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CHALLENGES IN ASSESSING AIR POLLUTION FROM RESIDENTIAL WOOD COMBUSTION

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Abstract: The paper highlights a number of important challenges in quantifying the impact of residential wood combustion on air quality. The fact that real life emissions are controlled by the behaviour of the users makes it a challenge to determine representative emission factors. Further, in respect to determination of particle emissions factors, there are inconsistences between countries due to different handling of condensable gases released from wood combustion. These and other challenges are discussed in the paper.

Key words: *residential wood combustion, wood stoves, emission factors.*

INTRODUCTION

Residential wood combustion is an important sector when it comes to air pollution, both in Europe and worldwide. Therefore, it is a common task for dispersion modellers to conduct assessments of the impact of residential wood combustion on air quality.

The large impact of residential wood combustion was recently quantified in an assessment of health costs associated with residential wood combustion in Denmark (Economic Council, 2016; Brandt et. al, 2016). The study estimated the health costs of using a wood stove for one hour at various locations in Denmark. According to the study, the health cost amounted to 5.5 Euro/hour for use of an old wood stove in Copenhagen, while it was less than 1 Euro/hour for a modern stove. In less populated regions the cost was smaller – e.g., 0.13 Eurocents/hour for a modern stove on the island of Bornholm. If a user were compelled to pay such costs, it would have dramatic influence on the use of residential wood combustion.

Results such as these demonstrate the importance of residential wood combustion as a source of pollution. However, it should be recognized that the estimates are also quite uncertain because they are based on many simplifying assumptions. The purpose of the present paper is to take a modeller's perspective and highlight important challenges in quantifying the impact of residential wood combustion on air quality. Modellers should be aware of the challenges to avoid misleading conclusions.

THE CHALLENGE OF REPRESENTATIVE EMISSION FACTORS

A major challenge is that for residential wood combustion, *test bench emissions cannot simply be considered representative of real-word emissions*. Figure 1 serves to illustrate this. It shows real world emission factors for particles from wood stoves measured at 12 houses on up to four days (over two winters). The data are from Glasius et al. (2005; 2007).

Each column represents one measurement period with duration 5-10 hours from ignition until fire is extinguished. The columns are grouped by house (ID). All wood stoves on the graph were classified as belonging to the same emission category (classified by age). During measurements the residents were instructed to use their stove as usual. For one user this implied that during one measurement period (5B) he included some painted wood for feeding his stove. The graph illustrates clearly that there is an enormous variability in emissions from house to house and from day to day.

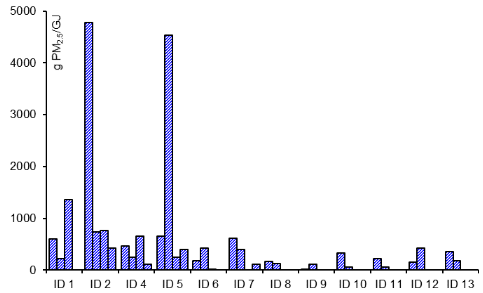

Figure 1. Emission factors for $PM_{2.5}$ for 12 houses with wood stoves. There are up to 4 measurements (bars) for each house. The graph includes data from two winter seasons and is based on data from Glasius et al. (2005; 2007).

When considering additional pollutants, there are further complications. Figure 2 is similar to Figure 1, but displays results for, respectively, particles, PAH and dioxin. The figure includes some of the data from Figure 1, but it is based on data from only one winter season. When comparing the patterns for the three substances in Figure 2 it is clear that the patterns are very dissimilar. Thus, a large emitter of particles is not a large emitter of PAH, and large emitters of dioxin are not large emitters of the other substances.

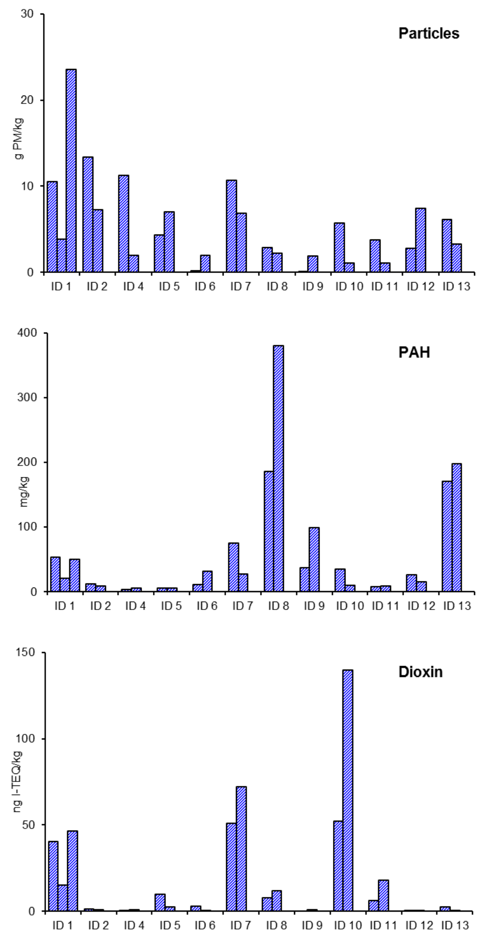

Figure 2. Emission factors for three pollutants – particles, PAH and dioxin – for 12 houses with wood stoves with up to 3 measurements (bars) for each house. There is data from one winter season only. The unit is pollutant mass per kg firewood. Data from Glasius et al. (2007).

The dissimilar patterns are a result of the fact that different processes are responsible for generation of, respectively, particles, PAH and dioxin. The graph demonstrates clearly that it is a gross simplification to assume that for a given stove technology emissions are simply proportional to the amount of wood burned.

The examples show that it is a major challenge to determine representative emission factors for a population of stoves. The fundamental reason behind this challenge is that residential wood combustion is a technology where the behaviour of the user plays a dominant role.

THE CHALLENGE OF COMBUSTION CONDITIONS

In all emission inventories, it is recognized that the type of combustion device is an important parameter. However, many other factors play a decisive role, but are not taken explicitly into account in emission inventories. Most of these factors relate to combustion conditions. A wealth of studies exist on the influence of combustion conditions on emission of air pollutants. Here, we will briefly recapitulate some important findings.

Insufficient oxygen supply provokes large particle emissions. Overload works in a similar manner. In a study of the effect of combustion conditions Klippel et al. (2007) found that compared to optimal combustion conditions (small load, completely dry wood), more typical conditions (moderate load, 20% moisture content in wood) resulted in 14 times higher particle concentrations. Moreover, very bad combustion conditions (filled stove, insufficient oxygen supply) resulted in a difference of more than a factor 300 compared to optimum conditions. (These particle measurements included condensables, see later.)

Moisture content in the wood is a further important factor. It should not exceed 20%, and preferably be less.

The type of firewood matters; in different regions, there are different favourite wood types.

Further, log size should not be too large, neither too small. One study where ‘logs’ had a quadratic cross-section found a dimension of 7 by 7 cm to be optimal, whereas larger and smaller dimensions increased particle pollution considerably. This result cannot immediately be generalized, as logs seldom are quadratic, and the result is presumably sensitive to the specific stove. However, it illustrates that changes in user behaviour can influence pollution.

When operating wood stoves in real life a large part of the total particle mass is emitted during the initial ignition period. Experiments have shown that generally the method of “ignition from above” (Nussbaumer et. al, 2008a) is to be recommended. It was found that in some cases cumulated particle pollution over an entire period of stove use could be reduced by as much as 80% by ignition from above.

Furthermore, chimney construction, ventilation of the house and the resulting draft are important factors.

When considering the above list of important factors it comes as no surprise that results such as those in Figure 1 and 2 can be found in practice. The whole range of challenges outlined are too many to take explicitly into account in modelling, but some understanding of them is important to avoid misleading conclusions. Neglecting the challenges may have as a consequence that focus is not on the most appropriate measures to reduce harmful air pollution from residential wood combustion

THE CHALLENGE OF CONDENSABLE GASES

An important challenge that modellers should be aware of is that emission factors are based on laboratory measurements according to standards, which vary from country to country. Different standards are a major reason why particle emission factors for wood stoves vary considerably between countries.

An all-important issue is whether particle mass measurement are performed on hot gas close to the stove, or whether the gas has been diluted and cooled. The first method (e.g. the German standard EN 13240

DIN+ HF.) will *not* include the mass of condensable gases which form particles when leaving the stack, whereas the second method (e.g. Norwegian standard NS 3058) will.

For optimal combustion conditions, the difference between the two approaches is not so large, but for less ideal conditions, it is of extreme importance. In a review of studies from many countries and combustion conditions (Nussbaumer et al., 2008b) found a factor between 2.5 and 10 between results from the two methodologies when conditions were not optimal.

This issue and its implication for modelling was addressed in a recent study by Denier van der Gon et al. (2015), where the authors compiled an emission inventory for Europe that used a new and more harmonised approach to residential wood combustion. The results suggest that that the contribution to particle pollution in terms of OC (organic carbon) from residential wood combustion should be augmented by a factor of 2-3 in most European countries, implying an increase of total European $PM_{2.5}$ emission by about 20%.

THE CHALLENGE OF ACTIVITY DATA

In all countries, it represents a challenge to compile realistic activity data for the consumption of firewood. Such inventories are best acquired through a combination of surveys among residents and registries of combustion appliances. Use of improved methods for compiling activity data can dramatically change the result of inventories. Thus, Lefebvre et al. (2014) reported that an improved methodology resulted in a 13-fold increase in particle emission from residential wood combustion in Flanders. A factor of 3.4 could be ascribed to wood consumption, and a factor of 4 to more realistic emission factors.

HOW TO MEET THE CHALLENGES

The sections above have outlined a number of challenges. These challenges inevitably have as consequence that modelling results for residential wood combustion will be more uncertain than modelling results for most other emission sectors. As modellers we should pay critical attention to the way emission inventories for residential wood combustion are compiled, having the considerable challenges in mind.

When considering standards for quantifying pollution from wood stoves the question of condensables is extremely important. However, there are also other important features that cause a variation between standards, such as differences in how the combustion cycle is defined. In response to these challenges, as well as the set of other challenges involved in reflecting real-world operating conditions, an EU project was initiated in 2013. It is the beReal project (Advanced Testing Methods for Better Real Life Performance of Biomass Heating Appliances; URL 1), which works with testing procedures, and can result in more harmonised and realistic inventories. At a recent international seminar with focus on the question of real world emissions from residential wood combustion some beReal project participants gave presentations; these can be found through URL 2.

There is formal standardisation work ongoing in the standardisation committee CEN/TC 295 (Residential solid fuel burning appliances). The outcome of that work is important because it deals with the crucial question on the choice between standards which do, respectively, do not, include condensable gases when measuring particle mass.
No matter what standard come out of that work modellers will need to take into account the effect of condensables in order to produce realistic results, as pointed out by Denier van der Gon et al. (2016).

The fact that the user has so much influence on the pollution from his wood stove has a positive side: There is potential for a dramatic reduction of pollution from wood stoves.
Much can be achieved by educating users. In Denmark, public campaigns during many years have gradually led to general changes in behaviour, which have supposedly led to reduced emission factors. However, this effect cannot be objectively quantified.

In order to minimize pollution from wood stoves there is one measure which may be efficient, but which presumably can only be applied locally or in limited periods: Banning their user. Disregarding that option, the optimum solution would be to eliminate the influence of the user. This can be achieved by automatic solutions that use sensor technology and have features such as automatic regulation of air supply for wood stoves. Such systems are a reality today, and e.g. in Denmark there is a commercial market for these modern, hi-tech woodstoves.

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