A proposal to overcome the ambiguity of the aerosol and communicate it more easily, with the help of Captain Sankey

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Problem

How can we answer to the simple question **"who is to blame for PM10 air pollution?"**.
How can we communicate, to a generic public, which are the main human activities affecting the air quality, in terms of aerosol concentration?

option #1: as simple as we can

In most of the cases primary particulate matter emissions are shown. Sometimes also the emissions of some gaseous precursors. While the first approach is misleading, since it implicitly excludes the formation of secondary aerosol, the latter can be confusing, since emissions of primary PM and emissions of the precursors (NO_x, VOCs, NH_3, SO_x) are not commensurable.

option #2: the complex answer

Chemistry-transport models (CTMs) are the solution to fill this knowledge gap, but often the plenty of information they give is complex and not so easy to condense in a straight answer – possibly a ranking.

option #3: understandable and accurate

We propose a method which is a compromise between the emission-ranking approach, simple and easy to communicate but possibly misleading, and the CTM approach, accurate but complex.

Method

The method proposed by de Leeuw (2002) and Johansson et al. (2003) is helpful, since the emission of each precursor can be expressed in terms of "**PM10 equivalent**", using their aerosol formation factors (AFs).

aerosol formation factor

This approach is similar to the "carbon-dioxide-tons-equivalent", widely used to assess and to communicate the contribution of single human activities or single countries to the greenhouse gases emissions.

$$AF = \frac{M_S}{M_P} \cdot Y \cdot F \qquad (1)$$

where M_P = molecular mass of the precursor, M_S = molecular mass of the corresponding secondary molecule in the aerosol, Y = fraction of emission potentially leading to aerosol formation, F = fraction of emitted mass converted into secondary aerosol.
The AFs suggested by de Leeuw (2002) and Johansson et al. (2003) are suitable for continental scale analysis, not for regional. Therefore we need to calculate regional scale AFs. We decided to **rescale the AFs**, assuming their proportions are constant.
In order to rescale the European-scale AFs, we need specific knowledge of the Po Valley air pollution dynamics, provided by a chemistry-transport model (CTM).

the NINFA modelling suite

- **CHIMERE** model (Menut et al., 2014) with MELCHIOR chemical module
- simulates separately primary and secondary aerosol
- domain covering northern Italy with a resolution of 5km (Stortini et al., 2007)
- met. input: COSMO-I7 non-hydrostatic model (Steppeler et al., 2003; Jongen & Bonafè, 2006)
- emission input (year 2010) provided by: ISPRA Italian national emission inventory (De Lauretis et al., 2009) and Emilia-Romagna regional emission inventory (Tugnoli & Rumberti, 2010)
- chemical boundary conditions: PREV'AIR (Rouil et al., 2009)

particulate matter partition

Through an annual simulation with the NINFA modeling system we estimated the following partition of the concentrations C of PM10 in the Emilia-Romagna region: 23% anthropogenic primary, 61% anthropogenic secondary, 16% natural primary (Fig.1).
On average, we assume **the same proportion in the emissions** E of the "PM10-equivalent":

$$\frac{E_{primary\ PM10}}{E_{secondary\ PM10}} = \frac{C_{primary\ PM10}}{C_{secondary\ PM10}} = \frac{23}{61} \qquad (2)$$

Therefore, the emissions of secondary PM10-equivalent are

$$E_{secondary\ PM10} = E_{primary\ PM10} \cdot \frac{61}{23} = 13638 \cdot \frac{61}{23}\, Mg \cdot y^{-1} = 36170\, Mg \cdot y^{-1} \qquad (3)$$

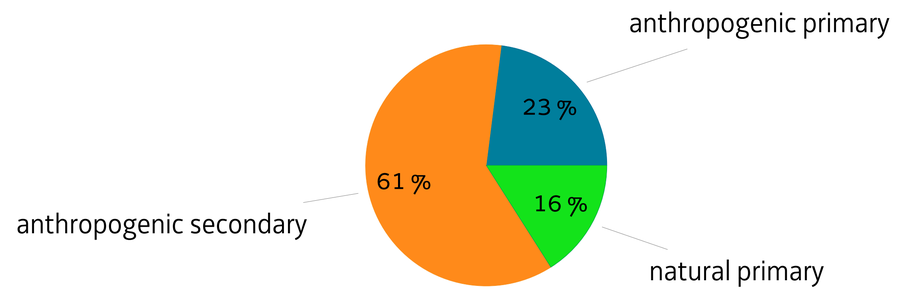

Figure 1: With the NINFA modeling system (annual simulation) the partition of the PM in the Emilia-Romagna region has been estimated.

AFs rescaling

The AFs suggested by de Leeuw (2002) and Johansson et al. (2003) (suitable for continental scale analysis) would lead to a different estimate $\tilde{E}_{secondary\ PM10}$ of the "emissions of secondary PM10"

$$\tilde{E}_{secondary\ PM10} = AF_{NO_2} \cdot E_{NO_2} + AF_{SO_2} \cdot E_{SO_2} + AF_{NH_3} \cdot E_{NH_3} + AF_{VOCs} \cdot E_{VOCs} = 138340\, Mg \cdot y^{-1} \qquad (4)$$

Therefore, in order to apply the AFs approach to the Emilia-Romagna domain, we need to rescale AFs. The rescaling factor F follows from Equations 4 and 3:

$$F = \frac{138340}{36170} \approx 3.8 \qquad (5)$$

The new AFs are shown in Table 1.

Table 1: Aerosol formation factors

AFs	primary PM	SO_2	NO_2	NH_3	VOCs
for European domain	1	0.54	0.88	0.64	0.02
for Emilia-Romagna	1	0.14	0.23	0.17	0.0055

Results

If one only considers primary PM10 emissions, domestic wood heating would stand out as the worst polluter. But considering the sum of all the precursors, each weighted with its own AF, we can get a more accurate overview, concluding that the road freight is indeed the prevailing anthropogenic source, but not overwhelmingly, representing about a quarter of the total (Table 2).

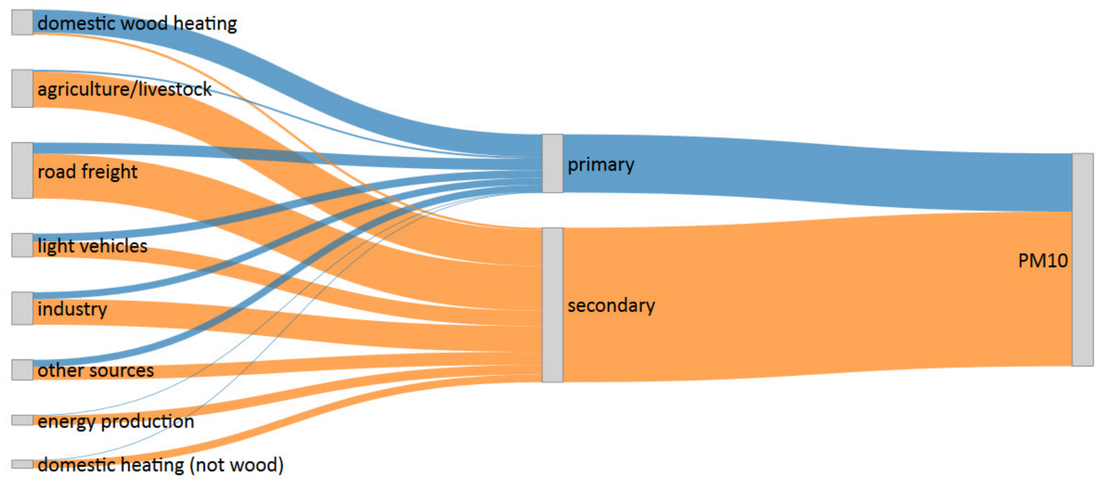

Figure 2: The AF allows expressing anthropogenic PM10 precursors in terms of "PM10 equivalent" in the domain. In this Sankey diagram (Sankey, 1896) the width of the connections is proportional to the "flow" of PM10 equivalent mass in the Emilia-Romagna region. On the left side, emissions are aggregated by emission sector; in the center, aggregated by category.

Table 2: Emissions in the Emilia-Romagna region, expressed in terms of PM10 equivalent ($Mg \cdot y^{-1}$)

source	primary PM10	NH_3	NO_2	SO_2	VOCs	total PM10
road freight	2636	9	10396	24	17	13082
agriculture/livestock	418	8381	147	0	0.3	8946
industry	1614	188	3519	2004	283	7608
domestic wood heating	5316	26	349	28	143	5862
light vehicles	1842	132	3470	27	21	5492
other sources	1646	23	2831	167	38	4705
energy production	86	0	2181	60	8	2335
domestic heating (not wood)	80	0	1659	139	4.4	1882

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