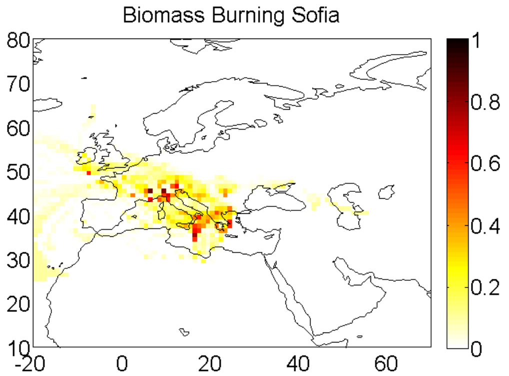
Highest **PM_{10}** concentration air masses from Northern Italy, European Turkey and the Caspian Sea.



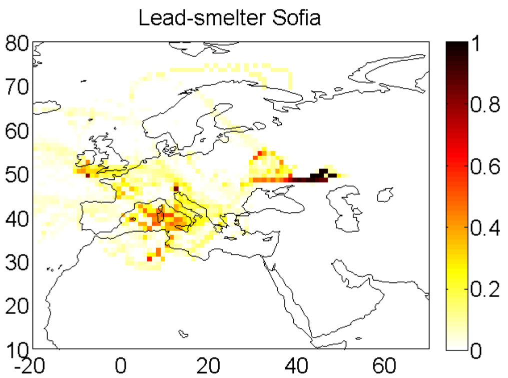
Resuspension has an Eastern origin mainly, with a sizeable contribution from the area of the Black Sea and beyond (UKR, RUS).



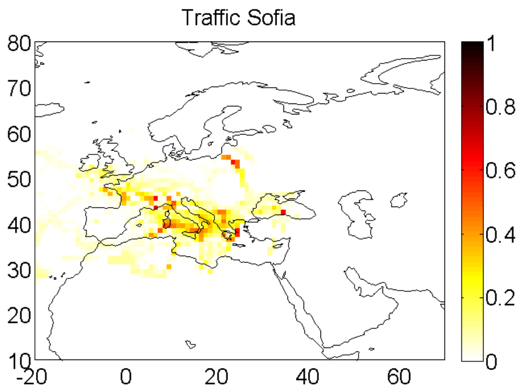
Seondary aerosol potential source areas in Belgrade and the Black Sea. Possible contribution from shipping.



The **biomass burning** potential area sources are mainly in Northern Italy, Serbia and Greece. Hot spot over Sicily likely due to African air masses.

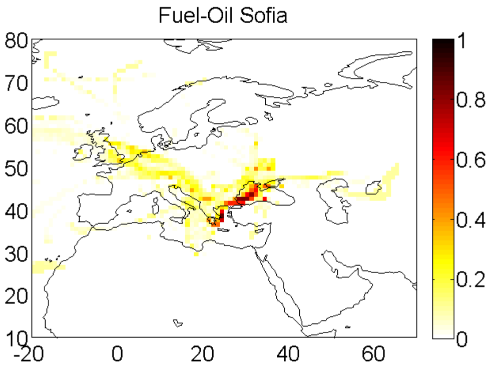


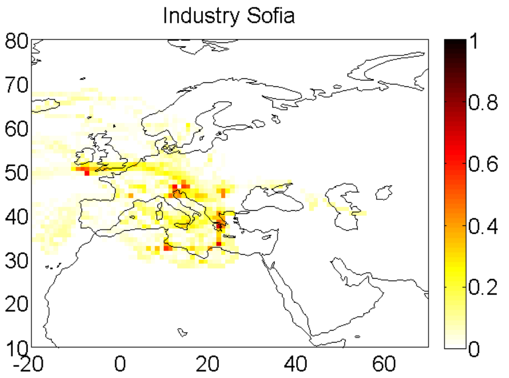
PSCF for **lead industrial** emissions show various potential area sources mainly from East and from the Mediterranean.



Potential area sources for **traffic exhaust** are likely local as there are no clear area sources

Figure 18: PSCF analysis for PM_{10} sources apportioned in Sofia.





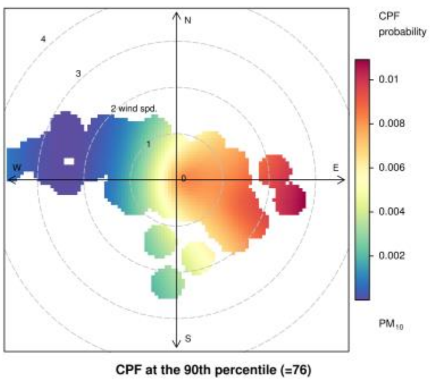
Potential area sources for **fuel oil** origin over the Black, Marmara and Aegean seas. Possible contribution from shipping.

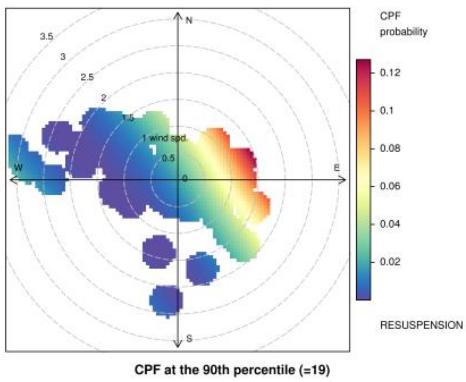
Potential area sources for the **industrial source** are widespread indicating no clear origin.

Figure 18: PSCF analysis for PM_{10} sources apportioned in Sofia (cont.).

6.3.2 Conditional Probability Function analysis results

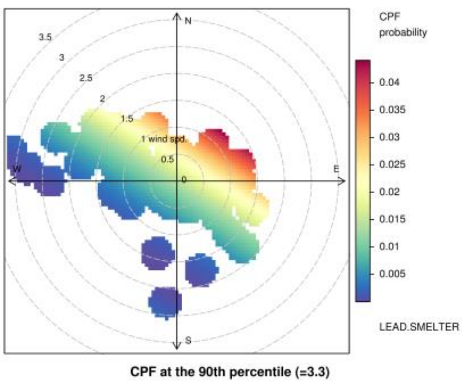
In figure 19 are presented the results of the CPF analysis for Sofia for the key gas pollutants and PM_{10}. Every diagram in the figure is commented in the caption.

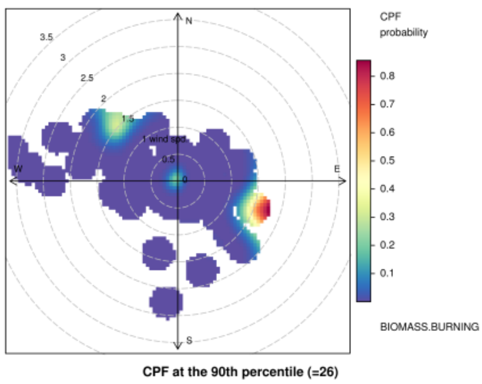




The highest $\mathbf{PM_{10}}$ concentration in Sofia,occur when the air masses originate from East.

Resuspension has a potential source originating from North-East.

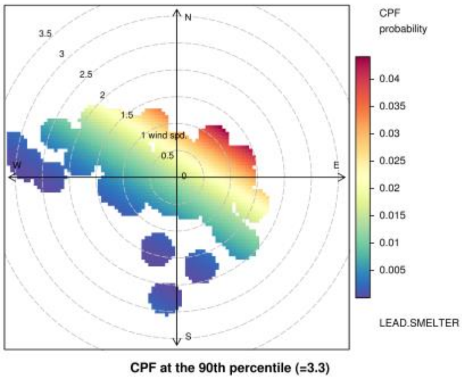




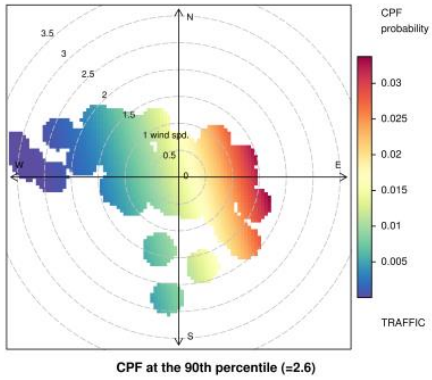
Secondary aerosol has a potential source originating from North-East.

The **biomass burning** potential area sources are mainly South-East at high wind speeds.

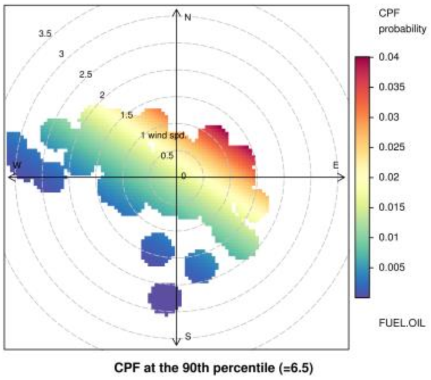
Figure 19: CPF analysis for PM_{10} sources apportioned in Sofia.



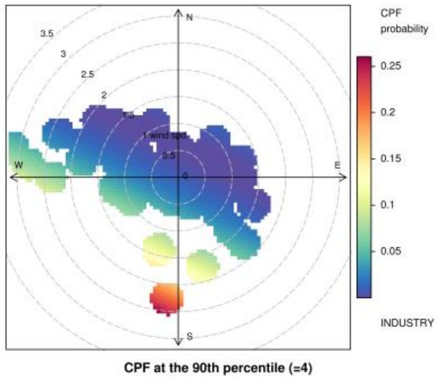
Lead industrial source has some potential area sources initiating from North-East.



Potential area sources for **traffic exhaust** must be mainly local as we observe random hot spots.



Potential area sources for **fuel oil** initiate from North-East.



Potential area sources for the **industrial** source are southwards.

Figure 19: CPF analysis for PM_{10} sources apportioned in Sofia (cont.).

PSCF for Sofia indicates that the Lead Industrial source initiates from the North-East (as far as Russia and Kazakshtan), shipping and local sources. Ammonium sulfate is originating from areas close to Bulgaria, like Serbia, Italy, Turkey and Black Sea. Resuspension source originates from the North-East (Russia, Ukraine and the Caspian Sea area). Fuel – oil source high concentrations occur for airmasses from the Black Sea and from North-East but there must be local influence and perhaps influence from ship emissions. Biomass burning has potential area sources from North Italy and shipping. Traffic sources must be local.

CPF analysis indicates that main circulation from east due to orgraphy. PM_{10} and traffic originate from the East when wind speeds are from 0 to 3 $m.s^{-1}$, so it mainly local. Also biomass burning is high when wind speed is low.. Ammonium Sulfate, Resuspension, Lead Smelters and Fuel – Oil sources originate from the North-East.

The backtrajectories for specific days (not shown) indicate that there are pollution episodes dominated by local sources prevail (17-26 December 2012) probably determined by high inversion and emissions from heating systems. On the contrary there are episodes like the one that took place on 19-23 February 2012 where there is a high probability of transport from a distant area source.

7. Main findings about pollution sources in the studied areas

7.1 Zagreb

Secondary aerosol rich in sulphate and nitrate (SEC) was found to be the strongest contributor to $PM_{2.5}$ in Zagreb (Croatia) on an annual basis (34%), together with biomass burning (28%) and traffic (22%), while industry and resuspension accounted for only 10% and 7.5%, respectively (Figure 20). When concentrations exceed the limit value the contributions of biomass burning are the ones with the higher increase and reach 42% of the $PM_{2.5}$. The contribution of resuspension is the only one that decreases during high pollution events. Traffic and Industrial contributions grow very little during the exceedances and, therefore, also their relative contributions decrease.

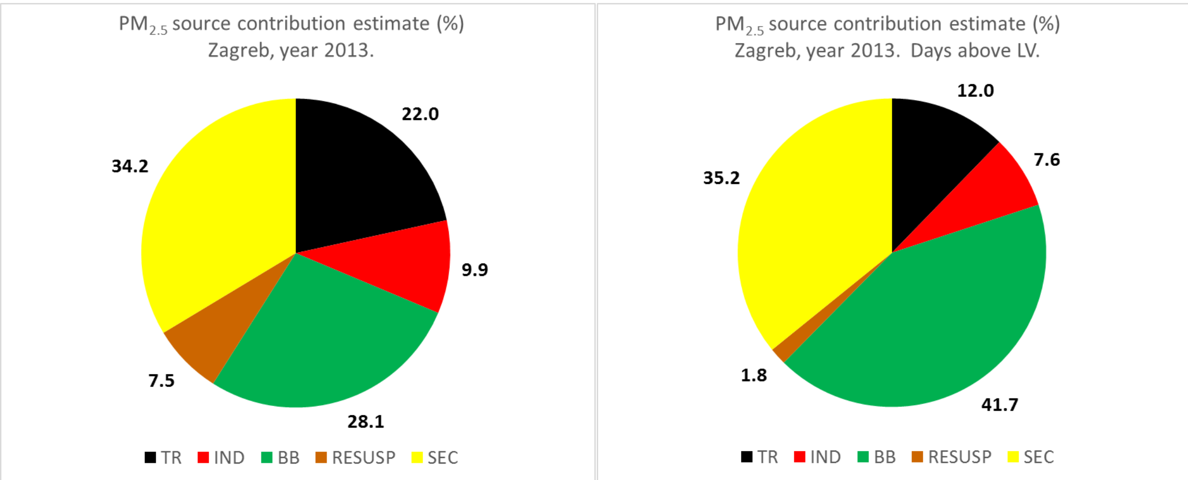


Figure 20. Average source contribution (%) to measured $PM_{2.5}$ concentrations in Zagreb (Croatia). On the left, period January December 2013. The average $PM_{2.5}$ concentration in the considered time window was 21.9 µg/m^3. On the right are reported the contributions for days with $PM_{2.5}$ above the limit value (25 µg/m^3, n=111).

According to the analysis of trajectories and wind speed and direction it has been established that local sources are the main responsible for the gaseous pollutants NO_2. Less clear is the origin of O_3 and CO. In addition, local sources are the main contributors of total $PM_{2.5}$ and of the sources biomass burning and traffic (from the city centre). On the other hand, gaseous SO_2 and the secondary aerosol and the industrial (metallurgy) contributing to $PM_{2.5}$ are likely emitted outside the city. SO_2 and sulphate source areas are likely located in the Balkans and the region including Ukraine, Belarus and western Russia. The industrial emissions are probably located to the east of the city. Resuspension is partially emitted by local sources (e.g. road dust) and is also the result of long-range transport episodes (e.g. African dust).

7.2 Budapest

Biomass burning (BB), resuspension (RES), secondary ammonium sulphate and nitrate (SEC), traffic (TR) and nitrate-rich (Nitrate-rich) were the most significant $PM_{2.5}$ sources in Budapest (Hungary) accounting for 23,3 % (BB), 22,5% (RES), 21,6% (SEC), 18,6% (TR) and 11,8% (Nitrate-rich) of $PM_{2.5}$ ambient concentrations for the period Feb-May 2015. Nitrate-rich source presents sizeable concentrations of levoglucosan, a marker of wood burning, suggesting it is aged aerosol consisting of secondary nitrate deriving from a relatively distant biomass burning source.

During the high pollution episodes ($PM_{2.5}$ > 25 µg/m^3) the contributions of secondary, nitrate rich and biomass burning sources are those showing the highest increase. On the contrary, the contribution of traffic is the only one that remains almost constant leading to a decrease in the relative contribution from 18% to 5%. The modest increase of resuspension during the episodes also leads to decrease in the relative contribution to $PM_{2.5}$ during the episodes. The increase in the unaccounted fraction is likely associated to loss of nitrate during the sampling. Therefore, the missing mass is likely attributable to the secondary and the nitrate rich biomass sources.

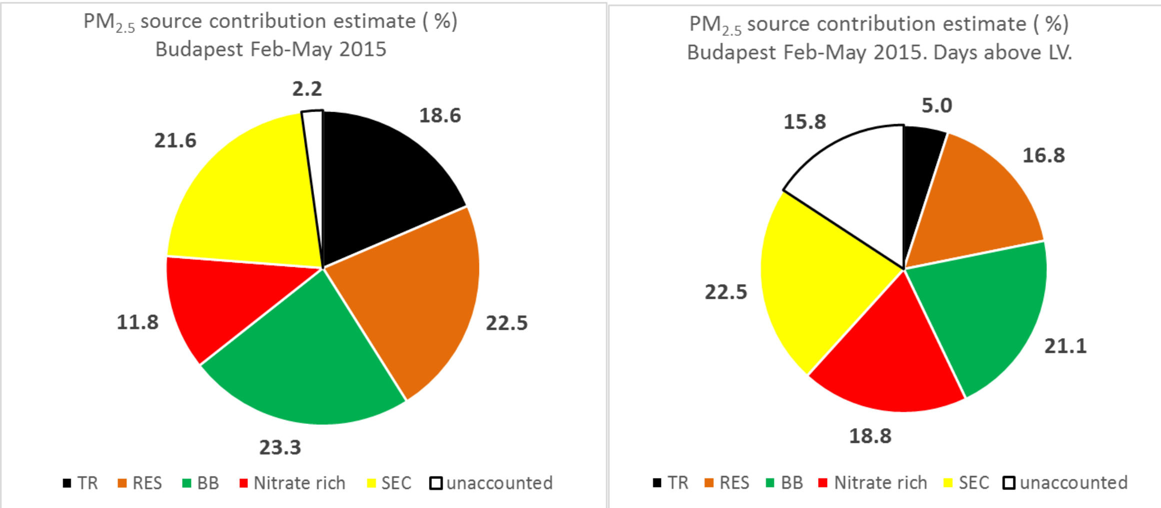


Figure 21. Average source contribution (%) to $PM_{2.5}$ concentrations in Budapest (Hungary). On the left, period Feb-May 2015. The average $PM_{2.5}$ in the considered time window was 17.4 µg/m^3. On the right are reported the contributions for days with $PM_{2.5}$ above the limit value (25 µg/m^3, n=24).

The analysis of trajectories and wind speed and direction in Budapest indicates that local sources are responsible for the gaseous pollutants NO_2, CO and for $PM_{2.5}$. In particular, the main local $PM_{2.5}$ emissions derived from traffic. Sources outside the city appear to be responsible for the observed concentrations of SO_2 and O_3. In the first case, area sources are the Balkans (Romania), Ukraine, Belarus and western Russia, while ozone is associated to westerlies. Potential area sources for the $PM_{2.5}$ nitrate rich source are similar to those of SO_2. Mixed origin, partially local and partially advected (transported), has been identified for resuspension (traffic and African), biomass burning and secondary. Biomass burning is transported from East either at short and long distances with area sources identified over Eastern Hungary, Romania and Ukraine. The origin of secondary is either local, South East of the monitoring site and resulting of long range transport from hotspots over Serbia, Turkey (the area around Marmara Sea) and Poland.

7.3 Sofia

Seondary aerosol (SEC) was found to be the strongest source (42.4%) for PM_{10} in Sofia (Bulgaria) in the years 2012-2013, followed by resuspension-road dust (RESUSP) (26.7%) and biomass burning (15.0%). Industry and fuel-oil accounted for lower contributions, 8.5% (the sum of IND2 and IND3) and 5.2% respectively. The traffic exhaust accounted for only 3.3% of the PM_{10}. Among the industrial sources, IND3 likely deriving from incinerator or cement/ lime production plant, had the highest SCE (2.1 µg/m^3) and the highest relative contribution (7.4 %) to PM_{10}.

During the high PM_{10} pollution episodes the contribution of sulphate still dominate while biomass burning becomes the second most important contributor. The contributions from resuspension remain relatively stable and therefore their relative contributions fall during the episodes. The relative contributions of combustion sources: traffic, fuel oil and industrial remain unchanged during the episodes.

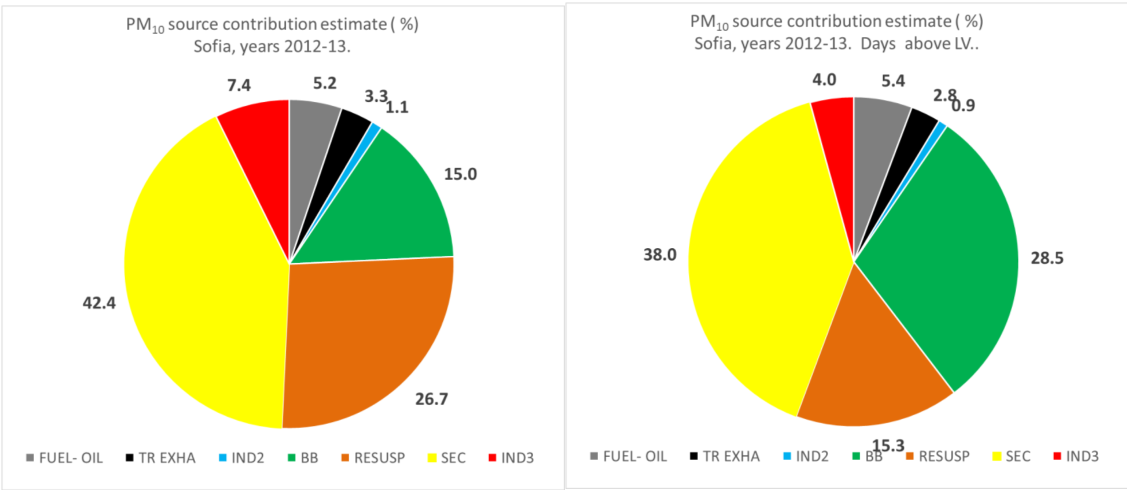


Figure 22. Average contribution (%) to PM_{10} concentrations in Sofia (Bulgaria) years 2012-2013. On the left are reported the averages of all samples. The average PM_{10} concentration in the considered time windows was 42.2 μg/m^3. On the right are reported the contributions for days with PM_{10} above the limit value (40 μg/m^3, n=22).

Interpretation of local wind in Sofia is not straightforward due to the influence of the orography. Local traffic exhaust and local industrial emissions (incinerator, cement, lime production) are considered to contribute to the PM_{10} in Sofia. On the other hand, resuspension, secondary aerosol, fuel oil and lead industrial sources are likely to be advected from areas outside the city. The PM_{10} fraction deriving from biomass burning is likely of both local and advected origin. Resuspension shows potential source areas North of the Black Sea including Ukraine and the area around Moscow. Fuel oil origin is observed over the Aegean, Marmara and Black seas and is likely linked to ship emissions. Similarly, secondary aerosol sources are located in the area around the Marmara Sea and the Black Sea. Even though contribution from shipping cannot be excluded, this factor likely represents also a wide range of aged aerosol deriving from primary SO_2 emissions.

8. Air pollution abatement measures

The results of this study demonstrate that many pollutants have their highest concentrations at low wind speeds, therefore from emission within the urban area (i.e traffic, biomass burning). Other pollutants are often transported from distant source areas (e.g. secondary ammonium sulphate and nitrate). In addition, there are pollutants that have mixed origin (e.g. biomass burning, resuspension). This outcome suggests that measures to reduce atmospheric pollution in the cities requires action at different levels: local, national and European.

8.1 Suggested measures

- Measures to reduce local pollution.

  Heating and traffic are tipical diffuse sources present in cities. In particular, the use of solid fuels like coal and wood for heating could contribute significantly to air pollution in the city and in the outskirts.

  - The substitution of low efficient stoves with improved ones could contribute to reduce the emitted PM and PAHs. Nevertheless, the emission factors of solid fuels are always higher than those of efficient applicances using liquid or gaseous fuels.
  - In the short term, to deal with high pollution episodes, ban the use of fireplaces or wood stoves on days that pollutant concentrations are expected to be very high.
  - The substitution of the circulating fleet (especially diesel powered) with vehicles that respect the latest standards contribute to limit their impact. Under the light of the recent developments about the impact of diesel vehicle emissions the latest standard EURO VI is the most recommendable. Nevertheless, this is a long term and expensive measure that has to be taken at national or regional level.
  - To limit the emissions from road transport it is also necessary to reduce the number of circulating vehicles. This has the advantage of tackling both exhaust and non exhaust emissions. To this end a number of measures to incentivate the use of public transport, increase the number of passenger per vehicle (car pooling), and the use of low impact vehicles (e.g. bycicles, electric cars) are required.
  - In the short term, limit the circulation of most polluting vehicles (e.g. EURO I to IV) when high concentrations of transported pollutants are expected.
  - Measures to reduce the potential of particles deposited on the streets and other surfaces to resuspend:
    a. Systematically clean streets and pavements after intense pollution events, in order to inmobilize and partially remove the heavy load of dust available for resuspension;
    b. Increase urban vegetation and reduce the free surfaces where particles may accumulate and easily resuspend; for instance, trees settle out, trap and hold particles, while grass terrains prevent further resuspension of local soil dust.

- Measures to reduce non local pollution.

  The present study clearly indicates the importance of gas to particle conversion processes in the atmospheric pollution of the cities. The transformation of gaseous emitted pollutants such as SO_2, NO_x and NH_3, lead to the formation of aerosols (so called secondary) which contribute to the PM_{10} and $PM_{2.5}$ levels. These aged pollutants may travel over medium to long distances and therefore could represent emissions in other areas of the same country or even from abroad. While SO_2 and NO_x derive mainly from combustion processes, NH_3 is emitted by agriculture.

At the European level the emission of the above mentioned pollutants are ruled under Directive 2001/81/EC also known as National Emission Ceilings (NEC) Directive. The legislation set upper limits for each Member State for the total emissions from 2010 onwards of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (SO_2, NO_x, volatile organic compounds [VOC] and NH_3), but leaves it largely to the Member States to decide which measures to take in order to comply.

The directive requires the Member States to draft National Programmes and to report emissions and projections to the Commission and the European Environment Agency. The EEA regularly publish the NEC Directive status report based on the reporting by Member States

The National Emission Ceilings Directive 2001/81/EC (NECD) is currently being reviewed as part of The Clean Air Policy Package. The new proposal includes fine particulate matter ($PM_{2.5}$) and methane (CH_4).

In order to support national authorities in the design of optimised abatemment plans it is necessary to consider the abatement potentials of the measures considering the specificity of every country.As mentioned elsewhere in this section, there is a considerable potential for abatement of this kind of emissions from power plants and industrial combustion processes at the national level, particularly in Hungary and Bulgaria, by applying end of pipe technological measures. Considerations about the cost-benefit analysis of such measures are beyond the scope of this study.

Additional information about abatement measures are provided in Annex 1.

8.2 Technical Measures

Emission control measures can be classified in threes groups: behavioural, structural, and technical (Amann et al., 2011). The first two categories are more relevant to global and national level, while the third one refers to 'end of pipe' measures.
This section discusses the potential for PM emission abatement of a set of technical measures evaluated with the GAINS model (http://gains.iiasa.ac.at/gains/EUN/) using the scenario PRIMES 2013 REF-CLE for the reference year 2010.
The "abatement potential" was calculated on the basis of the actual primary emissions of a given sector, the removal efficiency of the selected measure and the controlled capacities, i.e. the proportion of the actual emissions that could actually be subjected to the selected abatement measure.
Figures 23 to 25 report measures arranged on the basis of their decreasing abatement potentials down to 0.8 kilotonnes (kt). In certain cases, measures with different abatement potentials are evaluated for the same kind of emissions.
In Croatia (Figure 23), the highest abatement potentials for PM at the national level are those in the sectors of fertilizer production, coal fired power and district heat plants, and cement plants. Considerable emission reductions could be also achieved in the domestic wood burning, lime production and coal fuelled industrial boilers. For point sources the most effective measures are high efficiency dedusters followed by two-field electrostatic precipitators. For the domestic and commercial wood burning sector the most effective choice is the introduction of improved stoves. The abatement in the road traffic sector, modest at the country level, is important at the local scale. The best technological option is the introduction of EURO 4 on light and heavy duty diesel road vehicles.

Table 1. Most important abbreviations used in the GAINS model. The complete list is available at: http://gains.iiasa.ac.at/gains/EUN/

Abbreviation	SECTOR
PP_EX_L	Power & district heat plants, existing; brown coal/lignite and hard coal fired (> 50 MW el)
PP_EX_S	Power & district heat plants, existing; coal/lignite fired, small units (< 50 MW el)
PR_CEM	Ind. Process: Cement production
IN_BO_OTH_L	Industry: other sectors; combustion of brown coal/lignite and hard coal in large boilers (> 20 MW th)
PR_EARC	Ind. Process: Electric arc furnace
PR_OT_NFME	Ind. Process: Other non-ferrous metals prod. - primary and secondary
IN_BO_CHEM	Industry: chemical industry (combustion in boilers)
PR_GLASS	Ind. Process: Glass production (flat, blown, container glass)
PP_NEW	Power heat plants: New
PR_COKE	Ind. Process: Coke oven
DOM_STOVE_H	Residential-Commercial: Heating stoves
TRA_RD_LD4T	Light duty vehicles: light commercial trucks with 4-stroke engines
TRA_RD_HDT	Heavy duty vehicles - trucks

Abbreviation	ACTIVITY
NOF	No fuel use
HC1	Hard coal, grade 1
BC1	Brown coal/lignite, grade 1
FWD	Fuel wood direct
OS1	Biomass fuels

Abbreviation	TECHNOLOGY
HED	High efficiency deduster
ESP1	Electrostatic precipitator: 1 field
ESP2	Electrostatic precipitator: 2 fields
PR_CYC	Cyclone - industrial process
STV_IMP_B	Biomass stove improved

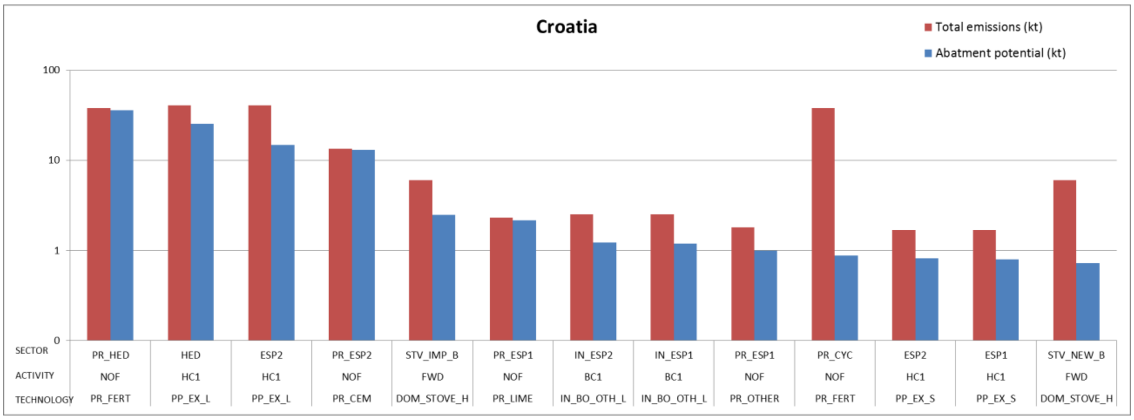


Figure 23. Total primary PM emissions and emission abatement potential of technical measures for Croatia. Abbreviations in table 1.

According to the analysed scenario the main PM abatement at the national level in Hungary would result from the application of technical measures to power plants and industrial combustion processes using coal as fuel (Figure 24). Significant reductions could also be achieved by treating non combustion emissions of plants for the production of cement, fertilizers, lime, coke and metallurgic industries. For the domestic wood burning emissions and the road traffic sectors, which are more relevant for the urban areas, the most suitable measures are similar to those already discussed for Zagreb: improved stoves and introduction of EURO IV standard for diesel vehicles.

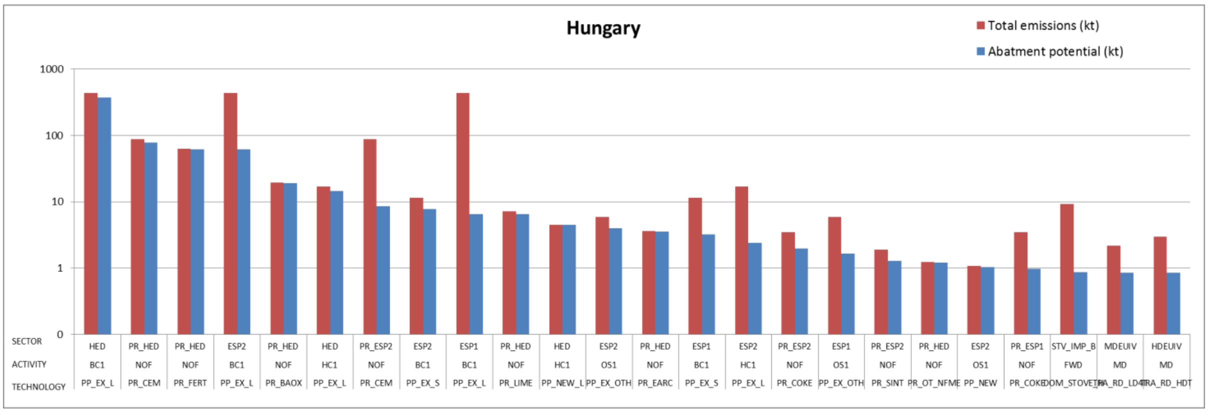


Figure 24. Total primary PM emissions and emission abatement potential of technical measures for Hungary. Abbreviations in table 1.

At the national level, the situation of Bulgaria resembles the one described in Hungary with the measures to abate emissions from combustion of coal combustion in power plants being the most significant (Figure 25). Most of the emissions in this sector derive from a group of power plants located in the eastern part of the country. Also industrial processes for the production of fertilizers, cement, lime, glass and metallurgic plants have sizeable abatement potentials. Introduction of improved stoves for the abatement of wood burning emissions from the domestic sector is among the ten most potentially effective measures. The introduction of EURO standards III and IV have similar abatement potentials

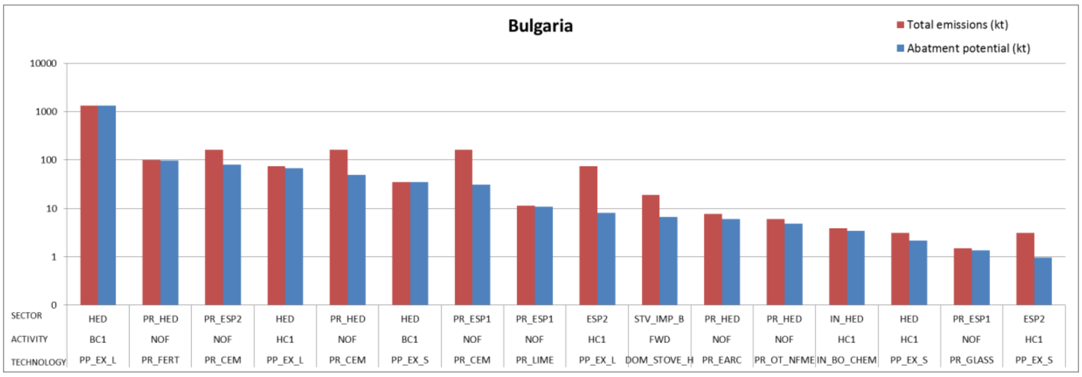


Figure 25. Total primary PM emissions and emission abatement potential of technical measures for Bulgaria. Abbreviations in table 1.

8.3 Catalogue of air quality measures

In addition to the end of pipe measures discussed above, measures consisting in structural improvements and behavioural changes should be also considered. A database with 70 measures that were implemented at local level in EU Member States to control atmospheric pollution is available online (https://luft.umweltbundesamt.at/measures/). The dataset is one of the outputs of the Air Implementation Pilot project promoted by DGENV. The measures were selected to be representative of different situations in the EU. The database is intended to support the implementation of the Air Quality Directive in EU member states by providing examples of successful (best practices) and unsuccessful measures.

Measures are flagged as successful when the goals (emission reduction, air quality improvements, changes in indicators) set beforehand by the responsible authority were achieved. Unsuccessful measures are those that did not meet the expectations, reduction effects are disputed or effects are lower due to improper implementation. Nevertheless, it should be considered there are many factors determining the effectiveness of air quality plans and, therefore, unsuccessful measures in a given situation might be successful under different circumstances.

Following measures were flagged as successful:

- <u>to reduce traffic emissions</u>: bike renting, extension of cycle paths, car sharing, introduction of cleaner vehicles (private and public), ban of heavy duty vehicles, city spatial planning, inter-modality, central logistics, reduction of public transport tickets price, increase of extension and velocity, congestion charges, low emissions zones, reduction of speed limit;
- <u>to control biomass and wood burning</u>: prohibition of open field agricultural waste burning, banning use of bituminous fuels and fuel oil for heating, extension of district heating and emission control, increase residential biomass combustion energy efficiency, emission limit value for domestic heating, tackling fuel poverty.

8.4 Appraisal Project

The objective of the project was to consolidate knowledge and common practices on air pollution assessment throughout Europe and to make them accessible to the policy makers at local and regional level. On the basis of the answers to a questionnaire on air quality plans at regional at local level, a database describing almost 60 air quality plans was built up (http://www.appraisal-fp7.eu/site/index.php). The database is structured in five topics: 1) Synergies among national, regional and local air quality plans, 2) Air quality assessment and planning, 3) Health impact assessment approaches, 4) Source apportionment, 5) Uncertainty, robustness and validation.

According to the information contained in the database more than half of the plans were developed on the basis of source apportionment accomplished using, either, receptor models and dispersion models. The main source categories considered in the reported quality plans were (between parenthesis the percentage of plans that included the considered source category): road transport (SNAP 7, 56%), combustion in energy and transformation industries and combustion in manufacturing industry (SNAP 1 and 3, 46% each), non-industrial combustion plants (SNAP2, 44%) and production processes (SNAP 4, 39%).

9. Conclusions

In the present work, the causes of air pollution in selected areas of the Danube region were studied using a combination of datasets and modelling tools. The adopted approach made it possible to quantify the contributions from different activity sectors, including natural sources and determine their geographical origin. On the basis of the characteristics of the sources, a series of measures were identified using public databases that are the outcome of European research and applied policy oriented projects.

The approach adopted in this study provided answers tailored to the particular characteristics of every urban area. The strength of the approach resides in the capability to combine a series of databases (measurements, emissions, meteorological variables, source fingerprints, abatement measures) using a set of affordable modelling tools. The outcome of the study demonstrates the potentials of an approach that can be adopted at the local level taking advantage of the available resources (personnel, data and equipment) with a reasonable additional effort.

The picture resulting from this study highlights the complexity of the pollution processes and the need to adopt flexible and multilevel measures to deal with it. Most of the pollutants are emitted locally while the medium to long range transport is considerable. For that reason, there is a need for action at the local level and also the national and international scales. Therefore, the success of the measures mostly depends on the coordination among different levels taking into account the needs and inputs from other relevant sectorial policies (e.g. climate change).

At the local level, measures to control diffuse sources from domestic heating and traffic are required. In these sectors the impact of technological measures (substitution of fleet and use of efficient stoves) is uncertain. Such measures are likely not enough to bring the emissions to acceptable levels and would, therefore, be accompanied by structural and behavioural changes. That means improvement of mobility in the cities to reduce the circulating fleet and promote centralised efficient heating systems using cleaner fuels. According to the analysis of the abatement potentials, end of pipe measures (high efficiency deduster and electrostatic precipitators) appear as the most suitable to deal with gaseous pollutants and secondary aerosol. For the latest category of pollutants, controlling the emissions of ammonia from agriculture is crucial. Some of the measures at the national level are already planned by the EU member states for the implementation of the directive on national emissions ceiling (NEC). In this study, long range pollution transport from EU eastern neighbours has been detected in the studied cities. Therefore, action is also needed to control international emissions in the power plants, industrial and shipping sectors.

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List of abbreviations and definitions

CH_4: methane

CPF: Conditional Probability Function

DAN: Danube Air Nexus

EEA: European Environmental Agency

EUSDR: European Union Strategy for the Danube Region

FLEXPART: Flexible Particle Dispersion Model

JRC: Joint Research Centre

NEC: National Emission Ceiling

NECD: National Emission Ceilings Directive 2001/81/EC

NH_3: ammonia

NO_x: nitrogen oxides

NO_2: nitric oxide

$\mu g/m^3$: micrograms per cubic meter

O_3: ozone

PM_{10}: particulate matter with aerodynamic diameter below 10 micrometers

$PM_{2.5}$: particulate matter with aerodynamic diameter below 2.5 micrometers

PMF: Positive Matrix Factorization

PSCF: Potential Source Contribution Function

SCE: source contribution estimates

SO_2: sulphurous anhydride

SO_4^{2-}: sulphate

VOC: volatile organic compounds

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Annex 1. Measures to abate PM

Three general emission sources have been identified as the main contributors to increased PM concentrations and exceedances of the EU air quality standards: Road traffic, Biomass burning and Secondary aerosol production by gaseous precursors (nitrogen and sulphur oxides and volatile organic compounds). Based on the project results a set of control measures have been compiled and provided as guidelines for the preparation of a National Air Quality Plan. The measures were based on PM speciation and source apportionment. Details on the implementation of the proposed measures are also included: (i) feasibility (in terms of degree of priority and effectiveness, ranging from 1 - 3, with 1 corresponding to the highest degree); (ii) minimum time required for implementation; (iii) preliminary estimation of costs; (iv) possible implementing authoritites; (v) means of implementation.

ROAD TRAFFIC

Low emission zones (LEZ): Implement free access for newer technology hybrid vehicles in the "green ring". In this area all other vehicles enter every second day according to an odd/even system with respect to their number plate last digit. The odd/even system should be expanded to motorcycles that have more than 60 hp. Finally vehicles larger than 2.2 tn are banned.

Priority: 1 / Effectiveness: 2

Actions proposed:

- o Traffic study to examine the expansion of the green ring area (12 months; 100.000 €)
- o Environmental Impact Study (10 months; 80.000 €)
- o Common ministerial decision (3 months)
- o Inspection and monitoring of the implementation of green ring (360.000 €/year)

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Parking: Creation of large parking lots at main transport interfaces (train and metro stations) at the outskirts of the city (park and ride system) with incentives (low fares) in order to promote the combined use of car and public transport.

Priority: 1 / Effectiveness: 1

Actions proposed:

- o Feasibility study (12 months; 200.000 €)
- o Environmental Impact Study (8 months; 150.000 €)
- o Studies and construction of parking lots (24 months; 1.500.000 €)

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Street cleaning: Tandem use of sweeping and, more importantly, water washing, especially during dry periods of the year. It is evident that non-exhaust traffic emissions lead to a major part of the coarse fraction of road dust that can be removed by street cleaning.

Priority: 3 / Effectiveness: 3

Actions proposed:

o Provision of the infrastructure required (15 months; 600.000 €)

o Implementation of the measure 600.000 €/year.

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Decentralised Administration Authorities

Promoting low-carbon and low-NOx vehicles and new technology vehicles: Implement further Reductions in Road Tax and Import Tax for low emission vehicles (for NO_2 and PM); Incentives to withdraw aged private vehicles and replacement with modern (E5/E6) vehicles; Incentives for installation of particle filters in heavy duty commercial vehicles.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Techno economic study for: i) the determination of the reduced Road Taxes and Registration Taxes and ii) the estimation of the expected public revenues in relation to the current revenues (15 months; 120.000 €)

o Environmental Impact Study (11 months; 90.000 €)

o Common ministerial decision (3 months)

This measure should be self-financed, the final cost, if any will be determined from the above study.

Implementation agencies:

Ministry of Finance

Ministry of Environment Energy and Climate Change

Expand public transport Network: Creation- expansion of Metro lines. Improvement of Public Bus Network for an efficient, ecologic and faster public transportation (metro, train, and tram)

Priority: 1 / Effectiveness: 1

Actions proposed:

o Construction or expansion of existing metro lines (construction times and costs not available)

o Origin-Destination Traffic Study (15 months; 500.000 €)

o Techno-economic Study (10 months; 150.000 €)

o Improvement of Public Bus network according to the conclusions of the Origin-Destination Study (10 months; costs determined by techno-economic study)

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Reducing road transportation for goods: Creating a terminal outside the City serviced by rail line to the harbour. Currently trucks travel within the central axis of the

City Area.

Priority: 3 / Effectiveness: 2

Actions proposed:

- Feasibility Study for the expansion of the railway network and the construction of the terminal (8 months; 80.000 €)
- Environmental Impact Study (12 months; 120.000 €)
- Technical studies and Construction works (24 months; cost determined from the studies required).

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Renewal of car/taxi fleet: Subsidies for increasing the share of hybrid, natural gas and new technology private vehicles and taxis.

Priority: 2 / Effectiveness: 2

Actions proposed:

- Techno-economic Study for: i) the determination of subsidies and ii) the estimation of the expected public revenues in relation to the current revenues (9 months; 60.000 €)
- Environmental Impact Study (8 months; 50.000 €)

This measure should be self-financed, the final cost, if any will be determined from the techno-economic study.

Implementation agencies:

Ministry of Finance

Ministry of Environment Energy and Climate Change

Reduced fares of public transport: Reduced fares for public transport during intensive Sahara dust intrusions or forecasted intense pollution episodes.

Priority: 2 / Effectiveness: 2

Actions proposed:

- Common ministerial decision (3 months)

Implementation agencies:

Ministry of Finance

Ministry of Environment Energy and Climate Change

Improving public fleet: Increase the share of natural gas buses. Enforce the measure of withdrawal of old technology urban and regional buses.

Priority: 2 / Effectiveness: 2

Actions proposed:

o Common ministerial decision for withdrawal of old technology urban and regional buses (3 months)

o Techno-economic Study for: i) the determination of subsidies and ii) the estimation of the expected public revenues in relation to the current revenues (9 months; 60.000 €)

o Environmental Impact Study (8 months; 50.000 €)

This measure especially for regional buses should be self-financed; the final cost, if any, will be determined from the techno-economic study.

Implementation agencies:

Ministry of Finance

Ministry of Environment Energy and Climate Change

Vehicle and road maintenance: Increase the frequency of inspection programmes to public vehicles to ensure that in-use engines continue to have functional controls and proper maintenance. Maintaining roads in good repair to reduce the contribution of PM from road surface wear.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Common ministerial decision for the implementation of inspection programmes (3 months)

o Enhanced programme of maintenance of road network (10.000.000 €/year)

Implementation agencies:

Ministry of Infrastructure, Transport and Networks

Ministry of Environment Energy and Climate Change

Decentralised and Local Administration Authorities

HEAVY OIL COMBUSTION / SHIPPING

Combat the illegal trade of adulterated fuel: Incidents of adulterated fuel circulation and use are still common. Continuous controls are needed to eliminate this phenomenon.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Application of inflow-outflow fuel control system in all gas stations (6 months)

o Inspection and control of the inflow-outflow fuel control system in gas stations (150.000 €/year)

Implementation agencies:

Ministry of Finance

Stricter legislation for industrial heavy fuel oil users: Monitor with inspection checks the fuel efficiency of burners, boilers and power generators of small and medium scale industries operating machinery using heavy fuel oil.

Priority: 2 / Effectiveness: 2

Actions proposed:

- Inspection and control of boilers and burners (100.000 €/year)

Implementation agencies:

Ministry of Environment Energy and Climate Change

Decentralised Administration Authorities

Industrial facilities: Impose high standards for fuels and increase inspections to facilities.

Priority: 2 / Effectiveness: 2

Actions proposed:

- Inspection and control of industrial facilities (150.000 €/year)
- Common Ministerial Decision (for setting fuel quality standards) (3 months)

Implementation agencies:

Ministry of Environment Energy and Climate Change

Decentralised Administration Authorities

Ministry of Infrastructure, Transport and Networks

Stricter legislation for harbour: Docking at the large commercial harbours is only permitted to vessel with engines operating with low sulphur content. These rules need to be enforced and monitored.

Priority: 1 / Effectiveness: 1

Actions proposed:

- Inspection and control of ships fuels (150.000 €/year)
- Common Ministerial Decision (for setting fuel quality standards) (3 months)

Implementation agencies:

Ministry of Environment Energy and Climate Change

Ministry of Infrastructure, Transport and Networks

Port Authorities

PRECURSORS OF SECONDARY AEROSOL

Reduce precursors of secondary particles, mainly SO_2: Very high levels of SO_4^{2-} were observed in the three cities. Sulphate is produced from SO_2 emitted mainly during energy production processes in the industrial and residential sectors. The introduction of natural gas in the national energy system constitutes a major priority of the national energy policy. Expansion projects of the gas system should be under way in order to link more cities and industries to the system. Moreover, in the areas connected to the natural gas network, natural gas stations for feeding CNG (Compressed Natural Gas) vehicles should be created.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Expansion of natural gas system (12 months; costs according to existing estimations regarding natural gas system expansion)

Implementation agencies:

Ministry of Environment Energy and Climate Change

Ministry of Infrastructure, Transport and Networks

Reduce trans-boundary pollution due to the use of fossil fuels in large industrial facilities and power plants in European neighbour countries.

The high levels of sulphate observed across the aforementioned countries and in the overall area of Southeast Europe may be partly due to long range transport of SO_4^{2-} or gaseous precursors (SO_2), and specifically from countries still using high sulphur content fuels. The low oxidation rate of SO_2 to SO_4^{2-} further supports this hypothesis. This is an area where policy makers must intensify efforts for resolving problems of trans-boundary pollution, by providing support and incentives to countries to turn towards cleaner fuels and production processes.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Techno-Economic Study for the reduction of air pollution from large industrial facilities and power plants in European developing countries (15 months; 120.000 €)

o Installation of anti-pollution systems to reduce industrial air pollution in developing countries in Europe (10 months; the cost will be specified from the techno-economic study)

Implementation agencies:

European Commission

BIOMASS BURNING

Reduction of low efficiency wood burning for residential heating: High price of diesel for residential heating during the economic crisis resulted in the use of wood in a large scale in the densely populated areas of urban centres, leading to high pollution episodes during stagnation periods in winter. Measures to discourage citizens from this inefficient form of energy are needed:

- Introduction of natural gas and renewable energy sources

- Improvement of the thermal behaviour of residential buildings

- Promotion of energy efficiency appliances and heating equipment

- News bulletins advising for reduction in wood burning during forecasted atmospheric stagnation periods

- Information material and training of citizens regarding the negative health impact of uncontrolled biomass burning.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Information campaigns in order to avoid biomass burning and to promote the use of high energy efficient appliances (50.000 €/year)

o Common Ministerial Decision for giving citizens subsides in order to be connected to the natural gas network (3 months)

o Subsidies for further penetration of natural gas for house holdings (2.000.000 €/year)

o News bulletin advising the reduction of biomass burning during atmospheric stagnation episodes.

Implementation agencies:

Ministry of Environment Energy and Climate Change

Ministry of Finance

POPULATION HABITS

Environmental education and awareness raising: Communication campaigns through the media and dissemination of "best practices" should be favoured in order to sensitize population on the opportunity of the previous measures.

Priority: 1 / Effectiveness: 1

Actions proposed:

o Information and awareness campaigns in order to promote the measures described above (80.000 €/year)

Implementation agencies:

Ministry of Environment Energy and Climate Change

Ministry of Infrastructure, Transport and Networks

Ministry of Health

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