Emissions from sustainable increases in residential wood combustion in Switzerland

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ABSTRACT: Existing fuel consumption and installation trends in the Swiss small scale residential wood combustion (RWC) fleet were parameterized and projected, giving an indication of potential future fleet characteristics. These usage projections were then applied to an in-house combustion emission inventory and estimates of future $PM_{2.5}$ emissions were made. Where possible uptake of new technology was accounted for. A cases study involving the costs benefit analysis of retrofitting one of the system classes (Fireplaces) with electrostatic precipitators (ESPs) was conducted. A scenario detailing 100% uptake of the ESPs is shown and identifies significant capital expenditure costs relative to improvements in air quality external costs.

Keywords – Residential wood combustion, Combustion Emissions, Air Quality, Renewable Energy and Climate change, Emission reduction

1 Introduction

In Switzerland residential wood combustion (RWC) supplies ~5% of the consumed primary heating energy [1] but is responsible for 20-50% of particulate and gas-phase emissions [2]. Future energy scenarios suggest that current levels of consumption could *sustainably* increase by a factor of two [3, 4], likely leading to increased emissions. RWC emissions can be reduced by replacing existing combustion systems with modern combustion technology or by installing after treatment devices [5-7].

An inventory of small-scale residential wood combustion systems and their annual emissions has been developed [8]. Analysis of the influence of appliance class and technology upon emission scenarios was considered (not shown). Estimates of future fuel combustion were then used to estimate future $PM_{2.5}$ emission for selected systems. Applying the projections of future energy consumption, appliance installation (not shown) and emissions, estimates of future costs were made for one of the systems (the Fireplace). The results presented in this work are utilized as the starting point for the forward-looking assessment of emissions from the present until the year 2030.

2 Methodology

2.1 Inventory Development

An inventory of residential wood combustion emissions has been presented in a previous work [8]. This inventory incorporated the influence of technology, combustion conditions and fuel-mix upon annual emissions in Switzerland (basis year 2009). Emission factors used in the inventory are representative of normal combustion (NC) conditions for both current and modern appliances and poor combustion (PC) conditions for current appliances. Emissions factors for both hard- and softwood combustion were incorporated where available. Estimated annual emission for each of the appliance classes are given in Figure 1.

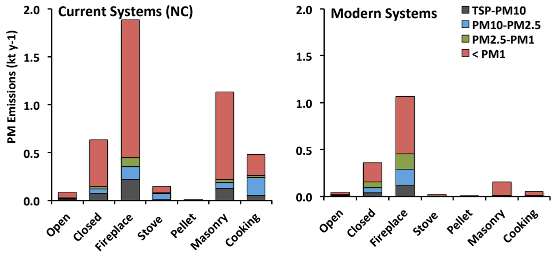

Figure 1. Estimated annual total particulate emissions (kt y^{-1}) for each of the RWC appliance classes.

3 Results and Discussions

3.1 Fuel Consumption Projections

Existing trends of fuel consumption [9] were parameterised and projected (Figure 2). Fuel usage by 3 of the 7 classes was shown to increase in the period 2010-2030 (upper panel). Analysis of future fuel availability and system production constraints need to be incorporated into the next stages of the analysis. Appliance number trends were also analysed (not shown here).

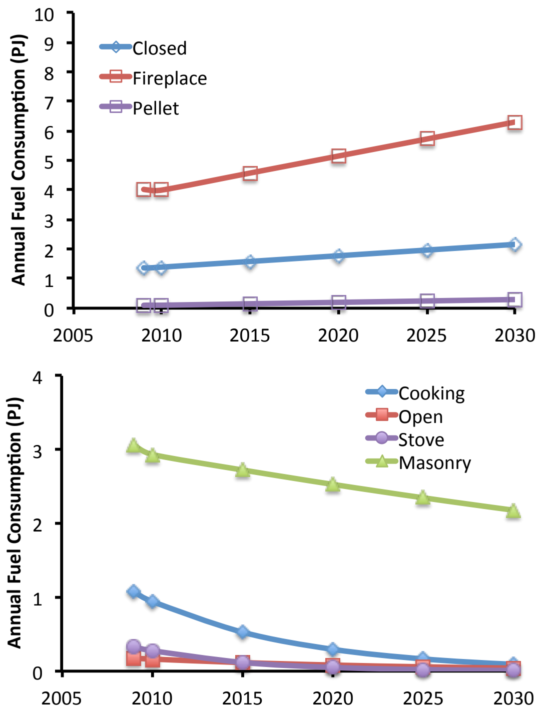

Figure 2. Fuel Consumption (PJ yr^{-1}) projections for the Swiss RWC systems (2010-2030)

3.2 Future $PM_{2.5}$ emissions:

Applying the PM2.5 emission factors ($mg_{PM2.5}$ MJ^{-1}) incorporated in the inventory to the fuel consumption (TJ) projections it was possible to estimate the emissions during the period 2010-2030. Of course, it is anticipated that, in general, system combustion efficiency should improve over this period, so this was also take into account (Figure 4). The current combustion efficiency improvement trend was maintained for the pellet systems. Based upon existing data, improvements in batch fired systems efficiencies were quite limited; as such this was increased by a factor of two. This factor represents current variances between “old” and “modern” systems.

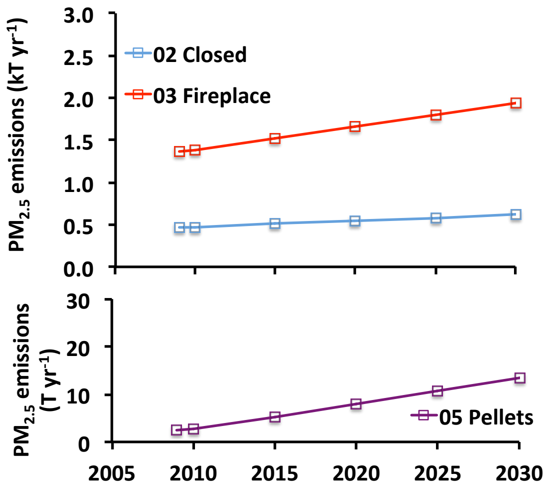

Figure 3. Increasing $PM_{2.5}$ emissions for those systems with expected increases in fuel consumption.

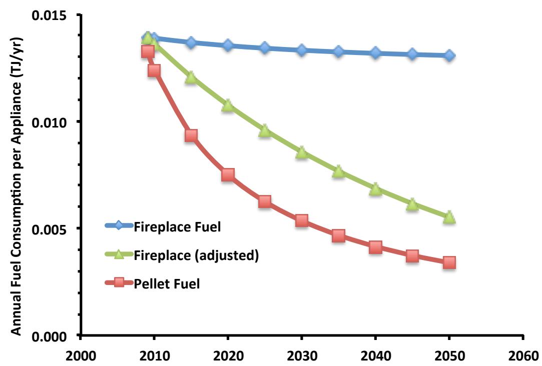

Figure 4. Improvements in fuel consumption (combustion efficiency) for selected systems.

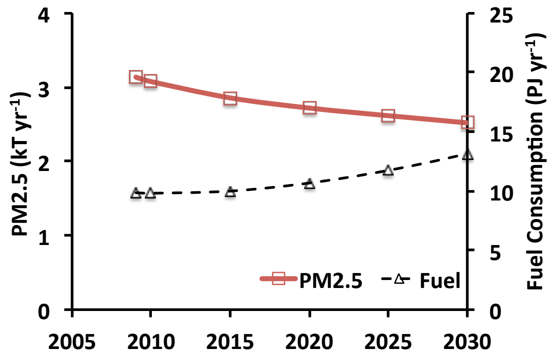

Figure 5. Projection of $PM2._5$ and absolute fuel consumption for all small-scale Swiss RWC systems. Current and estimates of future (modified) fleet trends are shown.

3.3 Cost Benefit Analysis of retrofitting Fireplaces with Electrostatic Precipitators

Based on usage and emission projections, future capital expenditure and partial external costs (air quality only) were estimated for 5-year periods (2010-2030).

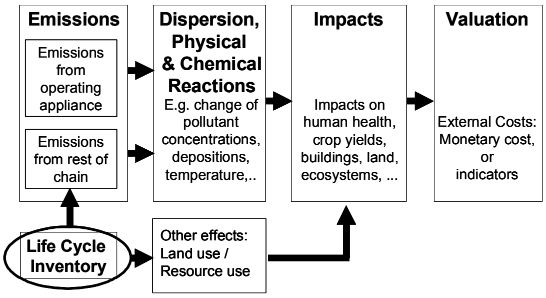

Figure 6: The impact pathway approach including life cycle assessment (Source: Heck & Meyer, 2010).

Capital expenditure was based on industry data and external cost estimates were based on internally prepared values for $PM_{2.5}$ and global warming potentials [10].

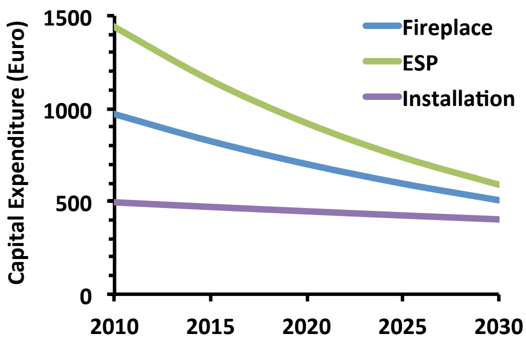

Figure 7. Estimated discount rate of fireplaces (3%), ESP's (4%) and installation costs (1%).

A number of scenarios representing the uptake of emission reduction devices were prepared. Figure 8 shows *only one* of these where the current uptake of ESP's is increased by a factor of 35, so that all Fireplaces are fitted with an ESP by 2030. Holding current conditions as a baseline estimates, an increase in external costs as the number of installed fireplaces increases was observed (upper panel). However, fitting the additional ESP's leads to a reduction in external costs of ~50%, albeit at significantly increased capital expenditure (lower panel). Analysing the lower panel in figure 8 closer, capital expenditure was observed to increase from 36 MEuro to 181 MEuro while external costs were observed to halve from 33 MEuro to 17 MEuro.

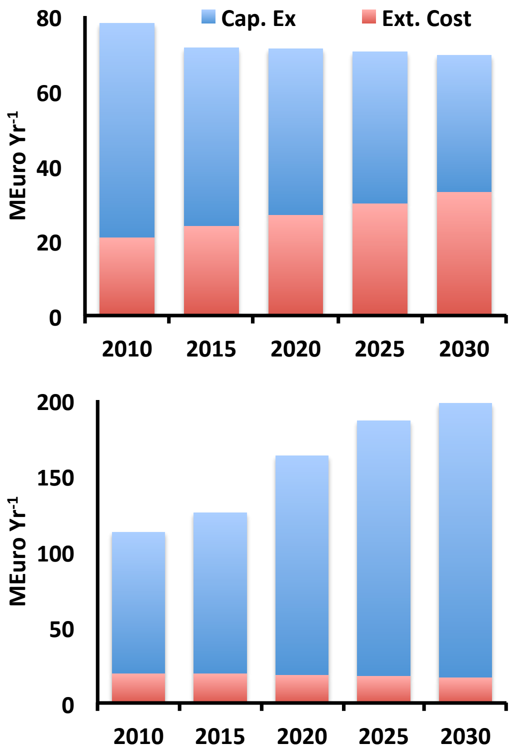

Figure 8. Cost-Benefits Analysis of Retrofitting of fireplace systems with Electrostatic Precipitators. A discount rate of 5% is employed for Cap. Ex. Projections. (Upper panel: Fireplace; Lower Panel - Fireplace & ESP)

4 Conclusions

Building upon the information available from the literature, it is apparent that sustainable increases in wood combustion will lead to increased future emissions (without intervention). These emissions could be reduced using after treatment devices. In the case of the model shown here, this could lead to a reduction in external costs of ~50%. However, our analysis suggests that emission reduction (through after-treatment) comes only with substantial additional capital expenditure. This work is ongoing.

5 Acknowledgements

This work was funded by the Competence Centre Environment and Sustainability of the ETH Domain (CCES) as part of the IMBALANCE project.

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Emissions from future increases in residential wood combustion in Switzerland

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Existing fuel consumption and installation trends in the Swiss small scale residential wood combustion fleet were parameterised and projected, giving an indication of potential future fleet characteristics. These usage projections were then applied to an in-house combustion emission inventory and estimates of future $PM_{2.5}$ emissions were made. Where possible uptake of new technology was accounted for. A cases study involving the costs benefit analysis of retrofitting one of the system classes (Fireplaces) with electrostatic precipitators (ESPs) was conducted. A scenario detailing 100% uptake of the ESPs is shown and identifies significant capital expenditure costs relative to improvements in air quality external costs .

Overview: Residential wood combustion (RWC) provides ~ 5% of heating energy but 20-50% of particulate and gas-phase emissions In Switzerland. Sustainable increases (factor ~2) will lead to increased emissions.

An inventory of small scale residential wood combustion systems and their annual emissions has been developed. Analysis of the influence of appliance class and technology upon emission scenarios was considered (not shown). Estimates of future fuel combustion were then used to estimate future $PM_{2.5}$ emission for selected appliances.

Applying the projections of future energy consumption, appliance installation (not shown) and emission, estimates of future costs were made of one of the systems (the Fireplace)

Inventory Preparation:

An inventory of residential wood combustion emissions has been presented in previous work [1]. This inventory incorporated the influence of technology, combustion conditions and fuel-mix upon annual emissions in Switzerland (basis year 2009). Emission factors used in the inventory are representative of normal combustion (NC) conditions for both current and modern appliances and poor combustion (PC) conditions for current appliances. Emissions factors for both hard- and softwood combustion were incorporated where available. Annual emission for each of the appliance classes are given in Fig. 1.
The results presented in this work are utilized as the starting point for the forward looking assessment of emissions from the year 2009 – 2050.

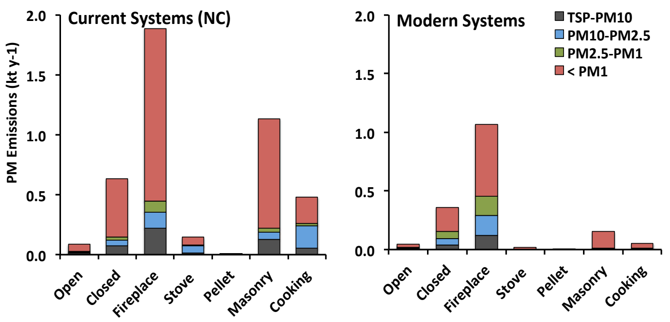

Figure 1. Estimates of emission from the current fleet of RWC appliances and a simulated fleet assuming 100% of systems are state of the art (Mod_{100})

Fuel Consumption Projections:

Existing trends of fuel consumption [2] were parameterised and projected (Fig 2.) Fuel usage by 3 of the 7 classes is expected to increase. Analysis of future fuel availability and system production constraint needs to incorporated into next stages of the analysis. Appliance number trends were also analysed (not shown)

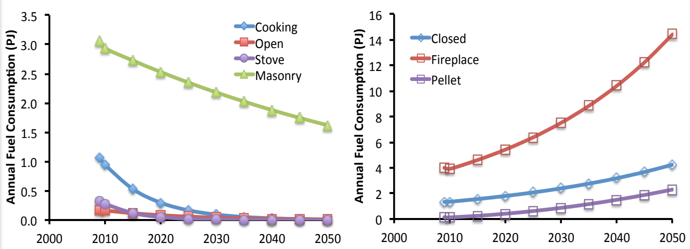

Figure 2. Forward projections of fuel consumption for residential wood combustion appliances in Switzerland

Results: Projection of future $PM_{2.5}$ Emissions and estimates of fuel consumption.

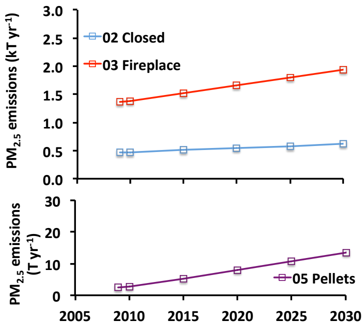

Figure 3a Increase in $PM_{2.5}$ emissions for selected systems with expected increases in fuel consumption

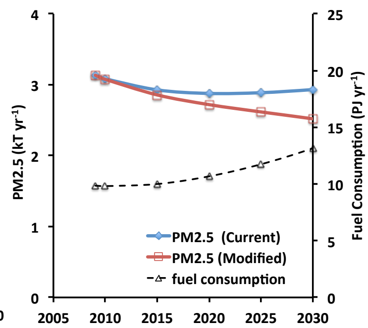

Figure 3b Projection of $PM2_{.5}$ and absolute fuel consumption for all small scale Swiss RWC systems. Current and estimates of future (modified) fleet trends are shown.

Results: Cost Benefit Analysis of retrofitting Fireplaces with Electrostatic Precipitators

Based on usage and emission projections, future capital expenditure and partial (air quality related) external costs were estimated for 5 year periods (2010-2030)
Cap. Ex. was based on industry data and external cost estimates were based on internally prepared values for $PM_{2.5}$ and global warming potentials [3].
Baseline estimates, based on current conditions imply an increase in external costs as the number of installed fireplaces increases. A number of scenarios representing the uptake of emission reduction devices were prepared. Fig. 4 shows one of these where the current uptake of ESP is increased by a factor of 35, so that all Fireplaces are fitted with an ESP by 2030. Extern Costs are reduced by ~50%, albeit at significantly increased capital expenditure.

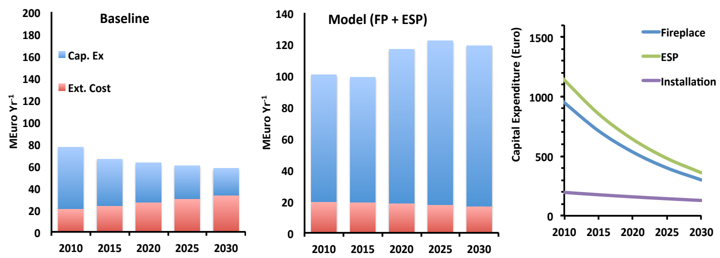

Figure 4. Cost-Benefits Analysis of Retrofitting of fireplace systems with Electrostatic Precipitators. A discount rate of 5% is employed for Cap. Ex. Projections.

Conclusions:

Future Appliance Usage *– potential exists for significant increase in wood fuel consumption.*
Future Emission Production – Net emissions likely to increase without intervention
Future Costs – preliminary analysis suggests that emission reduction comes only with substantial capital expenditure. Research is ongoing.

Next Steps:
Assessment and analysis of constraints on future sustainable supply of fuel and production of combustion and emission reduction systems.
Comparison with medium sized systems.

References:

[1] Meyer, N.K. submitted (2011)
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