UPDATING THE EMISSION MODEL FOR RESIDENTIAL WOOD COMBUSTION

Scientific Report from DCE – Danish Centre for Environment and Energy No. 442 2021

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Abstract:	The report documents the updates made to the emission estimation model for residential wood combustion. The revisions included new estimates for the total number of wood stoves through the time series, new replacement rates for stoves and update to a number of emission factors taking the most recent measurement studies into account. The report also documents some of the uncertainties involved with estimating emissions from residential wood combustion and highlights potential future improvements.

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Contents

Preface

This report documents the changes made to the residential wood combustion model in 2019 that was reported to the EU National Emission Ceilings Directive and the Convention on Long-Range Transboundary Air Pollution.

The authors would like to thank the following for valuable discussions and input during the revision of the model:

- Brian Kristensen, Heidi Ravnborg and Christian Lange Fogh, Ministry of Environment and Food
- Ole Moeslund and Ditte Kristensen, Danish Environmental Protection Agency
- Kjeld Vang, Foreningen af Danske Leverandører af Pejse og Brændeovne (DAPO)
- Danish association of Chimneysweepers.

Summary

Residential wood combustion is an important source of air pollution in Denmark and therefore attracts great attention. The share of residential wood combustion to several pollutants such as carbon monoxide, volatile organic compounds, fine particulate matter ($PM_{2.5}$) and polycyclic aromatic hydrocarbons (PAHs) are very high, and especially for the pollutants most associated with adverse impacts on human health such as particulate matter.

In 2019 and 2020, work was done to update and document the model used to estimate emissions from residential wood combustion. The results of this work is presented in this report.

The model has been described in Chapter 2 of this report including a description of the most important model parameters.

There is however, large uncertainties associated with the emission inventory, as there are many parameters in the emission calculation model, all of which have varying levels of uncertainty. The parameters include the number of appliances per technology, the age distribution, the wood consumption and the emission factors. To estimate the age distribution it is necessary to make assumptions on the expected lifetime and replacement rates of stoves and boilers.

The assumptions behind the total number of wood burning appliances and the replacement rates of various stove technologies were revisited and changes were made using the best available knowledge. The model improvement is based on a review of available literature and analysis of data from surveys, relevant projects and from the chimneysweeper association.

Time series for the number of wood burning appliances have been updated. The methodology has been updated so that time series is being based on replacement rates and sales numbers.

Unit consumptions per technology is used for bottom-up estimation of wood consumption. In accordance with the international guidelines for emission inventories submitted to the UN and the EU, the emissions from residential wood combustion must be based on the fuel consumption as given in the national energy statistics published by the Danish Energy Agency. To comply with the guidelines, the bottom-up estimated wood consumption is scaled to the fuel consumption as given in the national energy statistics.

For the emission factors, recent literature was analysed to update emission factors. The update focussed on the pollutants with the highest impact on national emissions, and categories (technologies) where the existing emission factors had been identified as being in need of updating. Revised emission factors were established for particulate matter (PM), black carbon (BC), polycyclic aromatic hydrocarbons (PAH), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), nitrogen oxides (NO_x), carbon monoxide (CO) and sulphur dioxide SO_2.

The updated model caused significant changes in emissions of several pollutants. The largest changes were related to particulate matter, carbon monoxide, black carbon, dioxins (PCDD/F) and PAHs. For the other pollutants, changes were smaller. The main recalculations are shown in the table below.

Pollutant	2005 2019 submission	2005 2020 submission	2017 2019 submission	2017 2020 submission
NMVOC	12461	11960	10063	9866
CO	86782	91573	72489	76001
$PM_{2.5}$	13742	9922	11923	8584
BC	1750	355	1831	554
PCDD/F (g)	12.3	14.6	11.3	24.3
Benzo(a)pyrene	1842	2624	1599	1688
Benzo(b)fluoranthene	1784	2160	1673	1567
Benzo(k)fluoranthene	661	1900	301	1071
Indeno(1,2,3-cd)pyrene	1055	2024	882	925

While the updated model and data are improved compared to the old model, there are still significant uncertainties associated with the estimation of emissions from residential wood burning. There are uncertainties associated with all parameters included in the model and while uncertainties can be lowered, emissions from residential wood combustion will continue to have a high uncertainty.

Future improvements to the model and input data will primarily depend on new and improved data becoming available. Emission measurement programmes producing emission factors are periodically carried out and the results of these measurements will continue to be of interest and may cause updates to the emission factors.

New data on the use of wood burning appliances are produced as part of the survey conducted for the energy statistics. While data historically have been very fluctuating making it difficult to draw firm conclusions, the results of these surveys will continue to be monitored.

For future improvement to the model and emission estimation, data on the number, type and age of the appliances could be an important element to update. The chimneysweepers inspect all appliances frequently at least once a year and it would be beneficial if further details was included in the registration and made available. This includes information about appliance age, further details about technology, and indication of the extent to which the appliances are used, e.g. primary heating, supplementary heating or occasionally. Such information can contribute to update the total appliance numbers, to improve the age and technology distribution and in the longer term to verify or improve the replacement rates.

Sammenfatning

Træfyring i husholdninger er en væsentlig kilde til luftforurening i Danmark, og tiltrækker sig derfor stor opmærksomhed. Træfyring i husholdningers andel af den samlede nationale emission er meget høj for flere forureningskomponenter, f.eks. kulmonooxid, kulbrinter, fine partikler ($PM_{2.5}$) og polycykliske aromatiske kulbrinter (PAH'er), og især for de forureningskomponenter, der har størst negativ indflydelse på sundhed, som f.eks. partikler.

I 2019 og 2020 er der blevet udført et arbejde med henblik på at opdatere og dokumentere modellen, der anvendes til at beregne emissioner fra træfyring i husholdninger. Resultatet af dette arbejde præsenteres i denne rapport.

Der er store usikkerheder forbundet med emissionsopgørelsen for træfyring i husholdninger, da mange parametre indgår i beregningen af emissionen, som alle har større eller mindre usikkerheder tilknyttet. Dette gælder antallet af anlæg per teknologi, aldersfordelingen, træforbruget og emissionsfaktorerne. For at skabe en tidsserie over aldersfordelingen er det derudover nødvendigt at gøre antagelser om gennemsnitlig levetid og udskiftningsrater for ovne og kedler.

Antagelserne bag det totale antal af træfyrede anlæg og udskiftningsrater for forskellige teknologier er blevet opdateret på baggrund af den bedst tilgængelige viden. Forbedringerne i modellen er baseret på en gennemgang af tilgængelig litteratur og analyse af data fra spørgeskemaundersøgelser, samt data fra Skorstensfejerlauget og dialog med branchen.

Tidsserien for antallet af træfyrede anlæg er blevet opdateret. Metoden baseres nu på udskiftningskurver og salgstal, mens antallet af ovne i historiske år er blevet genvurderet på baggrund af tilgængelige data.

Enhedsforbrug per teknologitype anvendes til bottom-up beregning af træforbruget. I overensstemmelse med internationale retningslinjer for emissionsopgørelser rapporteret til EU og FN, så skal emissionsopgørelsen baseres på den officielle energistatistik publiceret af Energistyrelsen. For at følge disse retningslinjer bliver det bottom-up beregnede træforbrug skaleret, så det stemmer overens med det opgivne træforbrug i energistatistikken.

For emissionsfaktorerne er der foretaget et litteraturstudie med henblik på at vurdere, hvor der var basis for at opdatere værdierne. Opdateringen fokuserede på forureningskomponenter med den højeste betydning for de samlede nationale emissioner og specifikke teknologier, som var blevet identificeret som havende brug for en opdatering. Opdaterede emissionsfaktorer er implementeret for partikler, sod (black carbon), polycykliske aromatiske forbindelser (PAH), dioxiner og furaner (PCDD/F), kvælstofoxider (NO_x), kulmonoxid (CO) og svovldioxid (SO_2).

Den opdaterede model medførte væsentlige ændringer i emissionerne af flere forureningskomponenter. De største ændringer var for partikler, kulmonoxid, black carbon, dioxin og PAH. For de resterende forureningskomponenter var ændringer mindre. De væsentligste genberegninger i vist i nedenstående tabel.

Forureningskomponent	2005 2019-aflevering	2005 2020-aflevering	2017 2019-aflevering	2017 2020-aflevering
NMVOC	12461	11960	10063	9866
CO	86782	91573	72489	76001
$PM_{2.5}$	13742	9922	11923	8584
BC	1750	355	1831	554
PCDD/F (g)	12,3	14,6	11,3	24,3
Benzo(a)pyren	1842	2624	1599	1688
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Benzo(k)fluoranthen	661	1900	301	1071
Indeno(1,2,3-cd)pyren	1055	2024	882	925

Selvom den opdaterede model er væsentlig forbedret i forhold til den tidligere model, så er det nødvendigt at understrege, at der fortsat er store usikkerhede forbundet med emissionsopgørelsen for træfyring i husholdninger. Der er usikkerheder forbundet med alle parametre i modellen og selvom, der fortsat vil blive arbejdet på at nedbringe usikkerhederne, så vil træfyring i husholdninger fortsat være forbundet med væsentlige usikkerheder.

Fremtidige forbedringer af modellen og inputdata vil primært afhænge af tilgængeligheden af nye og bedre data. Der udføres med mellemrum projekter som måler emissioner fra træfyringsanlæg, og resultaterne af disse måleprojekter vil fortsat være interessante og kan føre til opdateringer af emissionsfaktorerne.

Nye data for anvendelsen af træfyringsanlæg fremkommer som en del af den undersøgelse, som udføres hvert andet år som en del af arbejdet med energistatistikken. Selvom data i de tidligere undersøgelser har vist store fluktuationer mellem undersøgelser, hvilket gør det svært at lave konklusioner, vil resultaterne af disse undersøgelser fortsat blive analyseret.

I forhold til fremtidige forbedringer af modellen vil data for antal, type og alder af træfyringsanlæg være vigtige elementer at få opdateret. Skorstensfejerne inspicerer alle ildsteder jævnligt og mindst en gang om året, og det vil være af stor værdi, hvis yderligere detaljer blev registreret i forbindelse med disse inspektioner. Disse detaljer er f.eks. oplysninger omkring anlæggets alder, type og oplysninger om hvorvidt anlægget anvendes til primær opvarmning, sekundær opvarmning eller kun bruges lejlighedsvist. Oplysninger omkring dette vil direkte kunne bruges til at opdatere det totale antal, aldersfordeling, teknologifordeling og på længere sigt medvirke til at verificere eller forbedre antagelserne omkring udskiftningsrater.

1 Introduction

DCE (Danish Centre for Environment and Energy), Aarhus University is contracted by the Ministry of the Environment and Food and the Ministry of Energy, Utilities and Climate to complete emission inventories for Denmark. Department of Environmental Science, Aarhus University is responsible for calculation and reporting of the Danish national emission inventory to the EU (Monitoring Mechanism Regulation & Directive on reduction of national emissions of certain atmospheric pollutants) and the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long Range Transboundary Air Pollution) conventions.

Residential wood combustion is an important source of air pollution in Denmark and therefore attracts great attention. There is however, large uncertainties associated with the emission inventory, as there are many parameters in the emission calculation, all of which have varying levels of uncertainty. This consists of both the number of appliances per technology, the age distribution, the wood consumption and the emission factors. To create a time series, it is also necessary to have assumptions on the expected lifetime (to calculate the age distribution) and replacement rates of stoves and boilers.

The previous model is documented in the Informative Inventory Report (IIR) for 2019 (Nielsen at al., 2019).

The contribution from residential wood combustion to several pollutants is very high, and especially for some of the pollutants most associated with adverse impacts on human health such as particulate matter. For example, in 2018 residential wood combustion accounts for more than half of the emission of $PM_{2.5}$, more than 60 % of PAH emissions and more than 30 % of CO emission.

As residential wood combustion is also an important source in many other countries there is constantly being generated new knowledge, which should be reflected in the inventory to ensure that the emission estimate is as accurate as possible. Several Danish / Nordic studies have been carried out in recent years, which fed in to the update of the emission factors. Also, a general literature survey was carried out to further inform the update of the emission factors.

The following Chapters are documenting the various aspects of the model that were revised in this update. It includes the model itself, e.g. assumption on replacement curves, annual sales etc., the overall number of appliances and the emission factors. Finally, the results of the updated model is presented and compared to the previous model and the uncertainties are discussed.

2 Emission model

2.1 Overview

The model calculating emissions from residential wood combustion is using many parameters. The most important parameters are: number of wood burning appliances divided on technologies, replacement rates of appliances, unit wood consumption and emission factors for each pollutant and appliance. The emission is calculated using the equation:

$$\sum_i ADs_i \times EF_i \ ,$$

Where, ADs is the scaled activity data, EF is the emission factor, and i is the appliance type. ADs is calculated using the following equation:

$$ADs_i = N_i \times UC_i \times \frac{AD_{stat}}{\sum_i N_i \times UC_i} \ ,$$

Where, AD_{stst} is the statistical wood consumption from the energy statistics, N is the number of appliances, UC is the unit consumption and i is the appliance type.

A description of most of the parameters related to the activity data are described in this chapter, while the total number of wood burning appliances is described in Chapter 3. The emission factors are described in Chapter 4.

2.2 Wood burning appliances

The wood burning appliances included in the model are shown in table 2.1. For most pollutants, the newer technologies have significantly lower emissions compared to the older technologies. However, this is not true for all pollutants, e.g. black carbon and NO_x, for more information see Chapter 4 on emission factors. In terms of number, the largest category is stoves and the older stoves are continuously replaced by newer stoves, more information on the split is provided in Chapter 5. In the updated model, the category ‘other stoves’ has been split into two categories for low-emitting (e.g. masonry stoves) and high-emitting (e.g. fireplaces) stoves. In addition, the category for eco-labelled stoves have been subdivided and now include three subcategories instead of two.

Table 2.1 Type of wood burning appliances considered.

Appliance type	Further information
Stove (-1989)	
Stove (1990-2007)	Stove with Danish Standard mark
Stove (2008-2014)	Stove conforming with Danish legislation (2008)
Stove (2015-2016)	Stove conforming with Danish legislation (2015)
Stove (2017-)	Stove conforming with Danish legislation (2017)
Eco labelled stove / new advanced stove (-2014)	Stove conforming to the ecolabel (Svanemærket) until 2014
Eco labelled stove / new advanced stove (2015-2016)	Stove conforming to the ecolabel (Svanemærket) 2015-2016
Eco labelled stove / new advanced stove (2017-)	Stove conforming to the ecolabel (Svanemærket) from 2017
Open fireplaces and similar	
Masonry stoves and similar	
Boilers with accumulation tank (-1979)	
Boilers without accumulation tank (-1979)	
Boilers with accumulation tank (1980-)	
Boilers without accumulation tank (1980-)	
Pellet boilers/stoves	

2.3 Annual sales

The annual sales figures are not publically available, but a time series has been constructed based on information from the industrial association for suppliers of fireplaces and wood stoves (Kristensen, 2019) together with DCE assumptions.

Table 2.2 Annual sales of wood stoves.

Year	-1996	1997-2000	2001-2005	2006-2010	2011-2018
Annual sale	20000	25000	31000	22400	20500

The specific number varies between the years, but for the purpose of the model, approximate averages have been calculated and used in the model.

For the other technologies, there is no information on the annual sales. For boilers there is a fixed assumption on a replacement rate of 3.3 % per annum, corresponding to a lifetime of 30 years.

2.4 Replacement curves

Since detailed data are not available on annual scrapping of old stoves, construction of new stoves and replacement of existing stoves, the population of stoves has been modelled using a replacement curve. The curve has been constructed with input from the industry, chimneysweepers, the Danish EPA and the Ministry of Environment and Food.

The constructed curve assumes that the first stove is replaced / scrapped 15 years after being sold with the last stove being replaced / scrapped 50 years after being sold. The majority of stoves are being replaced / scrapped between the ages of 20 and 40.

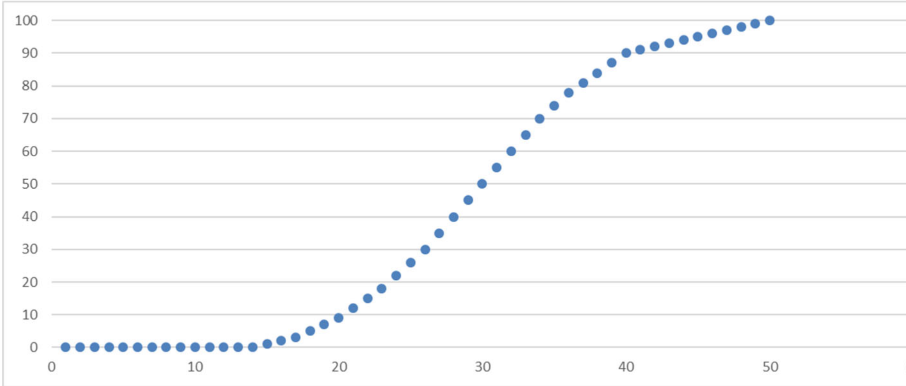

Figure 2.1 Replacement curve for wood burning stoves.

The age distribution of wood stoves are done using the replacement curves in combination with the information on annual sales.

For other technologies, there is either no age dependent technology split (wood pellet appliances, fireplaces and similar, masonry stoves and similar) or there is assumed a fixed rate replacement (wood boilers).

2.5 Unit consumption

For the different appliances, a unit consumption is used to estimate the total wood consumption. The unit consumption has not been changed in the update of the model with the exception that 'other stoves' has been subdivided. The unit consumption for all stoves are considered equal and the same is the case for the boilers. The data for unit consumption is referenced to Ea Energianalyse (2016) and the values are shown in Table 2.3. The unit consumptions are weighted between permanent residences and summerhouses based on the information provided in Ea Energianalyse (2016).

Table 2.3 Unit consumptions for different appliance types.

Appliance type	GJ/appliance
Stoves	23.4
Open fireplaces and similar	11.8
Masonry stoves and similar	42.1
Boilers	121.2

The study conducted by Ea Energianalyse (2016) did not show a significant difference in unit consumption based on the age of the appliance. The study indicated a slightly higher consumption in appliances newer than 2005 compared to older appliances. In permanent residences, there was a clear indication that the unit consumption is lower in Copenhagen and the Capital Region compared to the other regions of Denmark. This does not impact the national emission inventory, but is taken into account in the spatial distribution of emissions (Plejdrup et al. 2016 & Plejdrup et al., 2018)

2.6 Comparison to energy statistics

When calculating the wood consumption based on the number of appliances and the unit consumption, the total does not match the registered consumption in the Danish energy statistics (DEA, 2019). Since the inventory should be based on the official energy statistics, the wood consumption calculated bottom-up is scaled with the official wood consumption in the energy statistics. The scaling is done across all technologies of appliances using firewood, i.e.

all technologies except wood pellet stoves / boilers. This assumption is made since no other information is available. This will however, be analysed further in the future. The scaling factors are shown in Table 2.4. The wood consumption in the energy statistics is lower than the bottom-up calculation in the early part of the time series, so the calculated consumption is divided by the scaling factors shown in Table 2.4.

Table 2.4 Scaling factors for wood consumption to match the energy statistics.

Year	1990	2000	2005	2010	2015	2018
Scaling factor	2.5	1.8	1.2	1.0	1.0	1.0

It can be seen that the correlation between the bottom-up estimated wood consumption and the statistics are much better in the last part of the time series compared to the first part. This is partly connected to the fact that in later years the biennial surveys have been utilised both in the energy statistics and in the emission inventory. A graphical presentation of the scaling factors is included in Figure 2.2.

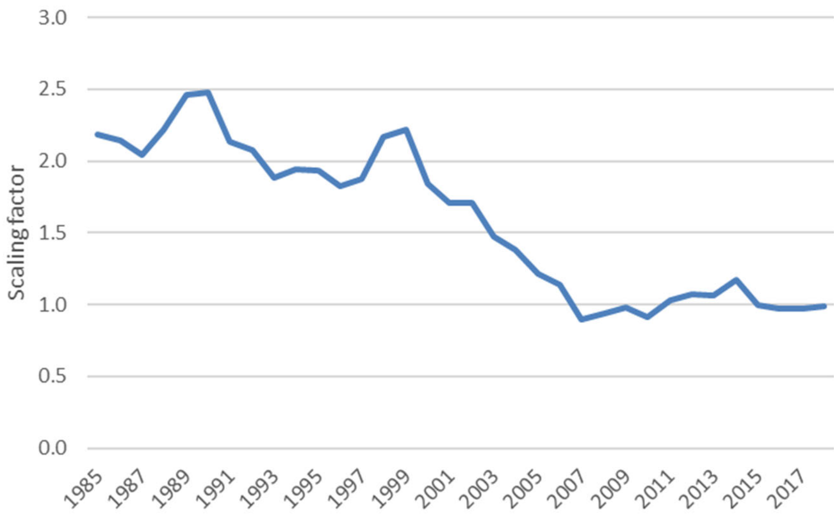

Figure 2.2 Scaling factors for 1985 to 2018.

The poor correlation in the beginning of the time series can possibly be attributed to a change in the energy statistics. The first survey on residential wood combustion was carried out for the year 2005 and showed a markedly higher wood consumption than previously considered in the statistics. A revision was made for 2000 to 2005 but not further back in time. As a result, the consumption of firewood shows a very large increase over these years as illustrated in Figure 2.3.

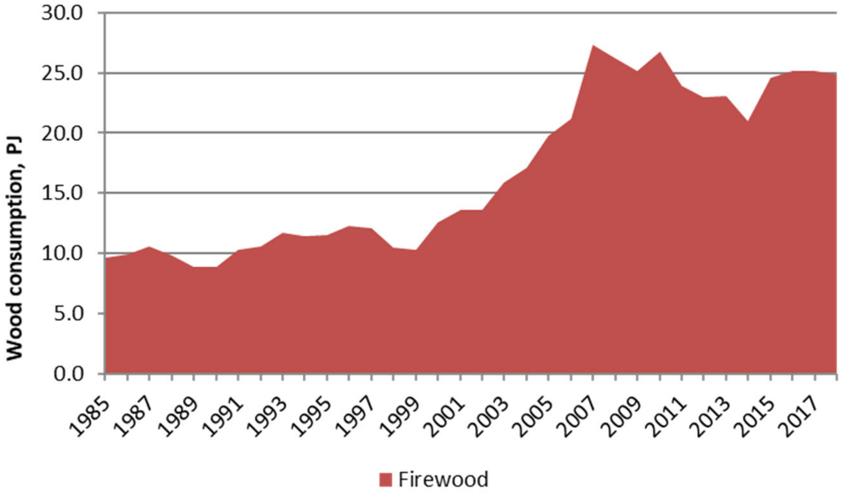

Figure 2.3 Firewood consumption in the energy statistics (DEA, 2019).

The firewood consumption increases by 118 % from 2000 to 2007 in the energy statistics. While there was an increase in the number of stoves in that period, there is no indications that it can justify that large an increase in wood consumption. The development has also been discussed with the industry and chimneysweepers and there is no evidence that the large increase is the result of actual change but rather mostly a result of changes in methodology in the statistics when starting to use surveys in the statistics in 2007 for the year 2005.

3 Number of wood burning appliances

The 2019 update of the residential wood combustion model includes an update of the number of appliances. A review of relevant data and literature have been carried out and used for decision of input data to the final time series for wood burning appliances. Updated time series have been made for the number of wood stoves. The time series for other stoves, masonry and wood boilers have been updated regarding the number of appliances, but no data has been found to support annual variation, and the number of these appliances are kept constant for the time series. The data and analysis behind the updated time series for appliance numbers are described in the following chapters.

3.1 Literature study

A literature study has been carried out to identify relevant information regarding the number of wood burning appliances in Denmark and the development over time.

3.1.1 Biennially surveys on residential wood consumption

Biennially surveys focusing on the residential wood consumption in Denmark have been carried out by Force Technology for the years 2005, 2007, 2009, 2011 and 2013 (Evald, 2006, 2008, 2010, 2012 & Hansen 2015), and by Ea Energianalyse for 2015 (Ea Energianalyse, 2016). The surveys focus on the latest year, but do not include any time series or update of results from earlier years' surveys.

The first surveys by Force Technology (Evald, 2006; Evald 2008) were based on phone interviews with around 1 000 respondents in 2005 and 2007, 2 000 respondents in 2009 and 2011, and around 2 100 respondents in 2013 (Table 3.1). The methodology was changed in the 2015-survey, where the survey was send by digital mail to 40 000 households, resulting in 13 229 respondents.

Table 3.1 Information from the biennial surveys on residential wood consumption in Denmark.

Year	Respondents	Stoves	Fireplace	Boilers	Masonry
2005	1 042	507 944	39 971	47 753	
2007	964	679 292	49 900	93 980	
2009	2 027	717 730	76 622	31 429	
2011	2 014	750 229	58 174	16 621	~3 500-5 000
2013	2 133	725 283	72 794	18 270	~5 000
2015	13 229	738 600	49 743	47 500	2 657

The same methodology and questionnaire was used in the 2005-survey and 2007-survey, see Evald (2006 and 2008).

In the 2009-survey (Evald, 2010), questions regarding the age distribution of appliances and the occurrence of appliances with the Nordic eco-label (Svanemærket). Further, the survey was changed to include a representative number of households with fixed line phone, mobile phone and both, in contrast to the earlier surveys only covering households with fixed line phone.

The 2011-survey (Evald, 2012) was extended with questions regarding the use of briquettes and the size and location of the household (rural or urban area).

The 2013-survey (Hansen, 2015) was extended with questions regarding use of other heating types, and if the wood burning appliances were used as primary or supplementing heating source.

The 2015-survey (Ea Energianalyse, 2016) followed a new methodology, as the questionnaire was send by digital mail, which made it possible to contact a much larger number of households, and thereby increase the number of respondents significantly. The questionnaire was changed due to the shift from phone interview to digital survey, but the subjects were rather similar.

The numbers of appliances on national level were estimated from the answers according to the number of households in Denmark (see Figure 3.1). Due to less respondents in the early surveys, the uncertainty is higher than for the later surveys with more respondents, especially for the less occurring appliance types; fireplaces and boilers, as the numbers are extrapolated to national level. The number of masonry separately is not included in the surveys 2005-2009, while the surveys for 2011 and 2013 include expert judgements. An estimate of the number of masonry is included in the 2015-survey.

A large increase of the number of stoves is seen from 2005-2009. Due to the large uncertainty, it is not possible to assess to what degree this trend reflect the real conditions. Due to the little number of respondents with boilers and fireplaces, the uncertainty is even larger for those technologies, it is not possible to deduce a trend, and the appliance numbers is not trustworthy either. The outcome of the 2015-survey is assumed to have less uncertainty due to the larger number of respondents, and the number of appliances are assumed to be in the right order of magnitude.

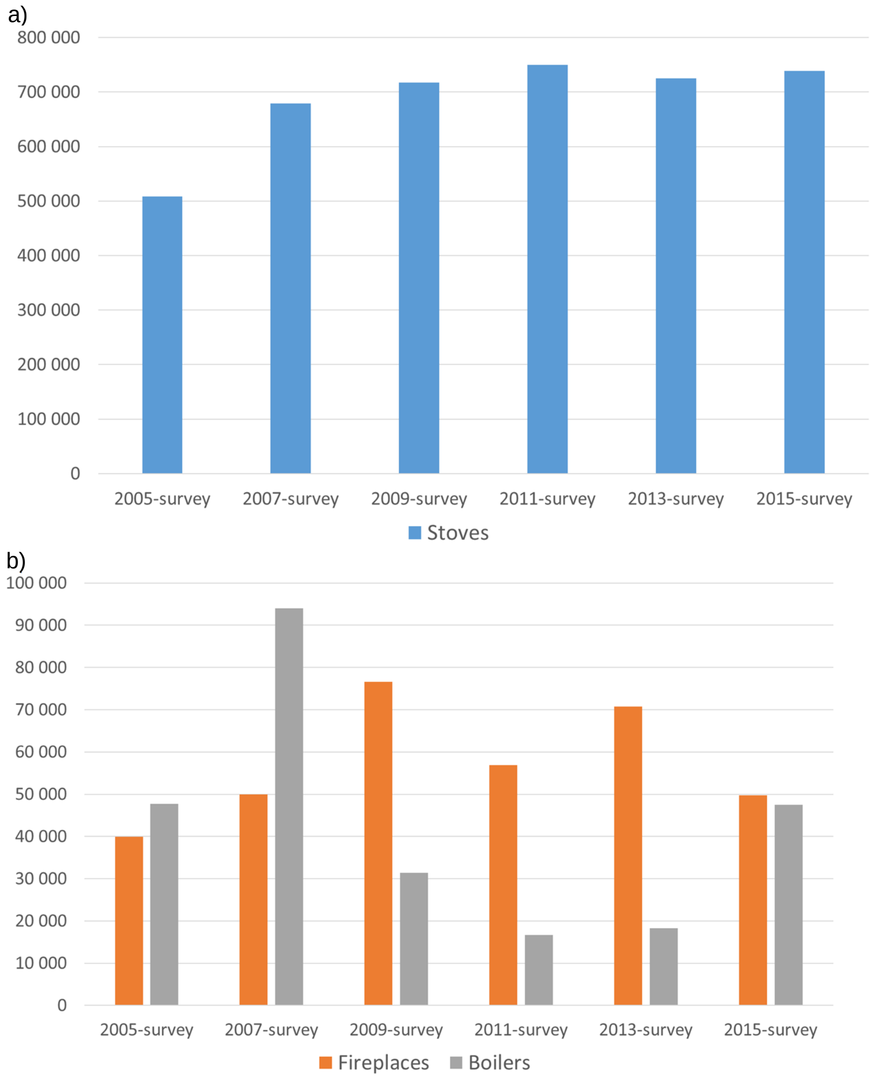

Figure 3.1 Number of appliances based on the biennial surveys on the residential wood consumption for a) stoves and b) fireplaces and boilers.

3.1.2 EPA projects on small wood burning appliances

A number of projects focussing on small wood burning appliances have been published by the Danish EPA. Miljøprojekt 1021 (Palmgren et al., 2005) was established due to an increasing number of wood stoves in Denmark, which gave rise to an increasing number of enquiries from the public regarding obnoxious smell. The emission calculations in the study were based on an estimate by the Technological Institute (TI) of 300 000 wood stoves and 90 000 wood boilers (hereof 25 000 pellet boilers). This is the lowest number of stoves identified in the literature study, but in contrast to other studies, the number only include stoves used to a degree that they contribute significantly to the heating of the building. In contrast, Palmgren et al. (2005) estimate the highest number of boilers.

In Miljøprojekt 1164 (Illerup et al., 2007), the numbers of wood burning appliances were updated based on two telephone surveys focusing on wood consumption in small wood burning appliances (Nikolaisen, 2005; Evald, 2006). The appliances are available by area type (urban, rural, holiday) and by technology (old stove, new stove, modern stove, old boiler, new boiler, pellet boiler, other boilers).

The EPA published the results from a study of VOC emissions from product use and households in 2009 (Schleicher et al., 2009). The numbers of wood burning appliances were based on the 2007-survey, which was not yet published at that time. It was found that the trend from 2005 (based on Illerup et al. (2007) to 2007, showing a massive increase, was unrealistic. It was concluded that the survey methodology with telephone interviews was not appropriate, and the fact that respondents were selected only among fixed line phones was questioned.

Iversen et al. (2010) provided updated fuel consumption data and a survey of emission factors for wood stoves and boilers. Number of appliances are based on the 2005-survey (Evald, 2006) and the distribution by technology was projected for the years 2006-2008 based on sales statistics from the industry and information from the chimneysweepers. The total number of appliances was kept constant at the 2005 level. An exchange rate of 5-8 % per year, corresponding 25 000-40 000 appliances, was estimated, and the number of discontinues and new installations was assumed to be about equal.

3.2 Data analysis

3.2.1 BBR data

Three data sets from the Building and Dwelling Register (BBR) is available for the analysis, covering data withdrawals from 2005, 2010 and 2017 respectively. The BBR data include information of primary heating source, heating fuel, and supplementary heating source (see Table 3.2, 3.3 and 3.4). Wood stoves and wood boilers are identified in the BBR based on the combination of the three heating categories. It is only possible to register one value for each category for each address in the BBR. This cause an underestimation of appliances in case more appliances occur on a single address. The fact that the house owners are responsible for updating the heating information the BBR increase the uncertainty of the data set, as this is often neglected. Case studies have shown large differences between the occurrence of wood stoves and the registration in the BBR.

Table 3.2 Primary heating categories in the BBR and appliance category.

ID	Primary heating category	Appliance category
1	District heating	
2	Boiler, one unit	Boiler
3	Stove	Stove
5	Heat pump	
6	Boiler, two unit	Boiler
7	Electricity appliance	
8	Gas appliance	
9	None	

Table 3.3 Fuel categories in the BBR and appliance category.

ID	Fuel	Appliance category
1	Electricity	
2	Town gas	
3	Liquid	
4	Solid	Wood stove
6	Straw	
7	Natural gas	
9	Other	

Table 3.4 Supplementary heating categories in the BBR and appliance category.

ID	Supplementary heating	Appliance category
1	Heat pump	
2	Stove, solid fuel	Wood stove
3	Stove, liquid fuel	
4	Solar	
5	Fireplace	Fireplace
6	Gas	
7	Electricity	
10	Biogas	
80	Other	
90	None	

The analysis of the three BBR data sets follow the same methodology and the same categorisation of appliances is used. The appliances in BBR are categorised based on primary heating, fuel and supplementary heating. A description of the methodology is included in Nielsen & Plejdrup (2018). Table 3.5 and Figure 3.2 list the number of appliances identified in the analysis for stoves, fireplaces and boilers. The category "stoves" cover old, new, modern and eco-label stoves in the inventory and the category "fireplaces" covers "other stoves" in the inventory. The number of appliances identified in the BBR data sets increase by 42 % from 2005 to 2010 and by 15 % from 2010 to 2017. As mentioned, the BBR data is subject to large uncertainties regarding the heating information. Registration is supposed to be more correct and comprehensive for new buildings, while updates of information for existing buildings, e.g. when a stove is installed or removed, might more often be neglected. Generally, the number of appliances are known to be underestimated in the BBR register, which is best shown with a comparison between the BBR data and data provided by the Danish chimneysweepers. For 2017 this comparison showed that the number of stoves was underestimated by around 37 % in the BBR (see Table 3.5 and 3.6), when taking into consideration, that the SLF data are missing for smaller areas and adjust by adding data from the BBR for these areas (this is further described in the chapter "SFL data"). SFL data are only available for 2017 and following it is not possible to assess the trend showing a 63% increase in number of stoves from 2005 to 2017 in the BBR data, based on SFL data.

Table 3.5 Number of appliances identified in the BBR data sets.

Data set	Stoves	Fireplaces	Boilers
BBR2005	258 958	16 419	35 723
BBR2010	366 700	24 329	52 034
BBR2017	420 893	28 334	83 813

Figure 3.2 Number of appliances identified in the BBR data sets.

3.2.2 SFL data

SFL2017

The Danish chimneysweeper association (SFL) has provided data including number and location of small wood burning appliances. The data set has been processed and analysed by DCE, as described in Nielsen & Plejdrup (2018). The SFL data are considered the most accurate data set available even though the coverage is not complete. SLF data are missing for a few areas (~10 % of the land area), and to complete the coverage, data from the BBR2017 data set have been supplemented for these areas. The supplement data make up around 5 % of the total number of appliances (see Table 3.6). The data set made up of the SFL2017 data and the supplement data from the BBR2017 is in the following referred to as SFL2017sup.

Table 3.6 Number of appliances identified in the SFL2017 data sets.

Data set	Stoves	Other appliances	Boilers
SFL2017	635 141	46 283	62 457
Supplement from BBR2017	34 205	2 020	5 614
SFL2017sup	669 346	48 303	68 071

The BBR data are subject to uncertainties regarding number of stoves and boilers, and this is transferred to the SFL2017sup when BBR is used as supplement. To evaluate this approach, the number of appliances used for supplement is compared to estimates from the chimneysweeper association on the number of appliances serviced by chimneysweepers, who are not member of the association. A rough estimate is that the around 25 000 stoves are serviced by chimneysweepers, who are part of the association “Frie Fejere”, and further an unknown number of stoves are serviced by chimneysweepers, who are not member of neither of these two associations. The latter include e.g. Brønderslev, but also part of Billund / Gl. Ølgod, Fyn, Lolland, Nordjylland, and Syd- / Sønderjylland The number of stoves in Brønderslev, according to the BBR2017, is 2 594. The total number of stoves from BBR2017 used as supplement to the SFL2017 is 36 225, which corresponds well to the estimate of stoves missing in the SFL2017 data (see Table 3.7).

Table 3.7 Number of stoves not included in the SFL2017.

	Number of stoves
Supplement from BBR2017 to SFL2017 for Denmark*	36 225
Frie fejere	25 000
Other chimneysweepers**	?
Supplement from BBR2017 to SFL2017 for Brønderslev	2 594
SUM	27 594

*Stoves and Other appliances.

**Not member of the chimneysweeper association or Frie Fejere, covering e.g. Brønderslev.

SFL2006

A data withdrawal from the SFL data in 2006 is available for a case area covering Ballerup, Herlev, Skævinge, Stenløse and Værløse. This data set have been analysed and compared to the SFL2017 to assess if a trend for the number of appliances could be identified, and if it could support assumptions of the share of new installations and discontinues.

Both the SFL2006 and the SFL2017 data are available on address level including postal code, road name and house number. The addresses in SFL2006 were joined to the corrected road names and postal codes from the analysis of the SFL2017 data, to increase the number of registrations, which could be joined. Analysis of the two data sets on address level was associated with far too many assumptions and uncertainties to make a useful outcome. It was not possible to distinguish if a change was due to installation / discontinue of a stove, or if it was a result of mix up of addresses. Further, too large a share of the addresses could not be joined between the two data sets. The methodology was changed to compare the number of stoves by road, but this introduced uncertainty, as many roads extended the limit of the SFL2006 coverage, and thereby a large number of houses was included in the count for SFL2017 data, but was not part of the SFL2006 data set.

Another methodology was tested, comparing the total number of appliances per postal code. This methodology was not applicable for most postal codes, as the case area did not follow the postal code areas. The output of this analysis is shown in Table 3.8.

It was decided to exclude the SFL2006 data set due to the large uncertainties in the comparisons, and because the case area is very small compared to national level. Further, the representativeness of the case area and the uncertainty related to an upscale of the trend to national level is unknown.

Table 3.8 Number of stoves and percentage increase from the SFL2006 to the SFL2017 data set.

Postal code	Stoves		
	SFL2006	SFL2017	Increase
0	2	34	1600%
2730	1 794	1 983	11%
2740	1 063	1 499	41%
2750	1 660	2 423	46%
2760	338	367	9%
2880	0	1 547	---
3300	0	4 293	---
3310	27	1 361	4941%
3320	765	748	-2%
3330	197	196	-1%
3400	11	4 009	36345%
3500	1 951	2 447	25%
3520	17	1 764	10276%
3540	2	740	36900%
3550	381	1 530	302%
3600	27	2 128	7781%
3660	1 683	1 692	1%
3670	300	458	53%
SUM	10 218	29 219	186%

3.2.3 Statistics Denmark

Figures from Statistics Denmark regarding import/export of small combustion appliances of iron and steel for solid fuels (statistical figure: KN8M; commodity category: 73218300), residential heating installations (statistical figure BOL105; heating: Central heating/without oil or nature gas; Stoves, other), have been assessed, but neither were useful to prepare a time series for wood burning appliances. No other statistical figures were identified, which included information that could be linked to production, sales, import/export or use of small wood burning appliances.

3.3 Data selection

The numbers of stoves, other appliances and boilers from the literature study and the data analysis are presented in Table 3.9, 3.10 and 3.11 and in Figure 3.3, 3.4 and 3.5. The evaluation of the data and selection of the input to the updated inventory model is included in the following chapters for stoves, other appliances and boilers, respectively.

Table 3.9 Number of stoves identified in the literature study and the data analysis.

ID	Reference	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	2005-survey	507 944												
2	2007-survey			679 292										
3	2009-survey					717 730								
4	2011-survey							750 229						
5	2013-survey									725 283				
6	2015-survey											738 600		
7	Palmgren et al., 2005	300 000												
8	Illerup et al., 2007	508 683												
9	Schleicher et al., 2009	550 915		732 194										
10	Iversen et al., 2010	527 394												
11	BBR2005	258 958												
12	BBR2010						366 700							
13	BBR2017													420 893
14	SFL2017sup													669 346

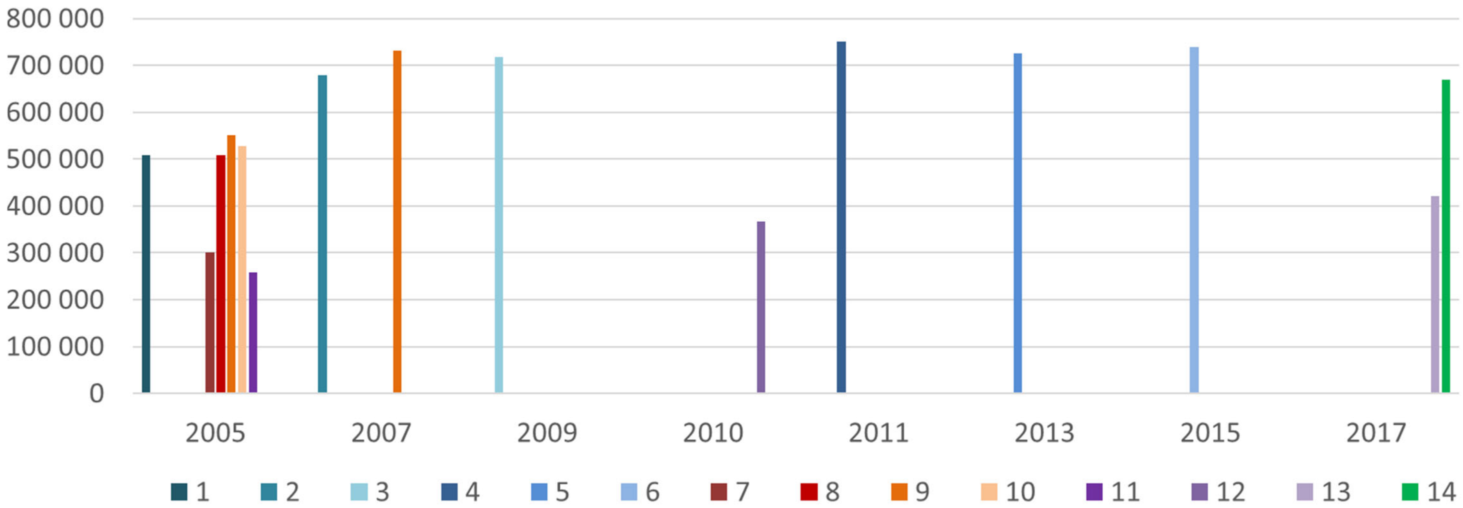

Figure 3.3 Number of stoves identified in the literature study and the data analysis.

Table 3.10 Number of other appliances identified in the literature study and the data analysis.

ID	Reference	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	2005-survey	39 971												
2	2007-survey			49 900										
3	2009-survey					76 622								
4	2011-survey							58 174						
5	2013-survey									72 794				
6	2015-survey											49 743		
7	Palmgren et al., 2005	no data												
8	Illerup et al., 2007	13 597												
9	Schleicher et al., 2009	no data		no data										
10	Iversen et al., 2010	16 664												
11	BBR2005	16 419												
12	BBR2010						24 329							
13	BBR2017													28 334
14	SFL2017sup *													48 303

*including 2 832 masonry.

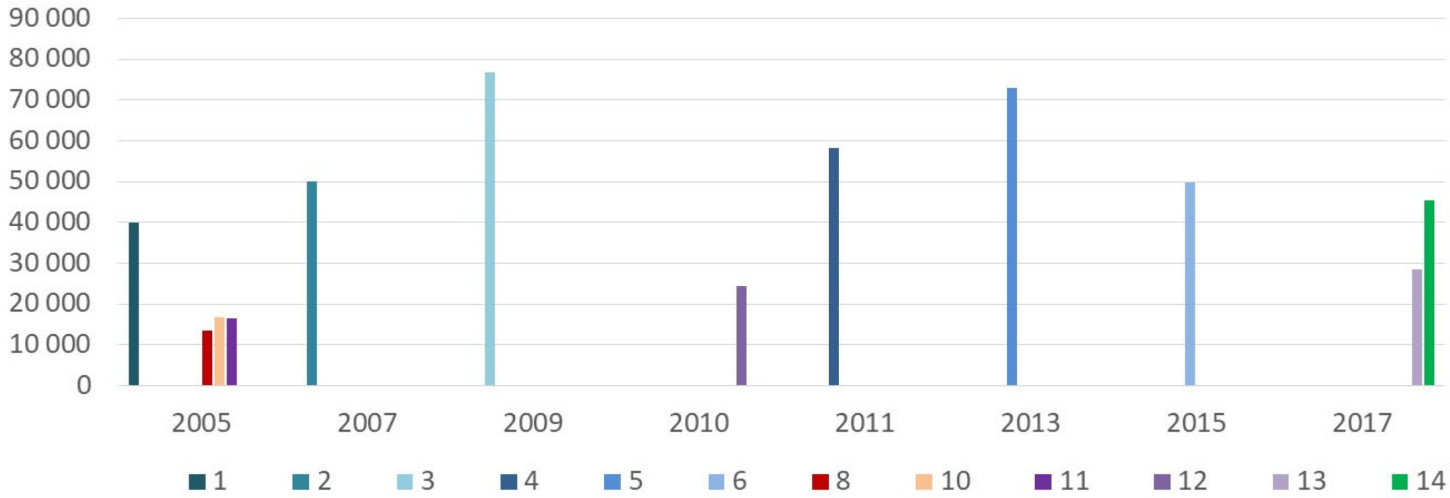

Figure 3.4 Number of other appliances identified in the literature study and the data analysis.

Table 3.11 Number of boilers identified in the literature study and the data analysis.

ID	Reference	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	2005-survey	47 753												
2	2007-survey			93 980										
3	2009-survey					31 429								
4	2011-survey							16 621						
5	2013-survey									18 270				
6	2015-survey											46 241		
7	Palmgren et al., 2005	65 000												
8	Illerup et al., 2007	47 753												
9	Schleicher et al., 2009	47 753		93 980										
10	Iversen et al., 2010	47 945												
11	BBR2005	35 723												
12	BBR2010						52 034							
13	BBR2017													83 813
14	SFL2017sup													68 071

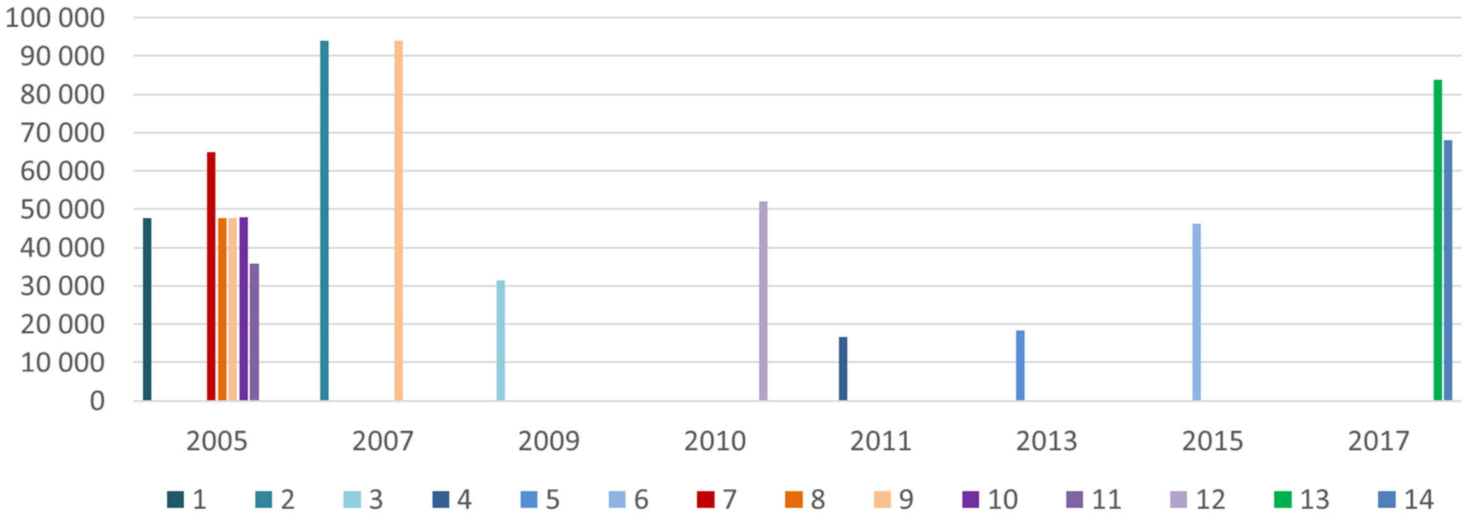

Figure 3.5 Number of boilers identified in the literature study and the data analysis.

3.3.1 Stoves

To create a time series for the number of stoves, six scenarios have been set up based on the data and information described in the previous chapters. The scenarios are described in the following.

The data set from the chimneysweepers supplemented with data from the BBR2017 (SFL2017sup) is considered the most accurate data set for 2017, and the number of stoves based on this analysis is included in all scenarios. The number might be subject to a minor underestimation due to the underestimation in the BBR data used as supplement. The uncertainty of the BBR is not systematic and it has been decided not to add any correction of the BBR, as this might lead to introduction of further uncertainty by assuming that the uncertainty is the same for all areas in Denmark. Further, overestimation might occur as the chimneysweeper register include all appliances regardless if it is used or not, as, by law, all appliances connected to a chimney must be serviced by a chimneysweeper.

The basic scenario corresponds to the previous methodology, where the number of stoves is fixed for the entire time series. The number of stoves have been updated according to the SFL2017 data supplemented with BBR2017 data for the missing areas (SFL2017sup).

The surveys for 2007, 2009, 2011, 2013 and 2015 all exceed the number of stoves in the SFL data, and due to the large uncertainty of the survey results, because of the upscaling from a rather low number of respondents to national level, these have been deselected for use in the scenarios. The result from the 2005-survey is expected to have even larger uncertainty due to the lower number of respondents, but is even though found to be among the best estimates available for 2005. Illerup et al. (2007) made an updated emission inventory based on the 2005-survey and other information, and the number of stoves for 2005 have been used in two scenarios (scenario 3 and 4). The number of stoves from Iversen et al. (2010), also based on the 2005-survey, has been used for 2005 in two scenarios (scenario 1 and 2).

The number of stoves identified in the BBR data sets are the lowest number identified for both 2005, 2010 and 2017. One scenario is set up using the number of stoves from the BBR for 2005 and 2010 (scenario 7). The BBR data are subject to large uncertainties regarding the number of stoves, which is obvious from the comparison with the SFL2017 data. The changes between the three BBR data sets might however reflect the actual trend. Two scenarios have been set up, back scaling the number of stoves in SFL2017sup, based on the percentage change between the years in the BBR. Both scenarios show an unexpectedly steep increase from 2005 to 2017 (scenario 5 and 6).

No information of the trend from 1990 to 2005 have been found. The production of wood stoves in Denmark started around 1950 and a linear trend from 1950 (zero stoves) to 2005 (number of stoves based on Illerup et al., 2007) have been applied in one scenario (scenario 4).

Another approach for estimating the number of stoves before 2005 is applied in two scenarios (scenario 3 and 6). The number of stoves have been back scaled according to the change in number of households in Denmark from figures published by Statistics Denmark. This methodology result in an increase of 24 % from 1980 to 2005.

Sales statistics have been provided by DAPO (Foreningen af Danske Leverandører af Pejse og Brændeovne) for the years 1997-2018. Figure 3.6 show the sales numbers and the share of the total number of stoves in scenario 3. On average, the sale correspond to 4 % the total number of stoves. An unknown part of the sale is replacement of older stoves and following, the total number of stoves do not increase. Assuming that the sale is evenly distributed between replacement and new installation, the annual growth rate is around 2 %. A scenario has been set up based on the assumption of an annual growth rate of 2 % for the years 1995-2005, and 1 % for the years 1980-1995 (scenario 2).

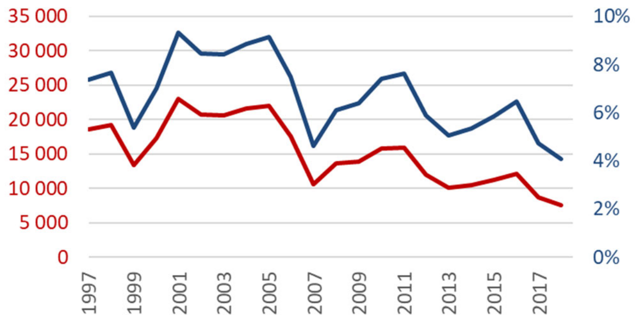

Figure 3.6 Sales statistics (number) including stoves and fireplace inserts provided by DAPO (red line), and share (%) of total number of stoves (scenario 3) (blue line).

The scenarios are listed in Table 3.12 with references to data and description of the assumptions.

Table 3.12 Scenarios for stoves.

Scenario	1990-2000	2000-2005	2005	2005-2010	2010	2010-2017	2017	2017-2050
Basic	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	SFL2017sup	Constant (2017 value)
1	Constant (2005 value)	Constant (2005 value)	Iversen et al., 2010	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
2	+ 1 % per year	+ 2 % per year	Iversen et al., 2010	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
3	Growth rate cf. number of households	Growth rate cf. number of households	Illerup et al., 2007	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
4	Linear interpolation from 1950 (zero) to 2005 (Illerup et al., 2007)	Linear interpolation from 1950 (zero) to 2005 (Illerup et al., 2007)	Illerup et al., 2007	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
5	Constant (2005 value)	Constant (2005 value)	Back scale of 2017 value cf. growth rates from BBR2005 to BBR2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
6	Growth rate cf. number of households	Growth rate cf. number of households	Back scale of 2010 value cf. growth rates from BBR2005 to BBR2010	Linear interpolation 2005-2010	Back scale of 2017 value cf. growth rates from BBR2010 to BBR2017	Linear interpolation 2010-2017	SFL2017sup	Constant (2017 value)
7	Constant (2005 value)	Constant (2005 value)	BBR2005	Linear interpolation 2005-2010	BBR2010	Linear interpolation 2010-2017	SFL2017sup	Constant (2017 value)

The numbers of stoves for the scenarios are shown in Figure 3.7.

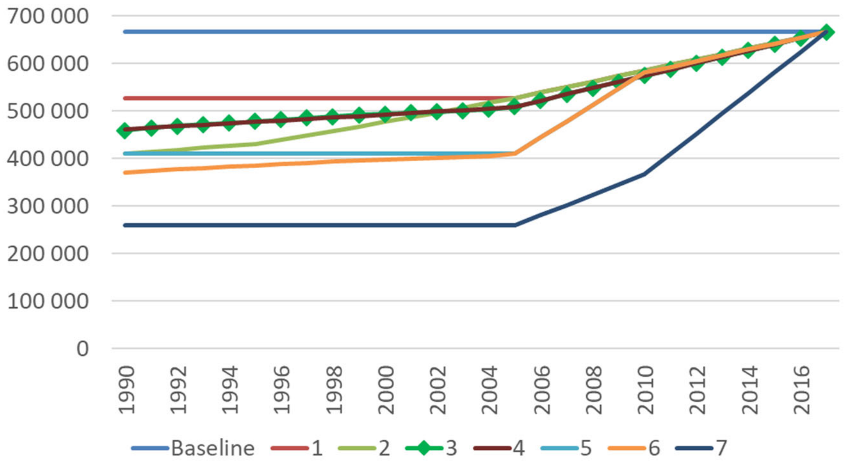

Figure 3.7 Number of stoves in the scenarios.

Evaluation of the scenarios regarding trends and number of stoves, have resulted in selection of scenario 3 as the best scenario. It is assumed that Illerup et al. (2007) is the best reference for 2005 and that SFL2017sup is the best reference for 2017. The trends for 2005-2010 and 2010-2017 based on BBR data is not supported by other data sources and is not included in the inventory model due to the large uncertainties for heating information in BBR. The trend before 2005 follow the trend for the number of households, as this is found to be the most appropriate assumption. The trend is increasing as expected but less dramatic as the result of a linear interpolation back to zero in 1950. No information is available that support a linear trend for 1950-2005, or if the trend should be steepest in early or later years. Using the household numbers as proxy is found more reasonable than using the growth rate based on sales statistics and assumption of the distribution between new installations and replacements (see Table 3.13 and Figure 3.8).

Table 3.13 Number of stoves for selected years as applied in the emission inventory model.

Year	Number of stoves
1990	459 140
1995	478 459
2000	493 676
2005	508 683
2010	575 626
2015	642 569
2017	669 346
2030	669 346

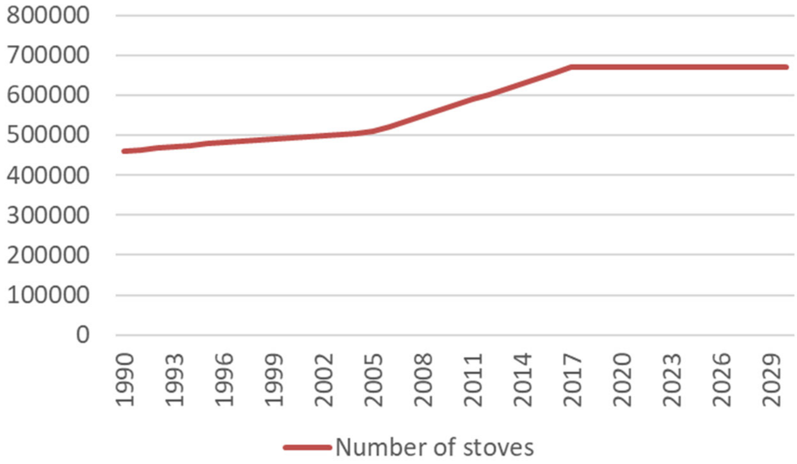

Figure 3.8 Number of stoves applied in the model.

The final decision has been to use the number of appliances in 2017 based on the data from the chimneysweeper association supplemented by data from the building and dwelling register for the areas not covered by the chimneysweeper data. The time series are prepared based on assumption of expected lifetime for appliances and replacement rates, as described in Chapter 2.4.

3.3.2 Other appliances

The same methodology and background data has been used to analyse the time series for the number of other appliances as for stoves. The same scenarios have been set up as for stoves. The scenarios are listed in Table 3.12 with references to data and description of the assumptions. The category 'other appliances' covers a number of different appliances, e.g. open fireplaces, masonry, pizza ovens, sauna ovens and cooking stoves. Open fireplaces and similar is the most common, while most other appliances are rather rare. Due to the large differences of the appliances in this category, it is divided into two categories in the inventory covering high and low emission appliances; Open fireplaces and similar, and Masonry heat accumulating stoves and similar.

The uncertainty for SFL2017sup is assumed to be small, and be the best reference for 2017. As the number of other appliances is far less that the number of stoves, the uncertainty of the results from the surveys is much larger for this category. The large uncertainty spread to the projects included in the literature study, which build on the survey data, here among Illerup et al. (2007), which therefore is not used to generate a time series for other stoves. The numbers of other appliances for the scenarios are shown in Figure 3.9.

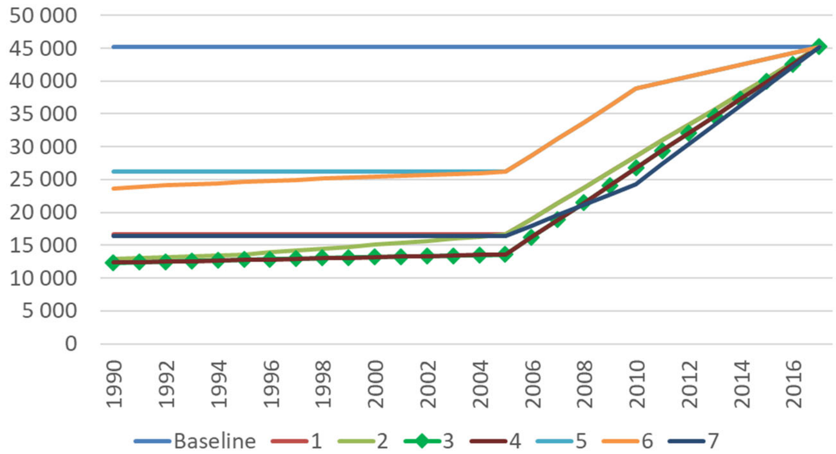

Figure 3.9 Number of other appliances in the scenarios.

Other appliance identified in the BBR data sets include registrations of fireplaces as supplementary heating. Information of supplementary heating is assumed to be subject to large uncertainties in the BBR, as house owners are responsible for updating the information. First registrations for new buildings might be more correct than for old households, where updates might have been neglected. Further, there might be more focus on updating primary than supplementary heating information. Fireplaces are more frequent as supplementary heating and in old buildings than as primary heating and in new buildings. Following, the number could very well be overestimated in the BBR register.

Missing updates when fireplaces are discarded or when fireplace inserts have been installed contribute to an overestimation, while neglecting registrations of fireplaces contribute to an underestimation. The BBR only allow registration of one primary and one supplementary heating installation, leading to missing registrations if more than one supplementary heating installation occur. The trends for 2005-2010 and 2010-2017 based on BBR data is not supported by other data sources and is not included in the inventory model due to the large uncertainties for heating information in BBR. The trend before 2005 are not supposed to follow the trend for the number of households as assumed for stoves. Due to the small number of other stoves and the large uncertainty of the analysed data, it is decided to apply a constant number in the model, based on SFL2017sup (45 471 high emission appliances, see Table 3.14).

Masonry is covered by a separate category (Masonry heat accumulating stoves and similar) as the emission factors are much different compared to open fireplaces etc. The 2011-survey and the 2013-survey mention 3 500-5 000 masonry and 5 000 masonry, respectively. The 2015-survey gives an estimate of 2 657 masonry, and the number in SFL2017sup is 2 832. Due to the few data available and no information for the prior years, it has been decided to use a constant number of 3 000 low emission appliances for the entire time series (see Table 3.14).

The emission inventory model has been updated to use the number of other stoves based on the SFL2017sup data set, taking into account the results from the surveys for low emission appliances. The number of high and low emission appliances applied in the model is listed in Table 3.14.

Table 3.14 Number of other appliances applied in the emission inventory model.

Year	Open fireplaces and similar	Masonry heat accumulating stoves and similar
All years	45 471	3 000

3.3.3 Boilers

To create a time series for the number of boilers, 12 scenarios have been set up based on the data and information described in the previous chapters. The scenarios Basic, 1-3 and 5-7 are similar to the scenarios for stoves. The scenarios are listed in Table 3.15 with references to data and description of the assumptions, and are described in the following.

The data set from the chimneysweepers supplemented with data from the BBR2017 (SFL2017sup) is considered the most accurate data set for 2017, and the number of boilers based on this analysis is included in all scenarios. The number might be subject to overestimation due to the overestimation in the BBR data used as supplement. The uncertainty of the BBR is not systematic and it has been decided not to add any correction of the BBR, as this might lead to introduction of further uncertainty by assuming that the uncertainty is the same for all areas in Denmark. Further, overestimation might occur as the chimneysweeper register include all appliances regardless of whether it is used or not, as, by law, all appliances connected to a chimney must be serviced by a chimneysweeper.

The basic scenario corresponds to the previous methodology, where the number of boilers is fixed for the entire time series. The number of boilers have been updated according to the SFL2017sup data (68 071 wood boilers, see Table 3.16).

The number of boilers estimated in the surveys for 2007, 2009, 2011, 2013 and 2015 show large variation and no trend can be derived from the data (see Figure 3.10). The uncertainty is expected to be very large due to the few respondents with boilers, and the following upscaling to national level. Illerup et al. (2007) made an updated emission inventory based on the 2005-survey and other information, and the number of boilers for 2005 have been used in one scenario (scenario 3). The number of boilers from Iversen et al. (2010), also based on the 2005-survey, has been used for 2005 in two scenarios (scenario 1 and 2).

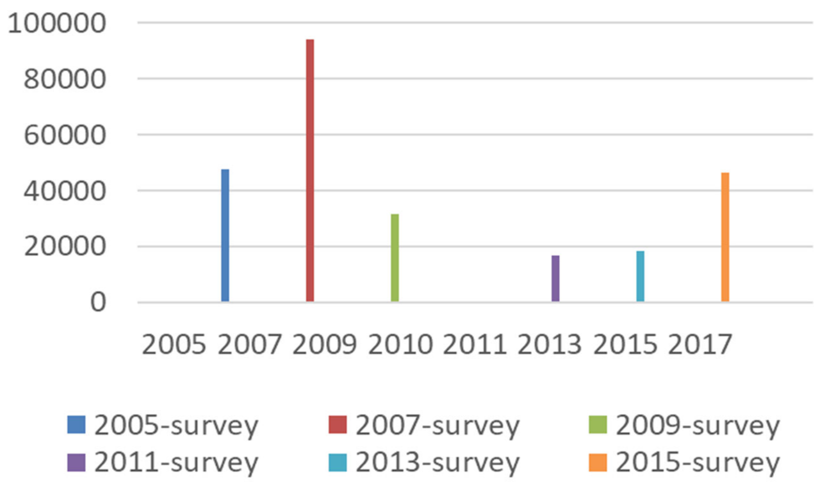

Figure 3.10 Number of boilers in the surveys.

The number of boilers identified in the BBR data sets show a large increase from 2005 to 2010 and to 2017 (see Figure 3.11). The BBR data are subject to large uncertainties regarding the number of boilers, which is obvious from the comparison with the SFL2017 data. The difference between the three BBR data sets is not expected to reflect the actual trend, as such dramatic increase is not the expected pattern. The number of wood boilers is rather expected to decrease in that period. One scenario has been set up based on the actual number of boilers in the BBR2005 and the BBR 2010 (scenario 7). Also, two scenarios have been set up, back scaling the number of boilers in SFL2017sup, based on the percentage change between the years in the BBR. Both scenarios show an unexpectedly steep increase from 2005 to 2017 (scenario 5 and 6).

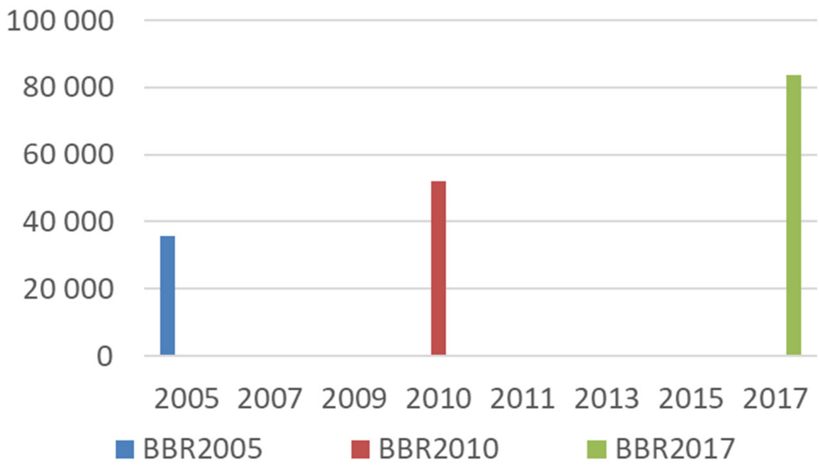

Figure 3.11 Number of boilers in the BBR analysis.

No information of the trend from 1990 to 2005 has been found. The production of wood boilers in Denmark started around 1955 and a linear trend from 1955 (zero boilers) to 2005 (number of boilers based on Palmgren et al., 2005) has been applied in one scenario (scenario 11). Another approach for estimating the number of boilers before 2005 is applied in four scenarios (scenario 3, 6, 10 and 12). The number of boilers have been back scaled according to the change in number of households in Denmark from figures published by Statistics Denmark. This methodology result in an increase of 24 % from 1980 to 2005.

Table 3.15 Scenarios for boilers.

Scenario	1990-2000	2000-2005	2005	2005-2010	2010	2010-2017	2017	2017-2050
Basic	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	SFL2017sup	Constant (2017 value)
1	Constant (2005 value)	Constant (2005 value)	Iversen et al., 2010	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
2	+ 1 % per year	+ 2 % per year	Iversen et al., 2010	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
3	Growth rate cf. number of households	Growth rate cf. number of households	Illerup et al., 2007	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
5	Constant (2005 value)	Constant (2005 value)	Back scale of 2017 value cf. growth rates from BBR2005 to BBR2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
6	Growth rate cf. number of households	Growth rate cf. number of households	Back scale of 2010 value cf. growth rates from BBR2005 to BBR2010	Linear interpolation 2005-2010	Back scale of 2017 value cf. growth rates from BBR2010 to BBR2017	Linear interpolation 2010-2017	SFL2017sup	Constant (2017 value)
7	Constant (2005 value)	Constant (2005 value)	BBR2005	Linear interpolation 2005-2010	BBR2010	Linear interpolation 2010-2017	SFL2017sup	Constant (2017 value)
8	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	Constant (2017 value)	SFL2017sup	Constant (2017 value)
9	Constant (2005 value)	Constant (2005 value)	Palmgren et al., 2005	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
10	Growth rate cf. number of households	Growth rate cf. number of households	Palmgren et al., 2005	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
11	Linear interpolation from 19550 (zero) to 2005 (Palmgren et al., 2005)	Linear interpolation from 19550 (zero) to 2005 (Palmgren et al., 2005)	Palmgren et al., 2005	Linear interpolation 2005-2017	Linear interpolation 2005-2017	Linear interpolation 2005-2017	SFL2017sup	Constant (2017 value)
12	Growth rate cf. number of households	Growth rate cf. number of households	Growth rate cf. number of households	Growth rate cf. number of households	Growth rate cf. number of households	Growth rate cf. number of households	SFL2017sup	Constant (2017 value)

The numbers of boilers from the scenarios are shown in Figure 3.12. Evaluation of the scenarios regarding trends and number of boilers, have resulted in selection of scenario 9 as input to the updated inventory model. It is assumed that Palmgren et al. (2005) is the best reference for 2005 and that SFL2017sup is the best reference for 2017. The trends for 2005-2010 and 2010-2017 based on BBR data is not supported by other data sources and is not included in the inventory model due to the large uncertainties for heating information in BBR. Instead, a linear trend is applied. No information is available regarding the trend before 2005 and it has been decided to apply the 2005-value for all previous years. The trend based on linear interpolation back to zero in 1955 is not applied, as no information is available that support a linear trend for 1955-2005, or if the trend should be steepest in early or later years. Using the household numbers as proxy leads to an increasing trend for 1980-2005, which is not expected to be the case, but rather a decreasing number of wood boilers, therefore this method is not used either.

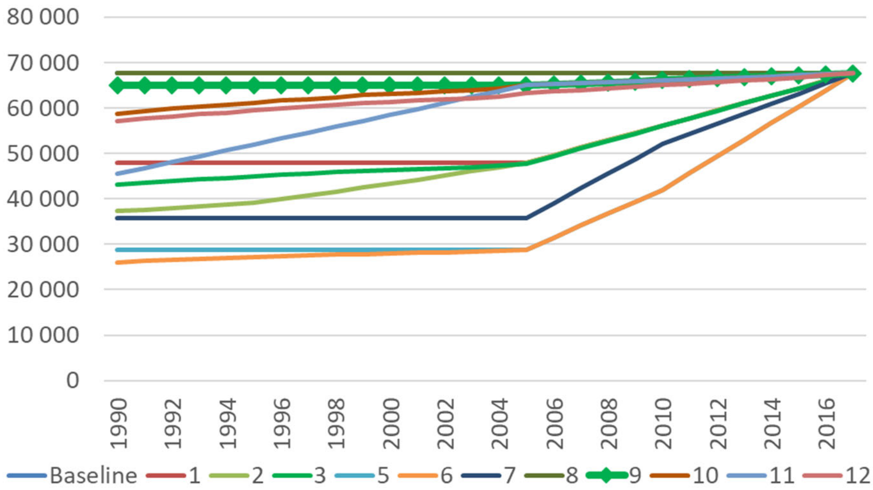

Figure 3.12 Number of boilers in the scenarios.

The emission inventory model has been updated to use the number of boilers based on the SFL2017sup data set, and the number of boilers is assumed constant for the time series (see Table 3.16).

Table 3.16 Number of boilers applied in the emission inventory model.

Year	Boilers
All years	68 071

4 Emission factors

Several Danish emission measurement programmes have been performed since the latest update of the emission factors for residential wood combustion. The results from these measurement programmes will be implemented in the emission inventory reported in 2020.

4.1 Former emission factors

The former emission factors refer mainly to the EEA Guidebook (EEA, 2016). These emission factors were implemented in the EEA Guidebook update from 2013 and the emission factors have not been revised in the later updates, including the 2019 update of the Guidebook. Thus, recent data of emission factor values have not been implemented in the Guidebook. However, it is now specified for some PM emission factors in the Guidebook whether the factors are for total particles (including condensable, measured with dilution tunnel) or for solid particles (measured with heated filter). For reporting, an approach with reporting PM emissions based on total particles is strongly encouraged (EEA, 2019).

For several of the former emission factors it was not well defined whether the emission factors were including or excluding condensable particles. However, emission factors including condensable were preferred if both datasets were available. The emission factors including condensable is considerably higher than the emission factors excluding condensable for residential wood combustion. Thus it is important to improve both consistency and transparency.

The emission factors for PM include emission limit values from Danish legislation as well as limit values for the Nordic Swan Ecolabel. The references also included a Danish study concerning PM emissions from residential wood combustion (Illerup et al., 2007).

The former emission factors for PCDD/F refer to EEA (2016). These emission factors are technology dependent. The revised emission factors for PCDD/F are not dependent on stove technology, see Chapter 4.3.

For CH_4 the former emission factors refer to a number of emission measurements performed in Sweden (Paulrud et al., 2005, Olsson & Kjällstrand, 2005, Johansson et al., 2004).

The former emission factors and references are shown in Annex 1.

4.2 Primary new Danish references and priority criteria

As mentioned above, reporting of PM emissions based on total particles is strongly encouraged (EEA, 2019). Thus, emission measurements performed in Denmark applying dilution tunnel (including condensable) have been prioritised in the revision of the PM emission factors. The difference between emission factors including and excluding condensable particles is considerable.

In addition to the measurement method, the in-situ use of the stoves and boilers is also important for the emission level for both PM and other pollutants. Thus, the preferred emission measurements are based on:

- Dilution tunnel measurements, including condensable.
- Full cycle measurements including cold start and burnout.
- In-situ measurements including full load / part load, moist and dry wood, different wood species and common misuse situations.
- Measurements performed on Danish or Scandinavian stoves and boilers.

A large number of references have been taken into account for the revised emission factors. The following references are the primary new[1] references taken into account:

- **Schleicher (2018), In-situ målinger af emissioner fra brændeovne i private boliger, Teknologisk Institut**
  The project includes in-situ emission measurements from nine wood stoves installed in Danish houses. The wood stoves are installed in 2004-2017. Emission measurements include TSP, BC (/EC), OC, dioxin and PAH. All measurements were including condensable particulates.
- **Emission Factors for SLCP[2] Emissions from Residential Wood Combustion in the Nordic Countries, Kindbom et al., 2017**
  The test programme included 10 wood boilers and 10 wood stoves. Emission measurements included $PM_{2.5}$, EC, CO, CH_4 and NMVOC. The emission measurements were performed according to EN standards: EN 303-5 for boilers and EN 16510 for room heaters. Sampling during the ignition phase is not included in EN standards, but was added in the measurement program. A few measurements were performed according to NS3058. All sampling for particulates was done in a dilution tunnel according to specifications in NS3058.
- **Laboratoriemålinger af emissioner fra brændeovne ved forskellige fyringsteknikker, Andersen & Hvidbjerg (2017)**
  Includes emission measurements from four ecolabelled stoves. Tests include emission measurements for misuse condition, moist fuel, dry fuel, part load. The emission measurements include CO, NO_x, TSP and OGC. Dilution tunnel was applied in the measurements.
- **PM emissioner fra brændekedler, Notat til Miljøstyrelsen, Teknologisk Institut (2018)**
  Includes emission data collection for boilers and suggested emission factors for TSP. Danish Technological Institute (2018). Data are based on Winther (2008) and the emission factors suggested are based on emission measurements including condensable.
- **Vurdering af brændekedlers partikelemission til luft i Danmark, Teknologisk Institut, Kim Winther, 2008**
  Includes emission measurements for old, new and approved boilers. The emission measurements include TSP, CO, NO_x, PAH and OGC. The TSP emission measurements include both measurements including and excluding condensable.

[1] After the update of the EEA Guidelines in 2013 (EEA, 2013).
[2] Short Lived Climate Pollutants (SLCP).

4.3 Revised emission factors

Based on the improved data for number of wood burning appliances the technology category "Other stove" have been replaced by the categories "Open fireplaces and similar" and "Masonry heat accumulating stoves and similar". In addition, the category "Ecolabelled stoves / new advanced stoves (2017-)" have been added. Finally, some technologies have been renamed.

For log wood and wood chips, all recalculations from g / kg to g / GJ have been based on the lower calorific value (LCV) 15.78 MJ / kg corresponding to a 15 % humidity and a LCV of dry wood of 19 MJ / kg.

For wood pellets, all recalculations from g / kg to g / GJ have been based on the LCV 17.5 MJ / kg corresponding to an 8 % humidity and a LCV of dry wood pellets of 19.25 MJ / kg (Boman et al., 2011).

4.3.1 TSP, PM_{10} and $PM_{2.5}$

The emission of PM from residential wood combustion depend on stove or boiler technology as well as on operating practice and type and moisture content of the applied wood. Data from full cycle emission measurements including ignition of cold stove / boiler and burnout is important for estimation of an accurate emission factor. In addition, common ways in operating the stoves / boilers needs to be considered. Thus, both full load, part load and common situations of poor combustion situations should be included in the emission factor.

As mentioned above, reporting of PM emissions based on total particles is strongly encouraged (EEA, 2019). Emission measurement data based on dilution tunnel includes condensable particles and results in much higher emission data than emission measurements based on undiluted flue gas and heated filter.

All references including emission measurements of either TSP, PM_{10} or $PM_{2.5}$ have been included in the data set for the revision of the PM emission factors. The difference between TSP, PM_{10} and $PM_{2.5}$ is low compared to the differences found between different references, different load situations etc.

The PM_{10} is assumed to account for 95 % of TSP and the $PM_{2.5}$ is assumed to account for 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

Table 4.1 below summarises all the data sets considered in establishing the PM emission factors. The rows highlighted with green shows the references used. The revised emission factors and references for TSP are shown in Table 4.2. For TSP, the selected emission factors are described below, the data sources considered in the selecting of the emission factors are shown in Table 4.1.

For stoves (- 1989), the emission data vary considerably. The emission factor 1000 g / GJ will be applied referring to Glasius et al. (2005). The emission factor in EEA Guidelines for old stoves is 800 g / GJ.

For stoves (1990 – 2007), the emissions reported by Glasius et al. (2005) are higher than the other references. The average emission of the four references (Kindbom et al., 2017; Schleicher, 2018; Glasius et al., 2005; Glasius et al., 2007) considered is 487 g/GJ and based on this the emission factor 500 g/GJ will be applied in future inventories.

For stoves (2008 – 2014), the emission measurements from Kindbom et al. (2017) based on the measurements according to Norwegian Standard NS3058 will be applied. The emission measurements from Schleicher (2018) are lower and these measurements were based on full cycle emission measurements from Danish stoves. However, the measured emissions were lower than for a large number of ecolabelled stoves (Andersen & Hvidbjerg, 2017), whereas the results from Kindbom et al. (2017) are, as expected, higher than emission measurements from ecolabelled stoves (Andersen & Hvidbjerg, 2017). The emission limit in Danish legislation of 10 g/kg (634 g/GJ) was much higher than the emission measurements reported by both Kindbom et al (2017) and Schleicher (2018).

For stoves (2015 – 2016), the emission limit according to Danish legislation (5 g/kg) will be applied. The full cycle in-situ emission measurement for stoves reported by Schleicher (2018) and the emission measurement results reported by Kindbom et al. (2017) supports that the emission factor based on the Danish legislation is reasonable.

For stoves (2017 onwards), the emission limit according to Danish legislation (4 g/kg) will be applied. The full cycle in-situ emission measurements reported by Schleicher (2018) are in agreement with this emission level.

For Eco labelled stoves / new advanced stoves (-2014), the emission data from Andersen & Hvidbjerg (2017) are in agreement with the emission limit values of the Nordic Swan Ecolabel. The emission limit of 4 g/kg is applied in the inventories.

For Eco labelled stoves / new advanced stoves (2015-2016), the emission data from Andersen & Hvidbjerg (2017) are in agreement with the emission limit values of the Nordic Swan Ecolabel. The emission limit of 3 g/kg is applied in the inventories.

For Eco labelled stoves / new advanced stoves (2017-), the emission data from Andersen & Hvidbjerg (2017) are in agreement with the emission limit values of the Nordic Swan Ecolabel. The emission limit of 2 g/kg is applied in the inventories.

For open fireplaces and similar, the emission data for open fireplaces from Alves et al. (2011) are in agreement with the results from Gonçalves et al. (2011) and Gonçalves et al. (2012). The emission data reported for sauna stoves reported by Kindbom et al. (2017) and Lamberg et al. (2011) are lower. Open fireplaces are more common in Denmark. The emission factor (882 g/GJ) from Alves et al. (2011) is used.

For masonry heat accumulation stoves and similar, the emission factor (63 g/GJ) refers to Tissari et al. (2007).

For old boilers (-1979) with heat accumulation, the revised emission factor (588 g/GJ) refers to Winther (2008) that includes emission factors for boilers with and without heat accumulation. The emission factor is in agreement with the resent work by TI (2018) and Kindbom et al. (2017).

For old boilers (-1979) without heat accumulation, the revised emission factor (736 g/GJ) refers to Winther (2008) that includes emission factors for boilers with and without heat accumulation.

For boilers (1980-) with heat accumulation the emission factor (64 g/GJ) for approved boilers with heat accumulation from Winther (2008) will be applied. The emission factor stated in the five different references are in the interval 16-96 g/GJ.

For boilers (1980-) without heat accumulation, emission measurements from Winther (2008) and Kindbom et al. (2017) are relevant. The emission factor (335 g/GJ) from Winther (2008) for new boilers without accumulation will be applied. It might be relevant to include the emission factor for approved boilers as well, but currently the fuel consumption is not disaggregated between the two.

The emission factor for wood chip boilers seems to be lower. However, the consumption of wood chips adds up to less than 0.5 % of the consumption of logwood in residential plants.

The same emission factor is applied for pellet stoves and boilers. The main part of the pellets is combusted in boilers and the selected emission factor 51 g/GJ refers to the pellet boiler measurements by Kindbom et al. (2017). This reference includes measurements from three pellet boilers, and it is based on 25 % part load and 75 % full load.

In general, the emission factor for pellet boilers is slightly lower than for pellet stoves. However, the consumption of pellets is currently not disaggregated to stoves and boilers and thus a common emission factor is applied.

Table 4.1 TSP emission measurements[3].

Reference	Technology	TSP emission, g/GJ	Comment
	Stoves (-1989)		
Glasius et al. (2005)	Woodstove number 2. Age unknown.	5253	Woodstove number 2. Assumed older than 1990. Crate of dried Birchwood logs.
Glasius et al. (2005)	Woodstove number 2. Age unknown.	817	Woodstove number 2. Assumed older than 1990. Crate of dried Birchwood logs.
Alves et al. (2011)	Cast iron stove	557 (233-906)	$PM_{2.5}$ emission measurements. Corresponds to approximately 599 g TSP / GJ. Cast iron stove, cold start not included.
Sternhufvud et al. (2004)	Conventional iron stoves	2000	$PM_{2.5}$ emission factor
	Stoves (1990-2007)		
Kindbom et al. (2017)	Older stove (including part load)	193	One cast iron stove. DCE estimate based on 25 % part load and 75 % nominal load. $PM_{2.5}$ emission factor. Corresponds to approximately 208 g TSP / GJ.
Kindbom et al. (2017)	Older stove, part load	330	One cast iron stove, nominal load. $PM_{2.5}$ emission factor. Corresponds to approximately 355 g TSP / GJ.
Kindbom et al. (2017)	Older stove, nominal load	147	One cast iron stove, nominal load. $PM_{2.5}$ emission factor. Corresponds to approximately 158 g TSP / GJ.
Schleicher (2018)	Average for stoves older than 2008	167	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 3 (2006)	119	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 4 (2004)	215	In-situ emission measurements, full cycle.
Glasius et al. (2005)	Average for stoves 1990-2007 (Stove 4, stove 5 and stove 6)	1195	Three stoves.
Glasius et al. (2007)	Wood stoves (and one boiler)	393	The average emission for all $PM_{2.5}$ emission measurements is 6.2 g/kg (page 21).
Glasius et al. (2007)	Wood stoves 2004 - 2007	349	
Glasius et al. (2007)	Wood stoves 1997 - 2003	488	
Glasius et al. (2007)	Wood stoves older than 1997	152	
	Stoves (2008-2014)		
Schleicher (2018)	Stoves	184 (96-423)	Average for all 9 stoves
Schleicher (2018)	Stoves, not including stove 3, 4, 7 and 8	189 (96-423)	Stove 3 and stove 4 were older than 2008. However, identical stoves were also sold after 2008. The stoves 7 and 8 were from 2017.
Kindbom et al. (2017)	Modern stoves, only including emission measurements according to NS3058	389 (347-430)	Two stoves. Emission measurements according to NS3058. $PM_{2.5}$ emission factor. Corresponds to approximately 418 g TSP / GJ.
Kindbom et al. (2017)	Modern stoves, nominal load	84	Modern stoves, nominal load. $PM_{2.5}$ emission factor.
Kindbom et al. (2017)	Modern stoves, moist fuel	423	Modern stoves, nominal load, moist fuel. $PM_{2.5}$ emission factor.
Kindbom et al. (2017)	Modern stoves, part load	145	Modern stoves, part load. $PM_{2.5}$ emission factor.
Kindbom et al. (2017)	Modern stoves, including part load and moist fuel	116	Modern stoves. DCE estimate based on 5 % moist fuel, 25 % part load and 70 % nominal load. $PM_{2.5}$ emission factor. Corresponds to approximately 124 g TSP / GJ.
DEPA (2007)	Danish legislation, 2007.	634	Danish legislation, limit value 10 g/kg. Bekendtgørelse 1432 af 11/12 2007. Bekendtgørelse om regulering af luftforurening fra brændeovne og brændekedler samt visse andre faste anlæg til energiproduktion.
	Stoves (2015-2016)		
DEPA (2015)	Danish legislation, 2015.	317	Danish legislation, limit value 5 g/kg. Bekendtgørelse 46 af 22/1 2015. Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW

[3] The rows highlighted with green shows the references applied for the revised emission factor.

Reference	Technology	TSP emission, g/GJ	Comment
Continued…	Stoves (2017-)		
DEPA (2015)	Danish legislation, 2015.	253	Danish legislation, limit value 4 g/kg. Bekendtgørelse 46 af 22/1 2015. Bekendtgørelse om regulering af luftforurening fra fyringsanlæg til fast brændsel under 1 MW
Schleicher (2018)	Wood stove 7 and 8 (2017)	188 (162-213)	In-situ emission measurements, full cycle.
	Eco labelled stoves / new advanced stoves		
Andersen & Hvidbjerg (2017)	The Nordic Swan Ecolabel. Average all stoves.	203	Ecolabelled stoves. Average for all stoves. Includes emission during misuse of stoves.
Andersen & Hvidbjerg (2017)	Average state-of-the-art stove	103	Ecolabelled stoves. Average for the state-of-the-art stove. Misuse conditions included in the average value.
Andersen & Hvidbjerg (2017)	Average 2014 stove	209	Ecolabelled stoves. Average for the 2014 stove. Misuse conditions included in the average value.
Andersen & Hvidbjerg (2017)	Average 2010 and 2012 stoves	271	Ecolabelled stoves. Average for the 2010 and 2012 stoves. Misuse conditions included in the average value.
Andersen & Hvidbjerg (2017)	Ecolabelled stoves, misuse conditions not included	186	Ecolabelled stoves, average emission not including moist wood, very dry wood, very low load
The Nordic Swan Ecolabel, -2014	The Nordic Swan Ecolabelled stoves	253	Emissions limit 4 g/kg.
The Nordic Swan Ecolabel, 2015-2016	The Nordic Swan Ecolabelled stoves	190	Emissions limit 3 g/kg.
The Nordic Swan Ecolabel, 2017 onwards	The Nordic Swan Ecolabelled stoves	127	Emissions limit 2 g/kg.
	Open fireplaces and similar		
Kindbom et al. (2017)	Sauna stove	105	According to EN16510 firing scheme.
Gonçalves et al. (2011)	Fireplace, cold start	427 – 1526	Wood logs, cold start. $PM_{2.5}$ emission data.
Gonçalves et al. (2011)	Fireplace, hot start	44 - 1142	Wood logs, hot start. $PM_{2.5}$ emission data.
Gonçalves et al. (2012)	Fireplace	689 (363-1105)	Fireplace, logs and briquettes. $PM_{2.5}$ emission data.
Lamberg et al. (2011)	Sauna stove	257	One sauna stove, PM_1 emissions. Corresponds to approximately 276 g TSP / GJ.
Alves et al. (2011)	Open fireplace	882 (591 - 1204)	The emission factor for $PM_{2.5}$ is 820 g/GJ. The emission factor for TSP has been calculated based on a 93 % $PM_{2.5}$ fraction.
Gullet et al. (2003)	Open fireplace	265	Oak and pine
	Masonry heat accumulating stoves and similar		
Tissari et al. (2007)	Four masonry heaters	63 (38-101)	Four different masonry heaters, one modern and three conventional. The average PM_1 emission is 59 g/GJ, corresponding to approximately 63 g TSP / GJ.
Kulmala (2014)	Modern masonry heater	76	Whole combustion cycle
	Boilers with / without accumulation tank (-1979)		
Winther (2008)	Old boilers with accumulation tank	588	Recommended emission factor for old boilers with heat accumulation tank.
Winther (2008)	Old boilers without accumulation tank	736	Recommended emission factor for old boilers without heat accumulation tank. Average of part load emission measurements from three old boilers.
TI (2018)	Boilers, - 1980	674	Boilers, - 1980, average of 6 boilers
Kindbom et al. (2017)	Traditional log wood boilers (including part load and moist wood measurements)	539	Two boilers. Aggregated emission factor based on 5 % moist logwood, 25 % part load and 70 % nominal load.
Glasius et al. (2005)	Old boiler	1410	Average for old boiler, assumed older than 1980.
Glasius et al. (2007)	Boilers	824	Average for 2 emission measurements.
Johansson et al. (2004)	Old-type wood boilers, full load	566 (87-2200)	Two boilers

Reference	Technology	TSP emission, g/GJ	Comment
Continued…	Boilers with accumulation tank (1980-)		
Winther (2008)	New boilers with heat accumulation tank	96	Recommended emission factor for new boilers with heat accumulation tank.
Winther (2008)	Approved boilers with heat accumulation tank	64	Recommended emission factor for approved boilers with heat accumulation tank.
TI (2018)	Sheet iron boilers, 1980 onwards, without oxygen control	21	Sheet iron boilers, 1980 onwards, average of 20 boilers without oxygen control. Two technology categories have been merged.
TI (2018)	Sheet iron boilers, 1980 onwards, with oxygen control	13	Sheet iron boilers, 2000 onwards, with oxygen control
Kindbom et al. (2017)	Modern log wood boilers (nominal load)	35	Suggested emission factor for modern log wood boilers at nominal load, Table 17.
Kindbom et al. (2017)	Wood chip boilers (nominal load)	50	Suggested emission factor for wood chip boilers at nominal load, Table 17.
Schmidl et al. (2011)	Wood chip boiler, 40 kW	34	Wood chip boiler, start-up phase, PM_{10} data.
Schmidl et al. (2011)	Wood chip boiler, 40 kW	16	Wood chip boiler, full load, PM_{10} data.
Schmidl et al. (2011)	Wood chip boiler, 40 kW	21	Wood chip boiler, part load, PM_{10} data.
Johansson et al. (2004)	Modern wood boilers, full load	36 (18-89)	Three boilers.
	Boilers without accumulation tank (1980-)		
Winther (2008)	New boilers without heat accumulation tank	335	Recommended emission factor for new boilers without heat accumulation tank.
Winther (2008)	Approved boilers without heat accumulation tank	233	Recommended emission factor for approved boilers without heat accumulation tank.
Kindbom et al. (2017)	Traditional log wood boilers (including part load and moist wood measurements)	539	Two traditional log wood boilers. DCE estimate based on 5 % moist log wood, 25 % part load and 70 % nominal load.
Kindbom et al. (2017)	Wood chip boilers (including part load and moist wood measurements)	93	One wood chip boiler. DCE estimate based on 5 % moist log wood, 25 % part load and 70 % nominal load.
Kindbom et al. (2017)	Traditional log wood boilers (part load)	1162	Two boilers, part load.
Kindbom et al. (2017)	Wood chip boilers (part load)	227	One wood chip boiler, part load.
Kindbom et al. (2017)	Traditional log wood boilers (nominal load)	318	Two boilers, nominal load.
Kindbom et al. (2017)	Wood chip boilers (nominal load)	48	One wood chip boiler, nominal load.
Kindbom et al. (2017)	Traditional log wood boilers (nominal load, moist log wood)	524	Two boilers, nominal load, moist log wood.
Kindbom et al. (2017)	Wood chip boilers (nominal load, moist wood chips)	61	One wood chip boiler, nominal load, moist wood chips.
	Pellet boilers / pellet stoves		
Kindbom et al. (2017)	Pellet boilers (including part load measurements)	51	Based on three pellet boilers. Aggregated emission factor based on 25 % part load and 75 % full load.
Kindbom et al. (2017)	Pellet boilers, full load	36	Full load. Based on three pellet boilers.
Kindbom et al. (2017)	Pellet boilers, part load	96	Part load. Based on three pellet boilers.
Kindbom et al. (2017)	Pellet stoves (including part load)	113	Measurements from one pellet stove. Aggregated emission factor based on 25 % part load and 75 % full load.
Kindbom et al. (2017)	Pellet stoves, full load	100	Full load. Based on one pellet stove.
Kindbom et al. (2017)	Pellet stoves, part load	153	Part load. Based on one pellet stove.
Boman et al. (2011)	Two pellet stoves, full load	20 (15-25)	Full load. PM_1 corresponds to approximately
Boman et al. (2011)	Two pellet stoves, part load	37 (22-47)	Part load.
Schmidl et al. (2011)	Pellet stove, ignition	10	Pellet stove, start-up phase. PM_{10} data.
Schmidl et al. (2011)	Pellet stove, full load	9	Pellet stove, full load. PM_{10} data.
Schmidl et al. (2011)	Pellet stove, part load	3	Pellet stove, part load. PM_{10} data.
Johansson et al. (2004)	Pellet boilers	32 (12-65)	9 measurements from 4 plants.
Sippula et al. (2007)	Top fed pellet stove	58 (47-604)	One pellet stove. Commercial pellets. PM_1 emission data, corresponding to approximately 63 mg TSP / GJ.
Sippula et al. (2007)	Top fed pellet stove	86	One pellet stove. Non-commercial stem pellets. PM_1 emission data, corresponding to approximately 92 mg TSP / GJ.
Sippula et al. (2007)	Top fed pellet stove	416	One pellet stove. Non-commercial bark pellets. PM_1 emission data, corresponding to approximately 447 mg TSP / GJ.
Lamberg et al. (2011)	Pellet boiler	19.7	One pellet boiler. PM_1 emission.

Reference	Technology	TSP emission, g/GJ	Comment
Bäfer et al. (2011)	Pellet stove	44 (29-58)	3 pellet stoves. PM_{10} emission corresponding to approximately 46 g TSP / GJ.
The Nordic Swan Ecolabel	Pellet stoves (15 mg/m^3 at 13 % O_2)	11	Recalculation based on Schmidl et al. (2011)

Table 4.2 Revised emission factors for TSP.

Technology	Emission factor, g/GJ	Reference
Stoves (-1989)	1000	Glasius et al. (2005)
Stoves (1990-2007)	500	Glasius et al. (2005), Glasius et al. (2007), Kindbom et al. (2017) and Schleicher (2018)
Stoves (2008-2014)	389	Kindbom et al. (2017)
Stoves (2015-2016)	317	DEPA (2015)
Stoves (2017-)	253	DEPA (2015)
Eco labelled stoves / new advanced stoves (-2014)	253	The Nordic Swan Ecolabel
Eco labelled stoves / new advanced stoves (2015-2016)	190	The Nordic Swan Ecolabel
Eco labelled stoves / new advanced stoves (2017-)	127	The Nordic Swan Ecolabel
Open fireplaces and similar	882	Alves et al. (2011)
Masonry heat accumulating stoves and similar	63	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	588	Winther (2008)
Boilers without accumulation tank (-1979)	736	Winther (2008)
Boilers with accumulation tank (1980-)	64	Winther (2008)
Boilers without accumulation tank (1980-)	335	Winther (2008)
Pellet boilers / pellet stoves	51	Kindbom et al. (2017)

The emission factors for PM_{10} and $PM_{2.5}$ are based on particle size distribution data. The PM fractions 95 % PM_{10} and 93 % $PM_{2.5}$ refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database. The revised emission factors are shown in Table 4.3.

Table 4.3 Revised emission factors for TSP, PM_{10} and $PM_{2.5}$

Technology	TSP, g/GJ	PM_{10}, g/GJ	$PM_{2.5}$, g/GJ
Stoves (-1989)	1000	950	930
Stoves (1990-2007)	500	475	465
Stoves (2008-2014)	389	370	362
Stoves (2015-2016)	317	301	295
Stoves (2017-)	253	240	235
Eco labelled stoves / new advanced stoves (-2014)	253	240	235
Eco labelled stoves / new advanced stoves (2015-2016)	190	181	177
Eco labelled stoves / new advanced stoves (2017-)	127	121	118
Open fireplaces and similar	882	838	820
Masonry heat accumulating stoves and similar	63	60	59
Boilers with accumulation tank (-1979)	588	559	547
Boilers without accumulation tank (-1979)	736	699	684
Boilers with accumulation tank (1980-)	64	61	60
Boilers without accumulation tank (1980-)	335	318	312
Pellet boilers / pellet stoves	51	48	47

4.3.2 Black Carbon

The BC emission is part of the solid PM emission, and in the EEA Guidebook (EEA, 2019) the BC emission data is stated as a fraction of the $PM_{2.5}$ emission factor (including condensable). The references for the BC emission factors should preferably have $PM_{2.5}$ emission levels that are in agreement with the applied $PM_{2.5}$ emission factors. Both the BC emission factor and the $PM_{2.5}$ emission factor is shown in Table 4.4 for each of the references for the BC emission factor.

Emissions of BC also depend on wood species, and the emission is higher from conifer wood than from hardwood (Gonçalves et al., 2011).

For stoves (- 1989), only two data references are available. The $PM_{2.5}$ emissions for both references are lower than the emission factor applied in the Danish inventories. However, taking into account the BC emission data for stoves from 1990-2007 the emission level seems to be quite similar. The emission factor 18 g/GJ referring to Alves et al. (2011) will be applied.

For stoves (1990 – 2007), the emission factor from recent Danish emission measurements 17 g/GJ referring to Schleicher et al. (2018) will be applied. This is the average value for the two stoves older than 2008 included in the project. The emission level reported for $PM_{2.5}$ is considerably lower than the $PM_{2.5}$ emission factor applied in the emission inventories. However, the BC emission data from Kindbom et al. (2017) and Fernandes et al. (2011) confirm the BC emission level.

For stoves (2008 – 2014), the BC emission measurement reported by Kindbom et al. (2017) performed according to NS3058 (76 g/GJ) and by Tissari et al. (2007) (57 g/GJ) are higher than in other references. The emission factor 23 g/GJ referring to the recent emission measurements from four Danish stoves (Schleicher et al., 2018) will be applied in future inventories.

For stoves (2015 – 2016), no data are available to develop a specific emission factor for this category. The emission measurement data for stoves from 2017 (next paragraph) will be applied in the inventories.

For stoves (2017 onwards), the average BC emission data for two Danish stoves, 44 g/GJ, reported by Schleicher (2018) will be applied.

For ecolabelled stoves / new advanced stoves, the emission data from Andersen & Hvidbjerg (2017) 31 g/GJ will be applied for all years.

For open fireplaces and similar, the BC emission data (34 g/GJ) for open fireplaces from Alves et al. (2011) are in agreement with the results from Gonçalves et al. (2011) and Kindbom et al. (2017). Alves et al. (2011) is also the reference for the $PM_{2.5}$ emission factor. Open fireplaces are more common in Denmark than sauna stoves.

For masonry heat accumulation stoves and similar, only two references have been identified. The emission factor 18 g/GJ refers to Tissari et al. (2007). The BC emission data from Kindbom et al. (2017) are high compared to other technologies.

For old boilers (-1979) with or without heat accumulation, the revised emission factor 24 g/GJ refers to Kindbom et al. (2017). The emission factor is based on two traditional log wood boilers.

For boilers (1980 -) with heat accumulation the emission factor 6 g/GJ refers to Kindbom et al. (2017). The emission factor is based on nominal load for modern log wood boilers.

For boilers (1980 -) without heat accumulation, the emission factor 6 g/GJ refers to Kindbom et al. (2017). The emission factor is based on part load for modern log wood boilers.

The same emission factor is applied for pellet stoves and boilers. The emission factor 7 g/GJ refers to Kindbom et al. (2017). The emission factor is based on emission measurements performed on three pellet boilers.

Table 4.4 BC emission measurements.

Reference	Technology	BC emission, g/GJ	$PM_{2.5}$ emission, g/GJ	BC / $PM_{2.5}$	Comment
	Stoves (-1989)				
Alves et al. (2011)	Cast iron stove	18 (9-35)	557 (233-906)	3.7% (1.9 - 7.7%)	Cast iron stove, cold start not included. Eight different wood species.
Gonçalves et al. (2010)	Chimney type logwood stove	-	-	22%	The EC share is higher for softwood than for hardwood.
Gonçalves et al. (2012)	Cast iron stove	19 (9-32)	434 (274 – 684)	4.8% (2 % - 12 %)	Cast iron stove. The same data are included in Fernandes et al. (2011)
	Stoves (1990-2007)				
Kindbom et al. (2017)	Older stove (including part load)	14	193	8%	One cast iron stove. DCE estimate based on 25 % part load and 75 % nominal load. $PM_{2.5}$ emission factor. Corresponds to approximately 208 g TSP / GJ.
Kindbom et al. (2017)	Older stove, part load	15	330	5%	One cast iron stove, nominal load.
Kindbom et al. (2017)	Older stove, nominal load	13	147	9%	One cast iron stove, nominal load.
Schleicher (2018)	Average for stoves older than 2008	17	167	10%	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 3 (2006)	10	119	8%	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 4 (2004)	23	215	11%	In-situ emission measurements, full cycle.
Fernandes et al. (2011)	Logwood stove	18 (14-23)	96 (59 – 152)	22 % (11 % – 39%)	Logwood stove. PM_{10} emission data.
Kupiainen & Klimont (2002)		36-200	-	-	
	Stoves (2008-2014)				
Schleicher (2018)	Stoves	25 (10-61)	184 (96-423)	14% (3-33 %)	Average for all 9 stoves
Schleicher (2018)	Stoves, not including stove 3, 4, 7 and 8	23 (13-32)	189 (96-423)	16% (3-33 %)	Stove 3 and stove 4 were older than 2008. However, identical stoves were also sold after 2008. The stoves 7 and 8 were from 2017.
Kindbom et al. (2017)	Modern stoves, only including emission measurements according to NS3058	76 (31-120)	389 (347-430)	19 % (9-28%)	Two stoves. Emission measurements according to NS3058.
Kindbom et al. (2017)	Modern stoves, nominal load	20 (3-42)	84 (53-106)	24 %	Modern stoves, nominal load.
Kindbom et al. (2017)	Modern stoves, moist fuel	10 (4-18)	423 (100-821)	2 %	Modern stoves, nominal load, moist fuel.
Kindbom et al. (2017)	Modern stoves, part load	14 (4-27)	145 (74-458)	10 %	Modern stoves, part load.
Kindbom et al. (2017)	Modern stoves, including part load and moist fuel	18	116	15 %	Modern stoves. DCE estimate based on 5 % moist fuel, 25 % part load and 70 % nominal load.
Tissari et al. (2007)	Stove	57	39	68 %	One stove. PM_1 emission data.
	Stoves (2015-2016)				
(no data available)					
	Stoves (2017-)				
Schleicher (2018)	Wood stove 7 and 8 (2017)	44	188 (162-213)	23% (17-29%)	In-situ emission measurements, full cycle.
	Eco labelled stoves / new advanced stoves				
Andersen & Hvidbjerg (2017)	The Nordic Swan Ecolabel. Average all stoves.	31	203	15 %	Ecolabelled stoves. Average for all stoves. Includes emission during misuse of stoves.
Andersen & Hvidbjerg (2017)	Average state-of-the-art stove	19	103	18 %	Ecolabelled stoves. Average for the state-of-the-art stove. Misuse conditions included in the average value.

Reference	Technology	BC emission, g/GJ	$PM_{2.5}$ emission, g/GJ	BC / $PM_{2.5}$	Comment
Continued…					
Andersen & Hvidbjerg (2017)	Average 2014 stove	41	209	20 %	Ecolabelled stoves. Average for the 2014 stove. Misuse conditions included in the average value.
Andersen & Hvidbjerg (2017)	Average 2010 and 2012 stoves	31	271	11 %	Ecolabelled stoves. Average for the 2010 and 2012 stoves. Misuse conditions included in the average value.
	Open fireplaces and similar				
Kindbom et al. (2017)	Sauna stove	52	104	50%	Sauna stove
Gonçalves et al. (2011)	Fireplace	-	44 – 1526	1.1 % – 17%	Wood logs, cold start. $PM_{2.5}$ emission data.
Gonçalves et al. (2012)	Fireplace	22 (15-36)	689 (363-1105)	4% (2%-9%)	Fireplace, logs and briquettes.
Lamberg et al. (2011)	Sauna stove	130 ± 23	257 ± 85	51%	One sauna stove, PM_1 emissions.
Alves et al. (2011)	Open fireplace	34 (19 - 59)	820 (591 - 1204)	4.1 % (2.2% - 7.5%)	One fireplace, eight different wood types.
Tissari et al. (2007)	Sauna stove	171	110	64 %	Sauna stove. PM_1 emission data.
Tissari et al. (2007)	Baking oven	51	18	36 %	Baking oven. PM_1 emission data.
Kupiainen & Klimont (2002)	Open fireplace, hardwood	5-50	-	-	Hardwood
Kupiainen & Klimont (2002)	Open fireplace, softwood	15-186	-	-	Softwood
	Masonry heat accumulating stoves and similar				
Tissari et al. (2007)	Four masonry heaters	18	59	32 %	Four different masonry heaters, one modern and three conventional.
Kindbom et al. (2017)	Tiled and masonry stove, nominal load	72 (22-122)	140 (82-198)	51 %	Nominal load
Kindbom et al. (2017)	Tiled and masonry stove, moist fuel	7	78	9 %	Moist fuel
Kindbom et al. (2017)	Tiled and masonry stove, part load	110	285	39 %	Part load
	Boilers with / without accumulation tank (-1979)				
Kindbom et al. (2017)	Traditional log wood boilers (including part load and moist wood measurements)	24	539	4%	Two boilers. Aggregated emission factor based on 5 % moist logwood, 25 % part load and 70 % nominal load.
Kindbom et al. (2017)	Traditional log wood boilers, nominal load	23 (19-27)	318 (317-320)	7%	Traditional log wood boilers, nominal load
Kindbom et al. (2017)	Traditional log wood boilers, moist fuel	>31	524	6%	Traditional log wood boilers, nominal load
Kindbom et al. (2017)	Traditional log wood boilers, part load	24 (15-35)	1162	2%	Traditional log wood boilers, nominal load
	Boilers with accumulation tank (1980-)				
Kindbom et al. (2017)	Modern log wood boilers, nominal load	6 (2-15)	32 (24-45)	19 %	Modern log wood boilers, nominal load
Kindbom et al. (2017)	Modern log wood boilers, moist fuel	4 (2-5)	43 (32-50)	9 %	Modern log wood boilers, moist fuel
Kindbom et al. (2017)	Modern log wood boilers, part load	6 (3-9)	61 (32-89)	10 %	Modern log wood boilers, part load
Kindbom et al. (2017)	Wood chip boilers (including part load and moist wood measurements)	2.8	93	3%	One wood chip boiler. DCE estimate based on 5 % moist logwood, 25 % part load and 70 % nominal load.
Kindbom et al. (2017)	Wood chip boilers, nominal load	1	48	2 %	One wood chip boiler, nominal load.
Kindbom et al. (2017)	Wood chip boilers, moist wood chips	6	61	10 %	One wood chip boiler, nominal load, moist wood chips.

Reference	Technology	BC emission, g/GJ	$PM_{2.5}$ emission, g/GJ	BC / $PM_{2.5}$	Comment
Continued…					
Kindbom et al. (2017)	Wood chip boilers, part load	7	227	3%	One wood chip boiler, part load
Schmidl et al. (2011)	Wood chip boiler, 40 kW	8	34	23.2 %	Wood chip boiler, start-up phase, PM_{10} data.
Schmidl et al. (2011)	Wood chip boiler, 40 kW	0.1	16	0.5 %	Wood chip boiler, full load, PM_{10} data.
Schmidl et al. (2011)	Wood chip boiler, 40 kW	7	21	32.8 %	Wood chip boiler, part load, PM_{10} data.
	Boilers without accumulation tank (1980-)				
Kindbom et al. (2017)	Traditional log wood boilers (including part load and moist wood measurements)	24	539	4%	Two traditional log wood boilers. DCE estimate based on 5 % moist logwood, 25 % part load and 70 % nominal load.
Kindbom et al. (2017)	Traditional log wood boilers, nominal load	23 (19-27)	318 (317-320)	7%	Traditional log wood boilers, nominal load
Kindbom et al. (2017)	Traditional log wood boilers, moist fuel	>31	524	6%	Traditional log wood boilers, nominal load
Kindbom et al. (2017)	Traditional log wood boilers, part load	24 (15-35)	1162	2%	Traditional log wood boilers, nominal load
Kindbom et al. (2017)	Modern log wood boilers, part load	6 (3-9)	61 (32-89)	10 %	Modern log wood boilers, part load
	Pellet boilers / pellet stoves				
Kindbom et al. (2017)	Pellet boilers (including part load measurements)	7	51	14 %	Based on three pellet boilers. Aggregated emission factor based on 25 % part load and 75 % full load.
Kindbom et al. (2017)	Pellet boilers, full load	6 (1-14)	36 (15-57)	17 %	Full load. Based on three pellet boilers.
Kindbom et al. (2017)	Pellet boilers, part load	10 (6-17)	96 (14-182)	10 %	Part load. Based on three pellet boilers.
Kindbom et al. (2017)	Pellet stoves (including part load)	9	113	8 %	Measurements from one pellet stove. Aggregated emission factor based on 25 % part load and 75 % full load.
Kindbom et al. (2017)	Pellet stoves, full load	10	100	10 %	Full load. Based on one pellet stove.
Kindbom et al. (2017)	Pellet stoves, part load	7	153	5%	Part load. Based on one pellet stove.
Schmidl et al. (2011)	Pellet stove, ignition	1.6	10	15.8 %	Pellet stove, start-up phase. PM_{10} data.
Schmidl et al. (2011)	Pellet stove, full load	1.2	9	13.7 %	Pellet stove, full load. PM_{10} data.
Schmidl et al. (2011)	Pellet stove, part load	0.4	3	13.8 %	Pellet stove, part load. PM_{10} data.
Sippula et al. (2007)	Top fed pellet stove	0.9	58 (47-604)	2%	One pellet stove. Commercial pellets.
Sippula et al. (2007)	Top fed pellet stove	0.8	86	1 %	One pellet stove. Non-commercial stem pellets. PM_1 emission data.
Sippula et al. (2007)	Top fed pellet stove	10	416	2 %	One pellet stove. Non-commercial bark pellets. PM_1 emission data.
Lamberg et al. (2011)	Pellet boiler	0.1	19.7	1 %	One pellet boiler. PM_1 emission.

The revised emission factors and references for BC are shown in Table 4.5.

Comparison of BC emission factors between technology groups applied in the Danish emission inventory might not be accurate due to use of different references. The emission measurement programmes do include all technology groups and the relation between BC emission and $PM_{2.5}$ emission is not simple. BC emission is also dependent on other factors than the PM emission and the sensitivity to wood species, temperature and misuse conditions are different for PM and BC.

Table 4.5 Revised emission factors for BC.

Technology	$PM_{2.5}$, g/GJ	BC, g/GJ	Former BC emission factor, g/GJ	Reference for updated BC emission factor
Stoves (-1989)	930	18	93	Alves et al. (2011)
Stoves (1990-2007)	465	17	74	Schleicher (2018)
Stoves (2008-2014)	362	23	82	Schleicher (2018)
Stoves (2015-2016)	295	44	41	Schleicher (2018)
Stoves (2017-)	235	44	33	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	235	31	58	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	177	31	43	Andersen & Hvidbjerg (2017)
Eco labelled stoves / new advanced stoves (2017-)	118	31	43	Andersen & Hvidbjerg (2017)
Open fireplaces and similar	820	34	74	Alves et al. (2011)
Masonry heat accumulating stoves and similar	59	18	74	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	547	24	144	Kindbom et al. (2017)
Boilers without accumulation tank (-1979)	684	24	288	Kindbom et al. (2017)
Boilers with accumulation tank (1980-)	60	6	58	Kindbom et al. (2017)
Boilers without accumulation tank (1980-)	312	6	116	Kindbom et al. (2017)
Pellet boilers / pellet stoves	47	7	4	Kindbom et al. (2017)

4.3.3 Polycyclic aromatic hydrocarbons

The former emission factors for the four polycyclic aromatic hydrocarbons (PAHs) included in the Danish emission inventories referred to the EEA Guidebook (EEA, 2016). Recent emission measurements from Danish plants have been implemented in the reference data. The references considered in establishing the emission factors are shown in Table 4.6, the revised emission factors are summarised in Table 4.7.

For stoves (- 1989), data are only available from Glasius et al. (2005). The emission factors for a single stove in that study (stove 2), which is an older stove will be applied.

For stoves (1990 – 2007), the emission factor will also refer to Glasius et al. (2005), except for benzo(b)flouranthene. The emission from the two stoves older than 2008 included in Schleicher (2018) is low compared to other data sets. However, based on the complete data set it was decided that the emission factor for benzo(b)fluoranthene refer to Schleicher (2018).

For stoves (2008 – 2014), the PAH emission factors will refer to Schleicher (2018). The average value for the tested stoves will be applied for all stoves from 2008 onwards. The emission data vary considerably between the stoves and between tests performed on the same stove.

For stoves (2015 – 2016), the emission factors refer to Schleicher (2018). The average value for the tested stoves will be applied for all stoves from 2008 onwards.

For stoves (2017 onwards), the emission factors refer to Schleicher (2018). The average value for the tested stoves will be applied for all stoves from 2008 onwards.

For ecolabelled stoves / new advanced stoves, the emission factors refer to Schleicher (2018). It was not specified in Schleicher (2018) whether the stoves were ecolabelled or not. The average value for all tested stoves will be applied for all stoves from 2008 onwards, regardless of ecolabel. The PAH emissions measured from ecolabelled stoves by Andersen & Hvidbjerg (2017) are higher for one stove and lower for the other stove.

For open fireplaces and similar, the emission factors from Gullet et al. (2003) will be applied. The emission factors are in agreement with one other data set for fireplaces, but much lower than the emission measurements from a sauna stove.

For masonry heat accumulation stoves and similar, the emission factor refer to Tissari et al. (2007).

For old boilers (-1979) with or without heat accumulation, the emission data from a Salamander boiler will be applied (Winther, 2008). More than half the boilers older than 1980 are Salamander boilers. It is likely that the PAH emissions from boilers without heat accumulation are higher than from boilers with heat accumulation, but sufficient data are not available to distinguish between the two technology groups.

For boilers (1980 -) with heat accumulation the emission factor refers to Johansson et al. (2006). The emission factors are in agreement with emission data for cold start of a log wood boiler (Orasche et al., 2012).

For boilers (1980 -) without heat accumulation, data are only available from Johansson et al. (2006) and this data set is applied.

According to all five references the PAH emission is lower for pellet stoves and boilers than for other residential wood combustion technologies. The emission factors refer to Orasche et al. (2012).

Table 4.6 PAH emission measurements.

Reference	Technology	Benzo(a)-pyrene, mg/GJ	Benzo(b) fluoranthene, mg/GJ	Benzo(k) fluoranthene, mg/GJ	Indeno(1,2,3-cd) pyrene, mg/GJ	Comment
	Stoves (-1989)					
Glasius et al. (2005)	Stove 2 (old stove)	116	55	119	62	Stove 2
	Stoves (1990-2007)					
Glasius et al. (2005)	Stove 1, 4, 5 and 6	31 (6-59)	17 (7-27)	33 (5-64)	18 (3-35)	Average value for stoves 1990-2007.
Glasius et al. (2005)	All stoves	48 (6-116)	25 (7-55)	50 (5-119)	27 (3-62)	Average value for all stoves.
Hedberg et al. (2002)	Commercial soapstone stove	228	387	<6	228	Commercial soapstone stove
Pettersson et al. (2011)	A commonly installed natural-draft wood stove	610	680	250	410	All measurements.
Pettersson et al. (2011)	A commonly installed natural-draft wood stove. Only normal stove conditions	117	210	68	106	Four measurements
Schleicher (2018)	Average for stoves older than 2008	35	59	15	24	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 3 (2006)	14	27	7.2	9	In-situ emission measurements, full cycle.
Schleicher (2018)	Stove 4 (2004)	56	90	23	39	In-situ emission measurements, full cycle.
Gonçalves et al. (2012)	Woodstove (not including briquettes/pellets)	16 (5-31)	33 (16-62)		9 (2-18)	All Benzofluoranthenes
Gullet et al. (2003)	Wood stove	28	19	22	101	Average, pine and oak
Paulrud et al. (2006)	Wood stove	5-180	10-170	5-100	10-110	
Paulrud et al. (2006)	Wood stove	5-20	5-20	5-10	5-20	
Orasche et al. (2012)	Log wood stove, cold start	13	30		10	All Benzofluoranthenes
Orasche et al. (2012)	Log wood stove, warm start	12	28		10	All Benzofluoranthenes
	Stoves (2008-2014)					
Schleicher (2018)	Stoves	43	65	19	31	Average for all 9 stoves
Schleicher (2018)	Stoves, not including stove 3, 4, 7 and 8	28	46	13	20	Stove 3 and stove 4 were older than 2008. However, identical stoves were also sold after 2008. The stoves 7 and 8 were from 2017.
Tissari et al. (2007)	Stove	-	16	16	10	One stove.
	Stoves (2015-2016)					
(no data available)		-	-	-	-	
	Stoves (2017-)					
Schleicher (2018)	Wood stove 7 and 8 (2017)	77	101	31	59	In-situ emission measurements, full cycle.
	Eco labelled stoves / new advanced stoves					
Andersen & Hvidbjerg (2017)	Ecolabelled stove, 2014	321	340	50	260	Original data in BaP
Andersen & Hvidbjerg (2017)	Ecolabelled stove, 2012 (state-of-the-art)	14	30	-	20	Original data in BaP
	Open fireplaces and similar					
Tissari et al. (2007)	Sauna stove	943	353	285	579	Sauna stove.
Gonçalves et al. (2012)	Fireplace (not including briquettes/pellets)	25 (4-50)	38 (6-83)		13 (2-25)	All Benzofluoranthenes
Gullet et al. (2003)	Fireplace	35	25	29	21	Average, pine and oak
	Masonry heat accumulating stoves and similar					
Tissari et al. (2007)	Three masonry heaters	17	7.6	9.5	25	Three different masonry heaters, one modern and two conventional.
Lamberg et al. (2011)	Modern masonry heater	1.7	2.4	0.3	0.6	One modern masonry heater
Lamberg et al. (2011)	Conventional masonry heater	106	63	59	47	Three conventional masonry heaters

Reference	Technology	Benzo(a)-pyrene, mg/GJ	Benzo(b) fluoranthene, mg/GJ	Benzo(k) fluoranthene, mg/GJ	Indeno(1,2,3-cd) pyrene, mg/GJ	Comment
Continued…	Boilers with / without accumulation tank (-1979)					
Glasius et al. (2005)	Old boiler	36	22	32	20	Assumed older than 1980
Winther (2008)	Salamander boiler	991	926	632	1092	
Winther (2008)	Viadrus Hercules boiler	2025	1951	1581	2490	
	Boilers with accumulation tank (1980-)					
Johansson et al. (2006)	Boilers with heat accumulation	90	60	40	40	Boilers with heat accumulation
Orasche et al. (2012)	Log wood boiler, warm start	0.1	0.6		0.1	All Benzofluoranthenes
Orasche et al. (2012)	Log wood boiler, cold start	18	48		22	All Benzofluoranthenes
Orasche et al. (2012)	Wood chip boiler, warm start	0.15	0.87		0.088	All Benzofluoranthenes
Orasche et al. (2012)	Wood chip boiler, cold start	1.9	2.6		2.3	All Benzofluoranthenes
	Boilers without accumulation tank (1980-)					
Johansson et al. (2006)	Boilers without heat accumulation	120	80	50	60	Boilers without heat accumulation
	Pellet boilers / pellet stoves					
Boman et al. (2011)	Pellet stoves, high load	0.2	0.4		0.4	Two pellet stoves. High load.
Boman et al. (2011)	Pellet stoves, low load	3.7	7.6		4.1	Two pellet stoves. Low load.
Lamberg et al. (2011)	Pellet boiler	0.1	0.1	0.1	0.1	
Gonçalves et al. (2012)	Briquettes/Pellets	3.1 (1.6-4.6)	8.6 (3.3-13.9)		1.8 (1.0-2.5)	All Benzofluoranthenes
Orasche et al. (2012)	Pellet boiler, cold start	0.9	2.5		1.2	All Benzofluoranthenes
Orasche et al. (2012)	Pellet boiler, nominal load	0.1	0.3		0.1	All Benzofluoranthenes
Bari et al. (2011)	Pellet oven	5	2	4	-	

The revised emission factors for PAHs are shown in Table 4.7.

Table 4.7 Revised emission factors for PAHs.

Technology	Benzo(a)-pyrene, mg/GJ	Benzo(b)-fluoranthene, mg/GJ	Benzo(k)-fluoranthene, mg/GJ	Indeno-(1,2,3-cd)-pyrene, mg/GJ	Reference
Stoves (-1989)	116	55	119	62	Glasius et al. (2005)
Stoves (1990-2007)	48	59	50	27	Glasius et al. (2005) except for Benzo(b)fluoranthene that refers to Schleicher (2018)
Stoves (2008-2014)	43	65	19	31	Schleicher (2018)
Stoves (2015-2016)	43	65	19	31	Schleicher (2018)
Stoves (2017-)	43	65	19	31	Schleicher (2018)
Eco labelled stoves / new advanced stoves (-2014)	43	65	19	31	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2015-2016)	43	65	19	31	Schleicher (2018)
Eco labelled stoves / new advanced stoves (2017-)	43	65	19	31	Schleicher (2018)
Open fireplaces and similar	35	25	29	21	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	17	7.6	9.5	25	Tissari et al. (2007)
Boilers with accumulation tank (-1979)	991	926	632	1092	Winther (2008)
Boilers without accumulation tank (-1979)	991	926	632	1092	Winther (2008)
Boilers with accumulation tank (1980-)	90	60	40	40	Johansson et al. (2006)
Boilers without accumulation tank (1980-)	120	80	50	60	Johansson et al. (2006)
Pellet boilers / pellet stoves	0.9	1.3	1.3	1.2	Orasche et al. (2012), distribution between Benzo(b)fluoranthene and Benzo(k)fluoranthene according to Lamberg et al. (2011).

4.3.4 Dioxin (PCDD/-F)

The former emission factors for dioxin are related to type of stove or boiler. However, according to Andersen & Hvidbjerg (2017) and Schleicher (2018) dioxin emissions from wood stove is related to wood type rather than the stove type.

Higher content of chlorine (Cl) in the wood due to high content of bark or wood grown in coastal areas or in towns (due to salting of streets) will cause higher dioxin emission. In addition, copper (Cu) is a catalyst for formation of dioxin (Andersen & Hvidbjerg, 2017).

Table 4.8 shows dioxin emission measurements from residential wood combustion.

In future inventories, only four different dioxin emission factors will be applied for residential wood combustion: one for stoves, one for boilers, one for open fireplaces and one for pellet stoves/boilers. The emission factors are shown in Table 4.9.

For stoves, the emission factor 1048 ng I-Teq/GJ will be applied in future inventories. This is an average value referring to Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017).

For boilers, the emission factor 282 ng I-Teq/GJ will be applied. The emission factor refer to Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006).

For open fireplaces, data are only available from Gullet et al. (2003) and this emission factor (55 ng I-TEq / GJ) will be applied.

For masonry heaters and similar, the emission factor have been assumed equal to boilers.

For pellet stoves and boilers, the emission factor (333 ng I-TEq / GJ) refers to Hedman et al. (2006).

Table 4.8 Dioxin emission measurements.

Reference	Technology and comments	Wood type	Dioxin emission, ng I-Teq /GJ
	Stoves		
Schleicher (2018)	Stoves 2006-2017 Average fir 9 wood stoves	Log wood	1838 (4-3795)
Schleicher (2018)	Stove 1	Local log wood (Copenhagen area) and pallets (minor part)	3795
Schleicher (2018)	Stove 2	Crate of dried logs	36
Schleicher (2018)	Stove 3	Crate of dried logs	4
Schleicher (2018)	Stove 4	Log wood	79
Schleicher (2018)	Stove 5	Log wood, birch and beech	283
Schleicher (2018)	Stove 6	Crate of dried logs, beech	7
Schleicher (2018)	Stove 7	Crate of dried logs	4
Schleicher (2018)	Stove 8	Local wood (Copenhagen area)	9731
Schleicher (2018)	Stove 9, before renovation	Local log wood (Copenhagen area)	2460
Schleicher (2018)	Stove 9, after renovation	Local log wood (Copenhagen area)	2741
Andersen & Hvidbjerg (2017)	Stove 2014 and 2012	Wood logs	695
Andersen & Hvidbjerg (2017)	Stove 2014	Wood logs	660
Andersen & Hvidbjerg (2017)	Stove 2014	Chlorinated wood logs	11660
Andersen & Hvidbjerg (2017)	Stove 2012	Wood logs	730
Glasius et al. (2005)	Average for six stoves	Log wood	455
Glasius et al. (2005)	Stove 1	Log wood	558 (399-716)
Glasius et al. (2005)	Stove 2	Crate of dried wood, birch	722 (323-1122)
Glasius et al. (2005)	Stove 4	Local birch logs	136 (82-190)
Glasius et al. (2005)	Stove 5	Birch logs and wood waste	44 (19-70)
Glasius et al. (2005)	Stove 6	Log wood, local	817 (722-913)
Glasius et al. (2007)	Average all 12 stoves and one boiler	Log wood	1204 (2-8872)
Glasius et al. (2007)	Stoves 2002-2005, 4 stoves	Log wood	1248
Glasius et al. (2007)	Stoves 1995-2001, 5 stoves	Log wood	608
Glasius et al. (2007)	Stoves from before 1995, 3 stoves	Log wood	773
Hübner et al. (2005)	Stove, continuous burning	Briquettes	27
Hübner et al. (2005)	Ten stoves, continuous burning	Log wood	929 (23-4500)
Hedman et al. (2006)	One stove	Log wood	247[3)]
Gullet et al. (2003)	Stove	Oak	16

Continued…	Open fireplace		
Gullet et al. (2003)	Fireplace	Oak/pine	55 (22-89)
Schtowitz et al. (1994) as cited in Paulrud et al. (2010)	Open fireplace	-	41-66
Bröcker et al. (1992) as cited in Paulrud et al. (2010)	Open fireplace	-	5-80
Hubner et al. (2005) as cited in Paulrud et al. (2010)	Open fireplace	-	45-4500
	Masonry heaters		
-	-	-	-
	Boilers		
Glasius et al. (2005)	Old boiler	Log wood	29 (19-38)
Glasius et al. (2007)	Old boiler	Log wood	4
Hübner et al. (2005)	Three boilers from 1982, 1991 and 1992	Wood chips	670 (2-2000)[1)]
Hübner et al. (2005)	Seven boilers	Log wood	416 (18-2600)[2)]
Hedman et al. (2006)	Old boilers	Log wood	482 [3)] (332-632)
Hedman et al. (2006)	Modern boilers	Log wood	91 [3)] (63-147)
	Pellet boilers/stoves		
Hedman et al. (2006)	Pellet boiler, full combustion cycle. One intermittent and two continuous.	Wood pellets	333 [3)] (105-579)
Hübner et al. (2005)	Pellet boiler	Wood pellets	2
Bergqvist et al. (2005) as cited in Paulrud et al. (2010)	Pellet burner	Wood pellets	7-820
Johansson (2005) as cited in Paulrud et al. (2010)	Pellet burner	Wood pellets	5-250

1) 3 ng I-Teq/GJ, 6 ng I-Teq/GJ and 2000 ng I-Teq/GJ.
2) 18-86 ng I-Teq/GJ for six boilers and one boiler 2600 ng I-Teq/GJ.
3) WHO-Teq.

The revised emission factors for PCDD/F are shown in Table 4.9.

Table 4.9 Revised emission factors for PCDD/-F.

Technology	PCDD/-F, ng I-Teq/GJ	Reference
Stoves (-1989)	1048	Schleicher (2018), Glasius et al. (2005), Glasius et al. (2007) and Andersen & Hvidbjerg (2017)
Stoves (1990-2007)	1048	
Stoves (2008-2014)	1048	
Stoves (2015-2016)	1048	
Stoves (2017-)	1048	
Eco labelled stoves / new advanced stoves (-2014)	1048	
Eco labelled stoves / new advanced stoves (2015-2016)	1048	
Eco labelled stoves / new advanced stoves (2017-)	1048	
Open fireplaces and similar	55	Gullet et al. (2003)
Masonry heat accumulating stoves and similar	282	Assumed equal to boilers
Boilers with accumulation tank (-1979)	282	Glasius et al. (2005), Glasius et al. (2007), Hübner et al. (2005) and Hedman et al. (2006)
Boilers without accumulation tank (-1979)	282	
Boilers with accumulation tank (1980-)	282	
Boilers without accumulation tank (1980-)	282	
Pellet boilers / pellet stoves	333	Hedman et al. (2006)

Dioxin emissions related to wood fuel specifications

According to Schleicher (2018), low dioxin emissions have been measured from stoves applying wood from crates of dried logs that is usually imported wood. The Cl content is expected to be low in imported wood compared to wood from Denmark. However, the Cl content was not analysed in the project.

The Cl content is higher for bark than for wood and different categories of wood in the energy statistics for wood might indicate a relatively high or low Cl content. However, the data are not considered sufficient for a dioxin emission estimate.

4.3.5 NO_x

The former emission factors referred to EEA (2016). The original reference for ecolabelled stoves, and results from Andersen & Hvidbjerg (2017) are compared in Table 4.10. The emission factor for ecolabelled stoves will be revised according to Andersen & Hvidbjerg (2017).

Table 4.10 NO_x emission factors.

Reference	Technology and comments	Wood type	NO_x emission, mg /GJ
Former emission factor, EEA (2019), table 3.42, Pettersson et al. (2011)	Eco labelled stoves / new advanced stoves	-	95
Andersen & Hvidbjerg (2017)	Ecolabelled stoves, average for all measurements	Wood logs and briquettes. Normal, very dry and moist wood	75 (28-105)

4.3.6 CO

CO emission measurements are included in Andersen & Hvidbjerg (2017), Kindbom et al. (2017), Danish Technological Institute (2018) and Winther (2008). The former emission factors have been compared to the relevant additional references in Table 4.11 below. The emission factors referred to in Appendix D of the 2013 EMEP/EEA Guidebook (EEA, 2013) have also been taken into account.

For stoves from 2008 onwards and ecolabelled stoves, the emission factors are very similar. A common emission factor will be applied (1900 g/GJ).

The emission factors for boilers have been revised referring to Winther (2008).

The emission data for pellet boilers from Kindbom et al. (2017) are higher than emission factors in EEA (2019) and data collected in Appendix D of the 2013 EMEP/EEA Guidebook (EEA, 2013). The emission factor has not been changed.

All CO emission factors are shown in Table 4.12.

Table 4.11 CO emission measurements.

Reference	Technology	CO emission, mg /GJ	Comment
Stoves (-1989)			
Former emission factor		8000	Assumed two times conventional stoves. EEA (2016),Small combustion, table 3.40, conventional stoves; 4000 g/GJ (1000 g/GJ - 10,000 g/GJ).
Stoves (1990-2007)			
Former emission factor	Conventional stoves	4000	EEA (2016), Small combustion, Table 3.40, conventional stoves.
Kindbom et al. (2017)	Older stoves	1422	Aggregated emission factor based on 75 % nominal load and 25 % part load.
Stoves (2008-)			
Former emission factor	Energy efficient stoves	4000	EEA (2016), Small combustion, Table 3.41, energy efficient stoves.
Kindbom et al. (2017)	Modern stoves	1849	Aggregated emission factor based on 70 % nominal load, 25 % part load and 5 % moist fuel.
Ecolabelled stoves			
Former emission factor	Nominal load	1117	Nordic Swan Ecolabel, before 2015.
Nordic Swan Ecolabel	Nominal load	713	Nordic Swan Ecolabel, version 4.3.
Andersen & Hvidbjerg (2017)	Ecolabelled stoves, average for all measurements	1979	Wood logs and briquettes. Normal, very dry and moist wood. Table 4, page 48.
Open fireplace and similar			
EEA (2019)	Open fireplace	4000	The original reference is Gonçalves et al. (2012).
Kindbom et al. (2017)	Sauna stoves	1405	Suggested emission factor at nominal load.
Masonry heat accumulating stoves and similar			
Kindbom et al. (2017)	Tiled and masonry stoves	2402	Aggregated emission factor based on 70 % nominal load, 25 % part load and 5 % moist fuel.
Boilers with/without accumulation tank (-1979)			
Former emission factor.	Conventional boilers	4000	Refers to EEA (2016), Small combustion, Table 3.43, conventional boilers. The original reference is Johansson et al. (2004). The emission factor in the EEA (2016) Guidebook is for conventional boilers not necessarily older than 1980.
Winther (2008)	Old boilers (-1979) with heat accumulation tank	9001	Recommended emission factor for old boilers with heat accumulation tank.
Winther (2008)	Old boilers (-1979) without heat accumulation tank	10890	Recommended emission factor for old boilers without heat accumulation tank.
Danish Technological Institute (2018)	Boilers before 1980	9001	
Kindbom et al. (2017)	Traditional log wood boilers (including part load and moist wood measurements)	4096	Two boilers. Aggregated emission factor based on 5 % moist logwood, 25 % part load and 70 % nominal load.
Boilers with/without accumulation tank (1980-)			
Former emission factor.	Boilers with accumulation tank (1980-)	1117	Assumed equal to ecolabelled stoves.
Former emission factor.	Boilers without accumulation tank (1980-)	2234	Assumed 2 times the emission from new boilers with heat accumulation tank.
EEA (2016)	Conventional boilers	4000	The original reference is Johansson et al. (2003).
EEA (2016)	Advanced / ecolabelled stoves and boilers	2000	The original reference is Johansson et al. (2003).
Kindbom et al. (2017)	Modern log wood boilers	1160	Suggested emission factor for nominal load.

Kindbom et al. (2017)	Wood chip boilers	1471	Aggregated emission factor based on 5 % moist wood chips, 25 % part load and 70% nominal load.
Continued…			
Winther (2008)	New boilers with heat accumulation tank	2616	
Winther (2008)	New boilers without heat accumulation tank	3165	
Winther (2008)	Approved boilers with heat accumulation tank	610	
Winther (2008)	Approved boilers without heat accumulation tank	738	
Danish Technological Institute (2018)	Boilers 1980-2000	1709	
Danish Technological Institute (2018)	Boilers 2000 onwards	373	
Danish Technological Institute (2018)	Boilers 1980 onwards (average for category 2, 3 and 4)	468	Only two emission measurements for boilers from 1980-2000.
Pellet stoves and boilers			
Former emission factor. EEA (2019)	Pellet stoves and boilers	300	Original references are Schmidl et al. (2011) and Johansson et al. (2004).
Kindbom et al. (2017)	Pellet boilers	534	Aggregated emission factor based on 25 % part load.
Kindbom et al. (2017)	Pellet boilers	295	Recommended emission factor for full load.

Table 4.12 Revised emission factors for CO.

Technology	Emission factor, g/GJ	Reference
Stoves (-1989)	8000	Assumed two times conventional stoves. EEA (2016),Small combustion, table 3.40, conventional stoves; 4000 g/GJ (1000 g/GJ - 10,000 g/GJ).
Stoves (1990-2007)	4000	EEA (2016), Small combustion, Table 3.40, conventional stoves.
Stoves (2008-2014)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2015-2016)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Stoves (2017-)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (-2014)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2015-2016)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Eco labelled stoves / new advanced stoves (2017-)	1900	Andersen & Hvidbjerg (2017) and Kindbom et al. (2017)
Open fireplaces and similar	4000	EEA (2019)
Masonry heat accumulating stoves and similar	2402	Kindbom et al. (2017)
Boilers with accumulation tank (-1979)	9001	Winther (2008)
Boilers without accumulation tank (-1979)	10890	Winther (2008)
Boilers with accumulation tank (1980-)	1613	Winther (2008)
Boilers without accumulation tank (1980-)	1952	Winther (2008)
Pellet boilers / pellet stoves	300	EEA (2019)

4.3.7 Sulphur dioxide

The sulphur content of wood is shown in Table 4.13 along with references. The sulphur content of wood (bark and bark pellets not taken into account) varies between 0.25 and 1400 mg/kg dry weight. Most references states < 100 mg/kg (dry), corresponding to 10 g/GJ.

The sulphur content of wood pellets is also < 100 mg/kg (dry). The sulphur content is however higher for bark pellets.

The US EPA emission factor 0.4 lb/ton (dry wood) corresponds to 11 g/GJ (US EPA (1996), AP-42 chapter 1.9). The emission factor 11 g/GJ will be applied for both wood and wood pellets referring to US EPA (1996).

Table 4.13 Sulphur content.

Reference	Country	Wood type	Sulphur content, mg/kg (dry)
Boman et al. (2011)	Sweden	Wood pellets	68-85
Boman et al. (2004)	Sweden	Wood sawdust	100-200
Boman et al. (2004)	Sweden	Bark	300-400
Fernandes et al. (2011)	Portugal	Maritime pine, eucalyptus and cork oak	<100
Fernandes et al. (2011)	Portugal	Golden wattle	<200
Gullet et al. (2003)	USA	Oak	<500
Gullet et al. (2003)	USA	Pine	<500
Johansson et al. (2003)	Sweden	Pellets	<100
Johansson et al. (2003)	Sweden	Briquettes	<100
Johansson et al. (2003)	Sweden	Forest residue	<400
Johansson et al. (2004)	Sweden	Wood pellets	<100
Johansson et al. (2004)	Sweden	Wood briquettes	<100
Johansson et al. (2004)	Sweden	Wood logs	<100
Johansson et al. (2004)	Sweden	Bark pellets	300
Schmidl et al. (2011)	Austria	Wood pellets	100
Schmidl et al. (2011)	Austria	Beech logs	200
Schmidl et al. (2011)	Austria	Briquettes	100
Schmidl et al. (2011)	Austria	Oak logs	100
Schmidl et al. (2011)	Austria	Spruce logs	100
Schmidl et al. (2011)	Austria	Wood chips	<100
Sippula et al. (2007)	Finland	Commercial wood pellets	52.7
Sippula et al. (2007)	Finland	Bark pellets	309-891
Sippula et al. (2007)	Finland	Stem pellets	81-169
Orasche et al. (2012)	Germany	Pellets	920-1400
Orasche et al. (2012)	Germany	Wood	150-170
Pettersson et al. (2011)	Sweden	Birch logs	90
Pettersson et al. (2011)	Sweden	Pine logs	68
Pettersson et al. (2011)	Sweden	Spruce logs	72
Syc et al. (2011)	Czech Republic	Beech logs	2430
Syc et al. (2011)	Czech Republic	Spruce logs	710

4.4 Overview of revised emission factors

Emission factors applied for residential wood combustion that are considered independent of technology are shown in Table 4.14. Emission factors that are considered technology dependent are shown in Table 4.15. The tables include both revised emission factors and emission factors that have not been revised.

Table 4.14 Revised emission factors, emission factors that are considered independent of residential wood combustion technology.

Pollutant	Emission factor		Reference
SO_2	11	g/GJ	EEA (2019), Small combustion Table 3.6 Residential wood
CO_2	112	kg/GJ	IPCC (2006)
N_2O	4	g/GJ	IPCC (2006), Tier 1, Table 2-5, Residential, wood
As	0.19	mg/GJ	EEA (2019), Tier 1, Small Combustion, Table 3.6 for residential biomass combustion
Cd	13	mg/GJ	
Cr	23	mg/GJ	
Cu	6	mg/GJ	
Hg	0.56	mg/GJ	
Ni	2	mg/GJ	
Pb	27	mg/GJ	
Se	0.5	mg/GJ	
Zn	512	mg/GJ	
HCB	5000	ng/GJ	EEA (2019) Small Combustion Table 3-6

Table 4.15 Revised emission factors, technology dependent.

Emission factor (g/GJ)	NOx, mg/GJ	NMVOC, mg/GJ	CH_4, mg/GJ	CO, mg/GJ	NH_3, mg/GJ	TSP, mg/GJ	PM_{10}, mg/GJ	$PM_{2.5}$, mg/GJ	BC, mg/GJ	PCDD/F, ng/GJ	PCBs, ng/GJ	Benzo(a) pyrene, µg/GJ	Benzo(b) fluoran-thene, µg/GJ	Benzo(k) fluoran-thene, µg/GJ	Indeno (1,2,3-cd) pyrene µg/GJ
Stoves (-1989)	50	1200	430	8000	70	1000	950	930	18	1048	7049	116	55	119	62
Stoves (1990-2007)	50	600	215	4000	70	500	475	465	17	1048	7049	48	59	50	27
Stoves (2008-2014)	80	350	125	1900	37	389	370	362	23	1048	931	43	65	19	31
Stoves (2015-2016)	80	350	125	1900	37	317	301	295	44	1048	931	43	65	19	31
Stoves (2017-)	80	350	125	1900	37	253	240	235	44	1048	931	43	65	19	31
Eco labelled stoves / new advanced stoves (-2014)	75	175	2	1900	37	253	240	235	31	1048	466	43	65	19	31
Ecolabelled stoves / new advanced stoves (2015-2016)	75	175	2	1900	37	190	181	177	31	1048	466	43	65	19	31
Ecolabelled stoves / new advanced stoves (2017-)	75	175	2	1900	37	127	121	118	31	1048	466	43	65	19	31
Open fireplaces and similar	50	600	430	4000	74	882	838	820	34	55	60	35	25	29	21
Masonry heat accumulating stoves and similar	50	600	215	2402	70	63	60	59	18	282	7049	17	8	10	25
Boilers with accumulation tank (-1979)	80	350	211	9001	74	588	559	547	24	282	7049	991	926	632	1092
Boilers without accumulation tank (-1979)	80	350	256	10890	74	736	699	684	24	282	7049	991	926	632	1092
Boilers with accumulation tank (1980-)	95	175	50	1613	37	64	61	60	6	282	466	90	60	40	40
Boilers without accumulation tank (1980-)	95	350	50	1952	37	335	318	312	6	282	931	120	80	50	60
Pellet boilers / pellet stoves	80	10	3	300	12	51	48	47	7	333	466	1	1	1	1

4.5 Recalculations caused by revised emission factors

Table 4.16 shows recalculations based on revised emission factors. Thus, the revised fuel consumption data for each category have not been taken into account here.

The recalculated PM emissions are between 24 % and 26 % lower for both 2017 and 2005 than reported last year. The PM emissions from residential wood combustion decrease from 2005 to 2017 by 14 % in the revised estimate whereas the decrease was 13 % in the last inventory.

The recalculated BC emissions are 70-80 % lower than reported last year. The BC emissions from residential wood combustion increase by 55 % from 2005 to 2017 in the revised estimate whereas the increase was only 5 % in the last inventory.

The recalculated PAH emissions are between 7 % lower and 187 % higher than reported last year. In general, the PAH emission estimates are higher in the revised estimate than reported last year. The PAH emissions from residential wood combustion decrease by 26 % - 54 % from 2005 to 2017 in the revised estimate whereas the increase was only 6% - 16 % in the last inventory.

The recalculated dioxin emission is much lower than reported last year, 82 % lower for 2005 and 57 % lower for 2017. The dioxin emission from residential wood combustion increases by 119 % in the revised estimate, whereas the emission was reported to decrease by 8 % in the last inventory for the period 2005 to 2017. The trend of the total Danish emission of dioxin (2005-2017) changes from a 21 % decrease to a 13 % decrease.

The recalculations for NO_x and CO are small, and the emission factor for SO_2 was not changed.

Table 4.16a Recalculations related to revised emission factors[4].

Pollutant		Emissions in 2017 from residential wood combustion, inventory 2019	Emissions in 2017 from residential wood combustion, revised inventory 2020	Emissions in 2005 from residential wood combustion, inventory 2019	Emissions in 2005 from residential wood combustion, revised inventory 2020
TSP	kt	12.9	9.6	14.9	11.2
PM_{10}	kt	12.2	9.1	14.1	10.6
$PM_{2.5}$	kt	11.9	8.9	13.7	10.4
BC	kt	1.8	0.5	1.7	0.3
Benzo(a)pyrene	t	1.6	1.7	1.8	2.6
Benzo(b)fluoranthene	t	1.7	1.6	1.8	2.1
Benzo(k)fluoranthene	t	0.6	1.1	0.7	1.9
Indeno(1,2,3-cd)pyrene	t	0.9	0.9	1.1	2.0
Dioxin	g	11.3	4.9	12.3	2.2
NO_x	kt	2.4	2.3	1.0	1.0
CO	kt	72.5	75.8	86.8	93.7
SO_2	kt	0.4	0.4	0.3	0.3

[4] Recalculations based on revised emission factors. Thus, the revised fuel consumption data for each category have not been taken into account here.

Table 4.16b Recalculations related to revised emission factors.

Pollutant		Recalculation for 2017	Recalculation for 2005	Recalculation for 2017, %	Recalculation for 2005, %	2005-2017 trend, inventory 2019	2005-2017 trend, inventory 2020
TSP	kt	-3.3	-3.7	-26%	-25%	87%	86%
PM_{10}	kt	-3.1	-3.5	-26%	-25%	87%	86%
$PM_{2.5}$	kt	-3.0	-3.4	-25%	-24%	87%	86%
BC	kt	-1.3	-1.4	-70%	-80%	105%	155%
Benzo(a)pyrene	t	0.1	0.7	4%	40%	87%	64%
Benzo(b)fluoranthene	t	-0.1	0.3	-7%	18%	94%	74%
Benzo(k)fluoranthene	t	0.5	1.2	76%	187%	91%	56%
Indeno(1,2,3-cd)pyrene	t	0.0	0.9	3%	87%	84%	46%
Dioxin	g	-6.5	-10.1	-57%	-82%	92%	219%
NO_x	kt	-0.1	0.0	-2%	0%	246%	240%
CO	kt	3.3	6.9	5%	8%	84%	81%
SO_2	kt	0.0	0.0	0%	0%	151%	151%

Table 4.16c Recalculations for the national total related to revised emission factors.

Pollutant		2017 reported in 2019	2005 reported in 2019	Recalculation 2017, %	Recalculation 2005, %	Trend 2017/2005 Original	Trend 2017/2005 revised	Trend change 2017/2005, %-point
TSP	kt	91.7	98.2	-4%	-4%	93%	94%	0%
PM_{10}	kt	31.1	37.3	-10%	-9%	83%	83%	1%
$PM_{2.5}$	kt	20.1	25.6	-15%	-13%	78%	77%	2%
BC	kt	4.0	6.1	-32%	-23%	66%	58%	8%
Benzo(a)pyrene	t	2.2	2.4	3%	31%	91%	72%	20%
Benzo(b)fluoranthene	t	2.5	2.5	-5%	13%	99%	83%	15%
Benzo(k)fluoranthene	t	1.0	1.0	46%	123%	98%	64%	34%
Indeno(1,2,3-cd)pyrene	t	1.4	1.7	2%	55%	83%	55%	29%
Dioxin	g	21.6	27.4	-30%	-37%	79%	87%	-8%
NO_x	kt	112.0	205.6	0%	0%	54%	54%	0.03%
CO	kt	241.2	418.2	1%	2%	58%	58%	0.17%
SO_2	kt	10.3	26.2	0%	0%	39%	39%	0.00%

5 Results of the updated model

As described in the previous chapters, many changes were made to the model related to replacement rates, annual sale, total number of appliances and emission factors. The most significant changes in terms of impact on emissions were the updates to the emission factors. The specific recalculations caused by the updates to the emission factors are described in Chapter 4.5.

The revised model formed the basis of the official submission in February 2020 to the EU and the UN.

The fuel consumption per appliance type is shown for selected years in Table 5.1 and in Figure 5.1.

Table 5.1 Wood consumption per appliance type, GJ.

Appliance type	1990	1995	2000	2005	2010	2015	2017
Stove (-1989)	5059257	5505055	4684251	4829195	4390216	2069329	1468786
Stove (1990-2007)	189417	1456029	3004106	6476280	8544953	7388887	7240864
Stove (2008-2014)	0	0	0	0	171778	349709	358451
Stove (2015-2016)	0	0	0	0	0	48050	98502
Stove (2017-)	0	0	0	0	0	0	49251
Eco labelled stove / new advanced stove (-2014)	0	0	0	1078736	4003050	5400328	5535337
Eco labelled stove / new advanced stove (2015-2016)	0	0	0	0	0	432448	886519
Eco labelled stove / new advanced stove (2017-)	0	0	0	0	0	0	443259
Open fireplaces and similar	215256	275775	289314	439387	580986	532726	546044
Masonry stoves and similar	51061	65416	68628	104226	137815	126367	129526
Boilers with accumulation tank (-1979)	1107655	1064367	744502	565545	529	0	0
Boilers without accumulation tank (-1979)	1107655	1064367	744502	565545	529	0	0
Boilers with accumulation tank (1980-)	681087	1354974	1964789	3865590	6307497	6194682	6433828
Boilers without accumulation tank (1980-)	426372	773257	1012164	1785857	2660814	2028673	1995111
Pellet boilers/stoves	116673	201425	2112265	6689515	10105428	12998690	15046044

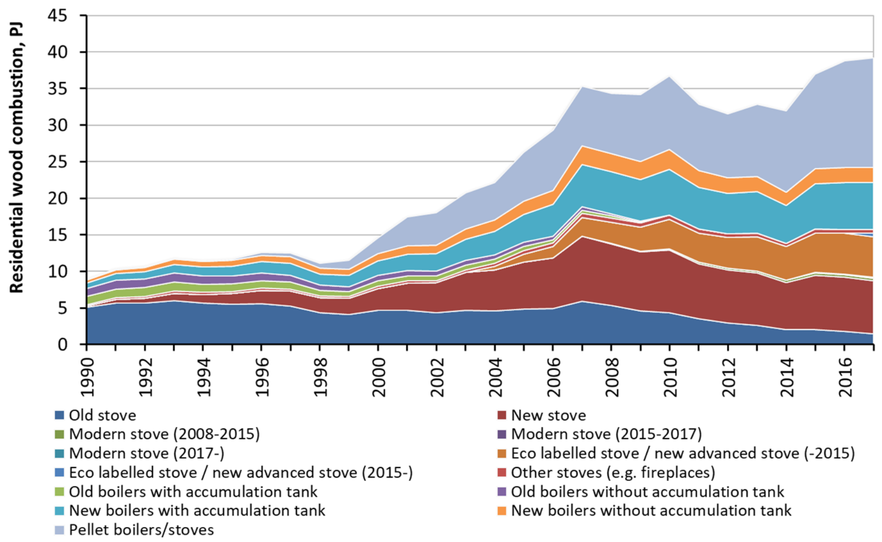

Figure 5.1 Wood consumption per appliance type.

Emissions of selected pollutants for 2005 and 2017 as reported in the 2020 submission are shown in Table 5.2 and Figure 5.2 and compared with the emissions from the previous model 2019 submission.

Table 5.1 Emissions from residential wood combustion for selected pollutants for 2005 and 2017 from the previous and updated model.

Pollutant	2005 2019 submission	2005 2020 submission	2017 2019 submission	2017 2020 submission
NO_x	1810	1836	3052	3029
NMVOC	12461	11960	10063	9866
CH_4	4563	4249	3250	2995
CO	86782	91573	72489	76001
NH_3	1272	1244	1434	1424
PM_{10}	14117	10134	12211	8766
$PM_{2.5}$	13742	9922	11923	8584
BC	1750	355	1831	554
PCDD/F (g)	12.3	14.6	11.3	24.3
Benzo(a)pyrene	1842	2624	1599	1688
Benzo(b)fluoranthene	1784	2160	1673	1567
Benzo(k)fluoranthene	661	1900	301	1071
Indeno(1,2,3-cd)pyrene	1055	2024	882	925

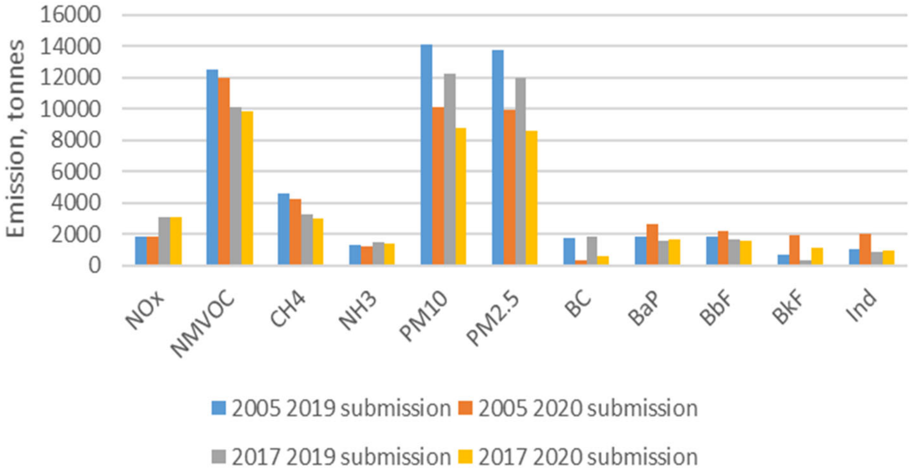

Figure 5.2 Comparison between previous and current model for selected pollutants.

It is clear that the largest changes were related to particulate matter, carbon monoxide, black carbon and PAHs. For the other pollutants, changes were smaller. As mentioned, the largest changes can be attributed to the updates to emission factors, presented and discussed in Chapter 4.

6 Uncertainties

Residential wood combustion is an important source of air pollution in Denmark and therefore attracts great attention. There is however, large uncertainties associated with the emission inventory, as there are many parameters in the emission calculation, all of which have varying levels of uncertainty. This consists on both the number of appliances per technology, the age distribution, the wood consumption and the emission factors. To create a time series, it is also necessary to have assumptions on the expected lifetime and replacement rates of stoves and boilers.

6.1 Wood consumption

The bottom-up calculation of the wood consumption based on the number of appliances and the unit consumption, does not match the registered consumption in the Danish energy statistics (DEA, 2019). Since the inventory should be based on the official energy statistics, the wood consumption calculated bottom-up is scaled with the official wood consumption in the energy statistics. The scaling is done across all technologies of appliances using firewood, i.e. all technologies except wood pellet stoves / boilers.

The correlation between the bottom-up estimated wood consumption and the statistics are much better in the recent part of the time series compared to the first part. This is partly connected to the fact that in later years the biennial surveys have been utilised both in the energy statistics and in the emission inventory. A graphical presentation of the scaling factors is included in Figure 2.2.

The poor correlation in the beginning of the time series can possibly be attributed to a change in the energy statistics. The first survey on residential wood combustion was carried out for the year 2005 and showed a markedly higher wood consumption than previously considered in the statistics. A revision was made for 2000 to 2005 but not further back in time. As a result, the consumption of firewood shows a very large increase over these years.

The firewood consumption increases by 118 % from 2000 to 2007 in the energy statistics. While there was an increase in the number of stoves in that period, there is no indications that it can justify that large an increase in wood consumption. The development has also been discussed with the industry and chimneysweepers and there is no evidence that the large increase is the result of actual change, but rather, mostly a result of changes in methodology in the statistics.

The unit consumptions used in the bottom-up calculation of the wood consumption are based on the biennial national survey of residential wood combustion in Denmark (Ea Energianalyse, 2016). The unit consumptions are weighted between permanent residences and summerhouses. The study conducted by Ea Energianalyse (2016) did not show a significant difference in unit consumption based on the age of the appliance. The study indicated a slightly higher consumption in appliances newer than 2005 compared to older appliances. In permanent residences, there was a clear indication that the unit consumption is lower in Copenhagen and the Capital Region compared to the other regions of Denmark. The unit consumption is kept constant for the time series, which cause uncertainty. The uncertainty for the unit consumption influence the emissions calculation as emission factors differ between the technology and age categories.

6.2 Emission factors

Emission factors for residential wood combustion show great variability depending on numerous parameters. Studies have shown that the emission from a specific appliance varies with the load of the appliance, the quality of the wood (e.g. moisture content and wood species), the firing technique and the measurement methods. This report will not go into detail describing the impact of the uncertainty associated with these parameters, but as an example, the table below indicates the intervals of emission factors as reported in Chapter 4.

Table 6.1 Span on emission factors included in the review for the update.

Technology	TSP EF		BC EF		$PM_{2.5}$ EF	
	g/GJ		g/GJ		g/GJ	
	min	max	min	max	min	max
Stoves (-1989)	557	5 253	18	19	434	557
Stoves (1990-2007)	119	1 195	10	118	96	330
Stoves (2008-2014)	84	634	10	76	39	423
Stoves (2015-2016)		317		no data		no data
Stoves (2017-)		253		44		188
Eco labelled stoves/new advanced stoves	103	271	19	41	103	271
Open fireplaces and similar	105	977	22	171	18	820
Masonry heat accumulating stoves and similar	63	76	7	110	59	285
Boilers with/without accumulation tank	539	1 410	23	31	318	1 162
Boilers with accumulation tank (1980-)	13	96	0.1	8	16	227
Boilers without accumulation tank (1980-)	48	1 162	6	31	61	1 162
Pellet boilers/pellet stoves	3	416	0.1	10	3	416

6.3 Number of appliances per technology

The number of appliances is based on data from the chimneysweeper association for 2017. This is the most accurate and complete data set for small wood fired appliances. The SFL2017 data set includes the number and location of small wood burning appliances. The coverage of the SFL2017 data is not complete as SLF data are missing for a few areas (~10 % of the land area). This owe to the fact that some chimneysweepers are not members of the association. To complete the coverage, data from the Danish Building and Dwelling Register for 2017 (BBR2017) have been supplemented for these areas. The supplement data make up around 5 % of the total number of appliances (see Table 3.6). The SFL2017 data set itself is subject to small uncertainties.

In Denmark, there is a legal obligation to get all chimneys, which are connected to wood-fired fireplaces or oil fired boilers, serviced by a chimneysweeper. The legal obligation does not consider if the appliance is in use or not. The obligation only cease if the appliance is closed and registered as closed by the chimneysweeper. Another uncertainty owe to the registration of appliance type in the chimneysweeper data, where an incorrect registration or misinterpretation of the appliance types might result in appliances ending up in a wrong category in the inventory system. This seems to cause larger uncertainty for boilers than for stoves and other appliances. Overall, the uncertainties for the SFL2017 data are assumed small.

The BBR data are subject to large uncertainties regarding number of stoves and boilers, and this is transferred to the total data set (SFL2017sup) when BBR is used as supplement. A comparison for stoves show that the number of appliances supplemented from the BBR2017 is around 30 % higher than expected from expert judgement from the chimneysweeper association of the number of stoves serviced by chimneysweepers not member of the association (see Table 3.7). In general, the BBR overestimate the number of oil fired boilers (around 60 %) and underestimate the number of wood stoves (around 35%). This can be attributed to the fact that the responsibility for updating the information rests with the home owner and hence a heating type increasing in popularity such as wood stoves will be under registered and a heating type in decline such as oil boilers will be over registered.

As data from the BBR is only used for smaller areas, this is not increasing the uncertainty for the SFL2017sup data set much compared to the SFL2017 data. The appliance numbers for 2017 are considered to have only small uncertainty.

6.4 Expected lifetime and replacement rates

The SFL data does not include any information about the age of the appliances or if boilers have accumulation tanks or not. Therefore, it is not possible to make an age distribution of the appliances based on the SFL data. An approach based on assumption about expected lifetime and replacement rates has been used to prepare time series of appliance numbers by technology.

Since detailed data are not available on annual scrapping of old stoves, construction of new stoves and replacement of existing stoves, the population of stoves has been modelled using a replacement curve. The curve has been constructed with input from the industry, chimneysweepers, the Danish EPA and the Ministry of Environment and Food (see Chapter 2.4).

Use of replacement curves and general assumption of expected lifetimes based on expert judgements to prepare time series for appliance numbers cause considerable uncertainty. This uncertainty is lowest in the early years, when the lowest number of technology categories are represented.

Concurrently with the phase-in of new technologies, the number of categories increase with increasing uncertainty of the distribution of appliances by technology. The uncertainty of the technology distribution will decrease in the projection as the oldest technologies are phased out.

7 Future work

A comprehensive review of all available data and information has been conducted as part of the update of the model for residential wood combustion. The updated model is based on the most applicable, up to date, and comprehensive sources. The model will be updated in the future as new knowledge and improved data become available.

Improvements of emission factors rely on results from new studies and measurements. Emission measurements for different technologies of stoves and boilers under various conditions regarding fuel type, firing technique and user behaviour are important to refine the emission factors. Information from national surveys on residential wood combustion can add information about the unit consumption, the fuel types and the age distribution of the appliances.

The total number of appliances is based on data from the chimneysweepers for 2017. Improvements can be implemented if data sets for later years become available. The chimneysweepers inspect all appliances frequently at least once a year and it would be beneficial if further details was included in the registration and made available. This include information about appliance age, further details about technology, and indication of the extent to which the appliances are used, e.g. primary heating, supplementary heating or occasionally. Such information can contribute to update the total appliance numbers, to improve the age and technology distribution and in the longer term to verify or improve the replacement rates.

Currently, the scaling of the wood consumption to match the statistical sale is done across all technologies using logwood. This could be considered further in a future update of the model as it might be more representative to only scale the consumption in stoves and boilers or even just stoves.

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Annex 1 - Former emission factors for residential wood stoves and boilers

	Pollutant	Emission factor	Unit	Reference
Old stove	NO_x	50	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	NO_x	50	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	NO_x	80	g/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	NO_x	80	g/GJ	Same as modern stove (2008-2015)
Modern stove (2018-)	NO_x	80	g/GJ	Same as modern stove (2008-2015)
Eco labelled stove / new advanced stove (-2015)	NO_x	95	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	NO_x	95	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	NO_x	50	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	NO_x	80	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	NO_x	80	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	NO_x	95	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	NO_x	95	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Pellet boilers/stoves	NO_x	80	g/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	NMVOC	1200	g/GJ	Assumed two times conventional stoves. EEA (2016),Small combustion, table 3.40, conventional stoves; 600 g/GJ (20 g/GJ - 3000 g/GJ).
New stove	NMVOC	600	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	NMVOC	350	g/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	NMVOC	350	g/GJ	Same as modern stove (2008-2015)
Modern stove (2018-)	NMVOC	350	g/GJ	Same as modern stove (2008-2015)
Eco labelled stove / new advanced stove (-2015)	NMVOC	175	g/GJ	Assumed ½ modern stove. The EEA (2016) emission factor for advanced / ecolabelled stoves and boilers is 250 g/GJ, but this emission factor has not been revised since the 2009 version of the Guidebook.
Eco labelled stove / new advanced stove (2015-)	NMVOC	175	g/GJ	Same as ecolabelled stoves.
Other stove	NMVOC	600	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	NMVOC	350	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	NMVOC	350	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	NMVOC	175	g/GJ	Assumed equal to ecolabelled stoves.
New boilers without hot water storage	NMVOC	350	g/GJ	Assumed 2 times the emission from new boilers with heat accumulation tank
Pellet boilers/stoves	NMVOC	10	g/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	CH_4	430	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al. (2005) (SMED report, Sweden)
New stove	CH_4	215	g/GJ	Assumed ½ the emission factor for old stoves.
Modern stove (2008-2015)	CH_4	125	g/GJ	Estimated based on the emission factor for new stoves and the emission factors for NMVOC.

	Pollutant	Emission factor	Unit	Reference
Modern stove (2015-2018)	CH_4	125	g/GJ	Same as modern stove (2008-2017)
Modern stove (2018-)	CH_4	125	g/GJ	Same as modern stove (2008-2017)
Eco labelled stove / new advanced stove (-2015)	CH_4	2	g/GJ	Low emissions from wood burning in an ecolabelled residential boiler. Olsson & Kjällstrand (2005).
Eco labelled stove / new advanced stove (2015-)	CH_4	2	g/GJ	Same as advanced / ecolabelled stoves
Other stove	CH_4	430	g/GJ	Assumed equal to old stove.
Old boilers with hot water storage	CH_4	211	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)
Old boilers without hot water storage	CH_4	256	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)
New boilers with hot water storage	CH_4	50	g/GJ	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
New boilers without hot water storage	CH_4	50	g/GJ	Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Johansson et al. (2004)
Pellet boilers/stoves	CH_4	3	g/GJ	Methane emissions from residential biomass combustion, Paulrud et al., 2005 (SMED report, Sweden)
Old stove	CO	8000	g/GJ	Assumed two times conventional stoves. EEA (2016),Small combustion, table 3.40, conventional stoves; 4000 g/GJ (1000 g/GJ - 10,000 g/GJ).
New stove	CO	4000	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	CO	4000	g/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	CO	4000	g/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	CO	4000	g/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	CO	1117	g/GJ	Nordic Swan Ecolabel limit. The EEA (2016) emission factor for advanced / ecolabelled stoves and boilers is 2000 g/GJ.
Eco labelled stove / new advanced stove (2015-)	CO	1117	g/GJ	Same as ecolabelled stoves.
Other stove	CO	4000	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	CO	4000	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	CO	4000	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	CO	1117	g/GJ	Assumed equal to ecolabelled stoves.
New boilers without hot water storage	CO	2234	g/GJ	Assumed 2 times the emission from new boilers with heat accumulation tank.
Pellet boilers/stoves	CO	300	g/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	NH_3	70	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	NH_3	70	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	NH_3	37	g/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	NH_3	37	g/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	NH_3	37	g/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	NH_3	37	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	NH_3	37	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	NH_3	70	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.

	Pollutant	Emission factor	Unit	Reference
Old boilers with hot water storage	NH_3	74	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	NH_3	74	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	NH_3	37	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	NH_3	37	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Pellet boilers/stoves	NH_3	12	g/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	TSP	1000	g/GJ	Glasius et al. (2005).
New stove	TSP	800	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	TSP	556	g/GJ	Limit value 10 g/kg. Calculation based on 18 MJ/kg.
Modern stove (2015-2018)	TSP	278	g/GJ	Limit value 5 g/kg. Calculation based on 18 MJ/kg.
Modern stove (2018-)	TSP	222	g/GJ	Limit value 4 g/kg. Calculation based on 18 MJ/kg.
Eco labelled stove / new advanced stove (-2015)	TSP	222	g/GJ	Nordic Swan Ecolabel limit 2012 update for hand fed stove for temporary firing or inset stove (4 g/kg). Calculation based on 18 MJ/kg. The EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers is 100 g/GJ.
Eco labelled stove / new advanced stove (2015-)	TSP	167	g/GJ	Nordic Swan Ecolabel label limit 2012 update for hand fed stove for temporary firing or inset stove (3 g/kg). Calculation based on 18 MJ/kg. EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers is 100 g/GJ.
Other stove	TSP	800	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	TSP	1000	g/GJ	Illerup et al. (2007). EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 500 g/GJ.
Old boilers without hot water storage	TSP	2000	g/GJ	Illerup et al. (2007). EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 500 g/GJ.
New boilers with hot water storage	TSP	222	g/GJ	Assumed equal to ecolabelled stoves.
New boilers without hot water storage	TSP	444	g/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	TSP	31	g/GJ	Boman et al. (2011)
Old stove	PM_{10}	950	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	PM_{10}	760	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	PM_{10}	528	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	PM_{10}	264	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2018-)	PM_{10}	211	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Eco labelled stove / new advanced stove (-2015)	PM_{10}	211	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	PM_{10}	159	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	PM_{10}	760	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	PM_{10}	950	g/GJ	Illerup et al. (2007). The EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 480 g/GJ.
Old boilers without hot water storage	PM_{10}	1900	g/GJ	Illerup et al. (2007). The EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 480 g/GJ.
New boilers with hot water storage	PM_{10}	211	g/GJ	Assumed equal to ecolabelled stoves.

	Pollutant	Emission factor	Unit	Reference
New boilers without hot water storage	PM_{10}	422	g/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	PM_{10}	29	g/GJ	Boman et al. (2011)
Old stove	$PM_{2.5}$	930	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	$PM_{2.5}$	740	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	$PM_{2.5}$	514	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	$PM_{2.5}$	257	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2018-)	$PM_{2.5}$	205	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Eco labelled stove / new advanced stove (-2015)	$PM_{2.5}$	206	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	$PM_{2.5}$	155	g/GJ	PM fractions refer to EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	$PM_{2.5}$	740	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	$PM_{2.5}$	900	g/GJ	Illerup et al. (2007). The EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 470 g/GJ.
Old boilers without hot water storage	$PM_{2.5}$	1800	g/GJ	Illerup et al. (2007). The EEA (2016) emission factor, Small combustion, table 3.43, conventional boilers is 470 g/GJ.
New boilers with hot water storage	$PM_{2.5}$	206	g/GJ	Assumed equal to ecolabelled stoves.
New boilers without hot water storage	$PM_{2.5}$	413	g/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	$PM_{2.5}$	29	g/GJ	Boman et al. (2011)
Old stove	PCDD/F	800	ng/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	PCDD/F	800	ng/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	PCDD/F	250	ng/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	PCDD/F	250	ng/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	PCDD/F	250	ng/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	PCDD/F	100	ng/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	PCDD/F	100	ng/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	PCDD/F	800	ng/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	PCDD/F	550	ng/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	PCDD/F	550	ng/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	PCDD/F	100	ng/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	PCDD/F	200	ng/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	PCDD/F	100	ng/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	Benzo(a)	121	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	Benzo(a)	121	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	Benzo(a)	61	µg/GJ	Assumed ½ the emission from old/new stoves
Modern stove (2015-2018)	Benzo(a)	61	µg/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	Benzo(a)	61	µg/GJ	Same as modern stove (2008-2015).

	Pollutant	Emission factor	Unit	Reference
Eco labelled stove / new advanced stove (-2015)	Benzo(a)	10	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	Benzo(a)	10	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	Benzo(a)	121	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	Benzo(a)	121	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	Benzo(a)	121	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	Benzo(a)	10	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	Benzo(a)	20	µg/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	Benzo(a)	10	µg/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	Benzo(b)	111	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	Benzo(b)	111	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	Benzo(b)	56	µg/GJ	Assumed ½ the emission from old/new stoves.
Modern stove (2015-2018)	Benzo(b)	56	µg/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	Benzo(b)	56	µg/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	Benzo(b)	16	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	Benzo(b)	16	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	Benzo(b)	111	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	Benzo(b)	111	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	Benzo(b)	111	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	Benzo(b)	16	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	Benzo(b)	32	µg/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	Benzo(b)	16	µg/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	Benzo(k)	42	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	Benzo(k)	42	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	Benzo(k)	21	µg/GJ	Assumed ½ the emission from old/new stoves.
Modern stove (2015-2018)	Benzo(k)	21	µg/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	Benzo(k)	21	µg/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	Benzo(k)	5	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	Benzo(k)	5	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	Benzo(k)	42	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	Benzo(k)	42	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	Benzo(k)	42	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	Benzo(k)	5	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	Benzo(k)	10	µg/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	Benzo(k)	5	µg/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.

	Pollutant	Emission factor	Unit	Reference
Old stove	Indeno	71	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	Indeno	71	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	Indeno	36	µg/GJ	Assumed ½ the emission from old/new stoves.
Modern stove (2015-2018)	Indeno	36	µg/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	Indeno	36	µg/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	Indeno	4	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Eco labelled stove / new advanced stove (2015-)	Indeno	4	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	Indeno	71	µg/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	Indeno	71	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	Indeno	71	µg/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	Indeno	4	µg/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	Indeno	8	µg/GJ	Assumed two times the emission from new boilers with accumulation tank.
Pellet boilers/stoves	Indeno	4	µg/GJ	EEA (2016), Small combustion, table 3.44, pellet stoves and boilers.
Old stove	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
New stove	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Modern stove (2008-2015)	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Modern stove (2015-2018)	dl-PCB	931	ng/GJ	Same as modern stove (2008-2016).
Modern stove (2018-)	dl-PCB	931	ng/GJ	Same as modern stove (2008-2016).
Eco labelled stove / new advanced stove (-2015)	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ modern boiler
Eco labelled stove / new advanced stove (2015-)	dl-PCB	466	ng/GJ	Same as advanced / ecolabelled stoves.
Other stove	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Old boilers with hot water storage	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Old boilers without hot water storage	dl-PCB	7049	ng/GJ	Hedman (2006), old boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
New boilers with hot water storage	dl-PCB	466	ng/GJ	Assumed equal to ecolabelled stoves.
New boilers without hot water storage	dl-PCB	931	ng/GJ	Hedman (2006), modern boiler. Recalculation from TEQ to sum of dioxin-like PCB *133 (Thistlethwaite, 2001).
Pellet boilers/stoves	dl-PCB	466	ng/GJ	Hedman (2006), assumed ½ modern boiler.
Old stove	BC	10% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
New stove	BC	10% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Modern stove (2008-2015)	BC	16% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.41, energy efficient stoves.
Modern stove (2015-2018)	BC	16% of $PM_{2.5}$	g/GJ	Same as modern stove (2008-2015).
Modern stove (2018-)	BC	16% of $PM_{2.5}$	g/GJ	Same as modern stove (2008-2015).
Eco labelled stove / new advanced stove (-2015)	BC	28% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.

	Pollutant	Emission factor	Unit	Reference
Eco labelled stove / new advanced stove (2015-)	BC	28% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Other stove	BC	10% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.40, conventional stoves.
Old boilers with hot water storage	BC	16% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
Old boilers without hot water storage	BC	16% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.43, conventional boilers.
New boilers with hot water storage	BC	28% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
New boilers without hot water storage	BC	28% of $PM_{2.5}$	g/GJ	EEA (2016), Small combustion, table 3.42, advanced / ecolabelled stoves and boilers.
Pellet boilers/stoves	BC	15% of $PM_{2.5}$	g/GJ	Schmidl et al. (2011).
Emission factors that are not technology specific				
All technologies	SO_2	11	g/GJ	EEA (2016)
All technologies	CO_2	112	kg/GJ	IPCC (2006)
All technologies	N_2O	4	g/GJ	IPCC (2006), Tier 1, Table 2-5, Residential, wood
All technologies	As	0.19	mg/GJ	EEA (2016)
All technologies	Cd	13	mg/GJ	EEA (2016)
All technologies	Cr	23	mg/GJ	EEA (2016)
All technologies	Cu	6	mg/GJ	EEA (2016)
All technologies	Hg	0.56	mg/GJ	EEA (2016)
All technologies	Ni	2	mg/GJ	EEA (2016)
All technologies	Pb	27	mg/GJ	EEA (2016)
All technologies	Se	0.5	mg/GJ	EEA (2016)
All technologies	Zn	512	mg/GJ	EEA (2016)
All technologies	HCB	5000	ng/GJ	EEA (2013)

UPDATING THE EMISSION MODEL FOR RESIDENTIAL WOOD COMBUSTION

The report documents the updates made to the emission estimation model for residential wood combustion. The revisions included new estimates for the total number of wood stoves through the time series, new replacement rates for stoves and update to a number of emission factors taking the most recent measurement studies into account. The report also documents some of the uncertainties involved with estimating emissions from residential wood combustion and highlights potential future improvements.

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