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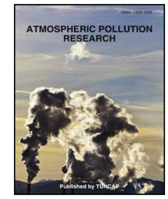

An uncertainty quantification of PM2.5 emissions from residential wood combustion in Italy

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ABSTRACT

Residential wood combustion from fireplaces and wood stoves represents a major source of aerosol emissions which can cause severe air quality deterioration, pose a serious threat to human health and climate change. Moreover, the emission estimates from this source have a high degree of uncertainty that in many emission inventories has not yet been assessed. This paper represents a first attempt to quantify the PM2.5 emission uncertainty from residential wood combustion in Italy. A bootstrap simulation analysis has been performed considering the data from the two most updated national surveys on wood consumption. The bootstrap simulations have been carried out both on a national and on a regional level varying wood consumption and emission factors of the different appliance type considered, but keeping constant their distribution in the whole national territory. The influence of the two resulting emission datasets on PM2.5 concentrations in Italy has been investigated with the MINNI model. The results show that the mean of PM2.5 total emissions for Italy is circa 120 kt, from a minimum of 97 kt to a maximum of 146 kt (−18.9%, +21.5% on the mean value). Moreover, a significant variation of annual average PM2.5 concentrations, with values higher than 10 $\mu g/m^3$ in the most polluted areas, is shown by model results. The distribution influence of the different appliance types has been explored with a sensitivity test in the Veneto Region. This test reveals the importance of emission factors and technology share as the most important parameters influencing the uncertainty analysis.

1. Introduction

In a number of communities in many parts of the world, residential wood combustion (RWC) from residential fireplaces and woodstoves has shown to be a major source of aerosol emissions which can cause severe air quality deterioration, pose serious threat to human health and climate change (Butt et al., 2016; WHO, 2015; Viana et al., 2013; Piazzalunga et al., 2011; Janssen et al., 2011; Akagi et al., 2011; Zielinska and Samburova, 2011; Saarikoski et al., 2008; Szidat et al., 2007; Gelencser et al., 2007). Moreover, the use of RWC is increasing in many European countries because of rising of fossil fuel prices and of climate change mitigation policies (Denier van der Gon et al., 2015; Nava et al., 2015). Despite being one of the major source of organic aerosol in Europe, especially in winter time (Gelencser et al., 2007; Puxbaum et al., 2007), the emission estimates from RWC are the most uncertain (for example, Bergstrom et al., 2012; Kostenidou et al., 2013) and previous studies suggested that wood burning is one of the major contributors to the uncertainty in air quality forecasting (Byun and Schere, 2006; Tian et al., 2009). Recent studies demonstrated how emissions from RWC are significantly underestimated (Denier van der Gon et al., 2015) and how RWC emissions have to be increased in order to improve the agreement between measured and predicted organic aerosol in CTMs (Chemical Transport Models) that will also influence source-receptor matrices and modeled source apportionment (Butt et al., 2016; Denier van der Gon et al., 2015; Fountoukis et al., 2014; Genberg et al., 2013).

The existence of uncertainty in particulate matter emission estimates (especially from RWC) is well-known: nevertheless, only 15 Member States quantified uncertainty in their emissions inventories of 2014 and, moreover, the pollutants considered and the assumptions behind the uncertainty analysis vary across Member States (EEA, 2016b).

Estimating the emission uncertainty represents an ongoing area of research (Pouliot et al., 2015) and the aim of the present paper is to offer a preliminary quantification of the uncertainties in fine particulate matter (PM2.5) emissions from RWC in the Italian emission inventory since it has not been assessed yet (ISPRA, 2017). Uncertainties in wood combustion emission inventories are linked to the large variety of wood

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burning devices in use, to the difficulties in obtaining an accurate count and spatial representation of each device type, to differences between standard wood burning device emissions tests in a laboratory and emissions from these devices when they are used in the real world (Kotchenruther, 2016). Moreover, several emissions studies from wood stoves have been performed in Europe that mainly reflect local/regional characteristics and are not applicable for countries with other individualities (Seljeskog et al., 2017; Nussbaumer et al., 2008b). Wood heating in Europe varies a lot from country to country due to climate differences, type of building, access to resources. A very recent study has also investigated the influence of users' behaviour on particulate emissions from residential wood and pellets stoves (Fachinger et al., 2017). In addition, different conventions, standard and methods for measuring particulate emissions are used because a common method in Europe has not yet been defined, entailing large differences in reported emission factors (EEA, 2016a; Nussbaumer et al., 2008b).

In the Italian national emission inventory, elaborated annually by ISPRA (Institute for Environmental Protection and Research, ISPRA, 2017), the non-industrial combustion plant represents the most emitting sector of PM2.5, 69% of total PM2.5 emissions in 2015, of which almost 99% derives from RWC. Being RWC in Italy one of the major primary PM2.5 emission source, a first quantification of the uncertainties in PM2.5 emissions from wood burning represents an area of great interest, especially considering that accurate wood combustion emission data are also fundamental to developing the corresponding abatement strategies (Fountoukis et al., 2014) and air quality policies.

2. Materials and methods

2.1. Methods for estimating wood burning emissions

Emissions from wood burning were estimated based on the amount of wood burned and emission factors. For each type of appliance, emissions were calculated by using Eq. (1):

$$E_p = \sum_j Act * EF_{p,j} * x_j \tag{1}$$

where p represents the pollutant type, E is annual emission of a particular type of pollutant (ton/year); Act is the annual wood consumption (in GJ); EF is the emission factor of wood for pollutant p for appliance type j (in g/GJ); x is the share of the applied appliance type j.

The detailed methods, activity data sources and emission factors are described in the following subsections.

2.1.1. Compilation of activity data

Reliable fuel wood statistics are difficult to obtain because fuel wood is often non-commercial and falls outside the economic administration (Denier van der Gon et al., 2015). In Italy, several surveys have been carried out to estimate national wood consumption in the domestic heating and the related types of appliances used (ISPRA, 2017). The first survey to estimate the Italian wood combustion (Gerardi and Perrella, 2001) was carried out in the year 1999; the second survey (Caserini et al., 2007), referred to the year 2006, was carried out using the CATI (Computer Aided Telephone Interview) method and different variables were taken into account, like the altitude or the municipal structure (Pastorello et al., 2011); the third survey (ISPRA, 2012) was related to the year 2012. The most recent survey was funded by the Ministry of Economic Development and infrastructure (MISE), carried out in 2014 by the national Institute of Statistics (ISTAT), and includes the fuel consumption of solid biomass, as wood and pellets (ISTAT, 2015). In this regard, the survey resulted in an official statistic for 2012 and 2013 of wood and pellet consumption at national and regional level. This survey has allowed the update of the whole wood consumption historical time series and offered a different regional consumption distribution. To compare wood consumption and its regional share, a common year for both surveys has been chosen: the year 2010.

Table 1
Residential wood consumption for the year 2010 at a regional level (data calculated in PJ based on Istat and ISPRA surveys).

ISTAT code	Region	Regional share (%)		Wood combustion (PJ)	
		ISPRA 2012	ISTAT 2015	ISPRA 2012	ISTAT 2015
1	Piemonte	9.32%	9.89%	12.19	29.60
2	Val d'Aosta	0.20%	0.46%	0.27	1.37
3	Lombardia	15.39%	8.92%	20.15	26.69
4	Trentino Alto Adige	1.52%	3.73%	1.99	11.17
5	Veneto	7.62%	9.29%	9.97	27.80
6	Friuli Venezia Giulia	2.22%	3.22%	2.90	9.65
7	Liguria	2.76%	2.12%	3.61	6.35
8	Emilia Romagna	7.36%	4.76%	9.64	14.26
9	Toscana	5.75%	7.18%	7.53	21.50
10	Umbria	1.22%	3.61%	1.59	10.80
11	Marche	2.60%	2.88%	3.41	8.63
12	Lazio	9.75%	8.35%	12.75	25.01
13	Abruzzo	2.25%	5.23%	2.94	15.66
14	Molise	0.72%	1.26%	0.95	3.77
15	Campania	9.46%	8.95%	12.38	26.79
16	Puglia	8.48%	4.13%	11.10	12.36
17	Basilicata	0.91%	2.40%	1.20	7.19
18	Calabria	4.22%	7.18%	5.52	21.50
19	Sicilia	5.31%	2.17%	6.95	6.51
20	Sardegna	2.93%	4.26%	3.84	12.76
	Total	100.00%	100.00%	130.88	299.35

In the present work, we have considered the wood consumption for the year 2010 of the 2015 and 2017 inventory submissions (ISPRA, 2015; 2017) and the regional wood distribution share of the two last national surveys (ISTAT, 2015) and (ISPRA, 2012) whose data are summarized in Table 1.

2.1.2. Determination of emission factors

Emission factors for wood combustion vary widely also for the same appliance type due to the influence of combustion type, fuel parameters and different operation conditions (Nussbaumer et al., 2008a, b; Ozgen et al., 2014). The emission factors considered in this study have been chosen mainly from the latest research results based upon local or domestic measurements, and in particular from the last national tests (Caserini et al., 2014). In order to quantify the uncertainties linked to the emission factors, we have collected also the data from previous submission of the national emission inventory (ISPRA, 2012). All the emission factors considered for the different appliance types are reported in Table 2.

2.1.3. Share of appliance types

A higher degree of uncertainty is linked to the share of the different appliance types. It is not easy to classify the distribution and usage of appliances types in the whole national territory. In our first attempt to

Table 2
Emission factors (EF in g/GJ) considered in the last submission of the national emission inventory (ISPRA, 2017 – sub 2017) and in the 2012 submission (ISPRA, 2012 – sub 2012) for the different appliance types used in Italy.

Pollutant: PM2.5	ISPRA emission inventory	
Technology	EF - year 2010 - inv sub 2012 (g/GJ)	EF - year 2010 - inv sub 2017 (g/GJ)
Open Fireplace (OF)	850	510
Close Fireplace (CF)	240	134
Traditional Stove (TS)	810	486
Advanced Stove (AS)	240	165
Pellets Stove (PS)	76	148