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# Spatial emission modelling for residential wood combustion in Denmark

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## HIGHLIGHTS

- A new model for high resolution spatial distribution of RWC emissions is prepared.
- Using detailed heating installation data from the Building and Dwelling Register.
- Improved accuracy by changing to high spatial resolution of 1 km × 1 km.
- Model verification for Copenhagen against the previous model and a case study.
- Improved accuracy independently of the weighting factors chosen.

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## ABSTRACT

Residential wood combustion (RWC) is a major contributor to atmospheric pollution especially for particulate matter. Air pollution has significant impact on human health, and it is therefore important to know the human exposure. For this purpose, it is necessary with a detailed high resolution spatial distribution of emissions. In previous studies as well as in the model previously used in Denmark, the spatial resolution is limited, e.g. municipality or county level. Further, in many cases models are mainly relying on population density data as the spatial proxy for distributing the emissions. This paper describes the new Danish model for high resolution spatial distribution of emissions from RWC to air. The new spatial emission model is based on information regarding building type, and primary and supplementary heating installations from the Danish Building and Dwelling Register (BBR), which holds detailed data for all buildings in Denmark. The new model provides a much more accurate distribution of emissions than the previous model used in Denmark, as the resolution has been increased from municipality level to a 1 km × 1 km resolution, and the distribution key has been significantly improved so that it no longer puts an excessive weight on population density. The new model has been verified for the city of Copenhagen, where emissions estimated using both the previous and the new model have been compared to the emissions estimated in a case study. This comparison shows that the new model with the developed weighting factors (76 ton $PM_{2.5}$) is in good agreement with the case study (95 ton $PM_{2.5}$), and that the new model has improved the spatial emission distribution significantly compared to the previous model (284 ton $PM_{2.5}$). Additionally, a sensitivity analysis was done to illustrate the impact of the weighting factors on the result, showing that the new model independently of the weighting factors chosen produce a more accurate result than the old model.



## 1. Introduction

Residential wood combustion (RWC) is an important emission source in Denmark contributing in 2013 with more than 60% of the emission of fine particles ($PM_{2.5}$), more than 70% of the emission of benzo(a)pyrene (BaP) and about 50% of the emission of dioxins and furans (PCDD/F) (Nielsen et al., 2016b). The corresponding shares for the 28 Member States of the European Union (EU-28) for residential combustion are 50% of $PM_{2.5}$, 71% of BaP and 37% of PCDD/F (CEIP, 2015a). RWC therefore has a significant effect on air quality and adverse impacts on human health. The World Health Organization (WHO) estimates that there were 3.7 million premature

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deaths in 2012 from urban and rural sources worldwide due to outdoor air pollution (WHO, 2014). Recent results (Brandt et al., 2013a, 2013b) show that outdoor air pollution caused a total number of 570.000 premature deaths in the year 2011 in Europe and around 3.500 premature deaths in Denmark alone. In Denmark, the RWC contributes with 30–40% of the premature deaths and the health related external costs due to air pollution from Danish emission sources alone, taking into account both primarily emitted particles and secondary formed inorganic aerosols (Brandt et al., 2013a).

High quality emission inventories of air pollutants are essential input to air pollution models. Likewise, air pollution modelling is an important input in human exposure models, which can further be applied for estimation of health effects and related costs used for decision support and air quality policy development. For modelling of air pollution on regional, national or local scale, there is a demand for high quality emission inventories on high spatial resolution. Modelling based on detailed spatially distributed emissions provides the opportunity to estimate effects of potential and implemented reduction measures and as such can be used as a decision support tool as described by e.g. Jensen et al. (2001) and Elbir et al. (2010).

Due to the need for spatially detailed emissions a number of high spatial resolution emission inventories have been prepared. Few studies have been prepared and documented to handle emissions at the national level, e.g. for Cyprus (Tsilingiridis et al., 2010), the United Kingdom (Tsagatakis et al., 2013) and Japan (Kannari et al., 2007), while more studies have been published documenting high resolution spatial emission inventories for single pollutants and/or sectors such as agricultural $NH_3$ emissions in Denmark (Skjøth et al., 2001) and in the UK (Hellsten et al., 2008), NMVOC emissions in China (Bo et al., 2008), PM emissions in Delhi (Sahu et al., 2011) and CO emissions in India (Dalvi et al., 2006).

Relatively few studies focusing specifically on residential combustion, or where the methodology behind the spatial distribution is thoroughly documented, have been published. Tian et al. (2004) presented a model for spatial variations of $PM_{2.5}$ emissions from residential wood burning in a study area in the central part of California. The model took into account several variables including demographic and climatic information. Also, information on forest accessibility and distinction between urban, suburban, and rural areas were considered in the modelling. Tian et al. (2004) found that the number of households using wood combustion was a more critical variable than the unit consumption. This indicates that the most critical issue is to estimate number and location. While the unit consumption (i.e. weighting between the installations) is still important, it is less critical to the overall result.

In 2010 the model “Spatial high resolution distribution model for emissions to air” (SPREAD; Plejdrup and Gyldenkærne, 2011) was developed in its first version, which has since then been improved continuously. The SPREAD model provides emissions on a 1 km × 1 km resolution grid, covering all pollutants and all anthropogenic sources in the Danish national emission inventories.

The SPREAD model is a relational database model handling emissions on source or sector level. National emissions are allocated geographically using source specific spatial distribution keys, i.e. normalised shares of the national emissions to be allocated to each single grid cell in the Danish territory. The level of detail reflects the importance of the source to total emissions and the spatial data available. One of the most important sub-models for emissions of several pollutants is the model for residential combustion.

In order to assess RWC's impact on local, national and regional air pollution levels, there has been an increased attention from policymakers and air pollution modellers to improve the spatial distribution of emissions from RWC and hereby decreasing the uncertainty of the input to air pollution models. Therefore, a new RWC distribution methodology has been developed. The new methodology does not rely on population density, which is the case in most published studies, as this is deemed to give an incorrect spatial distribution in Denmark, where the most densely populated areas are covered by district heating. Guttikunda and Calori (2013) used population density and income groups to spatially distribute emissions from the residential sector, and also, Wilson et al. (2006) used population density as the proxy for the spatial distribution. Ghilardi et al. (2007) combined supply and demand modelling to estimate consumption of fuelwood used in Mexico.

Compared to Tian et al. (2004) and to the previous model used in Denmark, the new model presented here is at a much higher resolution (1 km × 1 km) rather than on county or municipality level. Excluding population density from the spatial distribution and instead using location of RWC installations has further improved the model.

## 2. Methodology

### 2.1. National emission inventory methodology

Aarhus University prepares the official Danish emission inventories for greenhouse gases and air pollution according to the international technical guidelines (EEA, 2013; IPCC, 2006) for reporting to international conventions, i.e. the Convention on Long-Range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe and the United Nations Framework Convention on Climate Change. Details on the methodologies used in preparing the emission inventories are documented elsewhere (Nielsen et al., 2016a; 2016b).

The Danish air emission inventory for RWC is based on information on the total number of appliances and a distribution on the types of wood burning appliances in Denmark, the wood consumption as included in the official Danish energy statistics (DEA, 2014) and technology specific emission factors (EFs). The Danish approach corresponds to the Tier 2 methodology in the EMEP/EEA Guidebook (EEA, 2013). However, the methodology has been modified to take into account the specific RWC technologies used in Denmark.

Information on the number and type of the stoves and boilers is obtained from a number of national surveys (Evald, 2012; previous versions; Illerup et al., 2007; Hansen, 2015). The inventory distinguishes between five different technologies for stoves and four different technologies for boilers. The emission factors (EFs) are for some combinations of technology and pollutant country-specific and refers to Danish measurements while others are referenced to measurements carried out for similar technologies abroad. Finally, there is a number of EFs that is based on EEA (2013).

The number of appliances, unit consumption, and emission factors used in the estimation of emissions from RWC for 2013 is included as additional information. For particulate matter it is important to note that Danish measurements are carried out in a dilution tunnel, which means that the derived emission factors include a contribution from condensables.

The resulting national emissions for 2013 are shown in Table 1. While wood pellets account for about 30% of the fuel consumption, the emission shares for this technology ranges between 2.1% for $PM_{2.5}$ and 8.5% for PCDD/F.

### 2.2. Spatial emission distribution methodology

According to the reporting guidelines under the LRTAP convention (UNECE, 2014), Denmark is obligated to report the