Ecodesign directive for residential wood combustion appliances: impacts and emission reduction potential in Finland

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Abstract

A new EU clean air strategy is being prepared and proposals for emission reduction commitments for each member state have been announced. The list of pollutants in the revised NEC directive now includes fine particles (PM2.5) and also black carbon is mentioned, although without tangible ambition levels for emission cuts. For the above emissions, residential wood combustion (RWC) is the major source that is not currently regulated by EU level legislation and also national legislation is scarce. The proposed Ecodesign directive for small-scale wood combustion appliances is designed to address the issue. This study estimates the impacts of such legislation to the Finnish appliance stock and for reducing national RWC emissions by the year 2030. Ecodesign will only affect new appliances on the market and due to the long lifetime of commonly used stoves in Finland, there is a notable lag between the legislation entering into force and achieving visible results in emission reduction. In a studied baseline scenario, the implementation of Ecodesign from the start of 2022 will produce 6% reductions to PM2.5 emissions and 4% reductions to black carbon emissions. Although it is a step in the right direction, it takes a long time for the legislation to have notable effects on emissions, and it also doesn't address the single most important appliance type in Finland –sauna stoves. This means that additional measures are needed to reduce emissions in this sector.
Keywords: residential wood combustion, Ecodesign, particulate emissions, black carbon, solid fuel space heaters, boilers, emission reduction.

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1 Introduction

The heating of houses requires a substantial amount of energy in Finland. The energy consumption of the heating of residential buildings in Finland in 2010 was 214 PJ (or 15% of the Finnish total primary energy use), of which the heating of detached houses consumed 121 PJ (8%) (Statistics Finland [1]). Detached houses are heated mainly by kW-size-range house heating boilers using wood fuels or light fuel oil. Residential wood combustion (RWC) in Finland takes place mainly by using wood as a primary heating media in house boilers, and in stoves and fireplaces to supplement the primary heating of the house, to heat the sauna and for pleasure to create a cosy atmosphere. Wood is also combusted in stoves in summer cottages and in boilers in some commercial, industrial and agricultural buildings.

The activity of RWC in Finland has been steadily increasing from 1980s onwards and during the 2000s the increase has accelerated, approx. 4% per year on average. The development in latest years can be explained by positive image of wood as a domestic and renewable fuel and increasing prices of other heating forms, especially fuel oil and electricity. RWC has been promoted as a self-sufficient and efficient way to reduce CO_2 emissions, although its harmful environmental impacts have received a lot of scientific attention in recent years. Particulate emissions affect both human health and the radiative balance of the atmosphere.

Emission sources close to ground level cause the biggest relative impact to local air quality. The two most important sources of particulate emissions in Finland are residential combustion (42%) and traffic (25%) and they both occur close to ground (Hilden *et al.* [2]). Particulate emissions from traffic and machinery are covered by strict legislation and are expected to decrease significantly by 2020, although road dust will remain an issue. Residential wood combustion appliances, however, are not under such legislation and will become even more dominant source of emissions in the future. Most of the wood is combusted in non-urban areas. This is the case especially for household wood heating using central heating boilers. However, the popularity of stoves as a supplementary heater is steadily increasing in urban areas also. As supplementary heating happens also in the more densely populated areas, it also contributes more to population exposure. Paunu [3] has estimated that 80% of the total RWC-induced population exposure to $PM_{2.5}$ comes from supplementary heating in urban areas.

Particulate matter (PM) emissions from RWC are composed of ash components of wood and products of incomplete combustion (Figure 2). The non-combustible ash components partly volatilize in the combustion process and later when cooling down condensate/nucleate to form particles. The products of incomplete combustion consist of soot particles and organic gases that condensate on top of ash and soot particles (or form new particles). The main constituent of soot particles is black carbon (BC).

Most particles, i.e. aerosols, in the atmosphere reflect sunlight and thus act as climate cooling agents, but black carbon absorbs it and has a strong warming impact. It also greatly decreases the albedo of a bright surface and thus accelerates the melting of ice and snow when deposited on it. In addition black carbon has indirect climate effects as it influences the formation and properties of clouds. It has been estimated in several studies [4, 5] that BC is the second most important pollutant to climate warming after CO_2 and it has especially strong effect in the Arctic area.

The proposed Ecodesign directive on solid fuel boilers and local space heaters will be the first legislation in Finland that attempts to reduce particulate emissions from RWC. This study estimates the impacts of such legislation to the Finnish appliance stock and for reducing national RWC emissions by the year 2030, and also assesses other possible measures for further reductions. The study evaluates emission reduction potential and reduction costs for $PM_{2.5}$ and BC in three different scenarios with varying activity pathways for fuel wood consumption.

2 Methodology

Particle emissions for the scenarios, as well as the reduction potentials for different measures were calculated with Finnish Regional Emission Scenario, FRES model (Karvosenoja [6]). Activity estimates for wood use in 2030 were based on historical data, a user survey by Torvelainen [7] and the scenarios in the updated National Energy and Climate Strategy TEM [8]. Emission factors of PM for RWC appliances have been earlier estimated based on Finnish and international measurements reported in Karvosenoja [6]. Recently the emission factors of PM- and carbonaceous emissions have been updated on the basis of latest national measurements UEF [9].

The updated emission calculation scheme aims to estimate better the effects of poor combustion situations by including different user profiles. Emission factors from the measurements were used to represent normal combustion conditions for each stove type. For poor combustion higher emission factors were estimated, based on measurements on smouldering combustion by Frey *et al.* [10], Schmidl *et al.* [11] and expert opinions [12]. Three different combustion practice profiles for Finnish stove users was estimated (Table 1), giving the shares of normal and poor combustion for each of the profiles. The percentage of problem users was based on estimation by chimney sweeps in Helsinki metropolitan area. The calculation scheme with the user profiles is strongly simplified and the estimates about the shares of poor and normal combustion, as well as the shares of the

Table 1: Estimation for the share of poor combustion over Finnish stove users.

User profiles	**Share of profile**	**Share of poor combustion**
Accomplished user	25%	0%
Average user	60%	5%
Problem user	15%	50%
Average over profiles		**10.5%**

profiles are highly uncertain. However, the calculation update should be seen as a first step to include the effects of poor combustion in a transparent way to an emission inventory.

2.1 Emission reduction measures and technical parameters

In addition to the Ecodesign directive, two other emission reduction measures were estimated to be feasible: a national legislation for sauna stoves that would work in a similar way as Ecodesign and an informational campaign for stove users to make their combustion habits cleaner. The activity of wood consumption in the future will be the most important factor regarding the emissions, even though there will be changes in the appliance stock. For this study, three activity pathways were assessed: 1) Decreasing as in the national Energy strategy, where the need for wood heating stays close to current, but the energy efficiency of houses and combustion appliances increases significantly and reduces activity, 2) Stagnant, where the total activity stays the same as in 2010, although the appliance stock keeps renewing and 3) Increasing, where the activity keeps increasing at the same rate as during the last decade. Assumed activities for 2020 and 2030 are shown in table 2.

Table 2: Wood use activities in the three scenarios in PJ.

Scenario	2010	2020	2030
Decreasing	70	60	51
Stagnant	70	70	70
Increasing	70	88	105

The maximum emission factors in the current Ecodesign proposal (table 3) can't be directly compared with the emission factors in FRES model because the Ecodesign emission limit values do not represent real life emissions from every-day use of stoves. Emission factor values in the proposal have been set according to a measurement method where the emissions are measured from the flaming phase, not including the ignition and without diluting the flue gases, whereas the national measures have been taken from diluted flue gases and represent the average emissions over the combustion cycle of several batches. FRES model includes several different boiler and stove types and some of them are estimated to comply with the proposed limit values. With the implementation of Ecodesign, only these kinds of appliances are allowed in the market from 2022 onwards.

Table 3: Limits for PM emissions factors in the latest Ecodesign proposal.

Product	PM mg/m^3
Boiler	20
Closed fronted stove	40
Open fronted stove	50

Table 4 contains thermal efficiencies and cost information for the appliances involved in technical reduction measures. Interest rate for investments was set to be 4% and the repayment period 10a for sauna stoves and 20a for other appliances. Also operating costs for boilers were taken into account. Fuel costs for logs was estimated to be 71 €/ton.

Modern sauna stoves with considerably more efficient combustion have been in the market for some time, but sales have been minuscule due to higher price. No measured $PM_{2.5}$ emission factors were available for the modern sauna stoves, but from other published information a conservative estimate was set to be half of the emission factor of a conventional sauna stove.

Table 4: Efficiencies for appliances, their installation costs, cost for logs and average lifetimes Rouvinen *et al.* [13], Hulkkonen and Rautanen [14], Statistics Finland [15], Halkoliiteri [16].

Appliance	Efficiency	Installation cost [€]	Average lifetime [a]
Manually fed modern	0.9	9000	30
Manually fed with accumulator	0.88	6000	30
Conventional masonry heater	0.75	4000	35
Modern masonry heater	0.85	6000	35
Conventional iron stove	0.45	400	12.5
Modern iron stove	0.6	600	20
Conventional sauna stove	0.45	400	12.5
Modern sauna stove	0.6	800	20

Three cases for the scope of an information campaign was studied: all detached and recreational houses, all detached houses and detached houses in municipalities of 20 000 residents or more. The cost estimation – including production, printing and distribution of information leaflets, arrangements for lectures and the payments for experts involved – is based on a recent campaign in Helsinki metropolitan area. The cost per household in that campaign was 0.31€ (Myllynen [17]). This estimation is somewhat simplified, as the price per household will likely rise when population becomes more scarce. Reducing the amount of poor combustion by 50% was estimated the best case scenario for the effect of the campaigns, and this was to be the default result in order to figure out the maximum emission reduction potential of this measure. Emission reductions in this assessment were calculated for the year 2010.

3 Results and discussion

3.1 Emission reduction potential

Due to structural changes in the appliance stock, the average emission factor of the whole RWC sector is noticeably decreasing even in the baseline. As the

Ecodesign directive doesn't come into effect until 2022 it has a limited effect by 2030, as most appliances have an average lifetime of 30+ years. For iron stoves the effect is greater, but due to small activity their emission reduction potential is also somewhat negligible. Sauna stoves on the other hand have both high emissions and short average lifetime, and thus the legislation for them would have considerable effects by 2030. With current sales rates of each appliance type, these legislations would increase the share of modern heaters by 30 percentage points for log boilers, 7 for masonry heaters and 70 for iron stoves and sauna stoves. Out of these appliances, modern masonry heater is the only one that currently has a notable share in the market and is expected to increase in popularity even without new legislation. The only reduction measure that affects the emissions in 2020 is the informational campaign.

The emission reduction potentials for each measure and scenario are shown in table 5. In Ecodesign, approx. 70% of the $PM_{2.5}$ reductions and 60% of the BC reductions come from modernization of boilers, the stock renewal of masonry heaters being the second most important factor. The most significant of the studied measures was clearly the legislation for sauna stoves, which accounted for ~60% of the total emission reduction potential in each scenario.

Table 5: Emission reduction potentials for 2030.

Scenario/measure	**$PM_{2.5}$ reduction [ton/a]**	**BC reduction [ton/a]**
1) Decreasing		
Ecodesign	400	90
Legislation for sauna stoves	1330	520
Informational campaign	440	60
2) Stagnant		
Ecodesign	500	120
Lesislation for sauna stoves	1750	680
Informational campaign	720	110
3) Increasing		
Ecodesign	780	180
Legislation for sauna stoves	2630	1020
Informational campaign	1040	150

Emission reduction potentials for $PM_{2.5}$ are also shown in figure 1. By implementing Ecodesign only, emission reduction in RWC would be 6% for $PM_{2.5}$ and 4% for BC in 2030 in the baseline scenario (Decreasing). With all the measures, the maximum reduction potential for $PM_{2.5}$ was 2200–4400 ton/a, which makes 12–18% of Finnish estimated emissions in 2030. This shows that even though RWC is the most important source of $PM_{2.5}$ emissions in Finland, the realistic technical reduction potential is somewhat limited and wood consumption activity also plays a major role. However, if the appliance stock modernization would be complete by 2030, $PM_{2.5}$ and BC reductions in RWC would be approx. 60% compared to baseline. Thus the results imply that although slow to show effects, the legislation on new combustion appliances in the market is a very important step towards cleaner combustion in residential boilers and stoves.

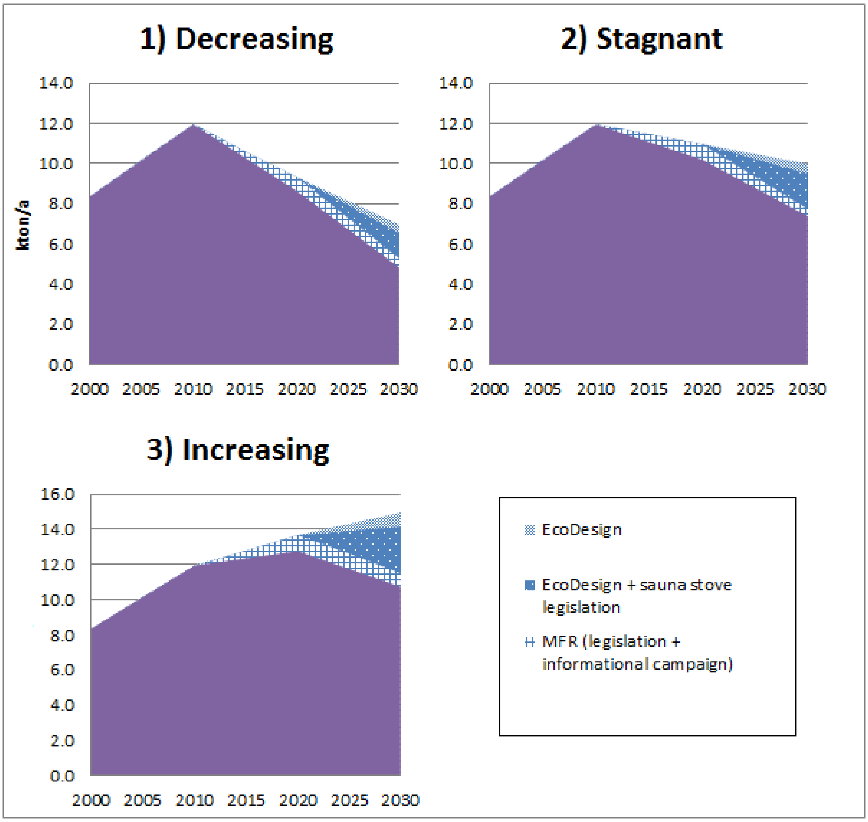

Figure 1: $PM_{2.5}$ reduction potentials for 2030.

3.2 Costs for emission reduction

Total annual costs and unit costs for $PM_{2.5}$ and BC reductions for the year 2030 are shown in table 6. Modernizing the sauna stove appliance stock is the most costly measure, due to the large amount and short lifetime of the stoves. However, it also has clearly the most significant reduction potential and so its unit cost is only half of Ecodesign's. Although new boilers are expensive to install, they have long average lifetime and high utilization rate, which explains their comparatively cheap costs. Informational campaign is by far the cheapest measure both in total costs and unit costs, but for the unit costs this is also due to very optimistic assumptions in the scope and effect of the campaign. This is studied more closely in the next chapter. Compared to the power sector for example, the reduction costs with new technology are somewhat higher as shown in Savolahti *et al.* [18], but so is the reduction potential, and emissions from power plants are already under ever-tightening legislation.

Table 6: Emission reduction costs and unit costs for the three scenarios in 2030.

Measure	**Cost range [M€/a]**	**Unit cost [k€/ton]**	
		$PM_{2.5}$	BC
Ecodesign	14–25	35	150
-boilers	4–8	15	75
-masonry heaters	8–14	100	310
-iron stoves	2–3	30	130
Sauna stoves	22–43	17	40
Informational campaign (all stoves)	0.3	0.5	3

3.3 Informational campaign

The effect of past informational campaigns is difficult to measure and a campaign that covers the whole of Finland has never been carried out. As the cost estimation per household in this study is based on a campaign in the Helsinki metropolitan area – where the population concentration is higher than the Finnish average – it is likely an underestimation. However, the total cost calculation assumes that the campaign would be an annual event, whereas in reality the same effect would probably be achieved by repeating the campaign every few years. 50% reduction in poor combustion is a very ambitious assumption for the campaign's effect and it was mainly used to estimate its maximum potential, but as table 7 shows, the unit costs for this measure are relatively cheap with even minor effects on emissions. Educating Finnish stove users about the negative impacts of wood

Table 7: The costs and emission reductions for different scopes of informational campaigns. The campaign is assumed to reduce the share of bad combustion by 50%, except in the last example.

Scope of campaign	**Cost [k€/a]**	**Unit cost [k€/a]**		**Reduction [ton/a]**	
		$PM_{2.5}$	**BC**	**$PM_{2.5}$**	**BC**
All stoves and fireplaces	300	0.4	2.5	780	120
Residential buildings only	300	0.4	2.9	670	100
Municipalities with a population centre of 20,000+	80	0.6	4	140	20
Municipalities with a population centre of 20,000+ (5% less poor comb)	80	6.1	40.2	14	2

combustion might also affect their attitude towards the subject, as it is now seen as a very environmental friendly activity by most. These campaigns can also be pinpointed to problem areas where RWC is common and the population density is relatively high. Paunu [3] has demonstrated that the clear majority of population exposure to RWC's fine particles in Finland is because of supplementary heating in urban areas.

3.4 Challenges in the new legislation

Finnish manufacturers have voiced a lot of concern considering two practical issues of the proposed legislation. First is about the two options for testing and emission measurements for stoves. They are based on different standards and give very different results for the same stove. Furthermore, neither of them is created to measure the true emissions over the whole period of combustion when the stove is used according to its manual. The manufacturers feel that these testing methods are not well suited for the most common stove in Finland – masonry heater.

Boiler manufacturers also had concerns about the emission measurements, as many of the small companies only make one of two parts of the appliance: the burner or the heat exchanger (i.e. "boiler"). In order to measure the emissions these have to be combined, and how this will be done is yet unclear.

With the new legislation, the cheapest appliances will likely disappear from the market, which might make the consumers delay the renewal of their current heater, or in the case of stoves they might opt for a home-made one. On the other hand, the price might also affect the consumers' habits and reduce the recreational and supplementary heating use of stoves. In the end however, modern appliances will be more consumer friendly, use less wood and last longer.

3.5 Other possible measures

Other measures to reduce emissions from RWC could include flue gas cleaning devices, banning of wood combustion in certain areas or the use of certain high-emitting device types and governmental incentives to upgrade the appliance stock to cleaner heaters. Lenz *et al.* [19] have shown promising results for many small-scale flue gas cleaning techniques, but this option still has too many uncertainties to be considered a country-level option. Governmental incentive programs might be feasible for sauna stoves, when the modern appliances become more common in the market, but for masonry heaters it would be too expensive and slow to take effect Savolahti *et al.* [20]. Wood combustion has such a strong position in the Finnish culture that any kind of banning would probably raise a huge amount of resistance, so that solution seems to fit mostly to local and situational problems.

3.6 Effects on the environment and human health

EU-legislation and national emission reduction targets are one factor, but when it comes to reduction measures, one should concentrate on reducing the impacts instead of just emissions. This is something that needs to be taken into account in the cost calculations and when deciding the most feasible and effective measures.

As pointed out earlier, the population exposure to RWC's $PM_{2.5}$ emissions in Finland happens mainly in urban areas, although the majority of emissions are in non-urban areas. With Finnish BC emissions it is shown that the most effective way to mitigate climate impacts is to reduce the emissions in winter, when the snow albedo effect plays a major role (Laaksonen *et al*. [21]). This means that although it is common to use fireplaces and sauna stoves at summer cottages, it might not be the most optimal target for emission control.

4 Conclusions

Although challenges and concerns remain in implementing the Ecodesign directive for boilers and stoves, it is definitely a step in the right direction. Residential wood combustion is the major source of $PM_{2.5}$ and BC emissions in Finland, and currently there is no legislation to control the emissions. It will take a long time for the Ecodesign to effect RWC emissions however, as the most common appliances have an average lifetime of 30+ years. Furthermore the current proposal doesn't include sauna stoves, which is the most important stove type in Finland regarding emissions. National legislation on sauna stoves would be an important supplement to Ecodesign and a cost effective way to reduce emissions from RWC. The most cost-effective and readily-usable measure is to try to increase the stove users' awareness on the negative environmental impacts of wood combustion and the role of their combustion habits. This study shows that the emission reduction potential with the combination of these measures in 2030 would be 2200–4000 ton/a for $PM_{2.5}$ and 600-1400 ton/a for BC, depending on the scenario. This accounts for 12–18% of Finnish total $PM_{2.5}$ emissions and 18–27% of BC emissions.

While residential wood combustion is likely the make or break sector when it comes to Finland's $PM_{2.5}$ reduction targets, emission reduction policies should first and foremost be targeted to reduction of impacts, in this case population exposure and climate effects. This requires spatial and temporal review of the emissions and will give a more accurate picture of the feasibility of possible measures.

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