Category		Title
NFR:	**1.A.4.a.i, 1.A.4.b.i, 1.A.4.c.i, 1.A.5.a**	**Small combustion**
SNAP:	**020100** **020103** **020104** **020105** **020106** **020200** **020202** **020203** **020204** **020205** **020300** **020302** **020303** **020304**	**Commercial/institutional plants** **Commercial/institutional — Combustion plants < 50 MW** **Stationary gas turbines** **Stationary engines** **Other stationary equipment** **Residential plants** **Residential — Combustion plants < 50 MW** **Stationary gas turbines** **Stationary engines** **Residential — Other stationary equipments (Stoves, fireplaces, cooking)** **Plants in agriculture, forestry and aquaculture** **Combustion plants < 50 MW** **Stationary gas turbines** **Stationary engines**
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Contents

1 Overview

This chapter covers the methods and data needed to estimate stationary combustion emissions under NFR sectors 1.A.4.a.i, 1.A.4.b.i, 1.A.4.c.i and 1.A.5.a. . The sectors cover combustion installations activities in the following sectors which, for the purpose of this guidance, are considered to have a thermal capacity ≤ 50 MW_{th}.

- 1.A.4.a — Commercial/institutional
- 1.A.4.b — Residential
- 1.A.4.c — Agriculture/forestry
- 1.A.5.a — Other (stationary combustion)

The activities essentially cover combustion in smaller-scale combustion units and installations than those in Chapter 1.A.1, Energy industries. The combustion technologies employed may be relevant to sectors in Chapter 1.A.1. Chapter 1.A.1 provides additional emission information for the activities in this chapter (and vice versa).

The sectors covered in this chapter include the following activities:

- commercial and institutional heating
- residential heating/cooking
- agriculture/forestry and
- other stationary combustion (including military).

The open-field burning of agricultural residues is not included in this chapter. The range of activities relevant to sector 1.A.4 are summarised in chapter 2. The most important pollutants emitted to atmosphere are summarised in Table 1-1

Table 1-1 Pollutants with potential for small combustion activities to be a key category

Source releases													
Activity	PM (TSP)	PM_{10}	$PM_{2.5}$	Oxides of sulphur	Oxides of nitrogen	Oxides of carbon	Hydrogen chloride, fluoride	Volatile organic compounds	Metals (excluding mercury and cadmium) and their compounds	Mercury, cadmium	PAH	Dioxins, PCB, HCB	Ammonia
Commercial / institutional plants	X	X	X	X	X	X	X	X	X	X	X	X	
Residential plants	X	X	X	X	X	X	X	X	X	X	X	X	X
Agriculture / forestry	X	X	X	X	X	X	X	X	X	X	X	X	

2 Description of sources

2.1 Process description

The small combustion installations included in this chapter are mainly intended for heating and provision of hot water in residential and commercial/institutional sectors. Some of these installations are also used for cooking (primarily in the residential sector). In the agricultural sector the heat generated by the installations is used also for crops drying and for heating greenhouses.

In some instances, combustion techniques and fuels can be specific to an NFR activity category; however most techniques are not specific to an NFR classification. The applications can be conveniently sub-divided considering the general size and the combustion techniques applied:

- residential heating — fireplaces, stoves, cookers, small boilers (< 50 kW);
- institutional/commercial/agricultural/other heating including:
  - heating — boilers, spaceheaters (> 50 kW),
  - smaller-scale combined heat and power generation (CHP).

Emissions from smaller combustion installations are significant due to their numbers, different type of combustion techniques employed, and range of efficiencies and emissions. Many of them have no abatement measures nor low efficiency measures. In some countries, particularly those with economies in transition, plants and equipment may be outdated, polluting and inefficient. In the residential sector in particular, the installations are very diverse, strongly depending on country and regional factors including local fuel supply.

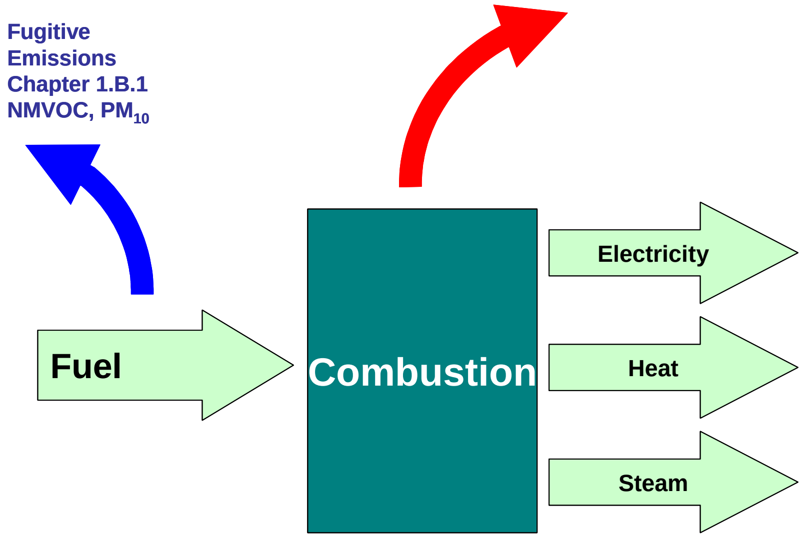

Figure 2-1 Illustration of the main process in small combustion installations; figure adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories

2.2 Techniques

2.2.1 Residential heating (1.A.4.b)

2.2.1.1 General

In small combustion installations a wide variety of fuels are used and several combustion technologies are applied. In the residential activity, smaller combustion appliances, especially older single household installations are of very simple design, while some modern installations of all capacities are significantly improved. Emissions strongly depend on the fuel, combustion technologies as well as on operational practices and maintenance.

For the combustion of liquid and gaseous fuels, the technologies used are similar to those for production of thermal energy in larger combustion activities, with the exception of the simple design of smaller appliances like fireplaces and stoves.

The technologies for solid fuels and biomass utilization vary widely due to different fuel properties and technical possibilities. Small combustion installations employ mainly fixed bed combustion technology, i.e. grate-firing combustion (*GF*) of solid fuels. Solid fuels include mineral and biomass solid fuels, with grain size varying from a few mm to 80 mm.

More detailed descriptions of techniques can be found in Kubica, et al., (2004).

2.2.1.2 Fireplaces overview

Fireplaces are the most simple combustion devices, and are often used as supplemental heating appliances primarily for aesthetic reasons in residential dwellings. There are solid- and gas-fuelled fireplaces. The fireplaces can be divided into open, partly-closed and closed fireplaces. Based on the type of construction materials used, they can be divided into cut stone and/or brick (masonry) fireplaces, or, and cast-iron or steel. Masonry fireplaces are usually built on site and integrated into the building structure, while iron or steel are prefabricated for installation with a suitable chimney or flue.

Solid fuel fireplaces

Solid fuel fireplaces are manually-fired fixed bed combustion appliances. The user intermittently adds solid fuels to the fire by hand. They can be distinguished into the following.

Open fireplaces

This type of fireplace is of very simple design — a basic combustion chamber, which is directly connected to the chimney. Fireplaces have large openings to the fire bed. Some of them have dampers above the combustion area to limit the room air intake and resulting heat losses when fireplace is not being used. The heat energy is transferred to the dwelling mainly by radiation. Open fireplaces are usually of masonry type and have very low efficiency while having significant emissions of total suspended particulates (TSP), CO, non-methane volatile organic compounds (NMVOC) and polycyclic aromatic hydrocarbons (PAH) resulting from the incomplete combustion of the fuels.

Partly-closed fireplaces

Equipped with louvers and glass doors to reduce the intake of combustion air. Some masonry fireplaces are designed or retrofitted in that way in order to improve their overall efficiency.

Closed fireplaces

These fireplaces equipped with front doors and may have distribution of combustion air to primary and secondary as well as a system to discharge the exhaust gases. They are prefabricated and installed as stand-alone units or as a fireplace inserts installed in existing masonry fireplaces. Because of the design and the combustion principle, closed fireplaces resemble stoves and their efficiency usually exceeds 50 %. They have similar emissions to stoves, i.e. lower than open or partly-closed fireplaces. For this reason they can be rated on a similar basis to stoves.

Fuels used in solid fuel fireplaces are mainly log, lump wood, biomass briquettes, and charcoal**,** coal and coal briquettes. Multifuel appliances are available which can burn a range of solid fuels including manufactured solid fuels and wood.

Gas-fuelled fireplaces

Gas fireplaces are also of simple design; materials and equipment are similar to those of solid fuels fireplaces, yet equipped with a gas burner. Because of the simple valves employed for adjustment of fuel/air ratio and non-premixing burners, NO_x emissions are lower, but emissions of CO and NMVOC can be higher in comparison to gas-fired boilers.

2.2.1.3 Stoves

Stoves are enclosed appliances in which useful heat is transmitted to the surroundings by radiation and convection. They can vary widely due to fuels type, application, design and construction materials, and also combustion process organisation.

The stoves utilizing solid fuels are usually used for heating of the rooms (room heaters), but also for cooking, and hot water preparation (boilers and water heaters), while liquid and gas stoves tend to be used mainly for space heating.

Solid fuel stoves

The solid fuel stoves can be classified on the basis of the combustion principle, which primarily depends on the airflow path through the charge of fuel in a combustion chamber. Two main types exist: up-draught (under-fire, down-burning combustion) and downdraught (up-burning combustion). The vast majority of older stoves are of the up-draught type, which is of simpler design, but has higher emissions.

Different kinds of solid fuels are used, such as coal and its products (usually anthracite, hard coal, brown coal, patent fuels, and brown coal briquettes) and biomass — wood logs, wood chips and wood pellets and briquettes. Coals of different grain sizes are used usually 20–40 mm, and above 40 mm, or mixtures of both. Peat is also occasionally used.

The stoves can be made as prefabricated iron or steel appliances or masonry stoves, which are usually assembled on site with bricks, stone or ceramic materials. Regarding the main mode of heat transfer, solid fuel stoves can be divided into two main subgroups which are radiating stoves, and heat storing or, heat accumulating stoves. Radiating stoves are usually prefabricated iron or steel appliances; some of them can provide water heating, indirect heating (boilers) and some are used as cooking stoves.

Conventional, traditional stoves

These have poorly organised combustion process resulting in low efficiency (40 % to 50 %) and significant emissions of pollutants mainly originating from incomplete combustion (TSP, CO, NMVOC and PAH). Their autonomy (i.e. the ability to operate without user intervention) is low, lasting from three to eight hours. Those, which are equipped with hot-plate zones, are used also for cooking — kitchen stoves. Some of them could also be used for hot water preparation.

Energy efficient conventional stoves

Essentially, traditional stoves with improved utilization of secondary air in the combustion chamber. Their efficiency is between 55 % and 75 % and emissions of pollutants are lower, their autonomy ranges from 6 to 12 hours.

Advanced combustion stoves

These stoves are characterized by multiple air inlets and pre-heating of secondary combustion air by heat exchange with hot flue gases. This design results in increased efficiency (near 70 % at full load) and reduced CO, NMVOC and TSP emissions in comparison with the conventional stoves. Most ecolabelled stoves burning woodlogs are advanced combustion stoves.

Modern pellet stoves

This is a type of advanced stove using pelletized fuels such as wood pellets, which are distributed to the combustion chamber by a fuel feeder from small fuel storage. Modern pellets stoves are often equipped with active control system for supply of the combustion air. They reach high combustion efficiencies by providing the proper air/fuel mixture ratio in the combustion chamber at all times (CITEPA, 2003). For this reason they are characterized by high efficiency (between 80 % and 90 %) and low emissions of CO, NMVOC, TSP and PAH.

Masonry (heat accumulating) stoves

These stoves are made of materials able to accumulate heat (e.g. fire brick, ceramic tiles or certain volcanic rocks (Finish stove for example)). Slow heat-release appliances are generally masonry stoves. A rapid heating in large thermal mass of masonry materials is achieved. Heat is slowly released by radiation to the surrounding area. Their combustion efficiency ranges from 70 to 80 % and their autonomy from 8 to 12 hours (CITEPA, 2003).

Catalytic combustor stoves

Stoves, in particular for wood combustion, can be equipped with a catalytic converter in order to reduce emissions caused by incomplete combustion. Due to more complete oxidation of the fuels, energy efficiency also increases. Catalytic combustors are not common for coal stoves.

Liquid/gas-fuelled stoves

The liquid/gas stoves have simple design; gas stoves are equipped with simple valves for fuel/air ratio adjustment and non-pre-mixing burners. For that reason emissions of NO_x from these are lower in comparison to gas-fired boilers. Simple liquid fuel stoves use evaporation systems for preparation of fuel/air mixture.

Regarding construction material and design, liquid and gas stoves are generally less diversified than those for solid fuels. They are made of steel and prefabricated.

2.2.1.4 Small boilers (single household/domestic heating) — indicative capacity ≤ 50 kW output

In general, boilers are devices which heat water for indirect heating. Small boilers of this capacity are used in flats and single houses. Designs are available for gaseous, liquid and solid fuels. They are mainly intended for generation of heat for the central heating system (including hot air systems) or hot water, or a combination of both.

Solid fuel small boilers

Small boilers for central heating for individual households are more widespread in temperate regions and usually have a nominal output between 12 kW to 50 kW. They use different types of solid fossil fuels and biomass usually depending on their regional availability. They could be divided into two broad categories regarding the organisation of combustion process: overfeed boiler (overfeed burning — over-fire and under-fire — down-burning) and underfeed boiler (underfeed burning — over-fire). They can be differentiated between conventional and advanced combustion boilers.

Conventional, coal/biomass boilers

Over-fire boilers

Over-fire boilers are commonly used in residential heating due to their simple operation and low investment cost. An incomplete combustion process takes place due to the non-optimal combustion air supply, which is usually generated by natural draught. The fuel is periodically fed onto the top of the burning fuel bed. The efficiency of the over-fire boiler is similar to the efficiency of conventional stoves, and is usually between 50 % and 65 %, depending on construction design and load. The emission of pollutants resulting from incomplete combustion of fuel may be very high particularly if they are operated at low load.

Under-fire boilers

Under-fire boilers have manual fuel feeding systems, and stationary or sloping grates. They have a two-part combustion chamber. The first part is used for storage of fuel and for partial devolatilization and combustion of the fuel layer. In the second part of the combustion chamber the combustible gases are oxidized. In older designs, natural draught is used. Combustion in under-fire boilers is more stable than in over-fire boilers, due to continuous gravity feed of fuel onto the fire bed. This results in higher energy efficiency (60-70 %) and lower emissions in comparison to overfeed combustion.

Advanced combustion boilers

Advanced, under-fire coal boilers

In general, the design and the combustion technique are similar to the conventional under-fire boiler. The main difference is that a fan controls the flue gases flow. Control system for the primary and secondary air might lead to increase in efficiency above 80 % (usually between 70 % and 80%).

Downdraught wood boilers

This type of boiler is considered state of the art in the lump wood combustion. It has two chambers, first one where the fuel is fed for partial devolatilisation and combustion of the fuel layer, and a secondary chamber, where burning of the released combustible gases occurs. The advantage of this boiler is that the flue gases are forced to flow down through holes in a ceramic grate and thus are burned at high temperature within the secondary combustion chamber and ceramic tunnel. Owing to the optimised combustion process, emissions due to incomplete combustion are low.

Stoker coal burners

The fuel with low ash contents and the grain size of between 4 mm up to 25 mm is automatically fed into to a retort by a screw conveyor. The stoker boiler is characterized by higher efficiency, usually above 80 %. The advantage of stoker boiler is that it can operate with high efficiency within load range from 30 % to nominal capacity. In a properly operated stoker, emissions of pollutants resulting from incomplete combustion are significantly lower; however, NO_x increases due to the higher combustion temperature.

Wood boilers

Automatic log-fired boilers are available. However. most small boilers are wood pellet or chip-fired. These have a fully automatic system for feeding of pellet or woodchip fuels and for supply of combustion air, which is distributed into primary and secondary. The boilers are equipped with a smaller fuel storage bin, which is fuelled manually or by an automatic system from a larger chamber storage. The pellets are introduced by screw into the burner. These boilers are characterised by a high efficiency (usually above 80 %) and their emissions are comparable to those of liquid fuel boilers.

Liquid/gas-fuelled small boilers

These are usually two-function appliances used for hot water preparation and for heat generation for the central heating system. In the capacity range below 50 kW output they are used mainly in single households. Water-tube low temperature boilers (temperature of water below 100 ^{o}C) with open combustion chamber are usually used. These devices can be made of cast iron or steel. The boilers with capacity below 50 kW, can be divided into two main groups, i.e. standard boiler and condensing boilers.

Standard boilers

Standard boilers have an open combustion chamber, having maximum energy efficiency above 80 %, because of the comparatively high flue gas losses. Due to very simple design of combustion process automation system they can have higher emissions of CO and VOC in comparison to larger boilers and industrial installations.

Condensing boilers (room-sealed boilers)

These devices recover more heat from the exhaust gases by condensing moisture released in the combustion process and can operate with efficiency more than 90 %. Condensing boilers are also available for oil-firing boilers.

2.2.1.5 Cooking

Domestic cooking using solid fuel

These appliances are usually made of iron or steel and the combustion chamber is often covered with fire bricks; modern devices may incorporate a hot-water boiler for indirect heating of a dwelling. Their combustion efficiency ranges from 50 to 70 % depending on the type and quality of the installation and also the operation mode. Their autonomy is a few hours. Pollutant emissions are quite high in old installations, while in the most recent ones, the use of secondary or tertiary air allows a better combustion control. Solid fuel barbecues (outdoor cooking including 'disposable' single use barbecue packs) are used seasonally.

Cooking using gas

Gas-fired units are widely used in the residential sector. These comprise hobs (including heating rings for pots) and ovens. Outdoor cooking uses bottled gas (LPG).

2.2.1.6 Outdoor heating and other combustion

Residential and commercial use of outdoor heating has increased in some countries in recent years through the use of gas-fired patio heaters and similar devices. Traditional solid fuel fire pits and chimney devices are also relevant.

Combustion appliances are used to heat stones used in saunas in Scandinavia.

2.2.2 Non-residential heating (1.A.4.a, 1.A.4.c, 1.A.5.a)

2.2.2.1 Boilers with indicative capacity between 50 kW and 50 MW_{th}

Boilers of such a capacity are used for heating in multi-residential houses, office, school, hospital and apartment blocks and are most commonly found small sources in commercial and institutional sector as well as in agriculture. The largest units are more likely to be associated with other NFR sectors but are included for convenience.

Solid fuel boilers

Fixed and moving bed combustion technology is commonly used for combustion of solid fuels in this capacity range. This is a well-established technology, and a great variety of fixed-bed layer and moving layer boilers (travelling grate combustion, stokers) are in use. In addition to fixed bed combustion, fluidised bed combustion boilers are in use in this capacity range, frequently for biomass combustion.

Installations are differentiated into two main subgroups:

- manually fuelled
- automatically fuelled.

Manual feed boilers

Due to economical and technical reasons manual-fired boilers usually have a capacity lower than 1 $MW_{th.}$

Coal/wood boilers

Manually fed boilers in this capacity range apply two combustion techniques, under-fire and upper-fire, similar as in boilers of lower capacity range (see subsection 2.2.1.4 of the present chapter).

1. Overfeed boilers, under-fire boilers: coal fuels of different grain size (usually between 5 mm and 40 mm) or lump wood are used in this type of installations. Their thermal efficiency ranges from 60 % to 80 % and depends on the air distribution into primary/secondary system and secondary sub-chamber design. The emissions of pollutants, i.e. CO, NMVOC, TSP and PAH resulting from incomplete combustion are generally high.
2. Overfeed boilers, upper-fire boilers: fine coal, or mixture of fine coal with biomass chips, which are periodically moved into combustion chamber are used in this type of boilers. The ignition is started from the top of the fuel charge. Their efficiency ranges from 75 % to 80 %. The emissions of pollutants of TSP, CO, NMVOC, PAH are lower in comparison to overfeed boilers due to different combustion process organization, which is similar to stoker combustion.

Both the under-fire and upper-fire boilers in this capacity range have better organisation of the combustion air compared with the ones used in single households.

Biomass/straw boilers

Overfeed boilers, biomass/straw fixed grate boilers are developed and applied for straw and cereal bale combustion. The straw bales are fed to the combustion chamber by hand. Due to the very fast combustion of this type of biomass, such installations contain a hot-water accumulation system. For this reason they are used only in small-scale applications up to a nominal boiler capacity of 1,5 MW_{th}. They are popular in the agricultural regions due to their relatively low costs and simple maintenance.

Automatic feed boilers

The automatic feed boilers usually have a capacity above 1 MW_{th}, but nowadays also lower capacity boilers are equipped with automatic feeding (including residential units). In addition, these installations have, in general, better control of the combustion process compared with manually fed ones. They typically require fuels of standardised and stable quality. These installations might also have particulate abatement equipment.

Moving bed (GF) combustion is commonly classified according to the way in which fuel is fed to the grate, as spreader stokers, overfeed stokers, and underfeed stokers.

Coal of smaller granulation or fine wood (e.g. wood pellet, chips or sawdust) is charged on a mechanical moving grate. The combustion temperatures are between 1 000 °C and 1 300 °C. The grate-fired installations are also suitable for co-combustion of coal with biomass. General applications are aimed at production of heat and/or hot water, and/or low-pressure steam for commercial and institutional users, in particular for district heating. Due to the highly controlled combustion process of solid fuels in moving-bed techniques and usually fully automatic process control systems, the emissions of pollutants, resulting from incomplete combustion, is significantly lower in comparison to manual feed boilers.

Advanced techniques

Underfeed coal/wood boilers; upper-fire burning, stoker boilers, underfeed rotating grate

These are used for both coal and wood combustion. The process principle is combustion in underfeeding stoker. The fuel with low ash contents (wood chips, sawdust, pellets; particle sizes up to 50 mm, or coal up to 30 mm) is fed into the combustion chamber through a screw conveyor and is transported to a retort when is oxidised.

Cigar straw boiler technology

This is applied for combustion of straw and cereal bales. The fuel bales are automatically transported to the combustion chamber by a hydraulic piston through an inlet tunnel into the combustion chamber.

Indirect combustor, gasification of wood biomass

This uses a separate gasification system for the chipped wood fuels, and the subsequent combustion of the product fuel gases in the gas boiler. An advantage of this technology is a possibility to use wet wood fuels of varying quality. This technique has low emissions of pollutants resulting from incomplete combustion of fuels.

Pre-ovens combustion system:

Wood chip combustion installations are used in some countries, especially in the countryside, heating larger houses and farms. This system contains automatic chips fuel feeding by a screw and pre-ovens (well-insulated chamber) and could be connected to an existing boiler. Pre-ovens systems apply a fully automatic combustion process and consequently emissions are low.

Advance automatically stoked wood chip and wood pellet boilers

They generally have a high level of autonomy. Inverted combustion is generally used with forced draught providing the best performances. The combustion efficiency ranges from 85 to 90 % and the degree of autonomy depends on the degree of automation applied to fuel and ash handling equipment (ranges from 24 hours to all the heating season).

Fluidised bed combustion

Fluidised bed combustion (FBC) can be divided into bubbling fluidised bed (BFB) and circulating fluidised bed combustion (CFB), depending on the fluidisation velocity. FBC is particularly suitable for low-quality, high-ash content coal or other ‘difficult’ solid fuels. The FBC is often used for co-combustion of coal with biomass. There are only few medium size installations of this type in operation.

Liquid/gas fuels

For gas and oil boilers the fuel and air are introduced as a mixture using dedicated burners in the combustion chamber. The burners on these small boilers tend to be self-contained units from specialist manufacturers which are fitted to a boiler.

Boilers fired with gaseous and liquid fuels are produced in a wide range of different designs and are classified according to burner configuration (injection burner or blow burner), construction material, the type of medium transferring heat (hot water, steam) and their power, the water temperature in the water boiler (which can be low temperature $\leq 100\ ^{o}C$, medium-temperature $> 100\ ^{o}C$ to $\leq 115\ ^{o}C$, high-temperature > 115 ^{o}C), the heat transfer method (water-tube, fire-tube) and the arrangement of the heat transfer surfaces (horizontal or vertical, straight or bent over tube).

Cast iron boilers

Produce mainly low-pressure steam or hot water. Typically, they are used in residential and commercial/institutional sectors up to a nominal boiler capacity of about 1,5 MW_{th}.

Steel boilers

Manufactured, up to a nominal capacity of 50 MW_{th}, from steel plates and pipes by means of welding. Their characteristic feature is the multiplicity of their design considering the orientation of heat transfer surface. The most common are water-tube boilers, fire-tube boilers and condensing boilers.

Water-tube boilers

Equipped with external steel water jacket. Water-tubes (water flows inside, exhaust gasses outside) are welded in the walls of the jacket.

Fire-tube boilers

In these boilers combustion gasses flow inside smoke tubes, which are surrounded by water. They are designed as cylinder or rectangular units.

Furnace-fire-tube boilers made of steel

These devices are produced as the horizontal cylinders. The cylinder made of rolled steel plate ends at both sides with bottoms. The front bottom in its lower part (under the cylinder axis) is equipped with a furnace tube, which plays the role of combustion chamber.

Condensing boilers

Partly utilize the latent heat of the water vapour in the flue gases due to its condensation in the heat exchanger. For that reason their efficiency is higher than for other boiler systems. Their efficiency is more than 90 %. They could efficiently operate at lower inlet water temperatures. Besides high efficiency their advantage is also a lower emission of NO_X.

2.2.2.2 Cooking

Commercial cooking using solid fuel

The extent of solid fuel use in commercial cooking is not known, but is likely to be in specialised areas such as bakeries and traditional wood-fired pizza ovens.

Cooking using gas

Gas-fired units are widely used in the commercial sectors. These comprise hobs (including heating rings for pots) and ovens. Outdoor cooking uses bottled gas (LPG).

2.2.2.3 Space heating (direct heating)

Fireplaces and stoves are residential spaceheaters which may also find use in commercial and institutional premises. However, larger gas and oil-fired combustion units are used for heating in the commercial and industrial sectors. Units can be fixed (to ceilings and walls) or semi-portable.

2.2.2.4 Outdoor heating and other combustion

Commercial use of outdoor heating has increased in some countries in recent years through the use of gas-fired patio heaters and similar devices. Larger hot air furnaces are often used to heat temporary buildings and marquees.

Combustion appliances are used to heat stones used in saunas in Scandinavia.

Steam cleaning equipment often incorporates an oil burner to provide hot water.

2.2.2.5 Combined heat and power (CHP)

Requirements to increase the efficiency of the energy transformation and the use of renewable energy sources have led to the development of small CHP units. Use of steam boiler plus back-pressure turbine for electricity generation is the traditional approach and can allow use of biomass fuels. However, use of small-scale internal combustion cogeneration technology (gas turbine or stationary engine with heat recovery) is increasingly common. The cogeneration technology can be applied in comparatively small applications using small gas-fired reciprocating engines, but large reciprocating engines and gas turbines are also applied. Tri-generation (CHP and cooling) is also applied using this technology.

There are examples of small-scale wood gasification technology, primarily for waste wood streams, but also capable of operation on non-waste wood.

2.3 Emissions

Relevant pollutants are SO_2, NO_x, CO, NMVOC, particulate matter (PM), black carbon (BC), heavy metals, PAH, polychlorinated dibenzo-dioxins and furans (PCDD/F) and hexachlorobenzene (HCB). For solid fuels, generally the emissions due to incomplete combustion are many times greater in small appliances than in bigger plants. This is particularly valid for manually-fed appliances and poorly controlled automatic installations.

For both gaseous and liquid fuels, the emissions of pollutants are not significantly higher in comparison to industrial scale boilers due to the quality of fuels and design of burners and boilers, except for gaseous- and liquid-fuelled fireplaces and stoves because of their simple organization of combustion process. However, ‘ultra-low’ NOx burner technology is available for gas combustion in larger appliances. In general, gas- and oil-fired installations generate the same type of pollutants as for solid fuels, but their quantities are significantly lower.

Emissions caused by incomplete combustion are mainly a result of insufficient mixing of combustion air and fuel in the combustion chamber (local fuel-rich combustion zone), an overall lack of available oxygen, too low temperature, short residence times and too high radical concentrations (Kubica, 1997/1 and 2003/1). The following components are emitted to the atmosphere as a result of incomplete combustion in small combustion installations: CO, PM and NMVOCs, NH_3 , PAHs as well as PCDD/F.

NH_3 — small amounts of ammonia may be emitted as a result of incomplete combustion process of all solid fuels containing nitrogen. This occurs in cases where the combustion temperatures are very low

(fireplaces, stoves, old design boilers). NH_3 emissions can generally be reduced by primary measures aiming to reduce products of incomplete combustion and increase efficiency.

TSP, PM_{10}, $PM_{2.5}$ — particulate matter in flue gases from combustion of fuels (in particular of solid mineral fuels and biomass) may be defined as carbon, smoke, soot, stack solid or fly ash. Emitted particulate matter can be classified into three groups of fuel combustion products.

The first group is formed via gaseous phase combustion or pyrolysis as a result of incomplete combustion of fuels (the products of incomplete combustion (PIC)): soot and organic carbon particles (OC) are formed during combustion as well as from gaseous precursors through nucleation and condensation processes (secondary organic carbon) as a product of aliphatic, aromatic radical reactions in a flame-reaction zone in the presence of hydrogen and oxygenated species; CO and some mineral compounds as catalytic species; and VOC, tar/heavy aromatic compounds species as a result of incomplete combustion of coal/biomass devolatilization/pyrolysis products (from the first combustion step), and secondary sulphuric and nitric compounds. Condensed heavy hydrocarbons (tar substances) are an important, and in some cases, the main contributor, to the total level of particles emission in small-scale solid fuels combustion appliances such as fireplaces, stoves and old design boilers.

The next groups (second and third) may contain ash particles or cenospheres that are largely produced from mineral matter in the fuel; they contain oxides and salts (S, Cl) of Ca, Mg, Si, Fe, K, Na, P, heavy metals, and unburned carbon formed from incomplete combustion of carbonaceous material; black carbon or elemental carbon — BC (Kupiainen, et al., 2004).

Particulate matter emission and size distribution from small installations largely depends on combustion conditions. Optimization of solid fuel combustion process by introduction of continuously controlled conditions (automatic fuel feeding, distribution of combustion air) leads to a decrease of TSP emission and to a change of PM distribution (Kubica, 2002/1 and Kubica et al., 2004/4). Several studies have shown that the use of modern and ‘low-emitting’ residential biomass combustion technologies leads to particle emissions dominated by submicron particles (< 1 μm) and the mass concentration of particles larger than 10 μm is normally < 10 % for small combustion installations (Boman et al., 2004 and 2005, Hays et al., 2003, Ehrlich et al, 2007).

Note that there are different conventions and standards for measuring particulate emissions. Particulate emissions can be defined by the measurement technique used including factors such as the type and temperature of filtration media and whether condensable fractions are measured. Other potential variations can include the use of manual gravimetric sampling techniques or aerosol instrumentation. Similarly, particulate emission data determined using methodology based on a dilution tunnel may differ from emission data determined by a direct extractive measurement on a stack. The main difference is whether the emission measurement is carried out in the hot flue gas, either in-stack or out-stack, or if the measurements is carried out after the semi-volatile compounds have condensed.

Typically the Swedish laboratory measurements (e.g. Johansson et al., 2004) are based on Swedish Standard (SS028426) which is an out-stack heated filter, meaning that the semi-volatile compounds will not have condensed. In the field measurements an in-stack filter was used to measure PM (Johansson et al., 2006).

The measurements carried out in Denmark all use out-stack methods with dilution tunnel comparable to the Norwegian Standard (Glasius et al., 2005, Glasius et al., 2007 and Winther, 2008). Therefore the measurement method can be the reason why the Swedish measurements show a significantly lower level compared to the Danish measurements.

A comparative study (Nussbaumer et al., 2008) of the different sampling methods showed that the emission factors determined when using a dilution tunnel are between 2.5 and 10 times higher than when only taking into account the solid particles measured directly in the chimney. This is illustrated in the figure below. This range is also reported by Bäfver (2008).

A test on a wood stove carried out by the Danish Technological Institute showed a ratio of approximately 4.8 between an in-stack measurement and a measurement in a dilution tunnel (Winther, 2008).

These issues regarding measurement methodology, and hence definition, mean that it can be difficult to compare reported emission data.

Black carbon (BC) – Black carbon is formed from incomplete combustion of organic compounds with lack of oxygen to fully oxidize the organic species to carbon dioxide and water.

BC is the term for a range of carbon containing compounds. It covers partly large polycyclic species, charred plants to highly graphitized soot. Black carbon originates from fossil fuel and biomass combustion and the properties of the resulting BC such as atmospheric lifetime and optical properties, are dependent on combustion temperature, oxygen concentration during combustion and for biomass burning also of wood moisture.

Combustion of fuels is the main source of BC emission. The same emission control techniques that limit the emission of PM will also reduce the emission of BC. However, measurement data that addresses the abatement efficiencies for BC are still very few. ***This means that in general it is assumed that the BC emission is reduced proportionally to the PM emission.*** The BC emission factors are expressed as percentage of the $PM_{2.5}$ emission. In many references elemental carbon (EC) is used synonymously with BC. However, organic carbon (OC) is contributing to the light absorption of particles but to a lesser extent than EC. To ensure the widest possible dataset all data for EC has been treated as part of the data basis for the BC EFs.

Heavy metals (HM) — the emission of heavy metals strongly depends on their contents in the fuels. Coal and its derivatives normally contain levels of heavy metals which are several orders of magnitude higher than in oil (except for Ni and V in heavy oils) and natural gas. All ‘virgin’ biomass also contains heavy metals. Their content depends on the type of biomass.

Most heavy metals considered (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn) are usually released as compounds associated and/or adsorbed with particles (e.g. sulphides, chlorides or organic compounds). Hg, Se, As and Pb are at least partially present in the vapour phase. Less volatile metal compounds tend to condensate onto the surface of smaller particles in the exhaust gases.

During the combustion of coal and biomass, particles undergo complex changes, which lead to vaporization of volatile elements. The rate of volatilization of heavy metal compounds depends on technology characteristics (type of boilers; combustion temperature) and on fuel characteristics (their contents of metals, fraction of inorganic species, such as chlorine, calcium, etc.). The chemical form of the mercury emitted may depend in particular on the presence of chlorine compounds. The nature of the combustion appliance used and any associated abatement equipment will also have an effect (Pye et al., 2005/1).

Mercury emitted from small combustion installations (SCIs), similarly to emission from large scale combustion, occurs in elementary form (elemental mercury vapour Hg^0), reactive gaseous form (reactive gaseous mercury (RGM)) and total particulate form (TPM) (Pacyna et al, 2004). Meanwhile, it has been shown (Pye et al., 2005) that in the case of SCIs, distribution of particular species of emitted mercury is different to the one observed under large scale combustion. Contamination of biomass fuels, such as impregnated or painted wood, may cause significantly higher amounts of heavy metals emitted (e.g. Cr, As). With the exception of Hg, As, Cd and Pb (which have a significant volatile component), heavy metals emissions can be reduced by secondary (particulate) emission reduction measures.

PCDD/F — the emissions of dioxins and furans are highly dependent on the conditions under which cooling of the combustion and exhaust gases is carried out. Carbon, chlorine, a catalyst and oxygen excess are necessary for the formation of PCDD/F. They are found to be consequence of the de-novo synthesis in the temperature interval between 180 ^oC and 500 ^oC (Karasek et al., 1987). Coal-fired stoves in particular were reported to release very high levels of PCDD/F when using certain kinds of coal (Quass U., et al., 2000). The emission of PCDD/F is significantly increased when plastic waste is co-combusted in residential appliances or when contaminated/treated wood is used. The emissions of PCDD/F can be reduced by introduction of advanced combustion techniques of solid fuels (Kubica, 2003/3).

HCB — emissions of HCB from combustion processes are highly uncertain but, on the whole, processes resulting in PCDD/F formation lead also to HCB emissions (Kakeraka, 2004).

PAH — emissions of polycyclic aromatic hydrocarbons results from incomplete (intermediate) conversion of fuels. Emissions of PAH depend on the combustion process, particularly on the temperature (too low temperature favourably increases their emission), the residence time in the reaction zone and the availability of oxygen (Kubica K., 1997/1, 2003/1). It was reported that coal stoves and old type boilers (hand-fuelled) emit several times higher amounts of PAH in comparison to new design boilers (capacity below 50 kW_{th}), such as boilers with semi-automatic feeding (Kubica K., 2003/1, 2002/1,3). Technology of co-combustion of coal and biomass that can be applied in commercial/institutional and in industrial SCIs leads to reduction of PAH emissions, as well as TSP, NMVOCs and CO (Kubica et al., 1997/2 and 2004/5).

CO — carbon monoxide is found in gas combustion products of all carbonaceous fuels, as an intermediate product of the combustion process and in particular for under-stoichiometric conditions. CO is the most important intermediate product of fuel conversion to CO_2; it is oxidized to CO_2 under appropriate temperature and oxygen availability. Thus CO can be considered as a good indicator of the combustion quality. The mechanisms of CO formation, thermal-NO, NMVOC and PAH are, in general, similarly influenced by the combustion conditions. The emissions level is also a function of the excess air ratio as well as of the combustion temperature and residence time of the combustion products in the reaction zone. Hence, small combustion installations with automatic feeding (and perhaps oxygen ‘lambda’ sensors) offer favourable conditions to achieve lower CO emission. For example, the emissions of CO from solid fuelled small appliances can be several thousand ppm in comparison to 50–100 ppm for industrial combustion chambers, used in power plants.

NMVOC — for small combustion installations (e.g. residential combustion) emissions of NMVOC can occur in considerable amounts; these emissions are mostly released from inefficiently working stoves (e.g. wood-burning stoves). VOC emissions released from wood-fired boilers (0.510 MW) can be significant. Emissions can be up to ten times higher at 20 % load than those at maximum load (Gustavsson et al, 1993). NMVOC are all intermediates in the oxidation of fuels. They can adsorb on, condense, and form particles. Similarly as for CO, emission of NMVOC is a result of low combustion temperature, short residence time in oxidation zone, and/or insufficient oxygen availability. The emissions of NMVOC tend to decrease as the capacity of the combustion installation increases, due to the use of advanced techniques, which are typically characterized by improved combustion efficiency.

Sulphur oxides — in the absence of emission abatement, the emission of SO_2 is dependent on the sulphur content of the fuel. The combustion technology can influence the release of SO_2 with (for solid mineral fuels) higher sulphur retention in ash than is commonly associated with larger combustion plant.

Nitrogen oxides — emission of NOx is generally in the form of nitric oxide (NO) with a small proportion present as nitrogen dioxide (NO_2). Although emissions of NOx are comparatively low in residential appliances compared to larger furnaces (due in part to lower furnace temperatures), the proportion of primary NO_2 is believed to be higher.

Carbon dioxide — refer to Intergovernmental Panel on Climate Change (IPCC) guidance.

Nitrous oxide — refer to IPCC guidance.

Methane — refer to IPCC guidance.

2.4 Controls

Reduction of emissions from combustion process can be achieved by either avoiding formation of such substances (primary measures) or by removal of pollutants from exhaust gases (secondary measures).

The key measure for residential appliances is combustion control; emission of PM, CO, NMVOC and PAH are very dependent on combustion control, and measures to improve this include better control of temperature, air distribution and fuel quality. A modern enclosed fireplace burning fuel of the correct quality is less polluting than an open fire.

Primary measures which change appliance population or fuel quality are not directly relevant to current emissions except for trying to assess how far national or regional policies may have been implemented. The timing or progress of implementation of national measures for primary measures is also relevant for projections.

Primary measures: there are several common possibilities (Kubica, 2002/3, Pye et al., 2004):

- modification of fuels composition and improvement of their quality; preparation and improvement of quality of solid fuels, in particular of coal (in reference to S, Cl, ash contents, and fuel size range); modification of the fuels granulation by means of compacting — briquetting, pelletizing;

pre-cleaning — washing; selection of grain size in relation to the requirements of the heating appliances (stove, boilers) and supervision of its distribution; partial replacement of coal with biomass (implementation of co-combustion technologies enabling reduction of SO_2, and NOx), application of combustion modifier; catalytic and S-sorbent additives (limestone, dolomite), reduction and modification of the moisture contents in the fuel, especially in the case of solid biomass fuels;

- replacing of coal by upgraded solid derived fuel, biomass, oil, gas;
- control optimization of combustion process;
- management of the combustion appliance population: replacement of low efficiency heating appliances with newly designed appliances, and supervision of their distribution by obligatory certification system; supervision over residential and communal system heating;
- improved construction of the combustion appliances; implementation of advanced technologies in fire places, stoves and boilers construction (implementation of Best Available Techniques (BAT) for combustion techniques and good combustion practice).

Co-combustion of coal and biomass that can be applied in commercial/institutional and in industrial SCIs leads to reduction of TSP and PIC emission, mainly PAHs, NMVOCs and CO, (Kubica et al., 1997/2 and 2004/5).

Secondary emission reduction measures: for small combustion installations a secondary measure can be applied to remove emissions, in particular PM. In this way emissions of pollutants linked with the PM, such as heavy metals, PAHs and PCDD/F can also be significantly reduced due to their removal together with particulate matter. These measures/controls are characterized by various dedusting efficiency (Perry at al., 1997 and Bryczkowski at al., 2002) and tend to be applied in accordance with national emission control requirements which vary considerably. For particulate matter the following options can be considered:

- settling chambers: gravity separation characterised by a low collection efficiency and ineffective for the fine particulate fraction;
- cyclone separators: commonly applied but have a comparatively low collection efficiency for fine particles (< 85 %);
- for higher effectiveness (94–99 %), units with multiple cyclones (cyclone batteries) are applied, and multi-cyclones allow for increased gas flow rates;
- electrostatic precipitators (their efficiency is between 99.5 % to 99.9 %) or fabric filters (with efficiency about 99.9 %) can be applied to the larger facilities.

The range of emission control encompasses manually-fired residential appliances with no control measures through to large boilers with fabric filters. Although emission control may be limited for small appliances, automatic biomass heating boilers as small as 100 kW output are commonly fitted with a cyclone.

Small (residential) wood combustion appliances, stoves in particular, can be equipped with a catalytic converter in order to reduce emissions caused by incomplete combustion. The catalytic converter is usually placed inside the flue gas channel beyond the main combustion chamber. When the flue gas passes through catalytic combustor, some pollutants are oxidized. The catalyst efficiency of emission reduction depends on the catalyst material, its construction (active surface), the conditions of flue gases flow inside converter (temperature, flow pattern, residence time, homogeneity, type of pollutants). For wood stoves with forced draught, equipped with catalytic converter (Hustad, et al., 1995) the efficiency of emission reduction of pollutants is as follows: CO 70–93 %, CH_4 29–77 %, other hydrocarbons more than 80 %, PAH 43–80 % and tar 56–60 %. Reduction of CO emissions from stoves equipped with catalytic converter is significant in comparison to an advanced downdraught staged-air wood stove under similar operating conditions (Skreiberg, 1994). However, the catalysts needs frequent inspection and cleaning. The lifetime of a catalyst in a wood stove with proper maintenance is usually about 10 000 hours. Modern wood appliances are generally not fitted with catalytic control systems.

FBC furnaces can incorporate lime injection into the combustion bed to capture SO_2.

3 Methods

3.1 Choice of method

Figure 3-1 presents the procedure to select the methods for estimating process emissions from the relevant activities. The main ideas behind the decision tree are:

- if detailed information is available, use it.

If the source category is a key source, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is easier to obtain the necessary input data for this approach than to collect facility level or appliance data needed for a Tier 3 estimate.

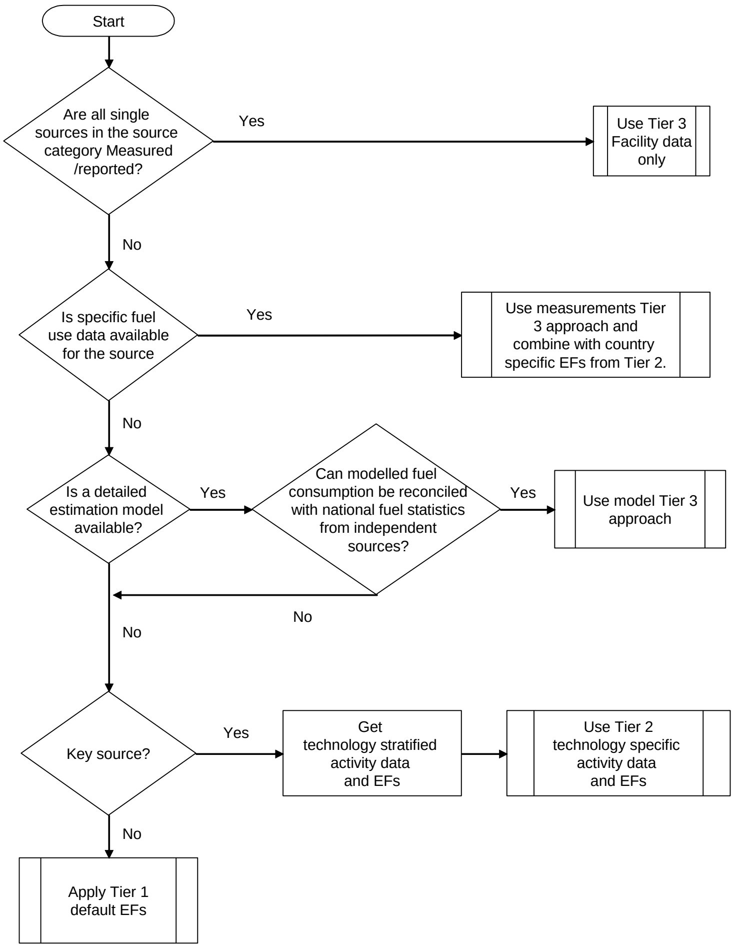

Figure 3-1 Decision tree for source category 1.A.4 Small combustion

For the combustion activities in this chapter it is unlikely that a facility-specific approach could be adopted because detailed information on individual installations is unlikely to be available. However, modelling of the NFR sector and appliance population is consistent with a Tier 3 approach.

3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for process emissions from small combustion installations uses the general equation:

$$E_{pollutant} = AR_{fuelconsumption} \times EF_{pollutant} \quad (1)$$

where:

$E_{pollutant}$ = the emission of the specified pollutant,

$AR_{fuelconsumption}$ = the activity rate for fuel consumption,

$EF_{pollutant}$ = the emission factor for this pollutant.

This equation is applied at the national level, using annual national fuel consumption for small combustion installations in various activities.

In cases where specific abatement options are to be taken into account, a Tier 1 method is not applicable and a Tier 2 or, if practical, Tier 3 approach must be used.

3.2.2 Default emission factors

Factors are provided for major fuel classifications and applying a distinction between residential and non-residential (institutional, commercial, agricultural and other) activities which can have significantly different emission characteristics.

Table 3-1 Summary of Tier 1 emission factor categories

Activity	Application
1.A.4.b Residential combustion	Hard coal and brown coal, natural gas, other liquid fuels, biomass
1.A.4.a/c, 1.A.5.a Non-residential (institutional/commercial plants, plants in agricultre/forestry/aquaculture and other stationary (including military))	Hard coal and brown coal, gaseous fuels, liquid fuels, biomass

The general Tier 1 fuel types are provided in Table 3-2. The hard and brown coal types are treated as one fuel type. Liquid fuels (heavy fuel oil and other liquid fuel) are treated as one fuel type. Similarly, natural gas and derived gases are treated as one fuel type at Tier 1.

Where ‘Guidebook 2006’ is referenced in the tables, the emissions factor is taken from chapter B216 of the 2006 Guidebook. The original reference could not be determined and the factor represents an expert judgement based on the available data.

Table 3-2 Summary of Tier 1 fuels

Tier 1 Fuel type	Associated fuel types
Hard coal and Brown coal	Coking coal, other bituminous coal, sub-bituminous coal, coke, manufactured 'patent' fuel Lignite, oil shale, manufactured 'patent' fuel, peat
Gaseous fuels	Natural gas, natural gas liquids, liquefied petroleum gas, gas works gas, coke oven gas, blast furnace gas
Other liquid fuels	Residual fuel oil, refinery feedstock, petroleum coke, orimulsion, bitumen, gas oil, kerosene, naphtha, shale oil
Biomass	Wood, charcoal, vegetable (agricultural) waste

Default Tier 1 emission factors are provided in Table 3-3 to

Table 3-9.

3.2.2.1 Residential combustion (1.A.4.b)

Table 3-3 Tier 1 emission factors for NFR source category 1.A.4.b, using hard coal and brown coal

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Hard Coal and Brown Coal				
Not applicable	HCH				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	110	g/GJ	36	200	Guidebook (2006) chapter B216
CO	4600	g/GJ	3000	7000	Guidebook (2006) chapter B216
NMVOC	484	g/GJ	250	840	Guidebook (2006) chapter B216
SOx	900	g/GJ	300	1000	Guidebook (2006) chapter B216
NH3	0.3	g/GJ	0.1	7	Guidebook (2006) chapter B216
TSP	444	g/GJ	80	600	Guidebook (2006) chapter B216
PM10	404	g/GJ	76	480	Guidebook (2006) chapter B216
PM2.5	398	g/GJ	72	480	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	130	mg/GJ	100	200	Guidebook (2006) chapter B216
Cd	1.5	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Hg	5.1	mg/GJ	3	6	Guidebook (2006) chapter B216
As	2.5	mg/GJ	1.5	5	Guidebook (2006) chapter B216
Cr	11.2	mg/GJ	10	15	Guidebook (2006) chapter B216
Cu	22.3	mg/GJ	20	30	Guidebook (2006) chapter B216
Ni	12.7	mg/GJ	10	20	Guidebook (2006) chapter B216
Se	1	mg/GJ	1	2.4	Expert judgement based on Guidebook (2006) chapter B216
Zn	220	mg/GJ	120	300	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	800	ng I-TEQ/GJ	300	1200	Guidebook (2006) chapter B216
Benzo(a)pyrene	230	mg/GJ	60	300	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	330	mg/GJ	102	480	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	130	mg/GJ	60	180	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	110	mg/GJ	48	144	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1.

Table 3-4 Tier 1 emission factors for NFR source category 1.A.4.b, using gaseous fuels

Tier 1 default emission factors				
	Code	Name		
NFR Source Category	1.A.4.b.i	Residential plants		
Fuel	Gaseous fuels			
Not applicable	HCH			
Not estimated	NH_3, PCB			
Pollutant	**Value**	**Unit**	**95% confidence**	**Reference**

			interval		
			Lower	Upper	
NOx	51	g/GJ	31	71	*
CO	26	g/GJ	18	42	*
NMVOC	1.9	g/GJ	1.1	2.6	*
SOx	0.3	g/GJ	0.2	0.4	*
TSP	1.2	g/GJ	0.7	1.7	*
PM10	1.2	g/GJ	0.7	1.7	*
PM2.5	1.2	g/GJ	0.7	1.7	*
BC	5.4	% of PM2.5	2.7	11	*
Pb	0.0015	mg/GJ	0.0008	0.003	*
Cd	0.00025	mg/GJ	0.0001	0.0005	*
Hg	0.68	mg/GJ	0.3	1.4	*
As	0.12	mg/GJ	0.06	0.24	*
Cr	0.00076	mg/GJ	0.0004	0.0015	*
Cu	0.000076	mg/GJ	0.00004	0.00015	*
Ni	0.00051	mg/GJ	0.0003	0.0010	*
Se	0.011	mg/GJ	0.004	0.011	*
Zn	0.0015	mg/GJ	0.0008	0.003	*
PCDD/F	1.5	ng I-TEQ/GJ	0.8	2.3	*
Benzo(a)pyrene	0.56	µg/GJ	0.19	0.56	*
Benzo(b)fluoranthene	0.84	µg/GJ	0.28	0.84	*
Benzo(k)fluoranthene	0.84	µg/GJ	0.28	0.84	*
Indeno(1,2,3-cd)pyrene	0.84	µg/GJ	0.28	0.84	*

* average of Tier 2 EFs for residential gaseous fuel combustion for all technologies

Table 3-5 Tier 1 emission factors for NFR source category 1.A.4.b, using liquid fuels

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	'Other' Liquid Fuels				
Not applicable	HCH				
Not estimated	NH_3, HCB, PCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	51	g/GJ	31	72	*
CO	57	g/GJ	34	80	*
NMVOC	0.69	g/GJ	0.4	1.0	*
SOx	70	g/GJ	42	97	*
TSP	1.9	g/GJ	1.1	2.6	*
PM10	1.9	g/GJ	1.1	2.6	*
PM2.5	1.9	g/GJ	1.1	2.6	*
BC	8.5	% of $PM_{2.5}$	4.8	17	*
Pb	0.012	mg/GJ	0.01	0.02	*
Cd	0.001	mg/GJ	0.0003	0.001	*
Hg	0.12	mg/GJ	0.03	0.12	*
As	0.002	mg/GJ	0.001	0.002	*
Cr	0.20	mg/GJ	0.10	0.40	*
Cu	0.13	mg/GJ	0.07	0.26	*
Ni	0.005	mg/GJ	0.003	0.010	*
Se	0.002	*mg/GJ*	0.001	0.002	*
Zn	0.42	mg/GJ	0.21	0.84	*
PCDD/F	5.9	ng I-TEQ/GJ	1.2	30	*
Benzo(a)pyrene	80	ug/GJ	16	120	*
Benzo(b)fluoranthene	40	ug/GJ	8	60	*
Benzo(k)fluoranthene	70	ug/GJ	14	105	*
Indeno(1,2,3-cd)pyrene	160	ug/GJ	32	240	*

* average of Tier 2 EFs for residential liquid fuel combustion for all technologies

Table 3-6 Tier 1 emission factors for NFR source category 1.A.4.b, using biomass [4)]

Tier 1 default emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Biomass				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	80	g/GJ	30	150	Pettersson et al. (2011) [1)]
CO	4000	g/GJ	1000	10000	Pettersson et al. (2011) and Goncalves et al. (2012) [2)]
NMVOC	600	g/GJ	20	3000	Pettersson et al. (2011) [2)]
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	70	g/GJ	35	140	Roe et al. (2004) [2)]
TSP	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) [3) 2)]
PM10	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) [3) 2)]
PM2.5	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) [3) 2)]
BC	10	% of $PM_{2.5}$	2	20	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989) [2)]
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCB	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006) [1)]
PCDD/F	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)[2)]
Benzo(a)pyrene	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	71	mg/GJ	7	710	
HCB	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional boilers
2) Assumed equal to conventional stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
4) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

3.2.2.2 Non-residential combustion (1.A.4.a, 1.A.4.c, 1.A.5)

Table 3-7 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using hard and brown coal

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Hard Coal and Brown Coal				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	173	g/GJ	150	200	Guidebook (2006) chapter B216
CO	931	g/GJ	150	2000	Guidebook (2006) chapter B216
NMVOC	88.8	g/GJ	10	300	Guidebook (2006) chapter B216
SOx	900	g/GJ	450	1000	Guidebook (2006) chapter B216
TSP	124	g/GJ	70	250	Guidebook (2006) chapter B216
PM10	117	g/GJ	60	240	Guidebook (2006) chapter B216
PM2.5	108	g/GJ	60	220	Guidebook (2006) chapter B216
BC	6.4	% of PM2.5	2	26	See Note
Pb	134	mg/GJ	50	300	Guidebook (2006) chapter B216
Cd	1.8	mg/GJ	0.2	5	Guidebook (2006) chapter B216
Hg	7.9	mg/GJ	5	10	Guidebook (2006) chapter B216
As	4	mg/GJ	0.2	8	Guidebook (2006) chapter B216
Cr	13.5	mg/GJ	0.5	20	Guidebook (2006) chapter B216
Cu	17.5	mg/GJ	5	50	Guidebook (2006) chapter B216
Ni	13	mg/GJ	0.5	30	Guidebook (2006) chapter B216
Se	1.8	mg/GJ	0.2	3	Guidebook (2006) chapter B216
Zn	200	mg/GJ	50	500	Guidebook (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	203	ng I-TEQ/GJ	40	500	Guidebook (2006) chapter B216
Benzo(a)pyrene	45.5	mg/GJ	10	150	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	58.9	mg/GJ	10	180	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	23.7	mg/GJ	8	100	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	18.5	mg/GJ	5	80	Guidebook (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1.
No information was specificcaly available for small boilers. The BC share is taken as the same value as for residential sources and referenced to Zhang et al. (2012).

Table 3-8 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Gaseous Fuels				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	74	g/GJ	46	103	*
CO	29	g/GJ	21	48	*
NMVOC	23	g/GJ	14	33	*
SOx	0.67	g/GJ	0.40	0.94	*
TSP	0.78	g/GJ	0.47	1.09	*
PM10	0.78	g/GJ	0.47	1.09	*
PM2.5	0.78	g/GJ	0.47	1.09	*
BC	*4.0*	*% of $PM_{2.5}$*	*2.1*	*7*	*
Pb	0.011	**mg/GJ**	0.006	0.022	*
Cd	0.0009	**mg/GJ**	0.0003	0.0011	*
Hg	0.54	**mg/GJ**	0.26	1.0	*
As	0.10	**mg/GJ**	0.05	0.19	*
Cr	0.013	**mg/GJ**	0.007	0.026	*
Cu	0.0026	**mg/GJ**	0.0013	0.0051	*
Ni	0.013	**mg/GJ**	0.006	0.026	*
Se	0.058	mg/GJ	0.015	0.058	*
Zn	0.73	**mg/GJ**	0.36	1.5	*
PCDD/F	0.52	ng I-TEQ/GJ	0.25	1.3	*
Benzo(a)pyrene	0.72	ug/GJ	0.20	1.9	*
Benzo(b)fluoranthene	2.9	ug/GJ	0.7	12	*
Benzo(k)fluoranthene	1.1	ug/GJ	0.3	2.8	*
Indeno(1,2,3-cd)pyrene	1.08	ug/GJ	0.30	2.9	*

* average of Tier 2 EFs for commercial/institutional gaseous fuel combustion for all technologies

Table 3-9 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using liquid fuels

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Liquid Fuels				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	513	g/GJ	308	718	*
CO	66	g/GJ	40	93	*
NMVOC	25	g/GJ	15	35	*
SOx	47	g/GJ	28	66	*
TSP	20	g/GJ	12	28	*
PM10	20	g/GJ	12	28	*
PM2.5	20	g/GJ	12	28	*
BC	56	*% of $PM_{2.5}$*	33	78	*
Pb	0.08	**mg/GJ**	0.04	0.16	*
Cd	0.006	**mg/GJ**	0.003	0.011	*
Hg	0.12	**mg/GJ**	0.04	0.17	*
As	0.03	**mg/GJ**	0.02	0.06	*
Cr	0.20	**mg/GJ**	0.10	0.40	*
Cu	0.22	**mg/GJ**	0.11	0.43	*
Ni	0.008	**mg/GJ**	0.004	0.015	*
Se	0.11	**mg/GJ**	0.06	0.22	*
Zn	29	**mg/GJ**	15	58	*
PCDD/F	1.4	*ng I-TEQ/GJ*	0.3	7.1	*
Benzo(a)pyrene	1.9	**ug/GJ**	0.2	1.9	*
Benzo(b)fluoranthene	15	**ug/GJ**	1.5	15	*
Benzo(k)fluoranthene	1.7	**ug/GJ**	0.2	1.7	*
Indeno(1,2,3-cd)pyrene	1.5	**ug/GJ**	0.2	1.5	*

* average of Tier 2 EFs for commercial/institutional liquid fuel combustion for all technologies

Table 3-10 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using biomass [5)]

Tier 1 emission factors					
	Code	Name			
NFR source category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Biomass				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	91	g/GJ	20	120	Lundgren et al. (2004) [1)]
CO	570	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 kW
NMVOC	300	g/GJ	5	500	Naturvårdsverket, Sweden
SO_2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH_3	37	g/GJ	18	74	Roe et al. (2004) [2)]
TSP	150	g/GJ	75	300	Naturvårdsverket, Sweden
PM_{10}	143	g/GJ	71	285	Naturvårdsverket, Sweden [3)]
PM2.5	140	g/GJ	70	279	Naturvårdsverket, Sweden [3)]
BC	28	% of $PM_{2.5}$	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) [4)]
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006)
PCDD/F	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	16	mg/GJ	8	32	
Benzo(k)fluoranthene	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	4	mg/GJ	2	8	
HCB	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Larger combustion chamber, 350 kW
2) Assumed equal to low emitting wood stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
4) Assumed equal to advanced/ecolabelled residential boilers
5) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

3.2.3 Activity data

Information on the use of energy suitable for estimating emissions using the Tier 1 simpler estimation methodology, is available from national statistics agencies or the International Energy Agency (IEA).

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 on Stationary combustion www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

The activity rate and the emission factor have to be determined on the same level of aggregation depending on the availability of data. The activity statistic should be determined within the considered country or region by using adequate statistics. The activity should refer to the energy input of the emission sources considered (net or inferior fuel consumption in [GJ]).

3.3 Tier 2 technology-specific approach

3.3.1 Algorithm

The Tier 2 approach is similar to the Tier 1 approach, using activity data and emission factors to estimate the emissions. The main difference is that the detailed methodology requires more fuel, technology and country-specific information. Development of the detailed methodology has to be focused to the combinations of the main installation types/fuels used in the country.

The annual emission is determined by an activity data and an emission factor:

$$E_i = \sum_{j,k} EF_{i,j,k} \cdot A_{j,k} \;, \qquad (1)$$

where

E_i = annual emission of pollutant *i*,

$EF_{i,j,k}$ = default emission factor of pollutant *i* for source type *j* and fuel *k*,

$A_{j,k}$ = annual consumption of fuel *k* in source type *j*.

For example, the sources may be characterised as:

- residential heating : fire places, water heaters, stoves, boilers, cookers;
- non-residential heating : space heating, boilers;
- CHP.

The non-residential activities need to be apportioned to the appropriate NFR activity sectors.

3.3.2 Technology-specific emission factors

Technology-specific emission factors for different fuels and technologies are shown in sections 3.3.2.1 for residential plants and in chapter 3.3.2.2 for non-residential plants. An overview of the tier 2 emission factor tables and a link to the technology describtion in chapter 2.2 is shown in Table 3-11.

The tier 2 emission factors can be used with knowledge of equipment populations and sectors to develop aggregate factors or emissions for the NFR subsectors. The development of national emission factors should consider the combination of installation types and fuels in the country and, where relevant, emission controls. When deriving specific emission factors, the emphasis has to be given to taking into account start-up emissions. These could, especially in the case of stoves and solid fuel small boilers, significantly influence the emissions of the total combustion cycle. The emission factors for small combustion plants burning wood take into account the whole combustion cycle.

Table 3-11 Tier 2 emission factor tables

	Tier	Fuel	Sector	Technology name	Chapter 2.2 technology name
Table 3-6	1	Biomass	Residential	Residential < 50 kW	-
Table 3-10	1	Biomass	Non-residential	Non-residential > 50 kW	-
Table 3-14	2	Wood	Residential	Open fireplaces	Open and partly closed fireplace
Table 3-17	2	Wood	Residential	Conventional stoves	Closed fireplace, conventional traditional stoves, domestic cooking
Table 3-18	2	Wood	Residential	Conventional boilers < 50 kW	Conventional biomass boilers
Table 3-23	2	Wood	Residential	Energy efficient stoves	Energy efficient conventional stoves, masonry heat accumulating stoves[1]
Table 3-24	2	Wood	Residential	Advanced/Ecolabelled stoves and boilers	Advanced combustion stoves, catalytic combustor stoves, advanced combustion boilers
Table 3-25	2	Wood	Residential	Pellet stoves and boilers	Modern pellet stoves, automatic wood boilers (pellets / chips)
Table 3-30	2	Wood	Non-residential	Manual boilers	Manual feed boilers
Table 3-31	2	Wood	Non-residential	Automatic boilers	Automatic feed boilers

[1] *Masonry heat accumulating stoves* might be included in *Advanced/ecolabelled stoves and boilers* instead depending on the technology.

3.3.2.1 Residential heating technologies (1.A.4.b)

Table 3-12 Tier 2 emission factors for source category 1.A.4.b.i, fireplaces burning solid fuel (except biomass)

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Solid Fuel (not biomass)				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Fireplaces, Saunas and Outdoor Heaters				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	60	g/GJ	36	84	Guidebook (2006) chapter B216
CO	5000	g/GJ	3000	7000	Guidebook (2006) chapter B216
NMVOC	600	g/GJ	360	840	Guidebook (2006) chapter B216
SOx	500	g/GJ	300	700	Guidebook (2006) chapter B216
NH_3	5	g/GJ	3	7	Guidebook (2006) chapter B216
TSP	350	g/GJ	210	490	Guidebook (2006) chapter B216
PM_{10}	330	g/GJ	198	462	Guidebook (2006) chapter B216
PM2.5	330	g/GJ	198	462	Guidebook (2006) chapter B216
BC	9.839	% of PM2.5	3	30	Engelbrecht et al., 2002
Pb	100	mg/GJ	60	140	Guidebook (2006) chapter B216
Cd	0.5	mg/GJ	0.3	0.7	Guidebook (2006) chapter B216
Hg	3	mg/GJ	1.8	4.2	Guidebook (2006) chapter B216
As	1.5	mg/GJ	0.9	2.1	Guidebook (2006) chapter B216
Cr	10	mg/GJ	6	14	Guidebook (2006) chapter B216
Cu	20	mg/GJ	12	28	Guidebook (2006) chapter B216
Ni	10	mg/GJ	6	14	Guidebook (2006) chapter B216
Se	1	mg/GJ	0.6	1.4	Guidebook (2006) chapter B216
Zn	200	mg/GJ	120	280	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	300	700	Guidebook (2006) chapter B216
Benzo(a)pyrene	100	mg/GJ	60	140	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	170	mg/GJ	102	238	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	60	140	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	80	mg/GJ	48	112	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
500 g/GJ of sulphur dioxide is equivalent to 0.8 % S of coal fuels of lower heating value of fuel on a dry basis 29 GJ/t and an average sulphur retention in ash value of 0.1.

Table 3-13 Tier 2 emission factors for source category 1.A.4.b.i, fireplaces burning natural gas

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Natural gas				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves, Fireplaces, Saunas and Outdoor Heaters				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	60	g/GJ	36	84	DGC (2009)
CO	30	g/GJ	18	42	DGC (2009)
NMVOC	2.0	g/GJ	1.2	2.8	Zhang et al. (2000)
SOx	0.3	g/GJ	0.18	0.42	DGC (2009)
TSP	2.2	g/GJ	1.3	3.1	Zhang et al. (2000)
PM10	2.2	g/GJ	1.3	3.1	*
PM2.5	2.2	g/GJ	1.3	3.1	*
BC	5.4	% of PM2.5	2.7	11	Hildemann et al. (1991), Muhlbaier (1981) **
Pb	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
Cd	0.00025	mg/GJ	0.00013	0.00050	Nielsen et al. (2013)
Hg	0.1	mg/GJ	0.0013	0.68	Nielsen et al. (2010)
As	0.12	mg/GJ	0.060	0.24	Nielsen et al. (2013)
Cr	0.00076	mg/GJ	0.00038	0.0015	Nielsen et al. (2013)
Cu	0.000076	mg/GJ	0.000038	0.00015	Nielsen et al. (2013)
Ni	0.00051	mg/GJ	0.00026	0.0010	Nielsen et al. (2013)
Se	0.011	mg/GJ	0.0038	0.011	US EPA (1998)
Zn	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
PCDD/F	1.5	ng I-TEQ/GJ	0.80	2.3	UNEP (2005)
Benzo(a)pyrene	0.56	ug/GJ	0.19	0.56	US EPA (1998)
Benzo(b)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Benzo(k)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Indeno(1,2,3-cd)pyrene	0.84	ug/GJ	0.28	0.84	US EPA (1998)

* assumption: EF(TSP) = EF(PM10) = EF(PM2.5)

** average of EFs from the listed references

Table 3-14 Tier 2 emission factors for source category 1.A.4.b.i, open fireplaces burning wood [4)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Open fireplaces				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	50	g/GJ	30	150	Pettersson et al. (2011) [1)]
CO	4000	g/GJ	1000	10000	Goncalves et al. (2012)
NMVOC	600	g/GJ	20	3000	Pettersson et al. (2011) and McDonald et al. (2000)
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	74	g/GJ	37	148	Roe et al. (2004)
TSP	880	g/GJ	440	1760	Alves et al. (2011) [2)]
PM10	840	g/GJ	420	1680	Alves et al. (2011) [2)]
PM2.5	820	g/GJ	410	1640	Alves et al. (2011) [2)]
BC	7	% of $PM_{2.5}$	2	18	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), Fine et al. (2002), Kupiainen & Klimont, IIASA (2004)
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006) [3)]
PCDD/F	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)[1)]
Benzo(a)pyrene	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	71	mg/GJ	7	710	
HCB	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional stoves
2) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3) Assumed equal to conventional boilers.
4) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-15 Tier 2 emission factors for source category 1.A.4.b.i, stoves burning solid fuel (except biomass)

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Solid Fuel (not biomass)				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	100	g/GJ	60	150	Guidebook (2006) chapter B216
CO	5000	g/GJ	3000	7000	Guidebook (2006) chapter B216
NMVOC	600	g/GJ	360	840	Guidebook (2006) chapter B216
SOx	900	g/GJ	540	1000	Guidebook (2006) chapter B216
TSP	500	g/GJ	240	600	Guidebook (2006) chapter B216
PM10	450	g/GJ	228	480	Guidebook (2006) chapter B216
PM2.5	450	g/GJ	216	480	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	60	240	Guidebook (2006) chapter B216
Cd	1	mg/GJ	0.6	3.6	Guidebook (2006) chapter B216
Hg	5	mg/GJ	3	7.2	Guidebook (2006) chapter B216
As	1.5	mg/GJ	0.9	6	Guidebook (2006) chapter B216
Cr	10	mg/GJ	6	18	Guidebook (2006) chapter B216
Cu	20	mg/GJ	12	36	Guidebook (2006) chapter B216
Ni	10	mg/GJ	6	24	Guidebook (2006) chapter B216
Se	2	mg/GJ	1.2	2.4	Guidebook (2006) chapter B216
Zn	200	mg/GJ	120	360	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	1000	ng I-TEQ/GJ	300	1200	Guidebook (2006) chapter B216
Benzo(a)pyrene	250	mg/GJ	150	324	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	400	mg/GJ	150	480	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	150	mg/GJ	60	180	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	120	mg/GJ	54	144	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Table 3-16 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning solid fuel (except biomass)

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Solid Fuel (not biomass)				
SNAP (if applicable)					
Technologies/Practices	Small (single household scale, capacity <=50 kWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	158	g/GJ	80	300	US EPA, 1998
CO	4787	g/GJ	3000	7000	US EPA, 1998
NMVOC	174	g/GJ	87	260	US EPA, 1998
SOx	900	g/GJ	540	1000	Guidebook (2006) chapter B216
TSP	261	g/GJ	130	400	US EPA, 1998
PM10	225	g/GJ	113	338	Tivari et al., 2012
PM2.5	201	g/GJ	100	300	Tivari et al., 2012
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	200	mg/GJ	60	240	Guidebook (2006) chapter B216
Cd	3	mg/GJ	0.6	3.6	Guidebook (2006) chapter B216
Hg	6	mg/GJ	3	7.2	Guidebook (2006) chapter B216
As	5	mg/GJ	0.9	6	Guidebook (2006) chapter B216
Cr	15	mg/GJ	6	18	Guidebook (2006) chapter B216
Cu	30	mg/GJ	12	36	Guidebook (2006) chapter B216
Ni	20	mg/GJ	6	24	Guidebook (2006) chapter B216
Se	2	mg/GJ	1.2	2.4	Guidebook (2006) chapter B216
Zn	300	mg/GJ	120	360	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	300	1200	Guidebook (2006) chapter B216
Benzo(a)pyrene	270	mg/GJ	150	324	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	250	mg/GJ	150	480	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	60	180	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	90	mg/GJ	54	144	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Table 3-17 Tier 2 emission factors for source category 1.A.4.b.i, conventional stoves burning wood and similar wood waste [3)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood and similar wood waste				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Conventional stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	50	g/GJ	30	150	Pettersson et al. (2011)
CO	4000	g/GJ	1000	10000	Pettersson et al. (2011) and Goncalves et al. (2012)
NMVOC	600	g/GJ	20	3000	Pettersson et al. (2011)
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	70	g/GJ	35	140	Roe et al. (2004)
TSP	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM10	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM2.5	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) [1)]
BC	10	% of $PM_{2.5}$	2	20	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989)
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	µg/GJ	0.006	0.6	Hedman et al. (2006) [2)]
PCDD/F	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)
Benzo(a)pyrene	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	71	mg/GJ	7	710	
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)

1) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
2) Assumed equal to conventional boilers.
3) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-18 Tier 2 emission factors for source category 1.A.4.b.i, conventional boilers < 50 kW burning wood and similar wood waste [6)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood and similar wood waste				
SNAP (if applicable)	020202	Residential plants, combustion plants < 50 MW (boilers)			
Technologies/Practices	Conventional boilers < 50 kWth				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	80	g/GJ	30	150	Pettersson et al. (2011)
CO	4000	g/GJ	500	10000	Johansson et al. (2003) [1)]
NMVOC	350	g/GJ	100	2000	Johansson et al. (2004) [2)]
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	74	g/GJ	37	148	Roe et al. (2004)
TSP	500	g/GJ	250	1000	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM10	480	g/GJ	240	960	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM2.5	470	g/GJ	235	940	Winther (2008) [3)] and Johansson et al. (2003) [4)]
BC	16	% of $PM_{2.5}$	5	30	Kupiainen & Klimont (2007) [5)]
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	µg/GJ	0.006	0.6	Hedman et al. (2006)
PCDD/F	550	I-Teq ng/GJ	20	2600	Hedman et al. (2006); Hübner et al. (2005)
Benzo(a)pyrene	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	71	mg/GJ	7	710	
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers have not been included.
2) Assumed old boilers.
3) Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers have not been included.
4) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
5) Based on the $PM_{2.5}$ emission factor 475 g/GJ
6) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-19 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning natural gas

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Natural Gas				
SNAP (if applicable)					
Technologies/Practices	Small (single household scale, capacity <=50 kWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, HCB, PCBs				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	42	g/GJ	25	59	DGC (2009)
CO	22	g/GJ	18	42	DGC (2009)
NMVOC	1.8	g/GJ	1.1	2.5	Italian Ministry for the Environment (2005)
SOx	0.30	g/GJ	0.18	0.42	DGC (2009)
TSP	0.20	g/GJ	0.12	0.28	BUWAL (2001)
PM10	0.20	g/GJ	0.12	0.28	BUWAL (2001)
PM2.5	0.20	g/GJ	0.12	0.28	*
BC	5.4	% of PM2.5	2.7	11	Hildemann et al. (1991), Muhlbaier (1981) **
Pb	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
Cd	0.00025	mg/GJ	0.00013	0.00050	Nielsen et al. (2013)
Hg	0.1	mg/GJ	0.0013	0.68	Nielsen et al. (2010)
As	0.12	mg/GJ	0.060	0.24	Nielsen et al. (2013)
Cr	0.00076	mg/GJ	0.00038	0.0015	Nielsen et al. (2013)
Cu	0.000076	mg/GJ	0.000038	0.00015	Nielsen et al. (2013)
Ni	0.00051	mg/GJ	0.00026	0.0010	Nielsen et al. (2013)
Se	0.011	mg/GJ	0.0038	0.011	US EPA (1998)
Zn	0.0015	mg/GJ	0.0008	0.003	Nielsen et al. (2013)
PCDD/F	1.5	ng I-TEQ/GJ	0.80	2.3	UNEP (2005)
Benzo(a)pyrene	0.56	ug/GJ	0.19	0.56	US EPA (1998)
Benzo(b)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Benzo(k)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Indeno(1,2,3-cd)pyrene	0.84	ug/GJ	0.28	0.84	US EPA (1998)

* assumption: EF(PM10) = EF(PM2.5)
** average of EFs from the listed references

Table 3-20 Tier 2 emission factors for source category 1.A.4.b.i, stoves burning liquid fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	**Gas oil**				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	34	g/GJ	20	48	UBA (2008)
CO	111	g/GJ	67	155	UBA (2008)
NMVOC	1.2	g/GJ	0.7	1.7	UBA (2008)
SO2	60	g/GJ	36	84	UBA (2008)
TSP	2.2	g/GJ	1.3	3.1	UBA (2008)
PM10	2.2	g/GJ	1.3	3.1	UBA (2008)
PM2.5	2.2	g/GJ	1.3	3.1	UBA (2008)
BC	*13*	*% of PM2.5*	*7.5*	*26*	*Bond et al. (2004)*
Pb	0.012	mg/GJ	0.006	0.024	Pulles et al. (2012)
Cd	0.001	mg/GJ	0.00025	0.001	Pulles et al. (2012)
Hg	0.12	mg/GJ	0.03	0.12	Pulles et al. (2012)
As	0.002	mg/GJ	0.0005	0.002	Pulles et al. (2012)
Cr	0.2	mg/GJ	0.1	0.40	Pulles et al. (2012)
Cu	0.13	mg/GJ	0.065	0.26	Pulles et al. (2012)
Ni	0.005	mg/GJ	0.0025	0.01	Pulles et al. (2012)
Se	*0.002*	*mg/GJ*	*0.0005*	*0.002*	*Pulles et al. (2012)*
Zn	0.42	mg/GJ	0.21	0.84	Pulles et al. (2012)
PCDD/F	10	ng I-TEQ/GJ	2	50	UNEP (2005)
Benzo(a)pyrene	80	ug/GJ	16	120	Berdowski et al. (1995)
Benzo(b)fluoranthene	40	ug/GJ	8	60	Berdowski et al. (1995)
Benzo(k)fluoranthene	70	ug/GJ	14	105	Berdowski et al. (1995)
Indeno(1,2,3-cd)pyrene	160	ug/GJ	32	240	Berdowski et al. (1995)

Table 3-21 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning liquid fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	**Gas oil**				
SNAP (if applicable)					
Technologies/Practices	Small (single household scale, capacity <=50 kWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	69	g/GJ	41	97	Italian Ministry for the Environment (2005)
CO	3.7	g/GJ	2	5	Italian Ministry for the Environment (2005)
NMVOC	0.17	g/GJ	0,06	0,51	Italian Ministry for the Environment (2005)
SO2	79	g/GJ	47	111	Italian Ministry for the Environment (2005)
TSP	1.5	g/GJ	1	2	Italian Ministry for the Environment (2005)
PM10	1.5	g/GJ	1	2	*
PM2.5	1.5	g/GJ	1	2	*
BC	3.9	% of PM2.5	2	8	US EPA (2011)
Pb	0.012	mg/GJ	0.006	0.024	Pulles et al. (2012)
Cd	0.001	mg/GJ	0.0003	0.001	Pulles et al. (2012)
Hg	0.12	mg/GJ	0.03	0.12	Pulles et al. (2012)
As	0.002	mg/GJ	0.0005	0.002	Pulles et al. (2012)
Cr	0.2	mg/GJ	0.1	0.4	Pulles et al. (2012)
Cu	0.13	mg/GJ	0.065	0.26	Pulles et al. (2012)
Ni	0.005	mg/GJ	0.0025	0.01	Pulles et al. (2012)
Se	0.002	mg/GJ	0.0005	0.002	Pulles et al. (2012)
Zn	0.42	mg/GJ	0.21	0.84	Pulles et al. (2012)
PCDD/F	1.8	ng I-TEQ/GJ	0.4	9	Pfeiffer et al. (2000)
Benzo(a)pyrene	80	ug/GJ	16	120	Berdowski et al. (1995)
Benzo(b)fluoranthene	40	ug/GJ	8	60	Berdowski et al. (1995)
Benzo(k)fluoranthene	70	ug/GJ	14	105	Berdowski et al. (1995)
Indeno(1,2,3-cd)pyrene	160	ug/GJ	32	240	Berdowski et al. (1995)

* assumption: EF(TSP) = EF(PM10) = EF(PM2.5)

Table 3-22 Tier 2 emission factors for source category 1.A.4.b.i, advanced stoves burning coal fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Coal Fuels				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Advanced coal combustion techniques <1MWth - Advanced stove				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	150	g/GJ	50	200	Guidebook (2006) chapter B216
CO	2000	g/GJ	200	3000	Guidebook (2006) chapter B216
NMVOC	300	g/GJ	20	400	Guidebook (2006) chapter B216
SOx	450	g/GJ	300	900	Guidebook (2006) chapter B216
TSP	250	g/GJ	80	260	Guidebook (2006) chapter B216
PM10	240	g/GJ	76	250	Guidebook (2006) chapter B216
PM2.5	220	g/GJ	72	230	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	80	200	Guidebook (2006) chapter B216
Cd	1	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Hg	5	mg/GJ	3	9	Guidebook (2006) chapter B216
As	1.5	mg/GJ	1	5	Guidebook (2006) chapter B216
Cr	10	mg/GJ	5	15	Guidebook (2006) chapter B216
Cu	15	mg/GJ	10	30	Guidebook (2006) chapter B216
Ni	10	mg/GJ	5	20	Guidebook (2006) chapter B216
Se	2	mg/GJ	1	2.4	Guidebook (2006) chapter B216
Zn	200	mg/GJ	120	300	Guidebook (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	40	600	Guidebook (2006) chapter B216
Benzo(a)pyrene	150	mg/GJ	13	180	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	180	mg/GJ	17	200	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	8	150	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	80	mg/GJ	6	100	Guidebook (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:

450 g/GJ of sulphur dioxide is equivalent to 0.6 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash value of 0.1.

Table 3-23 Tier 2 emission factors for source category 1.A.4.b.i, energy efficient stoves burning wood [6)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Energy efficient stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	80	g/GJ	30	150	Pettersson et al. (2011) [1)]
CO	4000	g/GJ	500	10000	Johansson et al. (2003) [2)]
NMVOC	350	g/GJ	100	2000	Johansson et al. (2004) [2)]
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	37	g/GJ	18	74	Roe et al. (2004) [3)]
TSP	400	g/GJ	200	800	Glasius et al. (2005) [4) 5)]
PM10	380	g/GJ	290	760	Glasius et al. (2005) [4) 5)]
PM2.5	370	g/GJ	285	740	Glasius et al. (2005) [4) 5)]
BC	16	% of $PM_{2.5}$	5	30	Kupiainen & Klimont (2007) [2)]
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCB	0.03	µg/GJ	0.003	0.3	Hedman et al. (2006)
PCDD/F	250	ng I-TEQ/GJ	20	2600	Hedman et al. (2006)
Benzo(a)pyrene	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	71	mg/GJ	7	710	
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional stoves.
2) Assumed equal to conventional boilers.
3) Assumed low emitting.
4) Wood stoves < 3 years old.
5) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
6) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-24 Tier 2 emission factors for source category 1.A.4.b.i, advanced / ecolabelled stoves and boilers burning wood [3)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Advanced / ecolabelled stoves and boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	95	g/GJ	50	150	Pettersson et al. (2011)
CO	2000	g/GJ	500	5000	Johansson et al. (2003)
NMVOC	250	g/GJ	20	500	(2009 update of the Guidebook)
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	37	g/GJ	18	74	Roe et al. (2004) [1)]
TSP	100	g/GJ	20	250	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
PM10	95	g/GJ	19	238	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
PM2.5	93	g/GJ	19	233	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
BC	28	% of $PM_{2.5}$	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011)
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCB	0.007	μg/GJ	0.0007	0.07	Hedman et al. (2006)
PCDD/F	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	16	mg/GJ	8	32	
Benzo(k)fluoranthene	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	4	mg/GJ	2	8	
HCB	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Assumed low emitting.
2) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-25 Tier 2 emission factors for source category 1.A.4.b.i, pellet stoves and boilers burning wood pellets [1)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Wood				
SNAP (if applicable)	020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices	Pellet stoves and boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	80	g/GJ	50	200	Pettersson et al. (2011)
CO	300	g/GJ	10	2500	Schmidl et al. (2011) and Johansson et al. (2004)
NMVOC	10	g/GJ	1	30	Johansson et al. (2004) and Boman et al. (2011)
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	12	g/GJ	6	24	Roe et al. (2004)
TSP	31	g/GJ	10	50	Boman et al. (2011) [1)]
PM10	29	g/GJ	10	48	Boman et al. (2011) [1)]
PM2.5	29	g/GJ	9	47	Boman et al. (2011) [1)]
BC	15	% of $PM_{2.5}$	6	39	Schmidl et al. (2011)
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCB	0.01	µg/GJ	0.001	0.1	Hedman et al. (2006)
PCDD/F	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006) [2)]
Benzo(a)pyrene	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	16	mg/GJ	8	32	
Benzo(k)fluoranthene	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	4	mg/GJ	2	8	
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)

1) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

3.3.2.2 Non-residential heating (1.A.4.a, 1.A.4.c, 1.A.5.a)

Table 3-26 Tier 2 emission factors for non-residential sources, medium-size (> 50 kWth to ≤ 1 MWth) boilers burning coal fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Coal Fuels				
SNAP (if applicable)					
Technologies/Practices	Medium size (>50 kWth to <=1 MWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	160	g/GJ	150	200	Guidebook (2006) chapter B216
CO	2000	g/GJ	200	3000	Guidebook (2006) chapter B216
NMVOC	200	g/GJ	20	300	Guidebook (2006) chapter B216
SOx	900	g/GJ	450	1000	Guidebook (2006) chapter B216
TSP	200	g/GJ	80	250	Guidebook (2006) chapter B216
PM10	190	g/GJ	76	240	Guidebook (2006) chapter B216
PM2.5	170	g/GJ	72	220	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	200	mg/GJ	80	300	Guidebook (2006) chapter B216
Cd	3	mg/GJ	1	5	Guidebook (2006) chapter B216
Hg	7	mg/GJ	5	9	Guidebook (2006) chapter B216
As	5	mg/GJ	0.5	8	Guidebook (2006) chapter B216
Cr	15	mg/GJ	1	20	Guidebook (2006) chapter B216
Cu	30	mg/GJ	8	50	Guidebook (2006) chapter B216
Ni	20	mg/GJ	2	30	Guidebook (2006) chapter B216
Se	2	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Zn	300	mg/GJ	100	500	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	400	ng I-TEQ/GJ	40	500	Guidebook (2006) chapter B216
Benzo(a)pyrene	100	mg/GJ	13	150	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	130	mg/GJ	17	180	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	50	mg/GJ	8	100	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	40	mg/GJ	6	80	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash as value of 0.1.

Table 3-27 Tier 2 emission factors for non-residential sources, medium-size (> 1 MWth to ≤ 50 MWth) boilers burning coal fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Coal Fuels				
SNAP (if applicable)					
Technologies/Practices	Medium size (>1 MWth to <=50 MWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	180	g/GJ	150	200	Guidebook (2006) chapter B216
CO	200	g/GJ	150	3000	Guidebook (2006) chapter B216
NMVOC	20	g/GJ	10	300	Guidebook (2006) chapter B216
SOx	900	g/GJ	450	1000	Guidebook (2006) chapter B216
TSP	80	g/GJ	70	250	Guidebook (2006) chapter B216
PM10	76	g/GJ	60	240	Guidebook (2006) chapter B216
PM2.5	72	g/GJ	60	220	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	80	200	Guidebook (2006) chapter B216
Cd	1	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Hg	9	mg/GJ	5	10	Guidebook (2006) chapter B216
As	4	mg/GJ	0.5	5	Guidebook (2006) chapter B216
Cr	15	mg/GJ	1	20	Guidebook (2006) chapter B216
Cu	10	mg/GJ	8	30	Guidebook (2006) chapter B216
Ni	10	mg/GJ	2	20	Guidebook (2006) chapter B216
Se	2	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Zn	150	mg/GJ	100	300	Guidebook (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	100	ng I-TEQ/GJ	40	500	Guidebook (2006) chapter B216
Benzo(a)pyrene	13	mg/GJ	10	150	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	17	mg/GJ	10	180	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	9	mg/GJ	8	100	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	6	mg/GJ	5	80	Guidebook (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash as value of 0.1.

Table 3-28 Tier 2 emission factors for non-residential sources, manual boilers burning coal fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Coal Fuels				
SNAP (if applicable)					
Technologies/Practices	Advanced coal combustion techniques <1MWth - Manual Boiler				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	200	g/GJ	150	300	Guidebook (2006) chapter B216
CO	1500	g/GJ	200	3000	Guidebook (2006) chapter B216
NMVOC	100	g/GJ	20	300	Guidebook (2006) chapter B216
SOx	450	g/GJ	300	900	Guidebook (2006) chapter B216
TSP	150	g/GJ	80	250	Guidebook (2006) chapter B216
PM10	140	g/GJ	76	240	Guidebook (2006) chapter B216
PM2.5	130	g/GJ	72	220	Guidebook (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	150	mg/GJ	80	200	Guidebook (2006) chapter B216
Cd	2	mg/GJ	1	3	Guidebook (2006) chapter B216
Hg	6	mg/GJ	5	9	Guidebook (2006) chapter B216
As	4	mg/GJ	0.5	5	Guidebook (2006) chapter B216
Cr	10	mg/GJ	1	15	Guidebook (2006) chapter B216
Cu	15	mg/GJ	8	30	Guidebook (2006) chapter B216
Ni	15	mg/GJ	2	20	Guidebook (2006) chapter B216
Se	2	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Zn	200	mg/GJ	100	300	Guidebook (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	200	ng I-TEQ/GJ	40	500	Guidebook (2006) chapter B216
Benzo(a)pyrene	90	mg/GJ	13	150	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	110	mg/GJ	17	180	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	50	mg/GJ	8	100	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	40	mg/GJ	6	80	Guidebook (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
450 g/GJ of sulphur dioxide corresponds to 0.6 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash as value of 0.1.

Table 3-29 Tier 2 emission factors for non-residential sources, automatic boilers burning coal fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Coal Fuels				
SNAP (if applicable)					
Technologies/Practices	Advanced coal combustion techniques <1MWth - Automatic Boiler				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	165	g/GJ	100	250	US EPA, 1998
CO	350	g/GJ	175	700	Thistlethwaite, 2001
NMVOC	23	g/GJ	10	100	US EPA, 1998
SOx	450	g/GJ	400	1000	Guidebook (2006) chapter B216
TSP	82	g/GJ	41	164	Thistlethwaite, 2001
PM10	78	g/GJ	39	156	Struschka et al., 2008
PM2.5	70	g/GJ	35	140	Struschka et al., 2008
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	167	mg/GJ	83	335	Thistlethwaite, 2001
Cd	1	mg/GJ	0.5	1.5	Thistlethwaite, 2001
Hg	16	mg/GJ	8	32	Thistlethwaite, 2001
As	46	mg/GJ	4.6	92	Thistlethwaite, 2001
Cr	6	mg/GJ	2	18	Thistlethwaite, 2001
Cu	192	mg/GJ	19.2	400	Thistlethwaite, 2001
Ni	37	mg/GJ	3.7	74	Thistlethwaite, 2001
Se	17	mg/GJ	1.7	34	Thistlethwaite, 2001
Zn	201	mg/GJ	50	500	Thistlethwaite, 2001
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	40	ng I-TEQ/GJ	20	500	Guidebook (2006) chapter B216
Benzo(a)pyrene	0.079	mg/GJ	0.008	0.8	Thistlethwaite, 2001
Benzo(b)fluoranthene	1.244	mg/GJ	0.12	12.4	Thistlethwaite, 2001
Benzo(k)fluoranthene	0.845	mg/GJ	0.08	8.5	Thistlethwaite, 2001
Indeno(1,2,3-cd)pyrene	0.617	mg/GJ	0.06	6.2	Thistlethwaite, 2001
HCB	0.62	μg/GJ	0.31	1.2	Guidebook (2006) chapter B216

Note:
450 g/GJ of sulphur dioxide corresponds to 0.6 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash as value of 0.1.

Table 3-30 Tier 2 emission factors for non-residential sources, manual boilers burning wood [4)]

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Wood				
SNAP (if applicable)	020100 020300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices	Wood combustion <1MW - Manual Boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated					
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NOx	91	g/GJ	20	120	Lundgren et al. (2004) [1)]
CO	570	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 kW
NMVOC	300	g/GJ	5	500	Naturvårdsverket, Sweden
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH3	37	g/GJ	18	74	Roe et al. (2004) [1)]
TSP	150	g/GJ	75	300	Naturvårdsverket, Sweden
PM10	143	g/GJ	71	285	Naturvårdsverket, Sweden [2)]
PM2.5	140	g/GJ	70	279	Naturvårdsverket, Sweden [2)]
BC	28	% of $PM_{2.5}$	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) [3)]
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCB	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006)
PCDD/F	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	16	mg/GJ	8	32	
Benzo(k)fluoranthene	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	4	mg/GJ	2	8	
HCB	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to low emitting wood stoves
2) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3) Assumed equal to advanced/ecolabelled residential boilers
4) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-31 Tier 2 emission factors for non-residential sources, automatic boilers burning wood [5)]

Tier 2 emission factors						
	Code	Name				
NFR source category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)				
Fuel	Wood					
SNAP (if applicable)	020100 020300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture				
Technologies/Practices	Wood combustion <1MW - Automatic Boilers					
Region or regional conditions	NA					
Abatement technologies	NA					
Not applicable	HCH					
Not estimated						
Pollutant	Value	Unit	95 % confidence interval		Reference	
			Lower	Upper		
NOx	91	g/GJ	20	120	Lundgren et al. (2004) [1)]	
CO	300	g/GJ	50	4000	German test standard for 500 kW-1MW boilers; Danish legislation (Luftvejledningen)	
NMVOC	12	g/GJ	5	300	Johansson et al. (2004) [1)]	
SO2	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9	
NH3	37	g/GJ	18	74	Roe et al. (2004) [2)]	
TSP	36	g/GJ	18	72	Johansson et al. (2004)	
PM10	34	g/GJ	17	68	Johansson et al. (2004) [3)]	
PM2.5	33	g/GJ	17	67	Johansson et al. (2004) [3)]	
BC	15	% of $PM_{2.5}$	6	39	Schmidl et al. (2011) [4)]	
Pb	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)	
Cd	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)	
Hg	0.56	mg/GJ	0.2	1	Struschka et al. (2008)	
As	0.19	mg/GJ	0.05	12	Struschka et al. (2008)	
Cr	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)	
Cu	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)	
Ni	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)	
Se	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)	
Zn	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)	
PCB	0.007	µg/GJ	0.0007	0.07	Hedman et al. (2006)	
PCDD/F	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)	
Benzo(a)pyrene	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)	
Benzo(b)fluoranthene	16	mg/GJ	8	32		
Benzo(k)fluoranthene	5	mg/GJ	2	10		
Indeno(1,2,3-cd)pyrene	4	mg/GJ	2	8		
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)	

1) Data for modern boilers
2) Assumed equal to low emitting wood stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
4) Assumed equal to residential pellet boilers
5) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Table 3-32 Tier 2 emission factors for non-residential sources, medium-sized (> 50 kWth to ≤ 1 MWth) boilers burning natural gas

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Natural Gas				
SNAP (if applicable)					
Technologies/Practices	Medium size (>50 kWth to <=1 MWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	73	g/GJ	44	103	Italian Ministry for the Environment (2005)
CO	24	g/GJ	18	42	Italian Ministry for the Environment (2005)
NMVOC	0.36	g/GJ	0.2	0.5	UBA (2008)
SOx	1.4	g/GJ	0.83	1.95	Italian Ministry for the Environment (2005)
TSP	0.45	g/GJ	0.27	0.63	Italian Ministry for the Environment (2005)
PM10	0.45	g/GJ	0.27	0.63	*
PM2.5	0.45	g/GJ	0.27	0.63	*
BC	5.4	% of PM2.5	2.7	11	Hildemann et al. (1991), Muhlbaier (1981) **
Pb	0.0015	mg/GJ	0.00075	0.003	Nielsen et al. (2013)
Cd	0.00025	mg/GJ	0.00013	0.0005	Nielsen et al. (2013)
Hg	0.1	mg/GJ	0.0013	0.68	Nielsen et al. (2010)
As	0.12	mg/GJ	0.060	0.24	Nielsen et al. (2013)
Cr	0.00076	mg/GJ	0.00038	0.0015	Nielsen et al. (2013)
Cu	0.000076	mg/GJ	0.000038	0.00015	Nielsen et al. (2013)
Ni	0.00051	mg/GJ	0.00026	0.001	Nielsen et al. (2013)
Se	0.011	mg/GJ	0.0037	0.011	US EPA (1998)
Zn	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
PCDD/F	0.5	ng I-TEQ/GJ	0.3	0.8	UNEP (2005)
Benzo(a)pyrene	0.56	ug/GJ	0.19	0.56	US EPA (1998)
Benzo(b)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Benzo(k)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Indeno(1,2,3-cd)pyrene	0.84	ug/GJ	0.28	0.84	US EPA (1998)

* assumption: EF(TSP) = EF(PM10) = EF(PM2.5)
** average of EFs from the listed references

Table 3-33 Tier 2 emission factors for non-residential sources, medium sized (> 1 MWth to ≤ 50 MWth) boilers burning natural gas

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel	Natural Gas				
SNAP (if applicable)					
Technologies/Practices	Medium size (>1 MWth to <=50 MWth) boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	40	g/GJ	30	55	DGC (2009)
CO	30	g/GJ	15	30	DGC (2009)
NMVOC	2	g/GJ	1.2	2.8	DGC (2009)
SOx	0.3	g/GJ	0.2	0.4	DGC (2009)
TSP	0.45	g/GJ	0.27	0.63	Italian Ministry for the Environment (2005)
PM10	0.45	g/GJ	0.27	0.63	*
PM2.5	0.45	g/GJ	0.27	0.63	*
BC	5.4	% of PM2.5	2.7	11	Hildemann et al. (1991), Muhlbaier (1981) **
Pb	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
Cd	0.00025	mg/GJ	0.00013	0.00050	Nielsen et al. (2013)
Hg	0.1	mg/GJ	0.0013	0.68	Nielsen et al. (2010)
As	0.12	mg/GJ	0.060	0.24	Nielsen et al. (2013)
Cr	0.00076	mg/GJ	0.00038	0.0015	Nielsen et al. (2013)
Cu	0.000076	mg/GJ	0.000038	0.00015	Nielsen et al. (2013)
Ni	0.00051	mg/GJ	0.00026	0.0010	Nielsen et al. (2013)
Se	0.011	mg/GJ	0.0037	0.011	US EPA (1998)
Zn	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
PCDD/F	0.5	ng I-TEQ/GJ	0.3	0.8	UNEP (2005)
Benzo(a)pyrene	0.56	ug/GJ	0.19	0.56	US EPA (1998)
Benzo(b)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Benzo(k)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Indeno(1,2,3-cd)pyrene	0.84	ug/GJ	0.28	0.84	US EPA (1998)

* assumption: EF(TSP) = EF(PM10) = EF(PM2.5)

** average of EFs from the listed references

Table 3-34 Tier 2 emission factors for non-residential sources, gas turbines burning natural gas

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.b.i 1.A.4.c.i	Commercial / institutional: stationary Residential plants Stationary			
Fuel	Natural Gas				
SNAP (if applicable)	020104 020203 020303	Comm./instit. - Stationary gas turbines Residential - Gas turbines Agri./forest/aqua. - Stationary gas turbines			
Technologies/Practices	Gas Turbines				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	48	g/GJ	29	67	Nielsen et al. (2010)
CO	4.8	g/GJ	1.8	42	Nielsen et al. (2010)
NMVOC	1.6	g/GJ	1.0	2.2	Nielsen et al. (2010)
SOx	0.5	g/GJ	0.30	0.70	BUWAL (2001)
TSP	0.2	g/GJ	0.12	0.28	BUWAL (2001)
PM_{10}	0.2	g/GJ	0.12	0.28	BUWAL (2001)
$PM_{2.5}$	0.2	g/GJ	0.12	0.28	*
BC	2.5	% of PM2.5	1.5	3.5	England et al. (2004), Wien et al. (2004) and US EPA (2011)
Pb	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
Cd	0.00025	mg/GJ	0.00013	0.00050	Nielsen et al. (2013)
Hg	0.1	mg/GJ	0.0013	0.68	Nielsen et al. (2010)
As	0.12	mg/GJ	0.060	0.24	Nielsen et al. (2013)
Cr	0.00076	mg/GJ	0.00038	0.0015	Nielsen et al. (2013)
Cu	0.000076	mg/GJ	0.000038	0.00015	Nielsen et al. (2013)
Ni	0.00051	mg/GJ	0.00026	0.0010	Nielsen et al. (2013)
Se	0.011	mg/GJ	0.0038	0.011	US EPA (1998)
Zn	0.0015	mg/GJ	0.00075	0.0030	Nielsen et al. (2013)
PCDD/F	0.5	ng I-TEQ/GJ	0.3	0.8	UNEP (2005)
Benzo(a)pyrene	0.56	ug/GJ	0.19	0.56	US EPA (1998)
Benzo(b)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Benzo(k)fluoranthene	0.84	ug/GJ	0.28	0.84	US EPA (1998)
Indeno(1,2,3-cd)pyrene	0.84	ug/GJ	0.28	0.84	US EPA (1998)

* assumption: EF(PM10) = EF(PM2.5)

Table 3-35 Tier 2 emission factors for non-residential sources, gas turbines burning gas oil

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.b.i 1.A.4.c.i	Commercial / institutional: stationary Residential plants Stationary			
Fuel	Gas Oil				
SNAP (if applicable)	020104 020203 020303	Comm./instit. - Stationary gas turbines Residential - Gas turbines Agri./forest/aqua. - Stationary gas turbines			
Technologies/Practices	Gas Turbines				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	83	g/GJ	50	116	Nielsen et al. (2010)
CO	2.6	g/GJ	2	4	Nielsen et al. (2010)
NMVOC	0.18	g/GJ	0.018	1.8	US EPA (2000)
SO_x	46	g/GJ	28	65	*
TSP	9.5	g/GJ	6	13	Nielsen et al. (2010)
PM10	9.5	g/GJ	6	13	**
PM2.5	9.5	g/GJ	6	13	**
BC	33.5	% of PM2.5	20.1	46.9	Hildemann et al. (1991) and Bond et al. (2006)
Pb	0.012	mg/GJ	0.006	0.024	Pulles et al. (2012)
Cd	0.001	mg/GJ	0.00025	0.001	Pulles et al. (2012)
Hg	0.12	mg/GJ	0.03	0.12	Pulles et al. (2012)
As	0.002	mg/GJ	0.0005	0.002	Pulles et al. (2012)
Cr	0.2	mg/GJ	0.1	0.4	Pulles et al. (2012)
Cu	0.13	mg/GJ	0.065	0.26	Pulles et al. (2012)
Ni	0.005	mg/GJ	0.0025	0.01	Pulles et al. (2012)
Se	0.002	mg/GJ	0.0005	0.002	Pulles et al. (2012)
Zn	0.42	mg/GJ	0.21	0.84	Pulles et al. (2012)
PCDD/F	1.8	ng I-TEQ/GJ	0.4	9	Pfeiffer et al. (2000)

* estimate based on 0.1 % S and LHV = 43.33 TJ/1000 tonnes
** assumption: EF(TSP) = EF(PM10) = EF(PM2.5)

Table 3-36 Tier 2 emission factors for non-residential sources, reciprocating engines burning gas fuels

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.b.i 1.A.4.c.i	Commercial / institutional: stationary Residential plants Stationary			
Fuel	**Natural gas**				
SNAP (if applicable)	020105 020204 020304	Comm./instit. - Stationary engines Residential - Stationary engines Agri./forest/aqua. - Stationary engines			
Technologies/Practices	Stationary reciprocating engines				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH3, PCB, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	135	g/GJ	81	189	Nielsen et al. (2010)
CO	56	g/GJ	34	78	Nielsen et al. (2010)
NMVOC	89	g/GJ	53	125	Nielsen et al. (2010)
SO_x	0.5	g/GJ	0.05	1	BUWAL (2001)
TSP	2	g/GJ	1	3	BUWAL (2001)
PM10	2	g/GJ	1	3	BUWAL (2001)
PM2.5	2	g/GJ	1	3	*
BC	2.5	% of PM2.5	1.5	3.5	England et al. (2004), Wien et al. (2004) and US EPA (2011)
Pb	0.04	mg/GJ	0.02	0.08	Nielsen et al. (2010)
Cd	0.003	mg/GJ	0.00075	0.003	Nielsen et al. (2010)
Hg	0.1	mg/GJ	0.025	0.1	Nielsen et al. (2010)
As	0.05	mg/GJ	0.0125	0.05	Nielsen et al. (2010)
Cr	0.05	mg/GJ	0.025	0.1	Nielsen et al. (2010)
Cu	0.01	mg/GJ	0.005	0.02	Nielsen et al. (2010)
Ni	0.05	mg/GJ	0.025	0.1	Nielsen et al. (2010)
Se	0.2	mg/GJ	0.05	0.2	Nielsen et al. (2010)
Zn	2.9	mg/GJ	1.5	5.8	Nielsen et al. (2010)
PCDD/F	0.57	ng I-TEQ/GJ	0.11	2.9	Nielsen et al. (2010)
Benzo(a)pyrene	1.2	ug/GJ	0.24	6	Nielsen et al. (2010)
Benzo(b)fluoranthene	9	ug/GJ	1.8	45	Nielsen et al. (2010)
Benzo(k)fluoranthene	1.7	ug/GJ	0.34	8.5	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	1.8	ug/GJ	0.36	9	Nielsen et al. (2010)

** assumption: EF(PM10) = EF(PM2.5)

Table 3-37 Tier 2 emission factors for non-residential sources, reciprocating engines burning gas oil

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.4.a.i 1.A.4.b.i 1.A.4.c.i	Commercial / institutional: stationary Residential plants Stationary			
Fuel	Gas Oil				
SNAP (if applicable)	020105 020204 020304	Comm./instit. - Stationary engines Residential - Stationary engines Agri./forest/aqua. - Stationary engines			
Technologies/Practices	Reciprocating Engines				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	HCH				
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	942	g/GJ	565	1319	Nielsen et al. (2010)
CO	130	g/GJ	78	182	Nielsen et al. (2010)
NMVOC	50	g/GJ	30	70	BUWAL (2001)
SO_x	48	g/GJ	29	67	BUWAL (2001)
TSP	30	g/GJ	18	42	BUWAL (2001)
PM10	30	g/GJ	18	42	BUWAL (2001)
PM2.5	30	g/GJ	18	42	*
BC	78	% of PM2.5	47	109	Hernandez et al. (2004)
Pb	0.15	mg/GJ	0.075	0.3	Nielsen et al. (2010)
Cd	0.01	mg/GJ	0.005	0.02	Nielsen et al. (2010)
Hg	0.11	mg/GJ	0.055	0.22	Nielsen et al. (2010)
As	0.06	mg/GJ	0.03	0.12	Nielsen et al. (2010)
Cr	0.2	mg/GJ	0.1	0.4	Nielsen et al. (2010)
Cu	0.3	mg/GJ	0.15	0.6	Nielsen et al. (2010)
Ni	0.01	mg/GJ	0.005	0.02	Nielsen et al. (2010)
Se	0.22	mg/GJ	0.11	0.44	Nielsen et al. (2010)
Zn	58	mg/GJ	29	116	Nielsen et al. (2010)
PCB	0.13	ng/GJ	0.013	0.13	Nielsen et al. (2010)
PCDD/F	0.99	ng I-TEQ/GJ	0.20	5.0	Nielsen et al. (2010)
Benzo(a)pyrene	1.9	ug/GJ	0.19	1.9	Nielsen et al. (2010)
Benzo(b)fluoranthene	15	ug/GJ	1.5	15	Nielsen et al. (2010)
Benzo(k)fluoranthene	1.7	ug/GJ	0.17	1.7	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	1.5	ug/GJ	0.15	1.5	Nielsen et al. (2010)
HCB	0.22	ug/GJ	0.022	0.22	Nielsen et al. (2010)

* assumption: EF(PM10) = EF(PM2.5)

3.3.3 Abatement

A limited number of add-on technologies exist that are aimed at reducing the emissions of primarily PM in these sectors. The resulting emission can be calculated by extending the technology-specific emission factor with an abated emission factor as given in the formula:

$$EF_{technology,abated} = (1 - \eta_{abatement}) \times EF_{technology,unabated} \quad (5)$$

However, as abatement technology is rarely specified in terms of efficiency, it may be more relevant to develop abated emission factors from the final emission concentrations achieved using abatement.

Guidance on estimating emission factors from concentrations is provided at subsection 4.3 of the present chapter.

3.3.4 Activity data

In most cases the statistical information includes data on annual fuel consumption in the relevant activities. However, data on use of fuels in different technologies may be limited. To fill these data gaps the following sources could be used:

- information from the fuel suppliers and individual companies
- energy conservation/climate change mitigation studies for relevant sectors
- residential, commercial/institutional and agriculture sector surveys
- energy demand modelling.

The data from different sources should be compared, taking into account their inherent uncertainties in order to obtain the best assessment of appliance population and fuel use. To improve reliability of the activity data, appropriate efforts should be made in order to encourage the institution responsible for national energy statistics to report the fuel consumption at the adequate level of sectoral disaggregation in their regular activity.

Also, when data on fuel consumption are provided at an appropriate level of sectoral split, they should be checked for possible anomalies. Wood and other types of biomass consumption (in some cases also gas oil consumption) in the residential sector requires particular consideration.

For example, the self-supply and direct purchase of the wood from farmers might not be taken into account when energy statistics are based mainly on the data obtained from the fuel suppliers. This could lead to a significant underestimation of the wood consumption, especially in the countries with abundant wood supplies and greater share of heating with stoves and small solid fuel boilers. In that case, the data on wood consumption should be adjusted. Consultation with the forestry experts and/or energy demand modelling is recommended.

The Tier 2 methodology requires further allocation of the fuel consumed according to the installation types. This is particularly relevant to the residential sector where, for example, the proportion of solid fuel burned in traditional low technology appliances is important to understand the significance of the emissions. The data needed are generally not available in statistics reports. In most cases the inventorying agency would have to use surrogate data to assess the activity data at the required level of desegregation. National approaches have to be developed depending on the availability and quality of surrogate data. Some examples of surrogate data sources are:

- residential, commercial/institutional and agriculture sector surveys
- energy conservation/climate change mitigation studies for relevant sectors
- energy demand modelling
- information from the fuel suppliers
- information from producers and sellers of heating appliances
- information from chimney sweeping organisations.

Particularly in the case of the residential sector it should be emphasised that the surveys have to be based on a representative sample. In some countries the means of heating of the households are regionally very inhomogeneous with a significantly greater share of solid-fuel stoves and boilers in traditionally coal mining regions and in some rural areas. Additional data could be obtained from the chimney-sweeper organisations and from environmental inspectorates, particularly for the commercial-institutional sector.

As described in Broderick & Houck (2003), a number of circumstances should be considered when preparing and conducting a survey study of residential wood consumption. More technical issues related to surveys are provided in Eastern Research Group (2000), which provides a detailed description on issues to be considered, when conducting a survey, e.g. survey techniques, sample size, elaboration of questions, handling of answers etc. In relation to residential wood consumption, it is important to include a clear definition of volume of wood, as a number of measures are used, e.g. loose volume of logs (logs thrown into e.g. a box), stacked volume of logs (around 70 % of loose volume) and stacked volume before cutting into logs. Further, it is important to include questions on type and technology of appliances. Age and certifications according to emission limits could be helpful information, as determination of appliance types is not simple, and homeowners might not be able to differentiate the types or have knowledge of the technology of their appliances. In both cases it might be beneficial to include drawings in the survey to assist both respondents and surveyors.

In order to estimate emissions from residential wood combustion it is necessary to include appliance population per installation type, to ensure use of appropriate emission factors. Sales statistics are valuable data sources for this purpose. Sales statistics from the past can be used to estimate the population of old appliances and statistics for more recent years can be used to incorporate substitution rates to newer appliances. Another or an additional approach is surveys, which can be used to estimate the appliance population on type level at the time of surveying. Sales statistics should be used to estimate substitution rates in order to make time series for the appliance population.

Another important source of data could be housing statistics. Within the scope of national census, the data on dwellings occupied by households are usually collected. Data on individual dwellings might include:

- number of residents,
- area of the dwelling,
- type of building (individual house, attached house, block of flats),

- construction year,
- primary (and secondary) heating source
- existence or not of central heating,
- central heating boiler in the flat or common for block of flats,fuels used for heating.

Dwelling statistics could be used to extrapolate results of the household survey or to perform detailed energy demand/emission modelling. Especially in the case where household emissions represent a key source or are of a great relevance due to local air quality, it is recommended to perform such an exercise. Detailed energy demand/emission modelling may be usually performed at local or regional level; however the extension to the national level does not pose significant additional requirements. To justify the additional effort required for energy demand/emission modelling of the households, the emission inventorying agency might find it appropriate to initiate a common project with other stakeholders, such as, for instance, agencies involved in energy conservation, climate change mitigation or energy supply.

Data from national or regional housing registers can be used to estimate the energy demand for households, based on e.g. area and construction year. National or regional models or statistics on residential energy consumption for space heating can be applied to estimate the residential heating demand from e.g. area and age of the dwellings.

Another approach to estimate the heating demand for different housing types, is to gather consumption data for other heating practices, e.g. district heating, and calculate a mean consumption for each housing type. The housing types should be in agreement with the types that can be identified in the national housing register. Also information on energy ratings could be included.

The Odyssee-Mure project provided data on heat consumption in residences in a number of European countries. Average heat consumption for residential space heating based on Odyssee (2012), are included in the table below and might be applied, if country specific data are not available.

Table 3-38. Energy consumption for residential space heating in selected European countries (Odyssee-Mure project, the Odyssee database (2012))

Party	Heat consumption for residential space heating *, MJ/m2
European Union	525.131
Austria	622.341
Belgium	896.896
Bulgaria	321.409
Croatia	416.823
Czech Rep.	654.534
Denmark	571.015
Estonia	693.783
Finland	746.278
France	567.273

Germany	633.611
Greece	430.970
Hungary	568.762
Ireland	534.639
Italy	342.077
Latvia	903.062
Lithuania	567.693
Netherlands	425.459
Poland	646.948
Portugal	55.049
Romania	663.094
Slovakia	509.279
Slovenia	658.428
Spain	211.285
Sweden	537.448
United Kingdom	558.961

To estimate the wood combustion in residential plants from the heating demand, it is necessary to include information on other heating sources in the dwellings. The price level of heating from different sources could be used as indicator for the proportion of the total heating demand, covered by the different heating sources. For example, if a dwelling is registered having both district heating and a wood stove, the share of the heating demand covered by residential wood combustion will depend on the price per energy unit of wood compared to district heating. The share of the different heating sources (wood and district heating in this example) will vary regionally according to variations between regions in the price for the different heating sources. As price levels, accessibility and consumer behaviour all affect the choice of heating source, surveys might be of great value to evaluate the share of the residential heating demand covered by wood combustion.

The table below propose RWC shares of total energy demand. It is good practice to apply country specific shares as both heating supply and demand vary significantly between countries. For example it should be considered, if the wood consumption, and thereby the share, is higher in countries or regions with large forest lands, where wood might be easily accessible.

Primary heating source	RWC share of heating demand
Wood	1.0
Expensive compared to wood	0.6
Similar price level as wood	0.5
Cheap compared to wood	0.2

Determining residential wood consumption is further complicated, as firing is not only due to the heating demand in dwellings but also for create cosy domesticity. The extent of wood firing for cosiness varies between countries and should be considered as it can induce an increased wood consumption. This might be examined through surveys.

3.4 Tier 3 emission modelling and use of facility data

Installation-specific emission estimation is not considered to be applicable for the activities detailed. However the Tier 3 methodology allows a modelling-based approach using more detailed appliance population data and applies more technology-specific emission factors — guidance on determining plant-specific emission factors is given in the Measurement Protocol. Relevant emission factors are also provided at Appendix A.

4 Data quality

4.1 Completeness

The potential for self-supply or other unrecorded fuel supply needs to be considered.

4.2 Avoiding double counting with other sectors

In cases where it is possible to split the emissions, it is good practice to do so. However, care must be taken that the emissions are not double counted.

4.3 Verification

4.3.1 Best Available Technique emission factors

The size of combustion appliance will generally fall below the threshold where guidance on BAT emission levels applies.

However, many countries apply emission controls on appliances in the size range considered and selected emission limit values are provided in the following sections. Details of the methodology applied to calculate emission factors from emission limits are provided in Appendix B.

4.3.2 Fuel sulphur content

For processes without SO_2 abatement, the sulphur content of the fuel provides a means to calculate the SO_2 emission factor.

$$EF_{SO2} = \frac{[S] \times 2 \times 1000}{100 \times CV}$$

where:

- EF_{SO2} is the SO_2 emission factor $g.GJ^{-1}$,
- [S] is the percent sulphur (w/w),
- CV is the net/inferior calorific value $GJ.kg^{-1}$,
- 2 is the ratio of the RMM of SO_2 to Sulphur.

This equation can be extended to include a factor for retention of SO_2 in ash.

Liquid fuels in the EC are subject to sulphur limits (EC SCOLF, 1999/2005) as summarised in Table 4-1. The SO_2 emission factors in Table 4-1 have been calculated assuming 100 % conversion of fuel sulphur and applying UK net calorific values for fuel oils (DUKES, 2007).

Table 4-1 Sulphur emission factors from oil sulphur limits

Fuel oil	Implementation date	Maximum sulphur content	SO_2 emission factor, $g.GJ^{-1}$	Comment
Heavy fuel oil	1.1.2003	1 %	485	Assumes net CV of 41.2 $GJ.tonne^{-1}$
Gas oil	Pre 1.1.2008	0.2 %	92	Assumes net CV of 43.4 $GJ.tonne^{-1}$
	Post 1.1.2008	0.1 %	46	

4.3.3 Residential and small (< 300 kW output) non residential solid fuel boilers

EN303 pt5 is a non-harmonised standard which incorporates emission 'classes' for CO, OGC (volatile organic compounds) and TSP. The emission factors associated with the emission concentrations are provided in Table 4-2.

Many countries operate type-approval schemes for residential coal and biomass appliances which apply TSP emission limits on solid fuel appliances and these can be developed into emission factors. Ecolabelling schemes for gas appliances may include labelling for NOx emissions.

The following emission factors are calculated using procedure described in Appendix B.

Table 4-2 EN303 Pt 5 emission classes as emission factors

Fuel	Fuel	Appliance	Emission concentration, mg m^{-3} at STP (0 ºC, 101.3 kPa), dry and 10 % O_2								
feed	type	output	CO			'OGC' (VOC)			PM		
type		kW	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Manual	biogenic	< 50	25 000	8 000	5 000	2 000	300	150	200	180	150
		50–150	12 500	5 000	2 500	1 500	200	100	200	180	150
		150–300	12 500	2 000	1 200	1 500	200	100	200	180	150
	fossil	< 50	25 000	8 000	5 000	2 000	300	150	180	150	125
		50–150	12 500	5 000	2 500	1 500	200	100	180	150	125
		150–300	12 500	2 000	1 200	1 500	200	100	180	150	125
Automatic	biogenic	< 50	15 000	5 000	3 000	1 750	200	100	200	180	150
		50–150	12 500	4 500	2 500	1 250	150	80	200	180	150
		150–300	12 500	2 000	1 200	1 250	150	80	200	180	150
	fossil	< 50	15 000	5 000	3 000	1 750	200	100	180	150	125
		50–150	12 500	4 500	2 500	1 250	150	80	180	150	125
		150–300	12 500	2 000	1 200	1 250	150	80	180	150	125
			Emission factors, g.GJ^{-1} (net thermal input)								
Manual	biogenic	< 50	13 181	4 218	2 636	1 054	158	79	105	95	79
		50–150	6 591	2 636	1 318	791	105	53	105	95	79
		150–300	6 591	1 054	633	791	105	53	105	95	79
	fossil	< 50	13 181	4 218	2 636	1 054	158	79	95	79	66
		50–150	6 591	2 636	1 318	791	105	53	95	79	66
		150–300	6 591	1 054	633	791	105	53	95	79	66
Automatic	biogenic	< 50	7 909	2 636	1 582	923	105	53	105	95	79
		50–150	6 591	2 373	1 318	659	79	42	105	95	79
		150–300	6 591	1 054	633	659	79	42	105	95	79
	fossil	< 50	7 909	2 636	1 582	923	105	53	95	79	66
		50–150	6 591	2 373	1 318	659	79	42	95	79	66
		150–300	6 591	1 054	633	659	79	42	95	79	66

4.3.4 Selected national emission limits for small combustion installations

Many countries apply emission controls to combustion appliances smaller than 50 MW_{th} and a summary of selected countries' pollutant limit values is provided as emission factors below; further details (and countries) are provided at Appendix C.

Table 4-3 Selected national emission limits as emission factors for coal-fired boilers

Country	Size	Ref.	Emission concentrations, $mg.m^{-3}$ at STP (0ºC, 101.3 kPa) dry at reference O_2 content							
		O2	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High		
France	20–50 MW	6	450	650	850	2 000	50	100	200	110
France	< 4 MW	6	550	825	2 000		150			
France	4–10 MW	6	550	825	2 000		100			
France	> 10 MW	6	550	825	2 000		100			
Finland	1–50 MW	6	275	550	1 100	1 100	55	140		
Germany	< 2.5 MW	7	300	500	350	1 300	50		150	
Germany	< 5 MW	7	300	500	350	1 300	50		150	
Germany	> 5 MW	7	300	500	350	1 300	20		150	
Germany	> 10 MW	7	300	400	350	1 300	20		150	
			Emission factor, $g.GJ^{-1}$ (net basis)							
France	20–50 MW		163	235	308	725	18	36	72	40
France	< 4 MW		199	299	725		54			
France	4–10 MW		199	299	725		36			
France	> 10 MW		199	299	725		36			
Finland	1–50 MW		100	199	398	398	20	51		
Germany	< 2.5 MW		116	194	136	505	19		58	
Germany	< 5 MW		116	194	136	505	19		58	
Germany	> 5 MW		116	194	136	505	8		58	
Germany	> 10 MW		116	155	136	505	8		58	

Table 4-4 Selected national emission limits as emission factors for wood-fired boilers

Country	Size	Ref.	Emission concentrations, mg.m^{-3} at STP (0ºC, 101.3 kPa) dry at reference O_2 content							
		O2	NO_x		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High		
France	20–50 MWth	11	400	650	200	2000	50	100	200	110
France	< 4 MW	11	500	750	200		150			
France	4–10 MW	11	500	750	200		100			
France	> 10 MW	11	500	750	200		100			
Finland	1–5 MW	6	250	500			250	375		
Finland	5–10 MW	6	250	500			125	250		
Finland	10–50 MW	6	250	500			50	125		
Germany	< 2.5 MW	11	250		350		100			10
Germany	< 5 MW	11	250		350		50			10
Germany	> 5 MW	11	250		350		20			10
			Emission factor, g.GJ^{-1} (net basis)							
France	20–50 MWth		232	377	116	1161	29	58	116	64
France	< 4 MW		290	435	116		87			
France	4–10 MW		290	435	116		58			
France	> 10 MW		290	435	116		58			
Finland	1–5 MW		96	193			96	145		
Finland	5–10 MW		96	193			48	96		
Finland	10–50 MW		96	193			19	48		
Germany	< 2.5 MW		145		203		58			6
Germany	< 5 MW		145		203		29			6
Germany	> 5 MW		145		203		12			6

Table 4-5 Selected national emission limits as emission factors for oil-fired boilers

Country	Size	Ref.	Emission concentrations, mg.m^{-3} at STP (0ºC, 101.3 kPa) dry at reference O_2 content							
		O2	NO_x		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High		
France	20–50 MWth	3	450	650	850	1 700	50	100	100	110
France	< 4 MW	3	550	825	1 700		150			
France	4–10 MW	3	550	825	1 700		100			
France	> 10 MW	3	500	750	1 700		100			
Finland	1–15 MW	3	800	900	1 700		50	200		
Finland	15–50 MW	3	500	670	1 700		50	140		
Germany	HWB	3	180	350			50		80	
Germany	LPS	3	200	350			50		80	
Germany	HPS	3	250	350			50		80	
			Emission factor, g.GJ^{-1} (net basis)							
France	20–50 MWth	3	127	184	241	481	14	28	28	31
France	< 4 MW		156	233	481		42			
France	4–10 MW		156	233	481		28			
France	> 10 MW	3	141	212	481		28			
Finland	1–15 MW	3	226	255	481		14	57		
Finland	15–50 MW	3	141	190	481		14	40		
Germany	HWB	3	51	99			14		23	
Germany	LPS	3	57	99			14		23	
Germany	HPS	3	71	99			14		23	

Table 4-6 Selected national emission limits as emission factors for gas-fired boilers

Country	Size	Ref.	Emission concentrations, mg.m^{-3} at STP (0ºC, 101.3 kPa) dry at reference O_2 content							
		O2	NO_x		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High		
France	20–50 MWth	3	120	350	35		5		100	110
France	< 10 MW	3	150	225	35		5			
France	> 10 MW	3	100	150	35		5			
Finland	1–15 MW	3	340	400						
Finland	15–50 MW	3	170	300						
Germany	HWB	3	100		10		5		50	
Germany	LPS	3	110		10		5		50	
Germany	HPS	3	150		10		5		50	
			Emission factor, g.GJ^{-1} (net basis)							
France	20–50 MWth		34	99	10		1		28	31
France	< 10 MW		42	64	10		1			
France	> 10 MW		28	42	10		1			
Finland	1–15 MW		96	113						
Finland	15–50 MW		48	85						
Germany	HWB		28		3		1		14	
Germany	LPS		31		3		1		14	
Germany	HPS		42		3		1		14	

4.4 Developing a consistent time series and recalculation

The emissions of non-CO_2 emissions from fuel combustion change with time as equipment and facilities are upgraded or replaced by less-polluting energy technology. The mix of technology used with each fuel will change with time and this has implications for the choice of emission factor at Tier 1 and Tier 2.

4.5 Uncertainty assessment

4.5.1 Emission factor uncertainties

There is uncertainty in the aggregated emission factors used to estimate emissions. The number of sources, range of use, sizes, fuel quality (particularly solid fuels and biomass) and technologies in the residential sector will impact on the uncertainty to be expected from the application of an ‘average’ emission factor.

4.5.2 Activity data uncertainties

The activity data for residential fuel use may be subject to uncertainty from issues of self-supply, waste disposal or 'unofficial' fuel sources.

4.6 Inventory quality assurance/quality control QA/QC

No specific issues

4.7 Mapping

No specific issues

4.8 Reporting and documentation

No specific issues

5 Glossary

Automatic feed boiler: boiler with fully automated fuel supply

Boiler: any technical apparatus in which fuels are oxidised in order to generate thermal energy, which is transferred to water or steam

Briquettes: refers to patent fuels from hard/sub-bituminous coal (NAPFUE 104) and brown coal briquettes (NAPFUE 106)

Brown coal: refers to brown coal/lignite (NAPFUE 105) of gross caloric value (GHV) less than 17 435 kJ/kg and containing more than 31 % volatile matter on a dry mineral matter free basis

Charcoal: refers to temperature treated wood (NAPFUE 112)

Chimney: brick, metal or concrete stack used to carry the exhaust gases into the free atmosphere and to generate draught

CHP: combined heat and power production

Coke: refers to the solid residue obtained from hard coal (NAPFUE 107) or brown coal (NAPFUE 108) by processing at high temperature in the absence of air

Efficiency: is the ratio of produced output heat energy to energy introduced with the fuel, with reference to net (low) calorific value of fuel

Fireplace: usually very simple combustion chamber, with or without front door, in which fuels are oxidized to obtain thermal energy, which is transferred to the dwelling mainly by radiation

Gaseous fuels: refers to natural gas (NAPFUE 301), natural gas liquids (NAPFUE 302) and liquefied petroleum gases (LPG; NAPFUE 303), biogas (NAPFUE 309)

Hard coal: coal of a gross caloric value > 17 435 kJ/kg on ash-free but moisture basis, i.e. steam coal (NAPFUE 102, GHV> 23 865 kJ/kg), sub-bituminous coal (NAPFUE 103, 17 435 kJ/kg < GHV<23 865 kJ/kg) and anthracite

Liquid fuels: refers to kerosene (NAPFUE 206), gas oil (gas/diesel oil (NAPFUE 204), residual oil, residual fuel oil (NAPFUE 203) & other liquid fuels (NAPFUE 225)

Manual feed boiler: boiler with periodical manual fuel supply

Patent fuels: manufactured smokeless fuels from hard/sub-bituminous coal (NAPPFUE 104)

Peat: refers to peat-like fuels (NAPFUE 113)

Solid biomass fuel: refers to wood fuels which are wood and similar wood wastes (NAPFUE 111) and wood wastes (NAPFUE 116) and agricultural wastes used as fuels (straw, corncobs, etc; NAPFUE 117)

Stove: simple appliance in which fuels are combusted to obtain thermal energy, which is transferred to the interior of the building by radiation and convection

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7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Appendix A Technology-specific emission factors

In this annex a compilation of various emission data is given to enable users' comparison with their own data.

Table A 1 Emission factors for small coal combustion installations

Installation	Pollutants						
	g/GJ					mg/GJ	
	SO_2	NO_x	CO	NMVOC 1)	VOC 1)	PAH	BaP
Domestic open fire	n.d	n.d	n.d.	14 1)	n.d.	n.d.	n.d.
Domestic closed stoves	2) 420	75	1500	n.d.	60	n.d.	n.d.
	3) 104 1)	8 1)	709 1)	n.d.	n.d.	n.d.	n.d.
Domestic boiler	4) 17.2 1)	6.2 1)	1.8 1)	n.d.	0.02 1)	n.d.	n.d.
Small commercial or institutional boiler	n.d.	n.d.	416 2)	n.d.	n.d.	n.d.	0.1 2)

Source: Hobson M., et al., 2003.

Notes:

1. No information about NMVOC and VOC standard reference — usual CH4 or C3H8 are used.
2. Original data in g/kg;.
3. Original data in g/kg; for recalculation Hu of 24 GJ/t (d.b.) was assumed.
4. Coal stove;.
5. Roomheater 12.5 kW, anthracite.
6. Boiler, bituminous coal; n.d. — no data.

Table A 2 Emission factors for combustion of manufactured solid fuels

Installation	Pollutants						
	g/GJ					Mg/GJ	
	SO_2	NO_x	CO	NMVOC 1)	VOC 1)	PAH	BaP
Domestic open fire	2) n.d	n.d	n.d.	n.d.	5.0–20	n.d.	n.d.
Domestic closed stoves	3) n.d.	n.d.	121–275 2)	10.5 2); 16.1 2)	n.d.	n.d.	n.d.
	4) 75 2) and 127 2)	4 2) and 7 2)	1 125 2); 1 193 2)	n.d.	n.d.	n.d.	n.d.
Domestic boiler	5) 371	382	12 400	n.d.	91	n.d.	n.d.
	6) n.d.	64–73	140–7 400	n.d.	0–500 7)	n.d.	n.d.
Small commercial or institutional boiler	8) n.d.	35	270	n.d.	2 7)	n.d.	n.d.

Source: Hobson M., et al., (2003). Notes:

3. No information about NMVOC and VOC standard reference — usually CH_4 or C_3H_8 are used.
4. Original data in g/kg.
5. 10 kW open fire, smokeless coal brands.
6. Stoves, charcoal and char briquettes, 12.5 kW roomheater, coke and manuf. briq.
7. UNECE TFEIP: Dutch fig. for coke use.

8. UNECE TFEIP: Sweden, pellet boilers, 1.8–2 MW.
9. As THC.
10. 8) UNECE TFEIP: Sweden, briquette boilers 1.8–2 MW; n.d.- no data.

Table A 3 Range of emission value from small coal appliances which employ fixed bed combustion with counter-current techniques (manually fuelled)

Types of appliances	**Efficiency %**	**Assortment of fuel**	**Emissions factor of pollutants**						
			CO G/GJ	**SO_2[a)] g/GJ**	**NO_x G/GJ**	**TSP g/GJ**	**16 PAH g/GJ**	**B[a)]P mg/GJ**	**VOC (C3) g/GJ**
Standard stove	45–75	Un-assortment coal	3 500–12 500	200–800	100–150	700–900	20–40	200–600	500–700
Masonry stove	60–75		2 500–11 000	200–800	100–200	600–1 200	15–25	150–350	400–800
Kitchen stove	40–60		3 600–11 000	200–800	50–150	300–1 000	50–90	400–650	500–1 100
Standard boiler	50–67		1 800–7 000	200–800	50–150	150–500	30–90	600–900	400–1 200
Advanced boiler	76–82	Assortment coal,	200–1 500	200–800	150–200	50–100	0.2–0.6	2–30	60–120

Source: Kubica, 2003/1.
Note:
[a)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors are for sulphur content between 0.5 % and 1.0 % with oxidation efficiency of sulphur about 90 %.

Table A 4 Range of emissions from small coal appliances which employ fixed bed combustion with co-current techniques (in principle automatic fuelled)

Types of appliances	**Efficiency %**	**Assortment of fuel**	**Emissions factor of pollutants**						
			CO g/GJ	**SO2[a)] g/GJ**	**NOx G/GJ**	**TSP g/GJ**	**16 PAH g/GJ**	**B [a)]P mg/GJ**	**VOC (C3) g/GJ**
Advanced boiler [b)]	76–80	Fine coal	2 800–1 100	250–750	150–200	50–200	0.2–0.8	3–50	100–250
Burners boiler	77–84	Fine coal	1 500–400	250–750	150–250	30–120	0.2–2.0	5–50	2–50
Stoker, retort boiler	77–89	5–25 mm [c)]	120–800	130–350	150–300	30–60	0.1–0.7	1–20	1–50

Source: Kubica, 2003/1.
Notes:
[a)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors are for sulphur content between 0.5 % and 1.0 % with oxidation efficiency of sulphur about 90 %.
[b)] Manually fuelled.
[c)] For capacity above 50 kW, grain size 5–30 mm.

Table A 5 Emission value of coal combustion in stoves and small boilers derived from measurement campaign in Poland

Parameter	Unit	Advance under-fire boiler 30 kW		Advance upper-fire, retort boiler		Stove 5.7 kW	
		Coal J	Coal W	50 kW	150 kW	Coal J	Coal W
Thermal efficiency	%	**67.8**	**70.9**	**82.9**	**82.0**	**54.7**	**51.2**
CO	g/GJ	3 939	2 994	48	793	3 271	2 360
SO_2	g/GJ	361.6	282.8	347.8	131.5	253.0	211.0
NOx as NO_2	g/GJ	190.3	162.3	172.9	160.0	81.2	104.0
VOCs (C3)	g/GJ	514.2	483.1	6.1	4.8	486.0	700.0
Dust; TSP	g/GJ	227.0	294.0	267	30.0	523.0	720.0
16 PAHs	Mg/GJ	26 688	29 676	87.2	0.2	39 500	3 2800
PCDD/F	Ng I-Teq/GJ	285.0	804.1	n.d.	n.d.	n.d.	n.d.

Source: Kubica, UN-ECE TFEIP, 2002/1.
Note:
n.d. — no data.

Table A 6 Emission factors for advanced coal-fire small boilers (< 1 MW) in Poland. Voluntary standard requirements

Pollutants	Advanced under-fire boilers, manual fuelled	Advanced upper-fire boilers, automatic fuelled
	Emission factors (g/GJ)	
Carbon monoxide, CO	≤ 2 000	≤ 1 000
Nitrogen dioxide; NO_x as NO_2	≤ 150	≤ 200
Sulphur dioxide; SO_2 [1)]	≤ 400	≤ 400
Dust; TSP	≤ 120	≤ 100
TOC [2)]	≤ 80	≤ 50
16 PAHs acc. EPA	≤ 1.2	≤ 0.8
Benzo(a)pyrene; B(a)P	≤ 0.08	≤ 0.05

Source: Kubica, 2003/1, Kubica, UN-ECE TFEIP, (2002/1).
Notes:
[1)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors were established for sulphur content of < 0.6 %.
[2)] TOC is the sum of organic pollutants both in the gaseous phase and as organic solvent soluble particles except C_1–C_5 (Kubica 2003/1).

Table A 7 Emission values of co-combustion of coal and wood in small and medium boilers in Poland

Parameter	Unit	Automatic fuelled burner boiler 25 kW		Fluidized bed boiler 63 MW		Travelling grate combustion; 10 MW		Travelling grate combustion, 25 MW	
		Coal	80 %m/m coal 20 % wood	Coal	91 % w/w coal 9 % wood	Coal	92 % w/w coal, 8 % wood	Coal	97 % w/w coal, 3 % dry sewage sludge
Thermal efficiency	%	79.1	81.6	87.4	86.2	81.1	81.4	84.4	85.7
CO	g/GJ	254	333	35.2	41.5	120	63	23.8	24.7
SO_2	g/GJ	464	353	379	311	290	251	490	557
NO_x as NO_2	g/GJ	269	232	109	96	150	155	137	141
VOCs (C3)	g/GJ	14.0	9.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Dust; TSP	g/GJ	50.3	37.6	6.6	7.7	735	948	133	111
16 PAHs	Mg/GJ	401	207	346	121	126	117	269	63

Source: Kubica, et al., 2003/2.
Note:
n.d. — no data.

Table A 8 Emission factors for combustion of biomass; comparison between poor and high standard furnace design

Emissions	Poor standard	High standard
Excess air ratio, λ	2–4	1.5–2
CO; g/GJ	625–3125	13–156
CxHy [2)]; g/GJ	63–312	< 6
PAH; mg/GJ	62–6 250	< 6.2
Particles, after cyclone; g/GJ	94–312	31–94

Source: van Loo, 2002.
Notes
1. [1)] Original data in mg/m^3_o at 11 % O_2, for recalculation H_u of 16 GJ/t and $10 m^3/kg$ of flue gases were assumed.
2. [2)] No information about CxHy standard reference — usually CH_4 or C_3H_8 are used.

Table A 9 Emission factors for pellet burners in Sweden

Type of the burners	TSP (g/GJ)	CO_2 (%)	O_2 (%)	THC [1)] (g/GJ)	NO_x (g/GJ)	Effect (kW)
Pellet burner (continuous operation)						
Nominal effect	22	9.5	11.1	3	73	10.7
6 kW capacity	4	6.0	14.6	78	70	6.2
6 kW generated power*	28	4.8	15.8	31	68	6.2
3 kW generated power	65	3.7	16.9	252	66	3.2
Pellet burner (electric ignition)						
Nominal effect	16	13.0	7.4	1	70	22.2
6 kW generated power	64	9.1	11.3	60	64	6.1
6 kW generated power+	-	10.6	9.7	41	174	6.3
3 kW generated power	15	8.6	11.9	10	67	3.1

Source: Bostrom, 2002.

Notes:

1. No information about THC standard reference — usual CH_4 or C_3H_8 are used.
2. *High ventilation, $^+$ wood with high ash content.

Table A 10 Emission factors for wood boilers in Sweden

Type of the burners	TSP (g/GJ)	CO_2 (%)	O_2 (%)	THC [1)] (g/GJ)	CO (g/GJ)	NO_x (g/GJ)
Water cooled boiler						
Intermittent log burning	89	6.8	13.4	1 111	4 774	71
Water cooled boiler						
Operation using accumulator	103	8.3	11.8	1 500	5 879	67
Intermittent log burning	n.d.	5.6	13.4	4 729	16 267	28
Cold-start	2 243	6.9	14.6	2 958	8 193	64

Source: Bostrom; (2002).

Note:

1) No information about THC standard reference — usual CH_4 or C_3H_8 are used.
2) n.d. — no data.

Table A 11 Arithmetic average emission values for wood combustion. The data were collected from investigations in various IEA countries (Norway, Switzerland, Finland, UK and Denmark)

Techniques	NO_x (g/GJ)	CO (g/GJ)	VOC [a)] (g/GJ)	THC as CH_4 (g/GJ)	Particles, TSP (g/GJ)	PAH (mg/GJ)
Cyclone furnaces	333	38	2.1	n.d.	59	n.d.
Fluidized bed boilers	170	0	n.d.	1	2	4
Pulverised fuel burners	69	164	n.d.	8	86	22
Grate plants	111	1 846	n.d.	67	122	4 040
Stoker burners	98	457	n.d.	4	59	9
Wood boilers	101	4 975	n.d.	1 330	n.d.	30
Modern wood-stoves	58	1 730	n.d.	200	98	26
Traditional wood-stoves	29	6 956	671	1 750	1 921	3 445
Fireplaces	n.d.	6 716	520	n.d.	6 053	105

Source: van Loo, (2002).
Notes
1. No information about VOC standard reference — usual CH_4 or C_3H_8 are used.
2. n.d. — no data.

Table A 12 Arithmetic averages of emission values from biomass combustion in small-scale applications

Techniques	Load (kW)	Excess air ratio	CO (g/GJ)	CxHy[a)] (g/GJ)	Part. TSP (g/GJ)	NO_x (g/GJ)	Temp. (^oC)	Efficiency (%)
Wood — stoves	9.33	2.43	3 116	363	81	74	307	70
Fire place inserts	14.07	2.87	2 702	303	41	96	283	74
Heat storing stoves	13.31	2.53	1 723	165	34	92	224	78
Pellet stoves	8.97	3.00	275	7	28	92	132	83
Catalytic wood-stoves	6.00	n.d.	586	n.d.	n.d.	n.d.	n.d.	n.d.

Source: van Loo, 2002.
Notes:
1. Original date in mg/m^3_o at 13 % O_2, for recalculation H_u of 16 GJ/t and $10m^3/kg$ of flue gases were assumed.
2. [a)] No information about CxHy standard reference — usual CH_4 or C_3H_8 are used.
3. n.d. — no data.

Table A 13 Emissions from small industrial wood-chip combustion applications in the Netherlands (g/GJ)

Type of operation	Combustion principle	Draught control	Capacity kW	CO	CxHy [a)]	NO_x	TSP	Efficiency (%)
Manual	Horizontal grate	Natural uncontrolled	36	1 494	78	97	13	85
		Forced uncontrolled	34.6	2 156	81	108	18	83.5
			30	410	13	114	21	90
Automatic	Stoker boiler	Forced controlled	~40	41	2	74	50	85.4
			320	19	2	116	32	89.1

Source: van Loo, 2002.

Notes:

1. Original date in mg/m^3_o at 11 % O_2, for recalculation H_u of 16 GJ/t and 10 m^3/kg of flue gases were assumed.
2. [a)] No information about CxHy standard reference — usual CH_4 or C_3H_8 are used.
3. n.d. — no data.

Table A 14 Emission value from biomass combustion in small-scale applications derived from measurement campaign in Poland

Techniques	Capacity (kW)	SO_2 (g/GJ)	CO (g/GJ)	VOC as C3 (g/GJ)	TSP (g/GJ)	NO_x (g/GJ)	16 PAH g/GJ	Efficiency (%)
Wood — log, stoves	5.7	9.8	6 290	1 660	1 610	69	33 550	64.4
Upper fire stocker, pellet combustion	25	29	200	21	9.9	179	71	80.4
Pellet burners	20.5	6.0	58.5	7.2	29.7	295	122	85.7
Gas fire, pre-oven	20.0	21.0	1 226	6.8	15.6	78.9	480	83.9

Source: Kubica, et al., 2002/2.

Table A 15 Emission value of biomass combustion in small and medium boilers derived from measurement campaign in Poland

Parameter	Unit	Straw fixed grate boiler 65 kW		Advance under-fire boiler 30 kW		Automatic boilers	
						3,5 MW	1,5 MW
		Rape straw	Wheat straw	Briquettes of sawdust	Lump pine wood	Mixture of cereal straws	
Thermal efficiency	%	81.	84.2	81.3	76	90.1	84.3
CO	g/GJ	2 230	4 172	1 757	2 403	427	1 484
SO_2	g/GJ	127.1	66.5	15.9	4.8	74.6	151.0
NO_x (as NO_2)	g/GJ	105.3	76.1	41.6	31.7	110.1	405.0
VOC (as C3)	g/GJ	n.a.	n.a.	176.1	336.4	n.a.	n.a.
TSP	g/GJ	654.0	901.0	39.0	116.0	31.5	109.0
TOC [1)]	g/GJ	59.4	39.4	98.6	176.0	18.1	39.0
16 PAHs acc EPA	Mg/GJ	9 489	3 381	9 100	9 716	197	0.4
PCDD/F	ng I-TEQ/GJ	840.9	746.2	107.5	1 603	n.a.	n.a.

Source: Kubica, 2003/1; Kubica, UN-ECE TFEIP, (2002/1)

Table A 16 Emission factors for 1.75 MW and 2 MW boilers in Sweden

Fuel	Effect (%)	O_2 (%)	CO (g/GJ)	THC (g/GJ) [a)]	CH_4 (g/GJ)	TSP (g/GJ)	NO_x (g/GJ)	NH_3 (g/GJ)
Pellets	20	4	7 400	500	400	43	17	6
Pellets	50	7	1 600	17	< 1	43	27	1
Pellets	100	4	140	< 1	< 1	32	37	< 1
Briquettes	100	6.3	270	2	< 1	36	35	< 1
Logging residue	100	6.5	42	< 1	< 1	71	74	< 1
Wood chips	100	7.2	3 900	48	31	51	25	2

Source: Bostrom C-A, UN-ECE TFEIP (2002).

Note:

[a)] No information about CxHy standard reference — usual CH_4 or C_3H_8 are used.

Table A 17 Emission factors for biomass small combustion installations

Installation	Pollutants						
	g/GJ					mg/GJ	
	SO_2	NO_x	CO	NMVOC [1)]	VOC [1)]	PAH	BaP
Domestic open fire	n.d	n.d	4 000	n.d	90–800	13 937; 10 062; 7 9371 [2)]	n.d
Domestic closed stoves	[3)] n.d.	29	7 000	1 750 [5)]	670	3 500	n.d
	[4)] n.d.	58	1 700	200 [5)]	n.d	26	n.d
Domestic boiler	[6)] n.d.	101	5 000	1 330 [5)]	n.d	n.d	n.d
Small commercial or institutional boiler	[7)] n.d.	25	3 900	n.d	n.d.	n.d.	n.d.
	[8)] n.d	n.d.	n.d.	480	n.d	n.d.	n.d.
	[9)] n.d.	n.d.	n.d.	96	n.d.	n.d.	n.d.

Source: Hobson M., et al., 2003.

Notes:

1. [1)] No information about NMVOC and VOC standard reference — usual CH_4 or C_3H_8 are used.
2. [2)] Original data in g/kg for recalculation H_u of 16 GJ/t was assumed and PAH that is ∑16 PAH.
3. [3)] Traditional wood stove.
4. [4)] Modern wood stove.
5. [5)] THC as CH_4.
6. [6)] Wood boilers.
7. [7)] Wood chips boilers 1.8–2 MW.
8. [8)] Wood, charcoal, 120 kW boiler, benchmark.
9. [9)] Wood, charcoal, 120 kW, improved boiler.
10. n.d. — no data.

Table A 18 Emission factors for domestic combustion processes (g/GJ) in the Netherlands

Pollutant	Fuel				
	Natural gas	Oil	LPG	Petroleum	Coal
VOC[1)]	6.3	15	2	10	60
SO_2	0.22	87	0.22	4.6	420
N_2O	0.1	0.6	0.1	0.6	1.5
NO_x (as NO_2)	57.5	50	40	50	75
CO	15.8	60	10	10	1 500
CO_2	55 920	73 000	66 000	73 000	103 000
TSP	0.3	5	10	2	200
PM_{10}	0.3	4.5	2	1.8	120
Particles >PM_{10}	-	0.5	-	0.2	80

Source: Heslinga D., 2002.

Note:

[1)] No information about VOC standard reference — usual CH_4 or C_3H_8 are used.

Table A 19 Emission factors for small combustion installations of gas and oil fuels (g/GJ) derived from measurement campaign in Poland

Pollutant	Fuel							
	Natural gas				Oil			
	35 kW	218 kW	210 kW	650 kW	35 kW	195 kW	400 kW	650 kW
NMVOC (as C3) [1)]	8.9	7.8	6.2	0.6	5	4.2	10	2.1
SO_2 [1)]	-	-	-	-	110	112	140	120.3
NO_x (as NO_2) [1)]	142	59.1	24.6	38.4	43	56.4	60	56.7
CO [1)]	10.3	30.9	21.2	15.3	46	44	45	33.6
TOC [1)]	5.5	6.4	4.2	4.5	25	20.8	15	7.5
SO_2 [2)]	n.d.	-	-	-	115–145 average 130	-	-	-
NO_x (as NO_2) [2)]	17–22 average 20	-	-	-	35–55 average 40	-	-	-
CO [2)]	7–12 average 9	-	-	-	10–12 average 11	-	-	-

Source: [1)] Kubica et al., 1999; [2)] Kubica et al., 2005/2 The measurements were done in the field.
Note:
n.d. — no data.

Table A 20 Emission factors for small combustion installations of gas and oil fuels (g/GJ) derived from measurement campaign in Poland

Pollutant	Fuel						
	Natural gas					Oil	
	2.1 MW	11.0 MW	5.8 MW	4.6 MW	2.3 MW	1.7 MW	2.2 MW
NO_x (as NO_2)	64	30	29	38	23	66	63
CO	3.1	0.0	0.0	3.6	0.4	0.0	1.4
SO_2	n.m.	n.m.	n.m.	n.m.	n.m.	105	69
TSP	n.m.	0.2	0.2	n.m.	0.1	n.m.	0.2

Source: Czekalski B et al., 2003.

Table A 21 Emission factors for gas-fired small combustion installations

Installation	Pollutants						
	g/GJ					mg/GJ	
	SO_2	NO_x	CO	NMVOC [1)]	VOC [1)]	PAH	BaP
Open fire	0.5	50	20	6	n.d.	n.d	n.d.
Closed stoves	0.5	50	10	3	n.d.	n.d.	n.d.
Domestic boiler	0.2; 0.5	40.2; 57.5	8.5; 15.8	3.0; 15.0	5–30	n.d	1.5 [2)]
Small commercial or institutional boiler	n.d.	n.d.	n.d.	1.0; 5.0	5.0	n.d.	0.1 [1)] 38 [3)]
Agricultural heater	0.22	65	10	n.d.	30	n.d.	n.d.
CHP Steam, gas turbine;	n.d.	179	43	2.1	n.d.	n.d.	n.d.

Source: Hobson M., et al., 2003.
Notes:.
1) No information about VOC standard reference — usual CH_4 or C_3H_8 are used. Original data in mg/t for recalculation H_u of 35 GJ/t was assumed.
2) mg/1000xm^3.
3) n.d. — no data.

Table A 22 Emission factors for LPG small combustion installations

Installation	Pollutants						
	g/GJ					mg/GJ	
	SO_2	**NO_x**	**CO**	**NMVOC [1)]**	**VOC [1)]**	**PAH**	**BaP**
Open fire	None						
Closed stoves	n.d.	n.d.	454 [1)]	447 [1)]	n.d	n.d	n.d
Domestic boiler	0.22	40	10	n.d.	2	n.d.	n.d.
Small commercial or institutional boiler	n.d.	n.d.	n.d.	n.d.	2	n.d.	n.d.
Agricultural heater	0.22	40	10	n.d.	2	n.d.	n.d.
CHP Steam, gas turbine	None						

Source: Hobson M., et al., 2003.
Notes
1) [1)] No information about VOC standard reference — usual CH_4 or C_3H_8 are used. Original data in g/kg for recalculation H_u of 42 GJ/t was assumed.
2) n.d. — no data.

Table A 23 Emission factors for burning oil (kerosene) small combustion installations

Installation	Pollutants						
	g/GJ					mg/GJ	
	SO_2	NO_x	CO	NMVOC 1)	VOC 1)	PAH	BaP
Domestic open fire	None						
Domestic closed stoves	n.d.	n.d.	421 2); 1 478 2)	354 2); 1 457 2)	n.d	n.d	n.d
Domestic boiler	87	50	60	1.5; 7.5	15	n.d.	0.1
Small commercial or institutional boiler	n.d.	n.d.	n.d.	1.0; 5.0	n.d.	n.d.	n.d.
Agricultural heater	0.22	50	10	n.d.	10	n.d.	n.d.
CHP Steam, gas turbine	None						

Source: Hobson M., et al., 2003.
Notes:
1) No information about VOC standard reference — usual CH_4 or C_3H_8 are used.
2) Original data in g/kg t for recalculation Hu of 42 GJ/t was assumed.
3) n.d. — no data.

Table A 24 Emission factors for fuel oil small combustion installations

Installation	Pollutants						
	g/GJ					Mg/GJ	
	SO_2	NO_x	CO	PM_{10}	NMVOC 1)	VOC 1)	PAH	BaP
Domestic open fire	None							
Domestic closed stoves	None							
Domestic boiler	n.d.	n.d.	n.d.	8.0–50	n.d.	10	n.d.	0.08 2)
Small commercial or institutional boiler	3) 449	62.4	15.6	3.1	n.d.	0.6	n.d.	n.d.
	4) 467	61.4	15.4	18.5	n.d.	0.6	n.d..	n.d.
	5) 488	169	15.4	26.4	n.d.	0.9	n.d.	n.d.
	n.d	n.d	n.d.	3–23	n.d.	8	n.d.	0.1 2); 0.5 2); 0.5 2)
Agricultural heater	n.d.	n.d.	n.d.		n.d.	n.d.	n.d.	0.08 2)
CHP 6)	n.d	186	14		2.1	6.8	n.d.	0.1 2)

Source: Hobson M., et al., 2003).
Notes:
1) No information about VOC standard reference — usual CH_4 or C_3H_8 are used.
2) Original data in g/Mt for recalculation H_u of 42 GJ/t was assumed.
3) 1.5 % of S.
4) 4.5 % of S.
5) 5.5 % of S.
6) Power station.
n.d. — no data.

Table A 25 Emission of pollutants for gaseous, liquid and coal fuels for small combustion installations in Italy

Installation		Pollutants						
		g/GJ						
		SO_2	NO_x	CO	VOC[1]	TSP	PM_{10}	$PM_{2.5}$
Natural gas	Range	0.22–0.5	7.8–350	20–50	0.5–10	0.03–3	0.03–3	0.03–0.5
	Average	0.5	50	25	5	0.2	0.2	0.2
LPG	Range	9.7–150	30–269	20–40	0.1–15	0.2–50	0.2–50	0.2–50
	Average	100	50	20	3	5	5	5
Burning oil	Range	69–150	24–370	5–40	1.1–48	1.5–60	1.5–60	1.5–50
	Average	150	150	16	10	40	40	30
Coal	Range	60–2 252	45–545	100–5 000	3–600	70–350	10–400	30–200
	Average	650	150	2 000	200	150	140	70

Source: Caserini S. 2004.
Note:
[1] No information about VOC standard reference — usual CH_4 or C_3H_8 are used.

Table A 26 Sectoral emission factors for firing appliances in Germany in the household and small consumer sectors, in 1995 (Pfeiffer et al. 2000)

Sector	Fuel	Pollutants g/GJ				
		SO_2	NO_x as NO_2	CO	CO_2	TSP
Households	High rank coal and products	456	51	4 846	95 732	254
	High rank coals	380	49	5 279	95 930	278
	Briquettes	561	54	4 246	95 457	221
	Coke from high rank coals	511	60	6 463	106 167	15
	Brown coal briquettes	261	71	3 732	96 021	86
	Natural wood	7	50	3 823	103 093	42
	Distillate oil	77	46	25	73 344	1.6
	Natural gas	0.5	38	14	55 796	0.03
Small consumers	High rank coal and products	419	108	564	95 930	278
	High rank coals	419	108	564	95 930	278
	Coke from high rank coals	370	61	1 498	106 167	12
	Brown coal briquettes	234	87	4 900	95 663	59
	Natural wood and wood wastes	9.1	78	2 752	101 099	45
	Distillate oil	77	47	14	73 344	1.7
	Residual oil	384	162	9.9	75 740	38
	Natural gas	0.5	31	11	55 796	0.03

Table A 27 Emission factors of CO, NOx and SO_2 for advanced combustion techniques of coal and biomass

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_x (as NO_2)	CO
BLT, 2000/1	Wood boilers with two combustion chambers and sonar Lambda	n.d.	100	141
BLT, 2005/1	Wood pellets and chip boiler 25 kW 100 % and 33 % of capacity	n.d.	127; n.d.	186; 589
	Pellets and wood chips boiler 43 kW 100 % and 33 % of capacity	n.d.	110; 71	60; 37
	Wood boiler 60 kW, air dry oak 100 % and 33 % of capacity	n.d.	79; n.d.	127; 720
	Boiler, wood chips 25 kW 100 % and 33 % of capacity	n.d.	115; n.d.	23; 358

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_x (as NO_2)	CO
	Pellets boiler 46.7 kW 100 % and 33 % of capacity	n.d.	110; 118	118; 172
BLT, 2003	Pellets and briq., boiler 7.7, 26 kW 100 % and 33 % of capacity	n.d.	67; n.d.	7; 44
BLT, 1999	Wood chips, boiler 500 kW 100 % and 33 % of capacity	n.d.	123; n.d.	16; 126
BLT, 2004/1	Wood chips, boiler 20 kW 100 % and 33 % of capacity	n.d.	44; n.d.	17; 108
BLT, 2004/2	Wood log and briq., boiler 50 kW 100 % and 33 % of capacity	n.d.	109; n.d.	44; n.d.
BLT, 2000/2	Wood briq., chamber boiler 60 kW 100 % and 33 % of capacity	n.d.	88; n.d.	30; 120
BLT, 2005/2	Wood log, chamber boiler 27 kW	n.d.	78	131
Houck et al., 2001 [1)]	Fireplaces; dry wood	n.d.	n.d.	4 010
Hübner et al.,20051 [2)]	Boiler < 50 kW; pelleted wood	n.d.	n.d.	120
	Boiler; chopped wood log	n.d.	n.d.	790–1 400
	Boiler; coke	n.d.	n.d.	2 400
	Boiler; wood and coke	n.d.	n.d.	3 500
	Boiler; wood, brown coal briquettes	n.d.	n.d.	4 200
	Boiler; wood logs (beech, spruce)	n.d.	n.d.	3 800
	Boiler; wood (beech, spruce), coke	n.d.	n.d.	2 100
	Stove; wood, brown coal briquettes wood	n.d.	n.d.	2 100
	Stove; beach wood logs	n.d.	n.d.	2 100–4 700
	Stove; wood	n.d.	n.d.	1 500
	Stove; spruce wood (small logs)	n.d.	n.d.	2 400
	Stove; wood (small logs)	n.d.	n.d.	1 600
	Stove; wood briquettes	n.d.	n.d.	4 600
Johansson at al., 2001 [1)]	Pellet boilers with fixed grates with moving scrapes 1.75–2.5 MW	n.d.	30–50	20–100
Houck et al., 2000 [1)]	Conventional stove, cordwood	n.d.	n.d.	7 200
	Pellet stoves, softwood	n.d.	n.d.	1 400–1 630
	Pellets stove, hardwood	n.d.	n.d.	125; 188; 219
	Pellets boiler, top-feed, softwood	n.d.	n.d.	146; 449; 510
	Pellets boiler, bottom-feed softwood	n.d.	n.d.	112; 169

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_x (as NO_2)	CO
Boman et al., 2005	Pellet stove 4.8 kW (high load)	n.d.	31–36; average 33	52–100; average 88
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	29–33; average 31	243–383; average 299
	Natural-draft wood stove, 9 kW; birch pine spruce	n.d.	37–71; average 50	1 200–7 700; average 3 800
	Pellet stove, 4–9.5 kW; pine and spruce (high load)	n.d.	57–65; average 61	110–170; average 140
	Pellet stove, 4- 9,5 kW; pine and spruce (low load 30 %)	n.d.	52–57; average 54	320–810; average 580
Kubica, 2004/2	Pellet boilers			
Kubica at al., 2005/4	Automatic-fuelled coal boilers - stocker; pea coal (qualified size)	120–450; average 260	96–260; average 190	90–850 average 280
	Automatic-fuelled coal boilers; fine coal (qualified coal size)	355–600 average 420	70–200 average 145	60–800 average 450
Kubica K.; 2004/1	Conventional stove 5 kW	253	81	2 272
Kubica, 2004/2	Boiler, stocker; wood pellets	n.d.	n.d.	300–500
	Chamber boiler, top feed; fine coal	250–700	100–150	1 100–2 800
	Automatic boiler, stocker; pea coal	130–350	100–250	120–800
	Automatic coal boiler; fine coal	250–700	100–250	400–1500
	Chamber boiler, advanced technique; qualified size coal	150–550	150–250	50–100
Kubica et al., 2005/1	Boilers with moving grate 5–32 MW	n.d.	116–137	10–24
	Boilers with moving grate 0.3–0.6 MW	n.d.	146–248	36–363 [4)]
	Automatic-fuelled coal boiler, fine coal	n.d.	140	130
	Automatic-fuelled coal boiler — stocker	n.d.	70–220	120–800
	Boiler, bottom feed, nut coals	n.d.	150–200	200–1500
	Boiler, top feed, nut coals	n.d.	50–150	1 800–3 500
	Boiler, bottom feed, log wood	n.d.	32	2 403
	Boiler, bottom feed, wood briquettes	n.d.	42	1 757
	Automatic-fuelled boiler — stocker 30 kW, pellets	n.d.	200	200
	Automatic-fuelled boiler, wood chips	n.d.	150	880

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_x (as NO_2)	CO
Kubica at al., 2005/23)	Automatic-fuelled coal boiler — stocker, ≤ 25 kW (120 pieces); pea coal	n.d.	67–207; average 161	104–320; average 150
	Automatic-fuelled coal boiler, ≤ 35 kW (68 pieces); fine coal,	155–496 average 252	64–208; average 122	119–435; average 232

Notes:

1) [1] Original factors in g/kg of fuels, for recalculation H_u of 24 GJ/t (d.b.) for hard coal was of 17 GJ/t (d.b.) for lignite and brown coal, of 30 GJ/t (d.b.) for anthracite, of 30 GJ/t (d.b.) for coke; of 16 GJ/t for wood, of 42 GJ/t for oil and of 35 GJ/t for natural gas were assumed.
2) [2] Capacity of all boilers < 50 kW and all stove < 10 kW.
3) [3] A measurement was done in the field.
4) n.d. — no data.

Table A 28 Wood burning appliance emission factors in British Columbia (Gulland, 2003)

Installation	Pollutants [1]						
	g/GJ						
	SO_2	NO_x	CO	VOC [1]	TSP	PM_{10}	$PM_{2.5}$
Fireplace							
Conventional with glass doors	12.5	87.5	6 162.5	1 312.5	843.75	812.5	806.25
Conventional without glass doors	12.5	87.5	4 856.3	406.3	1 206.3	1 156.3	1 156.3
Advanced technology	12.5	87.5	4 400	437.5	318.75	300	300
Insert; conventional	12.5	87.5	7 212.5	1 331.3	900	850	850
Insert; catalytic	12.5	87.5	4 400	437.5	318.8	300	300
Insert; advanced technology	12.5	87.5	4 400	437.5	318.8	300	300
Woodstove							
Conventional	12.5	87.5	6 250	2 218.8	1 537.5	1 450	1 450
Conventional, not air-tight	12.5	87.5	6 250	2 218.8	1 537.5	1 450	1 450
Conventional, air-tight	12.5	87.5	7 212.5	1 331.3	900	850	850
Advanced technology	12.5	87.5	4 400	437.5	318.8	300	300
Catalytic	12.5	87.5	4 400	437.5	318.8	300	300
Pellet stove	12.5	87.5	550	94	75	69.7	64
Boilers							
Central furnace/ boiler (inside)	12.5	87.5	4 281.3	1 331.3	881.3	831.3	831.3
Central furnace/ boiler (outside)	12.5	87.5	4 281.3	1 331.3	881.3	831.3	831.3
Other equipment	12.5	87.5	7 212.5	1 331.3	900	850	850

Note:
[1] Original factors in kg/tonne of fuels, for recalculation H_u of 16 GJ/t for wood was assumed.

Table A 29 Emission factors for particulate matter reported in the literature for coal and manufactured solid fuels combustion (g/GJ)

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
BUWAL, 2001 [1)]	Small furnaces	n.d.	110	270
	Domestic boiler	n.d.	90	150
CEPMEIP, 2002 [1)]	Residential, brown coal	70	140	350
	Residential, hard coal (‘high’)	60	120	300
	Residential, hard coal (‘low’)	25	50	100
	Residential, low grade hard coal	100	200	800
Pfeiffer et al., 2000 [1)]	Residential, hard coal	n.d.	n.d.	260–280
	Residential, brown coal briquettes	n.d.	n.d.	120–130
	Residential, coke	n.d.	n.d.	14
Spitzer et al., 1998 [1)]	Residential heating	n.d.	n.d.	153±50 %
	Single family house boiler, stoves	n.d.	n.d.	94±54 %
Winiwarter et al, 2001 [1)]	Residential plants	75	85	94
	Domestic stoves, fireplaces	122	138	153
UBA, 1999a [1)]	Domestic furnaces, hard coal	n.d.	n.d.	250
	Domestic furnaces, brown coal	n.d.	n.d.	350
EPA, 1998a [1)]	Small boilers, top loading	n.d.	n.d.	291
	Small boilers, bottom loading	n.d.	n.d.	273
	Hard coal, stoker firing	n.d.	n.d.	1 200
	Pulverized lignite boilers	n.d.	n.d.	1 105
Meier & Bischoff, 1996 [1)]	Grate firing, lignite	n.d.	n.d.	2 237
Hobson M. et al, 2003	Domestic open fire; < 10 kW, coal	n.d.	375 [2)] – 459 [2)]	n.d.
	Domestic open fire; < 10 kW, smokeless coal brands	n.d.	38–67 [2)]	n.d.
	Domestic open fire; < 10 kW, pet coke blends	n.d.	96–117 [2)]	n.d.
	Domestic open fire; < 5 kW coal	n.d.	1 683 [2)]	n.d.
	Domestic closed stove; US EPA, developing stoves charcoal	n.d.	n.d.	100 [2)]
	Domestic closed stove; US EPA, developing stoves char briquette	n.d.	n.d.	121 [2)]
	Domestic closed stove; CRE; < 10 kW, smokeless coal brands	n.d.	42-50 [2)]	n.d.

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Domestic closed stove; CRE; < 10 kW, pet coke blends	n.d.	108-133 [2)]	n.d.
	Domestic boilers; ERA research, boiler Efis, bituminous coal	n.d	250 [2)]	n.d.
	Domestic boilers; UNECE TFEIP, Dutch figures for coke use	n.d.	6	n.d.
	UNECE TFEIP; Sweden, briquette boilers 1.8–2 MW	n.d.	n.d.	36
Kubica, 2004/1	Conventional stove 5 kW	n.d.	n.d.	523
Kubica, 2004/2	Chamber boiler, top feed; fine coal	n.d.	n.d.	50–200
	Automatic-fuelled coal boiler, stocker	n.d.	n.d.	30–60
	Automatic-fuelled boiler, fine coal	n.d.	n.d.	30–120
	Chamber boiler, qualified size coal; distribution of combustion air	n.d.	n.d.	50–150
Kubica et al., 2005/1	Boilers with moving grate 5–32 MW	n.d.	n.d.	58–133
	Boilers with moving grate 0.3–0.6 MW	n.d.	n.d.	51–64
	Automatic-fuelled coal boiler, fine coal	n.d.	n.d.	50
	Automatic-fuelled coal boiler — stocker	n.d.	n.d.	30–60
	Boiler, bottom feed, nut coals	n.d.	n.d.	50–100
	Boiler, top feed, nut coals	n.d.	n.d.	300–1100
Kubica at al., 2005/2 [3)]	Automatic-fuelled coal boiler — stocker, 25 kW (120 pieces)	n.d.	n.d.	54–133 average 78
	Automatic-fuelled coal boiler, fine coal, 25 and 35 kW (68 pieces)	n.d.	n.d.	70–380 average 187
Kubica et al., 2005/3	Hard coal; stoves and boilers < 1 MW	25-100 average 65	25-1050 aver.270	30-1,200 average 360
	Hard coal; boilers > 1 MW < 50 MW	70-122 average 70	90-250 average 110	25-735 average 140
	Brown coal Residential/commercial/institutional/	140	260	350
	Coke Residential/commercial/institutional/	30 -80 average 80	96-108 average 90	14-133 average 110
Krucki A. et al., 2006 [2)]	Automatic-fuelled coal boiler — stocker, 100 kW	n.d.	n.d.	98
	Automatic-fuelled coal boiler, fine coal, 25 kW	n.d.	n.d.	13

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Automatic-fuelled coal boiler, fine coal, 90 kW	n.d.	n.d.	16
Lee et al., 2005 [2)]	Open fire place	n.d.	1 200	n.d.

Notes:
[1)] As quoted in Klimont et al., 2002.
[2)] Original data in g/kg for recalculation Hu of 24 GJ/t (d.b.) was assumed.
[3)] The measurements were done in the field.
n.d. — no data.

Table A 30 Particulate matter size fractions reported in the literature for coal combustion (per cent of TSP emissions)

Source	Installation type	PM2.5	PM10	TSP
UBA, 1999a [1)]	Domestic furnaces, hard coal	n.d.	90 %	100 %
EPA, 1998a [1)]	Small boilers, top loading	14 %	37 %	100 %
	Small boilers, bottom loading	25 %	41 %	100 %
Hlawiczka et al., 2002	Domestic furnaces, hard coal	n.m.	76 % [2)]	100 %

Notes:
1. [1)] As quoted in Klimont et al., 2002.
2. [2)] Original data 76 % of PM was emitted as the size fractions up to 12 µm.

Table A 31 Particulate matter emission factors reported in the literature for wood burning (g/GJ)

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
BUWAL, 2001 [1)]	Domestic open fire places	n.d.	150	150
	Domestic furnaces	n.d.	150	150
	Domestic small boilers, manual	n.d.	50	50
	Small boilers, automatic loading	n.d.	80	80
Karvosenoja, 2000 [1)]	Domestic furnaces	n.d.	n.d.	200–500
Dreiseidler, 1999 [1)]	Domestic furnaces	n.d.	n.d.	200
Baumbach, 1999 [1)]	Domestic furnaces	n.d.	n.d.	50–100
Pfeiffer et al., 2000 [1)]	Residential and domestic	n.d.	n.d.	41–65
CEPMEIP, 2002 [1)]	'High emissions'	270	285	300
	'Low emissions'	135	143	150
Winiwarter et al, 2001 [1)]	Residential plants	72	81	90
	Domestic stoves, fireplaces	118	133	148
NUTEK, 1997 [1)]	Single family house boiler, conventional	n.d.	n.d.	1 500
	Single family house boiler, modern with accumulator tank	n.d.	n.d.	17
Smith, 1987 [1)]	Residential heating stoves < 5 kW	n.d.	n.d.	1 350

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Residential cooking stoves < 5 kW	n.d.	n.d.	570
BUWAL, 1995 (1992 Swiss limit value) [1)]	up to 1 MW	n.d.	n.d.	106
Spitzer et al., 1998 [1)]	Residential heating	n.d.	n.d.	148±46 %
	Single family house boiler, stoves	n.d.	n.d.	90±26%
Zhang et al., 2000 [1)]	Firewood in China	n.d.	n.d.	760–1 080
Houck and Tiegs, 1998/1 [3)]	Conventional stove	n.d.	n.d.	1 680
	Conventional stove with densified fuel	n.d.	n.d.	1 200
	Non-catalytic stove	n.d.	n.d.	490
	Catalytic stove	n.d.	n.d.	440
	Masonry heater	n.d.	n.d.	250
	Pellet stove	n.d.	n.d.	130
	Fireplace, conventional	n.d.	n.d.	8 600
	Double-shell convection, national draft	n.d.	n.d.	4 600
	Convectiontubes, ‘C’ shaped, glass door	n.d.	n.d.	4 000
	Double-shell convection, blower, glass doors	n.d.	n.d.	1 900
	Masonry fireplace with shaped fire chambers and gladd doors	n.d.	n.d.	1 200
	Fireplace, non-catalytic insert	n.d.	n.d.	500
	Fireplace, catalytic insert	n.d.	n.d.	450
	Fireplace, pellet insert	n.d.	n.d.	130
EPA, 1998b [(1,2)]?	Open fireplaces	n.d.	805	875
	Wood stove	n.d.	724	787
Hobson M. et al, 2003	UNECE TFEIP, Sweden, wood chips boilers 1.8–2 MW	n.d.	n.d.	51
	Open fire < 5 kW, hardwood [2)]	n.d.	494	n.d.
	Domestic open fire: hundreds of source studies [2)]	n.d	n.d.	738
CITEPA, Paris, 2003	Open fire places	698	713	750
	Conventional closed fireplaces and inserts	288	295	310
	Conventional closed stoves and cooking	288	295	310
	Hand-stoked log wood boiler	233	238	250
	Automatically-stoked wood boiler	9	10	10
EPA, 1998a [4)]	Boilers, bark	n.d.	n.d.	2 266

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
Lammi et al., 1993 [4)]	Fluidized bed in large boilers	n.d.	n.d.	1 000 –3 000
	Grate firing in large boilers	n.d.	n.d.	250–1 500
Tullin et al.; 2000	Wood/pellet boilers and stoves	n.d.	n.d.	50
	Old wood boiler	n.d.	n.d.	1 000
Hays et al. (2003) [2)]	Wood stove	143.8–637.5	n.d.	n.d.
	Fireplaces	537.5	n.d.	n.d.
BLT, 2000/1	Wood boilers with two combustion chambers and sonar Lambda	n.d.	n.d.	20
BLT, 2005/1	Wood pellets and chip boiler 25 kW	n.d.	n.d.	14
	Pellets and wood chips boiler 43 kW–100 % and 33 % of capacity	n.d.	n.d.	23; 9
	Wood boiler 60 kW	n.d.	n.d.	28
	Boiler, wood chips 25 kW	n.d.	n.d.	18
	Pellets boiler 46.7 kW–100 % and 33 % of capacity	n.d.	n.d.	5; 12
BLT, 2003	Pellets and briquettes, boiler 7.7–26 kW	n.d.	n.d.	4
BLT, 1999	Wood chips, boiler 500 kW	n.d.	n.d.	28
BLT, 2004/1	Wood chips, boiler 20 kW	n.d.	n.d.	8
BLT, 2004/2	Wood log and briquettes, boiler 50 kW	n.d.	n.d.	16
BLT, 2000/2	Wood briquettes, chamber boiler 60 kW	n.d.	n.d.	10
BLT, 2005/2	Wood log, chamber boiler 27 kW	n.d.	n.d.	12
McDonald et. al., 2000 [2)]	Fireplaces	As $PM_{2.5}$.	n.d.	180–560; average 380
	Woodstove	n.d.	n.d.	140–450; average 270
Lee et al., 2005 [2)]	Open fire place	n.d.	425	n.d.
Gullet et al., 2003	Fireplace, pine	n.d.	n.d.	147
	Fireplace, artificial logs (wax and sawdust)	n.d.	n.d.	483
	Stove, oak	n.d.	n.d.	504
Fine et al., 2002 [2)]	Fireplaces; hardwood — yellow poplar	n.d.	n.d.	425 ± 50
	Fireplaces; hardwood — white ash	n.d.	n.d.	206 ± 19
	Fireplaces; hardwood — sweetgum	n.d.	n.d.	218 ± 25
	Fireplaces; hardwood — mockernut hickory	n.d.	n.d.	425 ± 56

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Fireplaces; softwood — loblolly Pine	n.d.	n.d.	231 ± 25
	Fireplaces; softwood — slash Pine	n.d.	n.d.	100 ± 19
Fine et al.; 2001 2)	Conventional masonry fireplaces; hardwood — red maple northern	n.d.	n.d.	206 ± 19
	Conventional masonry fireplaces; hardwood — red oak	n.d.	n.d.	356 ± 19
	Conventional masonry fireplaces; hardwood — paper birch	n.d.	n.d.	169 ± 19
	Conventional masonry fireplaces softwoods — eastern white pine	n.d.	n.d.	713 ± 125
	Conventional masonry fireplaces softwoods — eastern hemlock	n.d.	n.d.	231 ± 25
	Conventional masonry fireplaces softwoods — balsam fir	n.d.	n.d.	300 ± 31
	Fireplaces; wood	170–710	n.d.	n.d.
Boman et al., 2004	Pellet burner boilers 10–15 kW, overfeeding of the fuel; sawdust, logging residues and bark	n.d.	n.d.	114–377 average 240
	Pellet burner boilers 10–15 kW, horizontal feeding of the fuel; sawdust, logging residues and bark	n.d.	n.d.	57-157 average 95
	Pellet burner boilers 10–15 kW, underfeeding of the fuel; sawdust, logging residues and bark	n.d.	n.d.	64-192 average 140
Broderick et al. 2005 2)	All masonry and factory-built (zero clearance)	n.d.	n.d.	590
	Fireplaces, all cordwood	n.d.	n.d.	810
	Fireplaces, all dimensional lumber	n.d.	n.d.	410
	Fireplaces, all with closed doors	n.d.	n.d.	350
	Fireplaces, all with open doors	n.d.	n.d.	690
	Fireplaces, all masonry fireplaces	n.d.	n.d.	660
	Fireplaces, all factory-built fireplaces	n.d.	n.d.	580
	Fireplaces, cordwood, factory-built, open doors	n.d.	n.d.	870
	Fireplaces, dimensional lumber, factory built, open doors	n.d.	n.d.	510
	All fireplaces, all wood types	n.d.	n.d.	Average 590
	All factory-built fireplaces with open door, cordwood	n.d.	n.d.	Average 840

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
Gaegauf et al., 2001	Wood room heaters	n.d.	n.d.	70 ± 25
	Wood accumulating stoves	n.d.	n.d.	167 ±44
	Wood log boilers	n.d.	n.d.	28 ±11
	Pellet boilers	n.d.	n.d.	20 ±0.4
	Pellet room heaters	n.d.	n.d.	54 ± 3
	Wood chip boilers — dry fuel	n.d.	n.d.	94 ± 13
	Wood chip boilers — wet fuel	n.d.	n.d.	48 ± 6
	Wood chip boilers — residuals	n.d.	n.d.	64 ± 7
Johansson at al., 2001 [7)]	Pellet boilers with fixed grates with moving scrapes 1.75–2.5 MW	n.d.	n.d.	35–40
Nussbaumer, 2001 [2)]	All automatic wood furnaces	n.d.	n.d.	< 110
	Understoker furnaces	n.d.	n.d.	< 55
	Log wood boilers	n.d.	n.d.	34
	Wood chips boiler [5)]	n.d.	n.d.	68
	Wood residues, boiler [5)]	n.d.	n.d.	70
	Urban waste wood, boiler [6)]	n.d.	n.d.	1.5
Houck et al., 2000 [2)]	Conventional stove, cordwood	n.d.	n.d.	750
	Pellet stoves, softwood	n.d.	n.d.	80–170
	Pellets stove, hardwood	n.d.	n.d.	125; 190;220
	Pellets boiler, top-feed, softwood	n.d.	n.d.	27.5; 37.5; 62.5
	Pellets boiler, bottom-feed softwood	n.d.	n.d.	16.3; 25.0
Houck et al., 2005 [2)]	Conventional stove woodstove	890	n.d.	n.d.
	Catalytic certified woodstove	430	n.d.	n.d.
	Non-catalytic certified woodstove	330	n.d.	n.d.
	Pellet stove exempt	160	n.d.	n.d.
	Certified pellet stove	160	n.d.	n.d.
Boman et al., 2005	Pellet stove 4.8 kW (high load)	n.d.	n.d.	11–20 average 15
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	n.d.	32–81 average 51
	Natural-draft wood stove, 9 kW; birch pine spruce	n.d.	n.d.	37–350 average 160
	Pellet stove, 4–9,5 kW; pine and spruce (high load)	n.d.	n.d.	15–17; average 16

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Pellet stove, 4–9,5 kW; pine and spruce (low load 30 %)	n.d.	n.d.	21–43 average 34
Krucki et al., 2006 (2)	Biomass boiler, two stage combustor 95 kW, log wood	n.d.	n.d.	34
	Biomass boiler, two-stage combustor 22 kW, log wood	n.d.	n.d.	13
Kubica, 2004/1	Conventional stove 5 kW	n.d.	n.d.	1 610
Kubica, 2004/2	Pellet burner/boilers	n.d.	n.d.	20–60
	Chamber boiler (hand-fuelled), log wood	n.d.	n.d.	70–175
Kubica et al., 2005/1	Boiler, bottom feed, log wood	n.d.	n.d.	116
	Boiler, bottom feed, wood briquettes	n.d.	n.d.	39
	Automatic-fuelled boiler — stocker 30 kW, pellets	n.d.	n.d.	6
	Automatic-fuelled coal boiler, wood chips	n.d.	n.d.	60
Kubica et al., 2005/3	Residential/commercial/institutional/	9–698 average 450	10–713 average 490	17–4 000 average 520
	Boilers > 1MW < 50 MW	9–170 average 80	60–214 average 80	20–500 average 100
Hedberg et al., 2002 2)	Commercial soapstone stove, birch logs	6–163 average 81	n.d.	n.d.
Johansson et al, 2006	Single family house boiler, modern with accumulator tank	n.d.	n.d.	26–450
Johansson et al, 2006	Single family house boiler, conventional	n.d.	n.d.	73–260
Johansson et al, 2004 a	Single family house boiler, modern with accumulator tank	n.d.	n.d.	23–89
Johansson et al, 2004 a	Single family house boiler, conventional	n.d.	n.d.	87–2 200
Johansson et al, 2006	Single family house boiler, conventional	n.d.	n.d.	73–260
Johansson et al, 2004 a	Pellets burners/boiler	n.d.	n.d.	12–65
Ohlström, 2005	Wood log stove	90 8)	n.d.	100
	Sauna	190 8)	n.d.	200
	Pellets burner	70 8)	n.d.	n.d.
	Pellets burner	25 8)	n.d.	35
	Wood chips/pellets boiler 30–50 kW	15 8)	n.d.	20
	Wood chips boiler 30–50 kW	10 8)	n.d.	20

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Pellets boiler 30–50 kW	10 [8)]	n.d.	15
	Wood chips/pellets stoker [6)] 50–500 kW	20 [8)]	n.d.	40
	Wood chips stoker 30–500 kW [6)]	30 [8)]	n.d.	50
	Pellets stoker 50–500 kW [6)]	10 [8)]	n.d.	20
	Wood chips grate boiler 5–20 MW	20–55 [6)]		
	Wood chips Fluidized bed 20–100 MW	2–20 [7)]		
	Wood chips grate boiler 20–100 MW [7)]	3–10		
	Wood chips grate boiler 10 MW [6)]	3 [8)]	n.d.	10
Paulrud et al. 2006.	Wood log stove	n.d	n.d	22–181
Johansson et al, 2004b	Pellets stove	30–55	30–58	n.d.
	Pellets burner/boiler	10–60	10–75	n.d.
Glasius et al, 2005	Wood stove	n.d.	n.d.	200–5 500
Schauer et. al., 2001	Open fire place	330–630	n.d.	n.d.
Purvis et. al., 2000	Open fire place	n.d.	n.d.	170–780
Wierzbicka, 2005	Moving grate 1.5 MW saw dust, low load	36 [6,8)]	n.d.	
	Moving grate 1.5 MW saw dust, Medium load	28 [6,8)]	n.d.	
	Moving grate 1.5 MW saw dust, high load	25 [6,8)]	n.d.	n.d.
	Moving grate 1.5 MW pellets, low load	20 [6,8)]	n.d.	n.d.
	Moving grate 1.5 MW pellets, medium load	19 [6,8)]	n.d.	n.d.
	Moving grate 1 MW forest residue, medium load	676 [6,8)]	n.d.	n.d.
	Moving grate 1 MW forest residue, high load	57 [6,8)]	n.d.	n.d.
Strand. et al, 2004	Moving grate 6 MW forest residue, high load	43 [6,8)]	n.d.	n.d.
	Moving grate 12 MW forest residue, high load	77 [6,8)]	n.d.	n.d.
	Moving grate 0.9 MW pellets, low load	10 [6,8)]	n.d.	n.d.

Notes:
1. As quoted in Klimont et al., 2002.
2. Original factors in lb/ton or in g/kg for recalculation H_u of 16 GJ/t were assumed.
3. Original factors are estimated per unit of heat delivered, no conversion was made.
4. The data for large scale combustion for illustration only.
5. Cyclone separator-dust control.
6. Filter separator-dust control.
7. PM mainly 0.1-0.3 µm. Typically more than 80 % of all particles are smaller than 1 µm. The mean particle size is typically around 0.1 µm (between 50 nm to 200 nm).

8. Measured as PM1.
9. n.d. — no data.

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Appendix B Calculation of emission factors from emission concentrations

B.1 Standardisation of emission concentrations from combustion activities

Annual emissions, emission rates and emission limit values are generally expressed in terms of pollutant mass (for example tonnes.year^{-1}, kg.hr^{-1}, mg.m^{-3}). Note that a mass concentration is meaningless unless the volume conditions are defined — typically for a combustion process the conditions will be a dry volume, at STP (0 °C, 101.3 kPa) and normalised to a reference oxygen concentration. Consumption of fuel requires a minimum theoretical (stoichiometric) quantity of air. In practise, more air than the stoichiometric quantity is required to achieve combustion. The oxygen content in exhaust gases from a combustion appliance is indicative of the amount of excess air and air ingress in the combustion system. Normalisation to a reference oxygen content allows comparison between technologies as it removes a diluting (or concentrating) effect of different levels of excess air/air ingress on the pollutant concentration.

Common oxygen concentrations for emission normalisation are:

- oil- or gas-fired boilers — 3 % O_2
- solid-fuel boilers — 6, 7 % O_2
- wood-fired boilers — 6, 7, 10, 11 or 13 % O_2
- incineration — 11 % O_2
- gas turbines — 15 % O_2
- stationary engines — 5, 15 % O_2
- dryers — 17 % O_2.

Other normalisation oxygen concentrations are used including 0 % O_2 which is commonly used in the testing of residential gas appliances. Concentrations can also be normalised using carbon dioxide (although this is much less common).

Usually emission concentration data will be provided as mass concentrations at a specified oxygen content. However, where emission data are provided in other forms, the following equations may help the user manipulate the date into a more useful form.

Some pollutants are measured and reported on a wet basis and may require standardisation to the dry condition.

$$[X]_d = [X]_w \cdot \frac{100}{(100-[H_2O])}$$

where:

- $[X]_w$ is the measured concentration for a wet flue gas (ppm, mg.m^{-3}, %v/v),
- [X]d is the measured concentration for a dry flue gas (same units as the dry concentration),
- [H2O] is the flue gas moisture content as % v/v on a wet basis.

Many pollutants are measured as volume (molar) concentrations. Conversion to a mass concentration assumes ideal gas behaviour and is detailed below:

$$[X]_m = [X]_d \cdot \frac{MW}{22.4}$$

where:

- $[X]_d$ is the measured concentration in ppm (parts per million) by volume for a dry flue gas,
- $[X]_m$ is the measured concentration in $mg.m^{-3}$ by volume for a dry flue gas,
- MW is the relative molecular mass of the pollutant (for example 64 for SO_2),
- 22.4 is the volume occupied by 1 kgmole of an ideal gas at 0°C, 101.3 kPa (m^3).

Note that NO_x emission concentrations and emission factors are defined in terms of NO_2. Hence, the relative molecular mass used for NO_x is 46. VOC emission concentrations are often defined in terms of carbon. Hence, the relative molecular mass used for VOC is 12, but this will often be modified further for the calibration gas applied (for example MW for concentrations measured as propane C_3H_8 'equivalents' would 3 x 12 - 36).

Normalisation to a reference O_2 concentration is given by:

$$[X]_{ref} = [X]_m \cdot \frac{(20.9-[O_2]_{ref})}{(20.9-[O_2]_m)}$$

where :

- $[X]_{ref}$ is the standardised concentration of the pollutant at the reference O_2 content,
- $[x]_m$ is the measured concentration in $mg.m^{-3}$ for a dry flue gas,
- $[O_2]_m$ is the measured O_2 concentration in % on a dry basis,
- $[O_2]_{ref}$ is the reference O_2 concentration in % on a dry basis (for example 3, 6 or 15 %).

This calculation is appropriate where pollutant and O_2 concentrations are measured on a dry basis.

B.2 Calculation of emission factors

An emission factor relates the release of a pollutant to a process activity. For combustion processes, emission factors are commonly described as the mass of pollutant released per unit of fuel burned.

An emission factor can be calculated in several ways; the approach adopted uses the standardised pollutant emission concentrations and the specific theoretical (stoichiometric) volume of flue gas for the relevant fuel. This approach avoids measurement of exhaust gas flow and fuel flows which can have a high uncertainty and may not be practical at many combustion plant.

The approach requires knowledge of the fuel used, the pollutant concentration and the oxygen concentration.

Fuel analysis, where available, allows calculation of the specific flue gas volume from the elemental analysis. However, the US Environmental Protection Agency Method 19 provides flue gas volume for common fuels. For other fuels (for example derived gases, landfill gas, unrefined natural gas or waste-derived fuels) fuel analysis is advised to minimise uncertainty.

Fuel analysis route: the fuel analysis and combustion calculations are used to determine the stoichiometric air requirement and dry flue gas volume per volume or mass of fuel. Note that is important to understand the analysis reporting conditions, particularly for solid fuels. The calculations assume ideal gas behaviour. A dry flue gas volume is calculated for the reference O_2 concentration used to normalise the pollutant emission concentration. A pollutant emission factor (EF) can hence be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content.

Generally, the flue gas volumes generated from combustion of fuel can be calculated in accordance with the following equations.

$$C_XH_Y + (X+(Y/4)O_2 = X\ CO_2 + (Y/2)\ H_2O$$

Note that some of the oxygen may be sourced from the fuel. For combustion in air, each cubic metre of oxygen is associated with (79.1/20.9) cubic metres of nitrogen.

The dry flue gas volume at stoichiometric conditions ($DFGV_{SC}$) per unit mass of fuel (or volume for gaseous fuels) can be calculated and hence the dry flue gas volume at the normalised condition ($DFGV_{ref}$) for the required reference oxygen content:

$$DFGV_{ref} = DFGV_{SC} . (20.9/(20.9-[O_{2ref}]))$$

A pollutant emission factor (EF) can hence be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content. For example, at 15 % oxygen:

$$EF = [X]_{15\%} . DFGV_{15}$$

Emission factors are reported in several ways and these are generally recalculated using physical or other properties of the fuel.

For example, a thermal emission factor (as used in the Guidebook) can be derived by dividing the emission factor calculated above by the calorific value of the fuel. For the Guidebook, this is the net (inferior) CV.

$$EF_{thermal} = \frac{EF}{CV}$$

where:

- $EF_{thermal}$ is the thermal emission factor expressed in units to suit the user (for example g GJ^{-1}),
- CV is the net calorific value of the fuel in appropriate units to suit the units of the emission factor.

USEPA Method 19: the USEPA provides stoichiometric dry flue gas volume for fuel oil. The USEPA data can be found in USEPA Method 19 (US Code of Federal Regulations, Title 40 Part 60, Appendix

A). The USEPA 'F-factor' data are presented as the volume of dry flue gas at 20 °C associated with the gross thermal input of the fuel. These USEPA conditions are not consistent with the Guidebook or emission reporting practise in Europe and consequently some manipulation of the data is required. Calculations assume an ideal gas.

The USEPA method can be obtained here www.epa.gov/ttn/emc/methods/method19.html and the F-factors are provided below.

TABLE 19-2. F FACTORS FOR VARIOUS FUELS[1]

Fuel Type	F_d		F_w		F_c	
	dscm/J	dscf/10^6 Btu	wscm/J	wscf/10^6 Btu	scm/J	scf/10^6 Btu
Coal:						
Anthracite[2]	2.71×10^{-7}	10,100	2.83×10^{-7}	10,540	0.530×10^{-7}	1,970
Bituminus[2]	2.63×10^{-7}	9,780	2.86×10^{-7}	10,640	0.484×10^{-7}	1,800
Lignite	2.65×10^{-7}	9,860	3.21×10^{-7}	11,950	0.513×10^{-7}	1,910
Oil[3]	2.47×10^{-7}	9,190	2.77×10^{-7}	10,320	0.383×10^{-7}	1,420
Gas:						
Natural	2.34×10^{-7}	8,710	2.85×10^{-7}	10,610	0.287×10^{-7}	1,040
Propane	2.34×10^{-7}	8,710	2.74×10^{-7}	10,200	0.321×10^{-7}	1,190
Butane	2.34×10^{-7}	8,710	2.79×10^{-7}	10,390	0.337×10^{-7}	1,250
Wood	2.48×10^{-7}	9,240	--	--	0.492×10^{-7}	1,830
Wood Bark	2.58×10^{-7}	9,600	--	--	0.516×10^{-7}	1,920
Municipal	2.57×10^{-7}	9,570	--	--	0.488×10^{-7}	1,820
Solid Waste	--					

[1]Determined at standard conditions: 20 °C (68 °F) and 760 mm Hg (29.92 in. Hg)
[2]As classified according to ASTM D 388.
[3]Crude, residual, or distillate.

The F_d factors are used — these represent the dry stoichiometric flue gas volume per unit of energy input. The F_w and F_c factors represent the wet flue gas volume and CO_2 volumes respectively.

The USEPA dry flue gas volume at stoichiometric conditions are first recalculated to provide the flue gas volume ($DFGV_{ref}$) for the required oxygen content at STP and for the net energy input.

$$F_d' = F_d \cdot (273/293) \cdot ((CV_{gross})/CV_{net}))$$

where :

- F_d' is the stoichiometric dry flue gas volume at STP per unit of net energy input – $m^3.J^{-1}$,
- Fd is the USEPA factor (20 °C and gross energy input),
- 273/293 volume correction — ratio of temperatures in Kelvin.

Note that it is the ratio between the fuels' gross and net calorific values that is needed. Indicative ratios are provided below based on UK data (DUKES 2007).

Table B1 Fuel calorific values

Fuel	CVgross	CVnet	Units	Ratio
Power stn coal	26.2	24.9	$GJ.tonne^{-1}$	1.05
Industrial coal	26.6	25.3	$GJ.tonne^{-1}$	1.05
Wood	11.9	10	$GJ.tonne^{-1}$	1.08
HFO	43.3	41.2	$GJ.tonne^{-1}$	1.05
Gas oil	45.6	43.4	$GJ.tonne^{-1}$	1.05
Natural gas	39.8	35.8	$MJ.m^{-3}$	1.11

The dry flue gas volume at the normalised oxygen content can then be calculated:

$F_{dref} = F_d' . (20.9/(20.9-[O_{2ref}]))$

A pollutant emission factor ($EF_{thermal}$) can then be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content. For example at 15 % oxygen:

$EF_{thermal} = [X]_{15\%} . F_{d15\%}$

Emission factors are reported in several ways and these are generally recalculated using physical or other properties of the fuel.

For example, a mass emission factor can be derived by multiplying the thermal emission factor calculated above by the net calorific value of the fuel.

$EF = EF_{thermal} . CV$

where:

- $EF_{thermal}$ is the thermal emission factor expressed in units to suit the user (for example g GJ^{-1}),
- CV is the net calorific value of the fuel in appropriate units to suit the units of the emission factor.

Example figures for correlation of emission concentrations to emission factors from USEPA Method 19 F factors are provided in Figures B1 and B2 below.

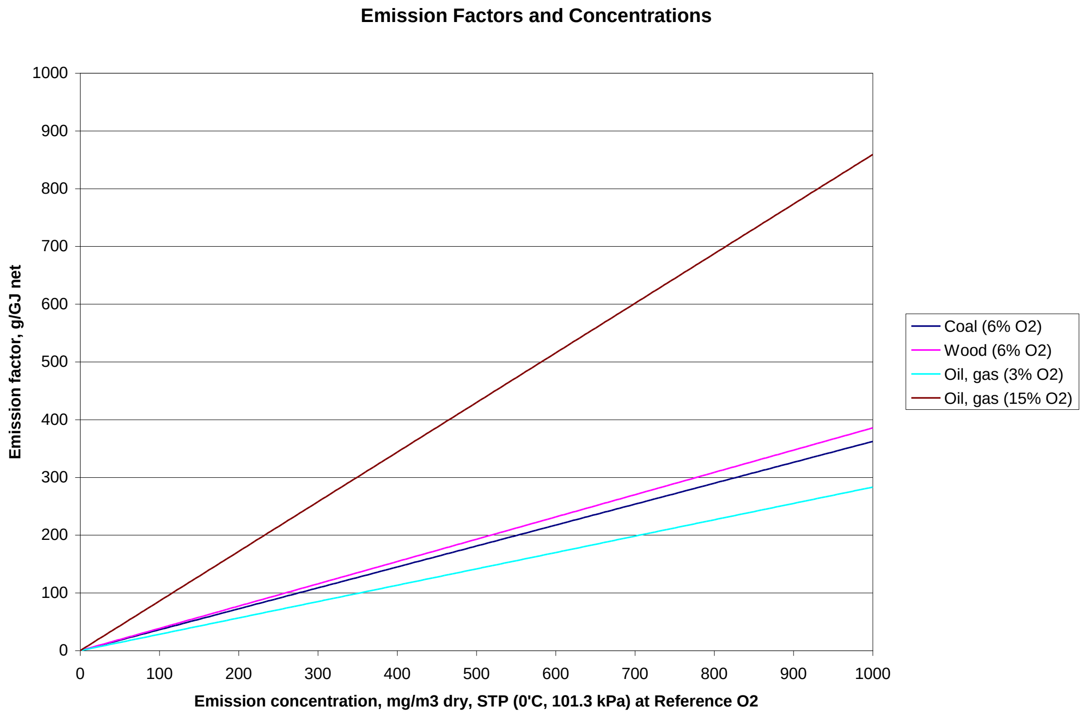

Figure B1 Emission factors — selected fuels and standardised concentrations up to 1 000 $mg.m^{-3}$

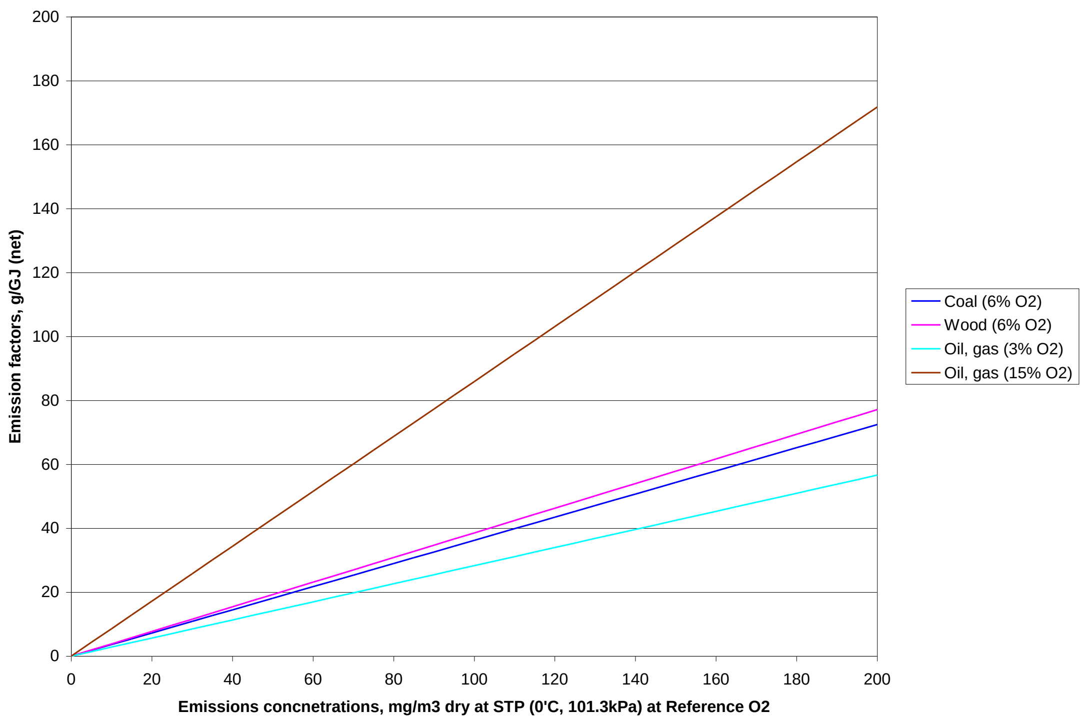

Figure B2 Emission factors — selected fuels and standardised concentrations up to 200 $mg.m^{-3}$

Appendix C Emission factors associated with emission limit values in selected countries

Table C1 Selected national emission limit values for small coal-fired combustion installations

Country	Size	Ref.	Emission concentrations, mg.m^{-3} at STP (0ºC, 101.3 kPa) d								Emission factor, g.GJ^{-1} (net basis)							
		O2	NOx		SO_2		PM		CO	VOC	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High			Low	High	Low	High	Low	High		
Belgium	0.3-5 MW	6	300	800	1250	1250	100	200	250		109	290	453	453	36	72	91	
Belgium	5-20 MW	6	300	800	1250	1250	50	200	200		109	290	453	453	18	72	72	
Belgium	20-50 MW	6	300	600	1250	1250	50	200	250		109	217	453	453	18	72	91	
Czech republic	0.2-50 MW	6	650				250		650	50	235				91		235	18
Czech republic	<50 MW	6	1500		800	2500			1000	50	543		290	906			362	18
France	20-50 MW	6	450	650	850	2000	50	100	200	110	163	235	308	725	18	36	72	40
France	<4 MW	6	550	825	2000		150				199	299	725		54			
France	4-10 MW	6	550	825	2000		100				199	299	725		36			
France	>10 MW	6	550	825	2000		100				199	299	725		36			
Finland	1-50 MW	6	275	550	1100	1100	55	140			100	199	398	398	20	51		
Germany	<2.5 MW	7	300	500	350	1300	50		150		116	194	136	505	19		58	
Germany	<5 MW	7	300	500	350	1300	50		**150**		116	194	136	505	19		58	
Germany	>5MW	7	300	500	350	1300	20		150		116	194	136	505	8		58	
Germany	>10 MW	7	300	400	350	1300	20		150		116	155	136	505	8		58	
Italy	20-50 MW	6	400		200		30		200	20	145		72		11		72	7
Latvia	<10 MW	6	600		2500		1000		2000		217		906		362		725	
Latvia	10-50 MW	6	600		2500		500		2000		217		906		181		725	
Norway	0.5-1 MW	7	250				100		150		97				39		58	
Norway	1-5 MW	7	250				20		100		97				8		39	
Norway	5-50 MW	7	200				20		100		78				8		39	
Poland	<5	6					630								228			
Poland	5-50 MW	6					400								145			
Portugal		6	1500		2700				1000	50	543		978				362	18
Slovakia	0.2-2 MW	6			2500		250						906		91			
Slovakia	02-50 MW	6					150								54			
Slovenia	1-50 MW	6	100		2000		150		100		36		725		54		36	
Slovenia	5-50 MW	6					50								18			
UK	20-50 MW	6	450	650	2000	3000	300		150		163	235	725	1087	109		54	

Notes:

1. All combustion unit sizes are MW_{th} (thermal input).
2. Range of concentrations (NO_x, SO_2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.

Table C2 Selected national emission limit values for small coal-fired combustion installations

Country	Size	Ref.	Emission concentrations, $mg.m^{-3}$ at STP (0ºC, 101.3 kPa) d								Emission factor, $g.GJ^{-1}$ (net basis)							
		O2	NOx		SO_2		PM		CO	VOC	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High			Low	High	Low	High	Low	High		
France	20-50 MWth	11	400	650	200	2000	50	100	200	110	232	377	116	1161	29	58	116	64
France	<4 MW	11	500	750	200		150				290	435	116		87			
France	4-10 MW	11	500	750	200		100				290	435	116		58			
France	>10 MW	11	500	750	200		100				290	435	116		58			
Finland	1-5 MW	6	250	500			250	375			96	193			96	145		
Finland	5-10 MW	6	250	500			125	250			96	193			48	96		
Finland	10-50 MW	6	250	500			50	125			96	193			19	48		
Germany	<2.5 MW	11	250		350		100			10	145		203		58			6
Germany	<5 MW	11	250		350		50			10	145		203		29			6
Germany	>5MW	11	250		350		20			10	145		203		12			6
Italy		6	400		200		30		200	20	154		77		12		77	8
Latvia	<10 MW	6	600		200		1000		2000		231		77		386		771	
Latvia	10-50 MW	6	600		200		500		2000		231		77		193		771	
Norway	0.5-1 MW	11	250				100	300	150		145				58	174	87	
Norway	1-5 MW	11	250				20	300	100		145				12	174	58	
Norway	5-20 MW	11	200	300			20	100	100		116	174			12	58	58	
Norway	20-50MW	11	200	300			20	50	100		116	174			12	29	58	
Poland	<5	6					700								270			
Poland	5-50 MW	6					400								154			
Portugal		6	1500		2700				1000	50	579		1041				386	19
UK	20-50 MW	6	450				300		150		174				116		58	

Notes:
All combustion unit sizes are MW_{th} (thermal input).
Range of concentrations (NO_x, SO_2 and PM) generally corresponds to ELVs for new and existing combustion plant.
Some countries apply BAT achievable emission levels rather than ELVs.

Table C3 Selected national emission limit values for small oil-fired combustion installations

Country	Size	Ref.	Emission concentrations, $mg.m^{-3}$ at STP (0ºC, 101.3 kPa) d								Emission factor, $g.GJ^{-1}$ (net basis)							
		O2	NOx		SO_2		PM		CO	VOC	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High			Low	High	Low	High	Low	High		
Czech republic		3			1700		100						481		28			
Czech republic		3			1700		100						481		28			
France	20-50 MWth	3	450	650	850	1700	50	100	100	110	127	184	241	481	14	28	28	31
France	<4 MW	3	550	825	1700		150				156	233	481		42			
France	4-10 MW	3	550	825	1700		100				156	233	481		28			
France	>10 MW	3	500	750	1700		100				141	212	481		28			
Finland	1-15 MW	3	800	900	1700		50	200			226	255	481		14	57		
Finland	15-50MW	3	500	670	1700		50	140			141	190	481		14	40		
Germany	HWB	3	180	350			50		80		51	99			14		23	
Germany	LPS	3	200	350			50		80		57	99			14		23	
Germany	HPS	3	250	350			50		80		71	99			14		23	
Italy	5-50 MW	3	500		1700		100				141		481		28			
Latvia	<10 MW	3	400		1700		50		400		113		481		14		113	
Latvia	10-50 MW	3	400		1700		50		400		113		481		14		113	
Norway	0.5-1 MW	3	250				100	100	10		71				28	28	3	
Norway	1-5 MW	3	250				20	100	10		71				6	28	3	
Norway	5-50 MW	3	200	600			20	150	10		57	170			6	42	3	
Poland	<5	3																
Portugal		3	1500		2700				1000	50	424		764				283	14
Slovakia	0.2-2 MW	3			1700		100						481		28			
Slovenia	1-50 MW	3			1700		50						481		14			
Slovenia	5-50 MW	3					50								14			
UK	20-50 MW	3	200	600	1700		100	150	150		57	170	481		28	42	42	

Notes

All combustion unit sizes are MW_{th} (thermal input).

Range of concentrations (NO_x, SO_2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.

Note that for SO_2, the ELV for unabated combustion units is determined by fuel sulphur content and Directive 1999/32/EC on sulphur content of certain liquid fuels (1 % for heavy fuel oil and 0.2 % for gas oil until 1.1.2008 when the gas oil sulphur limit will be 0.1 %).

Germany distinguishes NOx emissions by application; HWB — hot water boiler, LPS — steam boiler supplying steam at temperature up to 210 ºC and up to 1.8 Mpa, HPS — boilers supplying steam at temperature greater than 210 ºC or pressure over 1.8 Mpa.

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Table C4 Selected national emission limit values for small gas-fired combustion installations

Country	Size	Ref.	Emission concentrations, $mg.m^{-3}$ at STP (0ºC, 101.3 kPa) d								Emission factor, $g.GJ^{-1}$ (net basis)							
		O2	NOx		SO_2		PM		CO	VOC	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High			Low	High	Low	High	Low	High		
Czech republic		3			35		10						10		3			
Czech republic		3			35		10						10		3			
France	20-50 MWth	3	120	350	35		5		100	110	34	99	10		1		28	31
France	<10MW	3	150	225	35		5				42	64	10		1			
France	>10 MW	3	100	150	35		5				28	42	10		1			
Finland	1-15 MW	3	340	400							96	113						
Finland	15-50MW	3	170	300							48	85						
Germany	HWB	3	100		10		5		50		28		3		1		14	
Germany	LPS	3	110		10		5		50		31		3		1		14	
Germany	HPS	3	150		10		5		50		42		3		1		14	
Italy		3	350		35		5				99		10		1			
Latvia	<10 MW	3	350		35		5		150		99		10		1		42	
Latvia	10-50 MW	3	350		35		5		150		99		10		1		42	
Norway	0.5-1 MW	3	120						10		34						3	
Norway	1-5 MW	3	120						10		34						3	
Norway	5-50 MW	3	120	200					10		34	57					3	
Poland		3					5								1			
Portugal		3	1500		2700				1000	50	425		765				283	14
Slovakia	0.2-2 MW	3			35		10						10		3			
Slovenia	1-50 MW	3			35		5						10		1			
Slovenia	5-50 MW	3					5								1			
UK	20-50 MW	3	140		35		5		100		40		10		1		28	

Notes:

1. All combustion unit sizes are MW_{th} (thermal input).
2. Range of concentrations (NO_x, SO_2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.
3. Germany distinguishes NOx emissions by application; HWB — hot water boiler, LPS — steam boiler supplying steam at temperature up to 210 ºC and up to 1.8 Mpa, HPS — boilers supplying steam at temperature greater than 210 ºC or pressure over 1.8 Mpa.

Table C5 Selected national emission limit values for engines and gas turbines

Country	Fuel	Ref.	Emission concentrations, mg.m^{-3} at STP (0ºC, 101.3 kPa)								Emission factor, g.GJ^{-1} (net basis)							
		O2	NOx		SO_2		PM		CO	VOC	NOx		SO_2		PM		CO	VOC
		%	Low	High	Low	High	Low	High			Low	High	Low	High	Low	High		
Engines :																		
France	Gas	5	350								112							
France	Oil	5	1000								319							
Finland	Gas	15	750	1750							644	4561						
Finland	Oil	15	750	2300	600		60	70			644	5990	1563		156	182		
Germany	Gas, <3MW	5	1000				20		300	2000	319				19		290	1934
Germany	Gas	5	500				20		300	650	159				19		290	629
Germany	Oil, <3MW	5	1000				20		300		319				19		290	
Germany	Oil	5	500				20		300		159				19		290	
UK	Gas	15	500	750			50	100	450	200	430	1955			130	261	1173	521
UK	Oil	15	1100	1800			100		150	150	944	4688			260		391	391
Gas turbines :																		
Finland	Gas	15	115	175							99	150						
Finland	Oil	15	115	175							99	150						
Germany	Gas	15	75						100		64						86	
Germany	Oil	15	150						100		129						86	
UK	Gas	15	60	125					60		52	107					52	
UK	Oil	15	125	165					60		107	142					52	

Notes:

1. All combustion unit sizes are MW_{th} (thermal input).
2. Range of concentrations (NO_x, SO_2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission level ranges rather than ELVs.
3. Note that for $SO_{2,}$ the ELV for unabated combustion units is determined by fuel sulphur content and Directive 1999/32/EC on sulphur content of certain liquid fuels (1 % for heavy fuel oil and 0.2 % for gas oil until 1.1.2008 when the gas oil sulphur limit will be 0.1 %).

Appendix D 2013 update of methodologies for Small combustion (1A4)

Nielsen, O.-K., Plejdrup, M.S. & Nielsen, M. (2012)

Small combustion installations are in many countries a key category for several pollutants. Especially in countries with a high degree of stoves and boilers using biomass or solid fuels, this source category will be key for PM, NMVOC, CO, PAH and PCDD/F. In addition to the category's importance in terms of emissions, it is also associated with a high degree of uncertainty both regarding the activity data (especially for wood) and the emission factors (EFs). The EFs in the 2009 EMEP/EEA Guidebook (GB) were not referenced in a scientific manner. Practically all of the EFs are referenced to a previous version of the GB, where the EFs are not referenced. Therefore, it is not clear what the original references for the EFs are. Considering the large importance of this source sector this is highly objectionable.

This discussion paper covers a review of the EFs in the 2009 GB and provides the reasoning and references behind the EFs included in this present 2013 version.

A. Residential plants

The 2009 GB contains four tier 1 EF tables and a larger number of tier 2 EF tables as presented in the table below. In the 2009 GB there is no match between the technological descriptions in section 2.2 and the EFs provided in section 3 of the chapter. This necessitated a reevaluation of the descriptions of techniques and the EFs provided in the chapter.

List of EF tables for residential plants in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology
Table 3-3	1	Coal	Residential	
Table 3-4	1	Natural gas	Residential	
Table 3-5	1	Other liquid fuels	Residential	
Table 3-6	1	Biomass	Residential	
Table 3-12	2	Solid fuels	Residential	Fireplaces
Table 3-13	2	Gaseous fuels	Residential	Fireplaces
Table 3-14	2	Wood	Residential	Fireplaces
Table 3-15	2	Solid fuels	Residential	Stoves
Table 3-16	2	Solid fuels	Residential	Boilers < 50 kW
Table 3-17	2	Wood	Residential	Stoves
Table 3-18	2	Wood	Residential	Boilers < 50 kW
Table 3-19	2	Natural gas	Residential	Stoves
Table 3-20	2	Natural gas	Residential	Boilers < 50 kW
Table 3-21	2	Liquid fuels	Residential	Stoves
Table 3-22	2	Liquid fuels	Residential	Boilers < 50 kW

Table 3-23	2	Coal	Residential	Advanced stoves
Table 3-24	2	Wood	Residential	Advanced fireplaces
Table 3-25	2	Wood	Residential	Advanced stoves
Table 3-26	2	Wood	Residential	Pellet stoves

Biomass combustion

Emission factors are in the 2009 GB included in one tier 1 emission factor table and 6 tier 2 emission factor tables. The technology description in chapter 2.2 does not match the tier 2 emission factor tables. Suggested new technology names and the link to the technology description in chapter 2.2 are shown below. Emission factors for advanced fireplaces will be deleted and replaced by an emission factor table for energy efficient stoves.

List of EF tables for residential plants in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology	New technology name	Chapter 2.2 technology name
Table 3-6	1	Biomass	Residential		-	-
Table 3-14	2	Wood	Residential	Fireplaces	Open fireplaces	Open and partly closed fireplace
Table 3-17	2	Wood	Residential	Stoves	Conventional stoves	Closed fireplace, conventional traditional stoves, domestic cooking
Table 3-18	2	Wood	Residential	Boilers < 50 kW	Conventional boilers < 50 kW	Conventional biomass boilers
Table 3-24	2	Wood	Residential	Advanced fireplaces	Energy efficient stoves	Energy efficient conventional stoves, masonry heat accumulating stoves[2]
Table 3-25	2	Wood	Residential	Advanced stoves	Advanced/Ecolabelled stoves and boilers	Advanced combustion stoves, catalytic combustor stoves, advanced combustion boilers
Table 3-26	2	Wood	Residential	Pellet stoves	Pellet stoves and boilers	Modern pellet stoves, automatic wood boilers (pellets / chips)

In general, the emission factors in the 2009 update of the guidebook refer to the 2007 update of the guidebook. Emission factors have all been updated and references added.

If the emission factors in the literature survey are in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

[2] *Masonry heat accumulating stoves* might be included in *Advanced/ecolabelled stoves and boilers* instead depending on the technology.

Most emission factors have been rounded off to one or two significant digits.

In general, the Tier 1 emission factors for biomass have been based on the emission factors for conventional stoves combusting wood.

NO_x

The GB 2009 emission factors are in the range 50-120 g/GJ.

For open fireplaces, the GB 2009 emission factor is 50 g/GJ. This is higher than the AP-42 emission factor. However, the emission factor will be assumed equal to the emission factor for conventional stoves and thus the emission factor will not be revised.

For conventional stoves, the emission factor range in the literature is 35-84 g/GJ and the GB 2009 emission factor 50 g/GJ is in agreement with the general emission level found in the literature survey. The emission factor 50 g/GJ will be applied and a reference to Pettersson et al. (2011) will be added. The interval 30-150 g/GJ will not be changed.

For conventional boilers the emission factor range in the literature is 28-125 g/GJ and the GB 2009 emission factor is 120 g/GJ. The GB 2009 emission factor is above the general emission level found in the literature survey. The emission factor 80 g/GJ[3] will be applied and a reference to Pettersson et al. (2011) will be added. The interval 30-150 g/GJ will not be changed.

For energy efficient boilers the literature survey showed NO_x emission in the interval 25-74 g/GJ. The emission factor for conventional stoves and conventional boilers will be applied (80 g/GJ).

For ecolabelled/advanced stoves and boilers, the range in the literature is 54-126 g/GJ and the GB 2009 emission factor is 90 g/GJ. The GB 2009 emission factor is in line with the data found in the literature survey. The emission factor 95 g/GJ will be applied and a reference to Pettersson et al. (2011) will be added. The interval 50-150 g/GJ will not be changed.

For pellet stoves and boilers, the range in the literature is 49-282 g/GJ (49-180 g/GJ if one outlier is not included) and the GB 2009 emission factor is 90 g/GJ. The GB 2009 emission factor is slightly above the general emission level found in the literature survey. The emission factor 80 g/GJ will be applied and a reference to Pettersson et al. (2011) will be added. The interval 50-150 will be revised to 50-200 g/GJ.

Emission data for NO_x, g/GJ.

	Technology	Wood	NO_x emission, g/GJ
US EPA (1996), AP-42 Chapter 1.9	Fireplace	-	144
Pettersson et al. 2011	Stove	Wood logs	47 (35-66)
Fernandes et al., 2011	Cast iron stove	Wood logs	37-74
Tissari et al., 2007	Stove	Wood logs	25 (20-30)
Bäfver et al, 2011	Old stove	Wood logs	70-84
US EPA (1996), AP-42 Chapter 1.10	Wood stove, conventional	Wood logs	78
Li (2006)	-	Wood logs	61
Johansson et al., 2004	Old-type wood boilers	Wood logs	68 (28-72)
Johansson et al., 2004	Modern wood boilers	Wood logs	92 (60-125)

[3] Average of the emission factors for old and modern boilers.

Johansson et al., 2003a	Boilers, not ecolabelled	Wood logs	61 (28-72)
Todorovic et al., 2007	Boilers	-	36-100
Tissari et al., 2007	Several (with heat storage)	Wood logs	25-57
Lamberg et al., 2011	Modern masonry heater	Wood logs	74
Koyuncu & Pinar, 2007	Biomass stove (with secoundary air)	Firewood[1)]	12.54 (0.75-18.32)[1)]
Schmidl et al., 2011	Chimney type (C)	Briquettes and logs	60-111
Schmidl et al., 2011	Chimney type (D)	Briquettes and logs	54-106
Bäfver et al, 2011	Modern stove	Wood logs	74-110
Kistler et al., 2012	Chimney type	-	92 (58-132)
Johansson et al., 2003a	Boilers, ecolabelled	Wood logs	96 (56-126)
Austrian Environmental label	Hand fed stoves	Wood logs	120
Boman et al., 2011	Two pellet boilers	Pellets	49-62
Schmidl et al., 2011	Pellet stove	Pellets	79-83
Schmidl et al., 2011	Pellet boiler	Pellets	63-77
Johansson et al., 2004	Pellet boilers	Pellets	78 (62-180)
Sippula et al., 2007	Top fed pellet stove	Pellets, bark and stem	56 (56-282)
Lamberg et al., 2011	Pellet boiler	Pellets	49 (42-56)
Bäfver et al, 2011	Pellet stove	Pellets	68-170
Verma et al., 2011	Pellet boilers (5 different)	Pellets	< 60
Kistler et al., 2012	Pellet stove	Pellets	100 (74-131)
Todorovic et al., 2007	Boilers		68

1) The interval includes other biomass fuels

NO_x emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	NOx emission factor, g/GJ	Reference
Table 3-6	1	Biomass	Residential	-	80	Assumed equal to conventional boilers.
Table 3-14	2	Wood	Residential	Open fireplaces	50	Assumed equal to conventional stoves.
Table 3-17	2	Wood	Residential	Conventional stoves	50	Pettersson et al. (2011)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	80	Pettersson et al. (2011)
Table 3-24	2	Wood	Residential	Energy efficient stoves	80	Assumed equal to conventional stoves
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	95	Pettersson et al. (2011)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	80	Pettersson et al. (2011)

CO

The GB 2009 emission factors are in the range 500-6000 g/GJ.

For open fireplaces, the emission factor range in the literature is 750-12000 g/GJ and the GB 2009 emission factor is 6000 g/GJ. The GB 2009 emission factor is higher than the general emission level found in the literature survey. The emission factor 4000 g/GJ will be applied and a reference to Goncalves et al. (2012) will be added. The interval will be revised to 1000-10000 g/GJ.

For conventional stoves the range in the literature is 750-23700 g/GJ (750-10000 is one outlier is not included). The GB 2009 emission factor 6000 g/GJ is higher than the general emission level found in the literature survey. The emission factor 4000 g/GJ will be applied and a reference to Pettersson et al. (2011) and Goncalves et al. (2012) will be added. The interval will be revised to 1000-10000 g/GJ.

For conventional boilers the range in the literature is 500-16400 g/GJ and the GB 2009 emission factor is 4000 g/GJ. The GB 2009 emission factor is in agreement with the general emission level found in the literature survey. The emission factor 4000 g/GJ will be applied and a reference to Johansson et al. (2004) will be added[4]. The interval will be revised to 500-10000 g/GJ.

For energy efficient stoves, the emission factor range in the literature survey is 680-6250. The emission factor has been assumed equal to conventional boilers.

For ecolabelled/advanced stoves and boilers, the range in the literature is 500-5400 g/GJ and the GB 2009 emission factor is 3000 g/GJ. The GB 2009 emission factor is above the data found in the literature survey. The emission factor 2000 g/GJ will be applied and a reference to Johansson et al. (2003). The ecolabels include different CO emission limits. The interval will be revised to 500-5000 g/GJ.

For pellet stoves and boilers, the range in the literature is 5-2564 g/GJ and the GB 2009 emission factor is 500 g/GJ. The GB 2009 emission factor is above the general emission level found in the literature survey. The emission factor 300 g/GJ will be applied and a reference to Schmidl et al. (2011) and Johansson et al. (2004) will be added. The interval will be revised to 10-2500 g/GJ.

Emission data for CO, g/GJ.

	Technology	Wood	CO emission, g/GJ
Goncalves et al., 2012	Fireplace	logs (and briquettes)	2833-4750
US EPA (1996), AP-42 Chapter 1.9	Fireplace	Wood logs	7017
Naturvårdsverket	Open fireplaces	Wood logs	4000 (2100-12000)
Meyer, 2012	Open fireplace	Wood logs	750-6185
Pettersson et al. 2011	Stove	Wood logs	3600 (1100-7200)
Goncalves et al., 2012	Wood stove	split logs (and briquettes)	3172-5511
Tissari et al., 2007	Stove	Wood logs	1823 (1458-2188)
Pettersson et al., 2011	Stove	Wood logs	2400
Bäfver et al, 2011	Old stove	Wood logs	1800-3200
US EPA (1996), AP-42 Chapter 1.10	Wood stove, conventional	Wood logs	6411
Naturvårdsverket	Wood log stoves	Wood logs	2500 (5-23700)
Li (2006)	-	Wood logs	5689
Paulrud et al., 2006	Stove	-	2200 (750-4700)
Paulrud et al., 2006	Fireplace with inset	-	2200 (930-3700)
McDonald et al., 2000	wood stove	softwood and hardwood	7163 (5706-9922)
Hübner et al., 2005	Single stove, wood	-	2830 (1500-4700)
Johansson et al., 2004	Old-type wood boilers	Wood logs	5640 (4800-16400)[2)]
Johansson et al., 2004	Modern wood boilers	Wood logs	1324 (507-3781)
Winther 2008	Old boilers	Wood logs	9001-10890
Winther 2008	New boilers	Wood logs	2616-3165
Johansson et al., 2003a	Boilers, not ecolabelled	Wood logs	7000 (4100-16400)

[4] It has been assumed that 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers is not included.

Todorovic et al., 2007	Boilers	-	1300-12000
Hübner et al., 2005	Boilers, wood	Wood logs	3220 (540-4300)
Tissari et al., 2007	Several (with heat storage)	Wood logs	6250 (1458-6250)
Lamberg et al., 2011	Modern masonry heater	Wood logs	580
Koyuncu & Pinar, 2007	Biomass stove (with secoundary air)	Firewood[1)]	1489 (1403-3276)[1)]
Fernandes et al., 2011	Logwood stove	Wood logs	1527-3587
Schmidl et al., 2011	Chimney type (C)	Briquettes and logs	839-1751
Schmidl et al., 2011	Chimney type (D)	Briquettes and logs	939-1814
Bäfver et al, 2011	Modern stove	Wood logs	1200-1900
Kistler et al., 2012	Chimney type	-	2098 (1189-3681)
Johansson et al., 2003a	Boilers, ecolabelled	Wood logs	1952 (507-5400)
Austrian Environmental label	*Hand fed stoves*	*Wood logs*	*700[3)]*
Nordic Ecolabelling - Swan			*1117[3)]*
P-mark			*2464[3)]*
Boman et al., 2011	Two pellet boilers	Pellets	75-770
Schmidl et al., 2011	Pellet stove	Pellets	33-488[4)]
Schmidl et al., 2011	Pellet boiler	Pellets	5-319
Johansson et al., 2004	Pellet boilers	Pellets	464 (30-1100)
Sippula et al., 2007	Top fed pellet stove	Pellets, bark and stem	142 (142-2564)
Lamberg et al., 2011	Pellet boiler	Pellets	80 (13-147)
Bäfver et al, 2011	Pellet stove	Pellets	57-270
Verma et al., 2011	Pellet boilers (5 different)	Pellets	<200 (750)
Naturvårdsverket	Pellet burners	Pellets	300 (31-1700)
Kistler et al., 2012	Pellet stove	Pellets	184 (118-245)
Todorovic et al., 2007	Boilers		200
Hübner et al., 2005	Boilers, pellets and chips	Pellets and chips	853 (120-1400)
Nordic Ecolabelling - Swan		*Pellets*	*526[3)]*

1) The interval includes other biomass fuels
2) Average not including the value 16400 (outlier)
3) Emission limits are not comparable. The nordic ecolabel testing include start-up and part load whereas the Austrian enviromental label only includes testing at full load.
4) 33 g/GJ at full load.

CO emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	CO emission factor, g/GJ	Reference
Table 3-6	1	Biomass	Residential	-	4000	Assumed equal to conventional stoves.
Table 3-14	2	Wood	Residential	Open fireplaces	4000	Goncalves et al. (2012)
Table 3-17	2	Wood	Residential	Conventional stoves	4000	Pettersson et al. (2011) and Goncalves et al. (2012)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	4000	Johansson et al. (2003)
Table 3-24	2	Wood	Residential	Energy efficient stoves	4000	Assumed equal to conventional boilers
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	2000	Johansson et al. (2003)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	300	Schmidl et al. (2011) and Johansson et al. (2004)

NMVOC

The GB 2009 emission factors are in the range 20-1300 g/GJ.

For open fireplaces, the range McDonald et al. (2000) states the emission factor 452 g/GJ which is below the GB 2009 emission factor 1300 g/GJ. The emission factor 600 g/GJ will be applied assuming the same emission factor as for conventional stoves and adding the references Pettersson et al. (2011) and McDonald et al. (2000).

For conventional stoves, the range in the literature is 17-3072 g/GJ and the GB 2009 emission factor 1200 g/GJ. The GB 2009 emission factor is higher than the general emission level found in the literature survey. The emission factor 600 g/GJ will be applied and a reference to Pettersson et al. (2011) will be added. The interval will be revised to 20-3000 g/GJ.

For conventional boilers range in the literature is 12-2000 g/GJ and the GB 2009 emission factor is 400 g/GJ. The GB 2009 emission factor is slightly above the emission factor for old boilers from Johansson et al. (2004). The emission factor 350 g/GJ will be applied and a reference to old boilers in Johansson et al. (2004) will be added. The interval will be revised to 100-2000 g/GJ.

The emission factor for energy efficient stoves will be assumed equal to conventional boilers.

For ecolabelled/advanced stoves, the GB 2009 emission factor is 250 g/GJ. No data have been found in the literature survey but the emission level is reasonable considering the factors for other technologies. Thus, the emission factor and interval will not be revised.

For pellet stoves and boilers, the range in the literature is 1-26 g/GJ and the GB 2009 emission factor is 20 g/GJ. The GB 2009 emission factor is above the data found in the literature survey. The emission factor 10 g/GJ will be applied and a reference to Johansson et al. (2004) and Boman et al. (2011) will be added. The interval will be revised to 1-30 g/GJ.

Emission data for NMVOC, g/GJ.

	Technology	Wood	NMVOC emission, g/GJ
McDonald et al., 2000	Fireplace	Softwood and hardwood	452 (283-806)
Pettersson et al. 2011	Stove	Wood logs	560 (17-2300)
Pettersson et al., 2011	Stove	Wood logs	100
US EPA (1996), AP-42 Chapter 1.10	Wood stove, conventional	Wood logs	778
Li (2006)	-	Wood logs	372
Paulrud et al., 2006	Stove	-	80 (16-180)
Paulrud et al., 2006	Fireplace with inset	-	97 (17-260)
McDonald et al., 2000	wood stove	softwood and hardwood	VOC: 1308 (344-3072)
Johansson et al., 2004	Old-type wood boilers	Wood logs	350 (270-2000)
Johansson et al., 2004	Modern wood boilers	Wood logs	12 (1.3-43)
Todorovic et al., 2007	Boilers	-	180-2000
Boman et al., 2011	Two pellet boilers	Pellets	0.24-26
Johansson et al., 2004	Pellet boilers	Pellets	8 (1-23)
Todorovic et al., 2007	Boilers		2.8

NMVOC emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	NMVOC emission factor, g/GJ	Reference
Table 3-6	1	Biomass	Residential	-	600	Assumed equal to conventional stoves
Table 3-14	2	Wood	Residential	Open fireplaces	600	Pettersson et al. (2011) and McDonald et al. (2000)
Table 3-17	2	Wood	Residential	Conventional stoves	600	Pettersson et al. (2011)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	350	Johansson et al. (2004)
Table 3-24	2	Wood	Residential	Energy efficient stoves	350	Assumed equal to conventional boilers
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	250	(no reference - EMEP/EEA 2010 value)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	10	Johansson et al. (2004) and Boman et al. (2011)

SO_2

The GB 2009 emission factors are in the range 10-30 g/GJ. The emission factor from US EPA (1996) AP-42, chapter 1.9, is 11 g/GJ.

Fuel analysis from several European studies (Johansson et al. (2003); Fernandes et al. (2011); Goncalves et al. (2010); Boman et al. (2004) confirms that the emission level assuming full oxidation is in the range 8-40 g/GJ . The US EPA (1996) emission factor will be applied for all technologies.

Emission data for SO_2, g/GJ.

	SO_2 emission, g/GJ
US EPA (1996), AP-42 chapter 1.9	11
Johansson et al. (2003)	11-42
Fernandes et al. (2011)	11-22
Goncalves et al. (2010)	11-22
Boman et al (2004)	8-53

NH_3

The GB 2009 EF for NH_3 in the GB is unreferenced. It has proven difficult to obtain data for NH_3 emissions from residential wood fired installations. Roe et al. (2004) provides EFs for different wood combustion technologies, these EFs are summarised in the table below.

Emission data for NH_3 from Roe et al. (2004).

	EF - lb/ton	EF - kg/ton	EF - g/GJ[1]
Residential; Wood; Fireplaces	1.8	0.9	74.4
Residential; Wood; Non-catalytic Woodstoves: Conventional	1.7	0.85	70.2
Residential; Wood; Non-catalytic Woodstoves: Low Emitting	0.9	0.45	37.2

Residential; Wood; Non-catalytic Woodstoves: Pellet Fired	0.3	0.15	12.4
Residential; Wood; Boilers and Furnaces	1.8	0.9	74.4
Residential; Wood; Outdoor Equipment	1.8	0.9	74.4

[1] Converted using a NCV of 12.1 GJ/ton as an average of freshly cut and air-dried wood (OECD/IEA, 2005)

The EFs reported by Roe et al. (2004) are proposed to be included in the GB. The available EFs match fairly well the different types of technology in the GB. In the table below the EFs are presented for the different technologies in the GB.

NH_3 emission factors residential wood combustion

	Tier	Fuel	Sector	New technology name	NH_3 emission factor, g/GJ	Reference
Table 3-6	1	Biomass	Residential	-	70.2	Assumed equal to conventional stoves
Table 3-14	2	Wood	Residential	Open fireplaces	74.4	Roe et al. (2004)
Table 3-17	2	Wood	Residential	Conventional stoves	70.2	Roe et al. (2004)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	74.4	Roe et al. (2004)
Table 3-24	2	Wood	Residential	Energy efficient stoves	37.2	Roe et al. (2004) - Assumed as low emitting
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	37.2	Roe et al. (2004) - Assumed as low emitting
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	12.4	Roe et al. (2004)

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

The GB 2009 emission factors are in the range 80-900 g/GJ for TSP.

The applied emission measurement standards and combustion cycle during test have a considerable influence on the estimated emission data for PM. Thus, results are not necessarily comparable between the references stated below. This is also discussed in a separate discussion paper[5]. Recent studies based on diluted flue gas have been prioritised. In addition, the emission data that includes the whole combustion cycle have been prioritised as the emission during ignition, part load and burnout are much higher than at full load conditions.

Only a few of the references include data for TSP, PM_{10} and $PM_{2.5}$. For each technology, two of the three emission factors are based on the size distribution: The PM_{10} is estimated as 95 % of TSP and the $PM_{2.5}$ is estimated as 93 % of TSP. This is assumptions based on Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

For open fireplaces, the emission factor range for in the literature is 47-1167 g/GJ. The GB 2009 emission factors are 900 g/GJ for TSP, 860 g/GJ for PM_{10} and 850 g/GJ for $PM_{2.5}$. The literature survey confirms the GB 2009 emission factor level. The emission factor 820 g/GJ will be applied for

[5] Discussion paper – The importance of sampling methodology on emissions from small combustion installations

$PM_{2.5}$ and a reference to Alves et al. (2011) will be added. The intervals will be revised to ½ times to 2 times the emission factors.

For conventional stoves, the range in the literature is 20 – 1 400 g/GJ. The GB 2009 emission factors are 850 g/GJ for TSP, 810 g/GJ for PM_{10} and 810 g/GJ for $PM_{2.5}$. The literature survey confirms the emission factor level. The TSP emission factor 800 g/GJ will be applied and a reference to Alves et al. (2011) and Glasius et al. (2005) will be added. The intervals will be revised to ½ times to 2 times the emission factors.

For conventional boilers the range in the literature is 20-2200 g/GJ and the GB 2009 emission factor is 500 g/GJ for TSP, 475 g/GJ for PM_{10} and 475 g/GJ for $PM_{2.5}$. The GB 2009 emission factor is in agreement with the general emission level found in the literature survey. The TSP emission factor 500 g/GJ will be applied and a reference to Winther (2008)[6] and Johansson et al. (2003) will be added. The intervals will be revised to ½ times to 2 times the emission factors.

For energy efficient stoves, the emission factor 400 g/GJ will be applied and a reference to Glasius et al. (2005)[7] will be added. The intervals will be revised to ½ times to 2 times the emission factors.

For ecolabelled/advanced stoves and boilers, the GB 2009 emission factor is 250 g/GJ which is close to the limit value in the Nordic ecolabel. However, most emission measurements are considerably below this emission factor and the TSP emission factor 100 g/GJ will be applied and a reference to Johansson et al. (2003), Goncalves et al. (2010) and Schmidl et al. (2011) will be added. The interval for TSP will be revised to 20-250 g/GJ.

For pellet stoves and boilers, the range in the literature is 10-50 g/GJ whereas the GB 2009 emission factor is 80 g/GJ. The TSP emission factor 31 g/GJ will be applied and a reference to Boman et al. (2011) will be added. The interval will be revised to 10-50 g/GJ.

[6] It has been assumed that 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers is not included.
[7] Wood stoves < 3 years old

Emission data for PM, g/GJ.

	Technology	Wood	PM emission, g/GJ
Alves et al., 2011	Fireplace	Logs[1)]	PM2.5: 820 (550-1122)
Alves et al., 2011	Fireplace	Briquettes	PM2.5: 850
Nussbaumer 2010	Open fireplace		TSP: 50 - >1000
Goncalves et al., 2012	Fireplace	logs	PM2.5: 47-1611
Goncalves et al., 2012	Fireplace	logs (and briquettes)	PM2.5: 383-1167
Meyer, 2012	Open fireplace	Wood logs	266-910/235-771/194-712
Fine et al., 2002	Fireplace	-	PM2.5: 239 (89-378)
Bølling et al., 2009	Fireplace	-	TSP: 160-910
Nussbaumer et al., 2008	Fireplace	-	TSP: 860-910
US EPA (1996), AP-42 Chapter 1.9	Fireplace	Wood logs	PM10: 961
McDonald et al., 2000	Fireplace	softwood and hardwood	PM2.5: 322 (161-500)
Pettersson et al. 2011	Stove	Wood logs	TSP: 140 (38-350)
Nussbaumer 2010	Wood stoves	-	TSP: 20 - >1000
Alves et al., 2011	Wood stove	split logs	PM2.5: 689 (344-906)
Alves et al., 2011	Wood stove	briquettes	PM2.5: 233
Goncalves et al., 2012	Wood stove	split logs (and briquettes)	PM2.5: 289-722
Fernandes et al., 2011	Cast iron stove	Wood logs	PM2.5: 289-722
Meyer, 2012	Stove	Wood logs	50-766/49-689/48-637
Tissari et al., 2007	Stove	Wood logs	PM1: 47
Hedberg et al., 2002	Soapstone stove	Birch wood logs	PM2.5: 71 (5-142)
Pettersson et al., 2011	Stove	Wood logs	TSP: 110, PM2.5 and PM1: 95% and 85% respectively
Bäfver et al, 2011	Old stove	Wood logs	TSP: 55-78
Bølling et al., 2009	Conventional wood stoves	-	TSP: 50-2100
Nussbaumer et al., 2008	Wood stoves	-	TSP: 340-544
US EPA (1996), AP-42 Chapter 1.10	Wood stove, conventional	Wood logs	PM_{10}: 850
Glasius et al., 2005	Wood stoves >4 years old	Wood logs	TSP: 1396
Glasius et al. 2005	Wood (all)	Wood logs[4)]	TSP: 1033 (177-4605)
Li (2006)	-	Wood logs	TSP: 494
Gullett et al., 2003	Woodstove, steel, lined	Wood logs	PM_{10}: 504
Gullett et al., 2003	Fireplace	Wood logs	PM_{10}: 220
Tissari 2008	Wood stove	-	PM2.5: 50
McDonald et al., 2000	wood stove	softwood and hardwood	PM2.5: 242 (128-400)
Nussbaumer 2010	Log wood boilers	Wood logs	TSP: 20 - >1000
Johansson et al., 2004	Old-type wood boilers	Wood logs	PM_{10}: 157 (87-2200)
Johansson et al., 2004	Modern wood boilers	Wood logs	PM_{10}: 36 (18-89)
Bølling et al., 2009	Conventional boilers	-	TSP: 50-250
Winther 2008	Old boilers	Wood logs	TSP: 588-736
Winther 2008	New boilers	Wood logs	TSP: 96-335
Johansson et al., 2003a	Boilers, not ecolabelled	Wood logs	496 (87-2243)
Todorovic et al., 2007	Boilers	-	TSP: 44-1300
Glasius et al., 2005	Boilers	Wood	TSP: 1236
Tissari et al., 2007	Several (with heat storage)	Wood logs	PM1: 31-141
Lamberg et al., 2011	Modern masonry heater	Wood logs	PM1: 50.7
Glasius et al., 2005	Wood stoves < 3 years old	Wood	TSP: 441
Goncalves et al., 2010	Chimney type stove	Wood logs	PM_{10}: 62-161
Fernandes et al., 2011	Logwood stove	Wood logs	PM_{10}: 62-161
Schmidl et al., 2011	Chimney type (C)	Briquettes and logs	PM_{10}: 63-97
Schmidl et al., 2011	Chimney type (D)	Briquettes and logs	PM_{10}: 72-89

	Technology	Wood	PM emission, g/GJ
Bäfver et al, 2011	Modern stove	Wood logs	PM_{10}: 40-51, PM2.5: 30-46
Bølling et al., 2009	Modern woodstoves	-	TSP: 34-330
Kistler et al., 2012	Chimney type	-	Full load PM_{10}: 107 (20-626)
Johansson et al., 2003a	Boilers, ecolabelled	Wood logs	TSP: 37 (23-89)
Austrian Environmental label	*Hand fed stoves*	*Wood logs*	*TSP: 30* [2)]
Nordic Ecolabelling - Swan	*Stoves*		*TSP: 222* [2)]
Blue Angel			*TSP: 16* [2)]
P-mark			*TSP: 66* [2)]
Boman et al., 2011	Two pellet boilers	Pellets	TSP: 15-47, PM_{10}: 72-100 % of TSP PM1: 70-99 % of TSP
Nussbaumer 2010	Log wood boilers		TSP: 10-50
Schmidl et al., 2011	Pellet stove	Pellets	PM_{10}: 3-8
Schmidl et al., 2011	Pellet boiler	Pellets	PM_{10}: 11-34
Johansson et al., 2004	Pellet boilers	Pellets	PM_{10}: 32 (12-65)
Sippula et al., 2007	Top fed pellet stove	Pellets, bark and stem	PM1: 58 (47-604)
Lamberg et al., 2011	Pellet boiler	Pellets	PM1: 19.7 (18.1-21.3)
Bäfver et al, 2011	Pellet stove	Pellets	19-45/29-58/29-53
Bølling et al. 2009	Modern woodstoves	-	TSP: 10-50
Nussbaumer et al., 2008	Pellet stoves and boilers	Pellets	TSP: 10-50
Kistler et al., 2012	Pellet stove	Pellets	Full load PM_{10}: 23 (16-31)
Tissari 2008	Pellet burners and boilers	Pellets	PM1: 15 [3)]
Todorovic et al., 2007	Boilers		TSP: 28

1) And one test with briquettes
2) Data for the ecolabels are not comparable due to different measurement standards and combustion cycle during tests.
3) For wood. For other biomass pellets 16-26 g/GJ.
4) Wood waste not included

PM emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	TSP emission factor, g/GJ	PM_{10} emission factor, g/GJ	$PM_{2.5}$ emission factor, g/GJ	Reference
Table 3-6	1	Biomass	Residential	-	800	760	740	Assumed same emission factor as for conventional stoves
Table 3-14	2	Wood	Residential	Open fireplaces	880	840	**820**	Alves et al. (2011)
Table 3-17	2	Wood	Residential	Conventional stoves	**800**	760	740	Alves et al. (2011) and Glasius et al. (2005)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	**500**	480	470	Winther (2008)[8] and Johansson et al. (2003)
Table 3-24	2	Wood	Residential	Energy efficient	**400**	380	370	Glasius et al.

[8] It has been assumed that 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers is not included.

				stoves				(2005)[9]
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	**100**	95	93	Johansson et al. (2003), Goncalves et al. (2010) and Schmidl et al. (2011)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	**31**	29	29	Boman et al. (2011)

Metals

The collected emission data for metals are insufficient for estimating technology specific emission factors. The collected data are shown below.

Most references only include some of the heavy metals and in addition, outliers and data below the detection limits occur for all references for one or several of the metals. Thus, the emission factors will be based on average values of some of the references.

The primary emission factors are Hedberg et al. (2002), Tissari et al. (2007)[10], Struschka et al. (2008) and Lamberg et al. (2011)[11]. The revised emission factors have been calculated as an average value of data in those four references. Emission data below the detection limit have not been included. The revised emission factors and references are shown below.

The revised emission factors for Cd and Cr are considerably higher than the former emission factors.

Emission factors for metals, mg/GJ.

	Hedberg et al., 2002	Tissari et al., 2007	Tissari et al., 2007	US EPA, AP-42, Chapter 1.9	Naturvårds-verket (Sweden)	Li (2006)	Struschka et al. (2008)[12] (Germany)	Lamberg et al., 2011	Lamberg et al., 2011
	Stove	Stove	All units	Stove	Stove	Stove	Aggregated value	Energy efficient stove	Pellet boiler
Pb	19 (4-50)	63	<1-118	-	20 (5-60)	27	15	11	3.9
Cd	33 (0-87)	<27	<27	0.6	40 (<100)	1	2.1	3.1	0.17
Hg	<104 (<14)	-	-	-	<100		0.56	-	-
As	<14 (<2)	<6	<6	-		12	0.19	-	0.045
Cr	34 (2-115)	<27	<27	0.1	40 (3-100)	78	11	-	0.4
Cu	4 (4)	6	5-89	-	5 (5-5.3)	89	9.3	5.5	6.5
Ni	3 (1-16)	<27	<27	0.4	4 (0.7-20)	27	1.5	0.62	-
Se	0.5 (0.5-1.1)	-	-	-	0.6 (<1)	18	-	-	-
Zn	410 (81-670)	105	105-568	-	500 (100-800)	470	233	1300	84

(continued)

	Alves et al., 2011	Chandra-sekaran et al.,	Ross et al., 2002	Schauer et al. 2001	Sippula et al.	Schmidl et al. 2008

[9] Wood stoves < 3 years old
[10] Stove
[11] Energy efficient stove
[12] Struschka et al. (2008)

	2011				2007	
	Stoves / fireplaces average	150kW high efficient boiler	30 kW boiler, sawdust briquettes		*Fuel analysis,* pellets and chips	*Fuel analysis*
Pb	6.7 / 69	3.6-7.1	187	-	-	2
Cd	-	0.3-0.4	22	-	31	2
Hg	-	-	0.1	-	-	-
As	-	-	8.1	-	-	<1
Cr	-	0.2-3.4	11	-	-	21
Cu	-	3-14	79	-	-	13
Ni	2.1 / 0.6	-	19	-	-	4
Se	-	-	0.8	-	-	
Zn	14 / 47	39-76	1522	<26	3479	27

Emission factors for metals including references

	Unit	Former emission factor, mg/GJ	Emission factor, mg/GJ	Reference
Pb	mg/GJ	10-24.8	27	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	mg/GJ	0.3-1.8	13	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	mg/GJ	0.5-0.7	0.56	Struschka et al. (2008)
As	mg/GJ	0.5-1.4	0.19	Struschka et al. (2008)
Cr	mg/GJ	2-6.5	23	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	mg/GJ	2-4.6	6	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	mg/GJ	2-200	2	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	mg/GJ	0.5	0.5	Hedberg et al. (2002)
Zn	mg/GJ	5-114	512	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)

PCB

The GB 2009 emission factor is 0.06 mg/GJ for all residential wood combustion. Hedman et al. (2006) and Gullet et al. (2003) both state much lower emission factors (0.007-0.06 μg/GJ and 0.07 μg/GJ, respectively). Additional data from Syc et al. (2011) and Kakareka & Kukharchyk (2006) states much higher emission factors (100-1000 μg/GJ and 33 μg/GJ, respectively) .

The PCB emission factors for residential wood combustion plants will be based on Hedman et al. (2006) that includes emission data for both pellet boilers, ecolabelled boilers, energy efficient stoves and old boilers. Data have been converted to μg/GJ applying the NCV 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets. Data are based on the whole combustion cycle and the data for experiments including paper, plastic and straw pellets have been excluded.

The suggested emission factors for PCB are shown in the table below. The unit have been changed from mg/GJ to μg/GJ.

PCB emission factors residential wood combustion.

	Tier	Fuel	Sector	Technology	PCB emission factor, **μg/GJ**	Reference
Table 3-6	1	Biomass	Residential	-	0.06	Assumed equal to conventional boilers
Table 3-14	2	Wood	Residential	Open fireplaces	0.06	Assumed equal to conventional boilers
Table 3-17	2	Wood	Residential	Conventional stoves	0.06	Assumed equal to conventional boilers
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	0.06	Hedman et al., 2006
Table 3-24	2	Wood	Residential	Energy efficient stoves	0.03	Hedman et al., 2006
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	0.007	Hedman et al., 2006
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	0.01	Hedman et al., 2006

PCDD/-F

The GB 2009 emission factors are in the range 50-800 ng I-Teq/GJ. The GB 2009 emission factors are highest for old type stoves and lowest for advanced stoves and pellet boilers.

For open fireplaces, the emission factor and interval for conventional stoves will be applied.

For conventional stoves, the range in the literature is 2 – 7 778 ng I-Teq/GJ and the GB 2009 emission factor 800 ng I-Teq/GJ. The GB 2009 emission factor is in agreement with the emission level found in the literature survey. The emission factor 800 ng I-Teq/GJ will be applied and a reference to Glasius et al. (2007), Hedman et al. (2006) and Hübner et al. (2005) will be added. The interval will be revised to 20-5000 ng I-Teq/GJ.

For conventional boilers the GB 2009 emission factor 500 ng/I-Teq is in agreement with Hedman et al. (2006). The emission factor in Hübner et al. (2005) is higher. The emission factor will be revised to 550 ng I-Teq/GJ and a reference to the two mentioned references will be added. The interval will be assumed equal to conventional stoves – 20-2600 ng I-Teq/GJ.

For energy efficient stoves, the emission factor the emission factor 250 ng I-Teq/GJ will be applied and a reference to Hedman et al. (2006) added.

For advanced/ecolabelled stoves and boilers, the GB 2009 emission factor 300 ng/I-Teq is higher than data from Hedman et al. (2006). A reference to will be added and the emission factor revised. The interval will not be revised.

For pellet stoves and boilers the emission factor in Hedman et al. (2006) is 342 ng I-Teq/GJ and thus much higher than the GB 2009 emission factor for pellet stoves and boilers. However, Hübner states a very low emission factor for wood pellets (2 ng I-Teq/GJ) but a high emission factor for wood chips. It has been assumed that the emission factor is equal to ecolabelled stoves and boilers.

Emission data for PCDD/-F, ng I-Teq/GJ.

	Technology	Wood	PCDD/-F, ng I-Teq/GJ
Naturvårdsverket	Open fireplaces	Wood logs	5-4500
Glasius et al., 2005	Wood stoves >4 years old	Wood logs	613
Naturvårdsverket	Wood log stoves	Wood logs	20-1180
Hedman et al., 2006	Old boiler	Wood logs	508
Gullett et al., 2003	Woodstove, steel, lined	Wood logs	13
Gullett et al., 2003	Fireplace	Wood logs	46
Hübner et al., 2005	Single stove, wood	-	839
Glasius et al. 2005	Stoves	Wood (waste wood data not included)	437 (17-983)
Schleicher et al., 2001	-	-	Full load: 194
Glasius et al., 2007	Wood combustion (mainly stoves)	-	1056 (2-7778)
Naturvårdsverket	Wood log boilers	Wood logs	12-2600
Hedman et al., 2006	Old boiler	Wood logs	508
Hübner et al., 2005	Boilers, wood	Wood logs	416 (18-2600)
Glasius et al. 2005	Boiler (one boiler)	Wood logs	25 (17-33)
Glasius et al., 2005	Wood stoves < 3 years old	Wood logs	85
Hedman et al., 2006	New stove	Wood logs	261
Hedman et al., 2006	Ecolabelled stove	Wood logs	96
Naturvårdsverket	Pellet burners	Pellets	2-840
Hedman et al., 2006	Pellet boiler	Wood pellets	342 (105 at full load)
Hübner et al., 2005	Boilers	Pellets and chips	503 (2-2000)[1)]
Schleicher et al., 2001	Pellet boiler 19 kW	Pellets	Full load: 28 Part load: 11

1) 2 ng I-Teq/GJ for pellets

PCDD/-F emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	PCDD/-F emission factor, ng I-Teq/GJ	Reference
Table 3-6	1	Biomass	Residential	-	800	Assumed same emission factor as for conventional stoves.
Table 3-14	2	Wood	Residential	Open fireplaces	800	Assumed same emission factor as for conventional stoves
Table 3-17	2	Wood	Residential	Conventional stoves	800	Glasius et al. (2005), Hedman et al. (2006) and Hübner et al. (2005)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	550	Hedman et al. (2006) and Hübner et al. (2005)
Table 3-24	2	Wood	Residential	Energy efficient stoves	250	Hedman et al. (2006)
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	100	Hedman et al. (2006)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	100	Assumed same emission factor as for advanced/ecolabelled stoves and boilers.

PAH

PAH emissions are related to the emissions of particulate matter. Each of the applied references states very large intervals for emission measurements. The list below shows data from the collected references.

Emission data for PAH mg/GJ.

	Technology	Wood	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Indeno(1,2,3-cd)pyrene
Goncalves et al., 2012	Fireplace	logs (and briquettes)	1.4-43.6	-	-	0.8-21.5
Pettersson et al. 2011	Stove	Wood logs	610 (16-2400)	680 (30-2500)	250 (9.3-1000)	35 (1.4-120)
Goncalves et al., 2012	Wood stove	split logs (and briquettes)	4-24.4	-	-	1.8-15.5
Tissari et al., 2007	Stove	Wood logs	-	13	13	8 (11-874)
Hedberg et al., 2002	Soapstone stove	Birch wood logs	197 (11-874)	333 (16-1421)	<5	197 (11-710)
Pettersson et al., 2011	Stove	Wood logs	88 (16-300) [1)]	150 (30-500) [1)]	51 (9.3-160) [1)]	77 (13-240) [1)]
US EPA (1996), AP-42 Chapter 1.10	Wood stove, conventional	-	111	167	56	-
Glasius et al., 2005	Wood stoves >4 years old	Wood logs	48	24	46	27
Gullett et al., 2003	Woodstove, steel, lined	Wood logs	29	19	23	7
Gullett et al., 2003	Fireplace	Wood logs	23	16	18	13
Paulrud et al., 2006	Stove	-	40 (5-180)	10-170	5-20	10-110
Paulrud et al., 2006	Fireplace with inset	-	40 (5-270)	5-20	5-10	5-20
Johansson et al., 2003a	Boilers, not ecolabelled	Wood logs	151 (2-230)	160 (2-280)	50 (2-44)	52 (14-110)
Todorovic et al., 2007	Boilers	-	20-230	-	-	-
Tissari et al., 2007	Several (with heat storage)	Wood logs	8-775	3-290	2-234	1-476
Lamberg et al., 2011	Modern masonry heater	Wood logs	1.7	2.4	0.3	0.6
Glasius et al., 2005	Wood stoves < 3 years old	Wood logs	8	5	8	4
Johansson et al., 2003a	Boilers, ecolabelled	Wood logs	6 (<1-20) [1)]	10 (2-30) [1)]	3 (1-9) [1)]	5 (<1-20) [1)]
Boman et al., 2011	Two pellet boilers.	Pellets	0.0022-16	-	-	<0.0002-1.1
Johansson et al., 2004	Pellet boilers	Pellets	16 (<1-120)	21 (<1-140)	7 (<1-44)	12 (<1-86)
Lamberg et al., 2011	Pellet boiler	Pellets	0.00197	0.00197	<0.00197	<0.00197
Todorovic et al., 2007	Boilers	Pellets	1	-	-	-

1) Cold start not included

The table below shows references and estimated average values for each of the technologies. The technology specific average values are inconsistent for some PAHs/technologies. Instead two datasets for PAH will be applied: One for fireplaces, stoves and boilers and another for advanced/ecolabelled stoves/boilers and pellet boilers. The emission factors are shown below.

Technology specific PAH emission factors

	Open fireplace[1)]	Conventional stoves[1)]	Conventional boilers[2)]	Energy efficient stoves[3)]	Ecolabelled stoves[4)]	Pellet stoves[5)]
Benzo(a)pyrene	68	68	151	134	6	12
Benzo(b)fluoranthene	107	107	160	51	10	21
Benzo(k)fluoranthene	25	25	50	42	3	7
Indeno(1,2,3-cd)pyrene	49	49	52	81	5	6

1) Open fireplace and conventional stoves in one group. References: Goncalves et al., 2012, Tissari et al., 2007, Hedberg et al., 2002, Pettersson et al., 2011, Glasius et al., 2005 and Paulrud et al., 2006
2) Reference: Johansson et al., 2003a
3) References: Lamberg et al., 2011, Glasius et al., 2005 and Tissari et al., 2007
4) Reference: Johansson et al., 2003a
5) References: Boman et al., 2011 and Johansson et al., 2004

PAH emission factors, mg/GJ

	1)	Reference	2)	Reference
Benzo(a)pyrene	121	Goncalves et al., 2012, Tissari et al., 2007, Hedberg et al., 2002, Pettersson et al., 2011, Glasius et al., 2005, Paulrud et al., 2006, Johansson et al., 2003 and Lamberg et al., 2011	10	Boman et al., 2011 and Johansson et al., 2004
Benzo(b)fluoranthene	111		16	
Benzo(k)fluoranthene	42		5	
Indeno(1,2,3-cd)pyrene	71		4	

1) Open fireplace, conventional stoves, conventional boilers and energy efficient stoves
2) Advanced/ecolabelled stoves and boilers and pellet stoves and boilers

HCB

The GB 2009 emission factor is 6 µg/GJ for all residential wood combustion.

Hedman et al. (2006) reports much lower emission factors (0.04 µg/GJ). Syc et al. (2011) report HCB emission factors in the interval 0.5-10 µg/GJ. Gullet et al. (2003) reports 0.7-18 µg/GJ, Joas (2006) 28 µg/GJ, Kakareka & Kukharchyk (2006) 3 µg/GJ. The emission factor 5 µg/GJ will be applied and a reference to Syc et al. (2011) added.

HCB emission factors residential wood combustion.

	Tier	Fuel	Sector	New technology name	HCB emission factor, µg/GJ	Reference
Table 3-6	1	Biomass	Residential	-	5	Syc et al. (2011)
Table 3-14	2	Wood	Residential	Open fireplaces	5	Syc et al. (2011)
Table 3-17	2	Wood	Residential	Conventional stoves	5	Syc et al. (2011)
Table 3-18	2	Wood	Residential	Conventional boilers <50 kW	5	Syc et al. (2011)
Table 3-24	2	Wood	Residential	Energy efficient stoves	5	Syc et al. (2011)
Table 3-25	2	Wood	Residential	Advanced/Eco labelled stoves and boilers	5	Syc et al. (2011)
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	5	Syc et al. (2011)

Tier 1 Residential plants, Table 3-6

Tier 1 default emission factors								
			Code	Name				
NFR source category			1.A.4.b.i	Residential plants				
Fuel			Biomass					
SNAP (if applicable)			020200	Residential plants				
Technologies/Practices			NA					
Region or regional conditions			NA					
Abatement technologies			NA					
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	74.5	30	150	80	g/GJ	30	150	Pettersson et al. (2011) 1)
CO	5300	4000	6500	4000	g/GJ	1000	10000	Pettersson et al. (2011) and Goncalves et al. (2012) 2)
NMVOC	925	400	1500	600	g/GJ	20	3000	Pettersson et al. (2011) 2)
SO2	20	10	30	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	3.8	3.04	14	70	g/GJ	35	140	Roe et al. (2004) 2)
TSP	730	500	1260	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) 3) 2)
PM10	695	475	1200	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) 3) 2)
PM2.5	695	475	1190	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) 3) 2)
Pb	40	10	60	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	1.4	0.1	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)

Hg	0.5	0.2	0.6	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	1	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	2.9	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	8.6	0.5	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	4.4	1	250	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.25	0.75	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	130	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006) 1)
PCDD/F	700	500	1000	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)2)
Benzo(a)pyrene	210	130	300	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	220	150	260	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	130	60	180	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	140	80	200	71	mg/GJ	7	710	
HCB	6	3	9	5	μg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional boilers
2) Assumed equal to conventional stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

Tier 2 Open fireplaces, Table 3-14

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Biomass				
SNAP (if applicable)				020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices				Open fireplaces				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	50	30	70	50	g/GJ	30	150	Pettersson et al. (2011) [1)]
CO	6000	4000	6500	4000	g/GJ	1000	10000	Goncalves et al. (2012)
NMVOC	1300	780	1500	600	g/GJ	20	3000	Pettersson et al. (2011) and McDonald et al. (2000)
SO2	10	6	14	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	10	6	14	74	g/GJ	37	148	Roe et al. (2004)
TSP	900	540	1260	880	g/GJ	440	1760	Alves et al. (2011) [2)]
PM10	860	516	1200	840	g/GJ	420	1680	Alves et al. (2011) [2)]
PM2.5	850	510	1190	820	g/GJ	410	1640	Alves et al. (2011) [2)]
Pb	40	24	56	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	2	1.2	2.8	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.4	0.24	0.56	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.5	0.3	0.7	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	1	0.6	1.4	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	8	4.8	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	1.2	2.8	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.3	0.7	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	100	60	140	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.06	µg/GJ	0.006	0.6	Hedman et al. (2006) [3)]
PCDD/F	800	500	1000	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)[1)]
Benzo(a)pyrene	180	130	300	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	180	150	260	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	100	60	140	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	140	84	180	71	mg/GJ	7	710	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional stoves

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

3) Assumed equal to conventional boilers.

Tier 2 Conventional stoves, Table 3-17

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Wood and similar wood waste				
SNAP (if applicable)				020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices				Conventional stoves				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	50	30	150	50	g/GJ	30	150	Pettersson et al. (2011)
CO	6000	4000	6500	4000	g/GJ	1000	10000	Pettersson et al. (2011) and Goncalves et al. (2012)
NMVOC	1200	720	1500	600	g/GJ	20	3000	Pettersson et al. (2011)
SO2	10	6	40	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	5	3.8	7	70	g/GJ	35	140	Roe et al. (2004)
TSP	850	510	1190	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM10	810	486	1130	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM2.5	810	486	1130	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) [1)]
Pb	40	24	56	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	1	0.6	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.4	0.24	0.56	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.5	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	2	1.2	2.8	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	8	4.8	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	1.2	2.8	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.3	0.7	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	100	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	0.012	0.3	0.06	µg/GJ	0.006	0.6	Hedman et al. (2006) [2)]
PCDD/F	800	500	1000	800	ng I-TEQ/GJ	20	5000	Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)
Benzo(a)pyrene	250	150	300	121	mg/GJ	12	1210	Goncalves et al. (2012);
Benzo(b)fluoranthene	240	180	260	111	mg/GJ	11	1110	Tissari et al. (2007);

Benzo(k)fluoranthene	150	90	180	42	mg/GJ	4	420	Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Indeno(1,2,3-cd)pyrene	180	108	200	71	mg/GJ	7	710	
HCB	6	3	9	5	μg/GJ	0.1	30	Syc et al. (2011)

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

2) Assumed equal to conventional boilers.

Tier 2 Conventional boilers < 50 kW, Table 3-18

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Wood and similar wood waste				
SNAP (if applicable)				020202	Residential plants, combustion plants < 50 MW (boilers)			
Technologies/Practices				Conventional boilers < 50 kW				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	120	30	150	80	g/GJ	30	150	Pettersson et al. (2011)
CO	4000	3000	6500	4000	g/GJ	500	10000	Johansson et al. (2003) [1)]
NMVOC	400	300	1500	350	g/GJ	100	2000	Johansson et al. (2004) [2)]
SO2	30	6	40	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	3.8	3.04	14	74	g/GJ	37	148	Roe et al. (2004)
TSP	500	400	1190	500	g/GJ	250	1000	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM10	475	450	1130	480	g/GJ	240	960	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM2.5	475	450	1130	470	g/GJ	235	940	Winther (2008) [3)] and Johansson et al. (2003) [4)]
Pb	40	24	56	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	2	0.6	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.6	0.24	1	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	2	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	5	1.2	6	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	10	4.8	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	10	1.2	15	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.3	0.7	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	200	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006)

PCDD/F	500	400	1000	550	I-Teq ng/GJ	20	2600	Hedman et al. (2006); Hübner et al. (2005)
Benzo(a)pyrene	130	100	300	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	200	150	260	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	100	80	180	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	80	50	180	71	mg/GJ	7	710	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers have not been included.

2) Assumed old boilers.

3) Old boilers.

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

Tier 2 Energy efficient stoves, Table 3-24

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Wood				
SNAP (if applicable)				020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices				Energy efficient stoves				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	90	50	150	80	g/GJ	30	150	Pettersson et al. (2011) [1)]
CO	4500	300	5000	4000	g/GJ	500	10000	Johansson et al. (2003) [2)]
NMVOC	450	20	500	350	g/GJ	100	2000	Johansson et al. (2004) [2)]
SO2	20	15	50	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	-	-	-	37	g/GJ	18	74	Roe et al. (2004) [3)]
TSP	250	70	260	400	g/GJ	200	800	Glasius et al. (2005) [4) 5)]
PM10	240	66	250	380	g/GJ	290	760	Glasius et al. (2005) [4) 5)]
PM2.5	240	65	250	370	g/GJ	285	740	Glasius et al. (2005) [4) 5)]
Pb	30	20	60	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	1	0.5	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.4	0.2	0.6	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.5	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	8	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	2	1	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	0.1	200	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.25	0.75	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	80	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002),

								Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.03	µg/GJ	0.003	0.3	Hedman et al. (2006)
PCDD/F	300	30	500	250	ng I-TEQ/GJ	20	2600	Hedman et al. (2006)
Benzo(a)pyrene	100	12	150	121	mg/GJ	12	1210	Goncalves et al. (2012); Tissari et al. (2007); Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011)
Benzo(b)fluoranthene	90	14	120	111	mg/GJ	11	1110	
Benzo(k)fluoranthene	40	8	50	42	mg/GJ	4	420	
Indeno(1,2,3-cd)pyrene	60	6	80	71	mg/GJ	7	710	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to conventional stoves.
2) Assumed equal to conventional boilers.
3) Assumed low emitting.
4) Wood stoves < 3 years old.
5) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

Tier 2 Advanced / ecolabelled stoves and boilers, Table 3-25

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Wood				
SNAP (if applicable)				020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices				Advanced / ecolabelled stoves and boilers				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	90	50	150	95	g/GJ	50	150	Pettersson et al. (2011)
CO	3000	300	5000	2000	g/GJ	500	5000	Johansson et al. (2003)
NMVOC	250	20	500	250	g/GJ	20	500	*(2009 update of the guidebook)*
SO2	20	15	50	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	-	-	-	37	g/GJ	18	74	Roe et al. (2004) [1)]
TSP	250	70	260	100	g/GJ	20	250	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
PM10	240	66	250	95	g/GJ	19	238	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
PM2.5	240	65	250	93	g/GJ	19	233	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
Pb	30	20	60	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	1	0.5	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.4	0.2	0.6	0.56	mg/GJ	0.2	1	Struschka et al. (2008)

As	0.5	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	8	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	2	1	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	1	200	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.25	0.75	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	80	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.007	µg/GJ	0.0007	0.07	Hedman et al. (2006)
PCDD/F	300	30	500	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	100	12	150	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	90	14	120	16	mg/GJ	8	32	
Benzo(k)fluoranthene	40	8	50	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	60	6	80	4	mg/GJ	2	8	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed low emitting.

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

Tier 2 Pellet stoves and boilers, Table 3-26

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Wood				
SNAP (if applicable)				020205	Residential - Other equipments (stoves, fireplaces, cooking,...)			
Technologies/Practices				Pellet stoves and boilers				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	90	50	150	80	g/GJ	50	200	Pettersson et al. (2011)
CO	500	300	5000	300	g/GJ	10	2500	Schmidl et al. (2011) and Johansson et al. (2004)
NMVOC	20	10	500	10	g/GJ	1	30	Johansson et al. (2004) and Boman et al. (2011)
SO2	20	15	50	11	g/GJ	8	40	US EPA (1996) AP-42, chapter 1.9
NH3	-	-	-	12	g/GJ	6	24	Roe et al. (2004)
TSP	80	70	250	31	g/GJ	10	50	Boman et al. (2011) [1)]
PM10	76	66	240	29	g/GJ	10	48	Boman et al. (2011) [1)]
PM2.5	76	65	240	29	g/GJ	9	47	Boman et al. (2011) [1)]
Pb	20	10	60	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	0.5	0.1	2.5	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.4	0.2	0.6	0.56	mg/GJ	0.2	1	Struschka et al. (2008)

As	0.5	0.3	2.5	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	3	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	1	0.5	11.2	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	1	200	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.25	0.75	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	80	60	250	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06	0.012	0.3	0.01	μg/GJ	0.001	0.1	Hedman et al. (2006)
PCDD/F	50	30	500	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006) 2)
Benzo(a)pyrene	50	12	100	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	15	14	120	16	mg/GJ	8	32	
Benzo(k)fluoranthene	16	8	40	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	10	6	60	4	mg/GJ	2	8	
HCB	6	3	9	5	μg/GJ	0.1	30	Syc et al. (2011)

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

2) Assumed equal to advanced/ecolabelled stoves and boilers.

Solid fuel combustion

Below is listed the EF tables in the 2009 GB for solid fuels for residential plants.

	Tier	Fuel	Sector	New technology name
Table 3-3	1	Hard Coal and Brown Coal	Residential	
Table 3-12	2	Solid Fuel (not biomass)	Residential	Open fireplaces
Table 3-15	2	Solid Fuel (not biomass)	Residential	Conventional stoves
Table 3-16	2	Solid Fuel (not biomass)	Residential	Small boilers (Single household, capacity <=50 kW)
Table 3-23	2	Solid Fuel (not biomass)	Residential	Advanced stoves and boilers

In comparison to biomass very few data are available for combustion of coal in residential plants. This makes it very difficult to get a solid data foundation for implementing new EFs.

It has not been possible to find any data for coal combustion in fireplaces, wherefore the GB 2009 EF table is left unchanged despite all EFs being referenced to the earlier version of the GB.

The tier 2 EFs in the 2009 GB are shown in the table below.

GB	Fireplaces	Stoves	Boilers	Advanced stoves
NOx	60	100	130	150
CO	5000	5000	4000	2000
NMVOC	600	600	300	300
SO2	500	900	900	450
NH3	5			
TSP	350	500	400	250
PM10	330	450	380	240

PM25	330	450	360	220
Pb	100	100	200	100
Cd	0.5	1	3	1
Hg	3	5	6	5
As	1.5	1.5	5	1.5
Cr	10	10	15	10
Cu	20	20	30	15
Ni	10	10	20	10
Se	1	2	2	2
Zn	200	200	300	200
PCBs	170	170	170	170
PCDD/F	500	1000	500	500
Benzo(a)	100	250	270	150
Benzo(b)	170	400	250	180
Benzo(k)	100	150	100	100
Indeno	80	120	90	80
HCB	0.62	0.62	0.62	0.62

For many of the pollutants all the EFs are the same or very similar. Additionally, there is some strange variations, e.g. that the boiler despite lower PM EFs has higher EFs for all the metals (except selenium). Also, the PCDD/F EF for stoves is twice as high as the EFs for fireplaces and boilers. For fireplaces it can also be noted that the EFs for PAHs are the lowest of the available EFs and even lower or equal to the EFs for advanced combustion.

In the US EPA (AP-42) there is only very limited information on coal combustion in small installations. The table below provides the available data.

		Residential space heater	Spreader stoker, bituminous	Spreader Stoker, sub-bituminous	Overfeed stoker	Underfeed stoker	Hand-fed units
NOx	lb/ton	3	11	8.8	7.5	9.5	9.1
CO	lb/ton	275	5	5	6	11	275
NMVOC	lb/ton		0.05	0.05	0.05	1.3	10
SO2	lb/ton						
NH3	lb/ton						
TSP	lb/ton	10	66	66	16	15	15
PM10	lb/ton		13.2	13.2	6	6.2	6.2
PM25	lb/ton		4.6	4.6	2.2	3.8	3.8
Pb	lb/10^12 BTU		507	507	507		
Cd	lb/10^12 BTU		21-43	21-43	43-82		
Hg	lb/10^12 BTU		16	16			
As	lb/10^12 BTU		264-542	264-543	542-1030		
Cr	lb/10^12 BTU		942-1570	942-1570			
Cu	lb/10^12 BTU						
Ni	lb/10^12 BTU		775-1290	775-1290			
Se	lb/10^12 BTU						
Zn	lb/10^12 BTU						
PCBs							
PCDD/F							
Benzo(a)		5.30E-06					
Benzo(b)							
Benzo(k)		2.50E-05					
Indeno		6.90E-06					
HCB							

As seen from the table, there are EFs available for very few pollutants. For hand-fed units only EFs for NO_x, CO, NMVOC and PM are available. For residential space heaters the fuel used is anthracite and EFs are available for NO_x, CO, TSP and three of the PAHs.

Butcher & Ellenbecker (1992) measured CO and TSP from coal fired stoves. Four measurements were carried out on a stove burning anthracite an one measurement were done with bituminous coal. The EFs are presented as g/kg and has been converted using the calorific value in the article. It is not explicitly stated whether the calorific values are NCV or GCV, but considering that the paper is from the United States, it has been assumed that it is GCV and the factors have therefore been corrected using a factor of 0.95.

		Anthracite	Anthracite	Anthracite	Anthracite	Bituminous
PM	g/kg	0.33	0.56	0.62	0.5	10.4
CO	g/kg			27	15	116
PM	g/GJ	11.6	19.8	21.9	17.6	395.7
CO	g/GJ			952.4	529.1	4414.0

The EFs for bituminous coal are quite close to the GB 2009 EFs for stoves, while the EFs for anthracite is much lower.

Lee et al. (2005) resports EFs of PM_{10} and POPs. The EFs are reported by units of mass and has been converted using the calorific value provided in the article converted to NCV by applying a factor of 0.95.

	Unit	EF
PM10	g/kg	40
PCDD/F	ng/kg	3
PCB	ng/kg	0.2
Benzo(a)	mg/kg	8
Benzo(b)	mg/kg	5.1
Benzo(k)	mg/kg	2.3
Indeno	mg/kg	4.5
PM10	g/GJ	1332
PCDD/F	ng/GJ	100
PCB	ng/GJ	7
Benzo(a)	mg/GJ	266
Benzo(b)	mg/GJ	170
Benzo(k)	mg/GJ	77
Indeno	mg/GJ	150

The PM10 EF is much higher than the EF in the 2009 GB, while the PCDD/F and PCBs EFs are much lower. For PAHs the values are closer to the GB 2009 EFs.

Paradiz et al. (2008) reports EFs for a number of main pollutants, PM and a few POPs.

Stove	Unit	EF
CO	kg/t	16.3
NOx	kg/t	3.4
SO2	kg/t	3
VOC	kg/t	9.3
PM	kg/t	3.8
Benzo(a)	g/t	1.5
PCDD/F	mikrog/t	1326
PCDD/F[1]	mikrog/t	126

CO	g/GJ	543
NOx	g/GJ	113
SO2	g/GJ	100
VOC	g/GJ	310
PM	g/GJ	127
Benzo(a)	mg/GJ	50
PCDD/F	ng/GJ	44200
PCDD/F[1]	ng/GJ	4200

[1] These values are for a non-insulated chimney. The rest of the EFs are taken for an insulated chimney. The difference between the insulated and non-insulated chimney is by far largest for PCDD/F.

The EF reported for NO_x is close to the 2009 GB value, while the PCDD/F EF is significantly higher. For all the remaining pollutants reported the EFs are much lower than in the 2009 GB.

Chen et al. (2004) reports PAH EFs from residential coal combustion in China. No calorific value has been provided, so the values have been converted using the NCV from Paradiz et al. (2008). The EFs reported are very low and far lower than any of the other references found.

Stove	Unit	EF
Benzo(a)	mikrog/kg	0.171
Benzo(b)	mikrog/kg	1.2
Benzo(k)	mikrog/kg	1.2
Indeno	mikrog/kg	0.829
Benzo(a)	mg/GJ	0.0057
Benzo(b)	mg/GJ	0.04
Benzo(k)	mg/GJ	0.04
Indeno	mg/GJ	0.0276

Shen et al. (2011) reports EFs for PAHs from residential coal combustion in China.

	EF1 – mg/kg	EF2 – mg/kg	EF3 – mg/kg	EF1 – mg/GJ	EF2 – mg/GJ	EF3 – mg/GJ
Benzo(a)	6.27	9.58	0.521	190	342	22
Benzo(b)	6.57	8.41	0.409	199	300	17
Benzo(k)	3.93	6.43	0.463	119	230	19
Indeno	9.69	14.1	0.445	294	504	19

The average values of the first two experiments are quite close to the GB 2009 EFs.

Another Chinese study (Liu et al., 2009) reported EFs that are significantly higher for bituminous coal and much lower for anthracite.

Based on the references analysed, it is not possible to update the EF references in the GB. There is simply to few measurements available and the EFs reported are exhibiting large variations that makes it impossible to conclude on the best representative EF for coal combustion in stoves.

For boilers it is proposed to use the US EPA data for hand-fed units. This would update the EFs of NO_x, CO, NMVOC and TSP. Regarding the particle size distribution, it is considered to use the data from Tivari et al. (2012), see below for further information.

The particle size distribution for the different technologies in the GB is inconsistent. The percentages are shown in the table below.

	Fireplaces	Stoves	Boilers	Advanced stoves
PM_{10} percentage	94.3%	90.0%	95.0%	96.0%
$PM_{2.5}$ percentage	94.3%	90.0%	90.0%	88.0%

The US EPA reports a very different particle size distribution while a more recent paper (Tivari et al., 2012) showed that PM_{10} and $PM_{2.5}$ were respectively 86 % and 77 % of TSP.

For advanced stoves, it is similarly to stoves not possible to conclude on EFs based on the data available. Therefore, the GB 2009 EF table is maintained.

Other fuel combustion

A literature study has been carried out in order to update the emission factors for small stationary combustion appliances burning gaseous and liquid fuels. A large part of the EFs included in the present version of the guidebook were missing references and it has been of high importance to update all EFs to values with reference to accessible literature. The updates will be described table by table in the following. The tables inserted below include the new updated emission factors and the emission factors from the present version of the guidebook for comparison.

	Tier	Fuel	Sector	Technology
Table 3-4	1	Natural gas	Residential	
Table 3-5	1	Other liquid fuels	Residential	
Table 3-13	2	Gaseous fuels	Residential	Fireplaces
Table 3-19	2	Natural gas	Residential	Stoves
Table 3-20	2	Natural gas	Residential	Boilers < 50 kW
Table 3-21	2	Liquid fuels	Residential	Stoves
Table 3-22	2	Liquid fuels	Residential	Boilers < 50 kW

EFs for main pollutants are updated as no references were included in the GB. The updated EFs refer to combustion in small appliances (stoves, water heaters and radiators) as given in DGC (2009). The new values are in the same range as the old values.

DGC (2009) does not include EFs for NMVOC and PMs for this source, and therefore EFs from Zhang et al. (2000) for natural gas fired stoves has been applied. The NMVOC EF is lower than the old value (2 g/GJ vs. 20 g/GJ), while the PM EFs are higher (2.2 g/GJ vs. 0.5 g/GJ). It is assumed that EF $PM_{2.5}$ = EF PM_{10} = EF TSP. Also UBA (2008) and US EPA (1998) indicate that all particles have an aerodynamic diameter below 2.5 μm. EFs from Zhang et al. (2000) are based on measurements for Chinese and Indian appliances of which a large fraction are in use world-wide according to Zhang et al. (2000). Zhang et al. (2000) also holds EFs for SO_2, NO_x and CO. The NO_x EF are almost similar (56.339), while the SO_2 and CO EF are considerably lower than given in DGC (2009) (1/10 and 1/6 respectively). Although, EFs from DGC (2009) are applied as they refer to European (Danish) conditions.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on measurements of the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

EFs for PAHs and PCD/F are maintained.

Table 3-13 Residential fireplaces, saunas and outdoor heaters burning natural gas

Table 3-13

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Gaseous fuels				
SNAP (if applicable)				020205				
Technologies/Practices				Fireplaces, saunas and outdoor heaters				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inte		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	50	30	70	60	g/GJ			DGC, 2009
CO	50	30	70	30	g/GJ			DGC, 2009
NMVOC	20	12	28	2	g/GJ			Zhang et al, 2000
SO2	0.5	0.3	0.7	0.3	g/GJ			DGC, 2009
NH3								
TSP	0.5	0.3	0.7	2.2	g/GJ			Zhang et al, 2000
PM10	0.5	0.3	0.7	2.2	g/GJ			assumption: PM10 = TSP
PM2.5	0.5	0.3	0.7	2.2	g/GJ			assumption: PM2.5 = TSP
Pb	0.984	0.492	1.97	0.00150	mg/GJ			Nielsen et al, 2012
Cd	0.515	0.172	1.55	0.00025	mg/GJ			Nielsen et al, 2012
Hg	0.234	0.0781	0.703	0.68	mg/GJ			Nielsen et al, 2012
As	0.0937	0.0312	0.281	0.12	mg/GJ			Nielsen et al, 2012
Cr	0.656	0.219	1.97	0.00076	mg/GJ			Nielsen et al, 2012
Cu	0.398	0.199	0.796	0.000076	mg/GJ			Nielsen et al, 2012
Ni	0.984	0.492	1.97	0.00051	mg/GJ			Nielsen et al, 2012
Se	0.0112	0.00375	0.0337	0.011	mg/GJ		0.011	USEPA 1998, chapter 1.4
Zn	13.6	4.53	40.7	0.0015	mg/GJ			Nielsen et al, 2012
PCDD/F	1.5	0.9	2.1	1.5	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	0.562	0.187	0.562	0.56	ug/GJ		0.56	USEPA 1998, chapter 1.4
Benzo(b)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Benzo(k)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Indeno(1,2,3-cd)pyrene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4

It has not been possible to find emission factors for stoves that differ from the emission factors included in table 3-13. Therefore Table 3-19 has been deleted from GB 2013, and Stoves has been added to the Technologies/Practices covered by Table 3-13.

EFs for NO_x, CO and SO_2 are updated as no references were included in the GB. The updated EFs refer to combustion in small traditional boilers with reference to DGC (2009). The new values are in the same range as the old values. The NMVOC EF, which is based on field measurements for Italian heating boilers (The Italian Ministry for the Environment, 2005), is lower than the present value. The new value is in quite good agreement with NMVOC EF by Buonicore & Davis (1992) at 2.2 g/GJ.

EFs for PMs are updated to values from BUWAL (2001). The new EFs are slightly below the 95 % confidence interval of the old values. Low EFs are expected as very limited amounts of particles are formed during natural gas combustion. It is assumed that EF $PM_{2.5}$ = EF PM_{10}.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

EFs for PAHs and PCDD/F are maintained.

Table 3-20 Residential small boilers (single house scale <= 50 kWh) burning natural gas

Table 3-20

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Natural gas				
SNAP (if applicable)								
Technologies/Practices				Small boilers (single house scale <= 50 kWh)				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inte		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	70	35	200	42	g/GJ			DGC, 2009
CO	30	18	42	22	g/GJ			DGC, 2009
NMVOC	10	6	14	1.75	g/GJ			Italian Ministry for the Environment, 2005
SO2	0.5	0.05	1	0.3	g/GJ			DGC, 2009
NH3								
TSP	0.5	0.3	0.7	0.2	g/GJ			BUWAL, 2001
PM10	0.5	0.3	0.7	0.2	g/GJ			BUWAL, 2001
PM2.5	0.5	0.3	0.7	0.2	g/GJ			assumption: EF(PM2.5) =EF(PM10)
Pb	0.984	0.492	1.97	0.00150	mg/GJ			Nielsen et al, 2012
Cd	0.515	0.172	1.55	0.00025	mg/GJ			Nielsen et al, 2012
Hg	0.234	0.0781	0.703	0.68	mg/GJ			Nielsen et al, 2012
As	0.0937	0.0312	0.281	0.12	mg/GJ			Nielsen et al, 2012
Cr	0.656	0.219	1.97	0.00076	mg/GJ			Nielsen et al, 2012
Cu	0.398	0.199	0.796	0.000076	mg/GJ			Nielsen et al, 2012
Ni	0.984	0.492	1.97	0.00051	mg/GJ			Nielsen et al, 2012
Se	0.0112	0.00375	0.0337	0.011	mg/GJ		0.011	USEPA 1998, chapter 1.4
Zn	13.6	4.53	40.7	0.0015	mg/GJ			Nielsen et al, 2012
PCDD/F	1.5	0.8	2.3	1.5	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	0.562	0.187	0.562	0.56	ug/GJ		0.56	USEPA 1998, chapter 1.4
Benzo(b)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Benzo(k)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Indeno(1,2,3-cd)pyrene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4

It is assumed that the main fuel used in residential stoves is gas oil (including diesel oil, distillate oil, No. 2 fuel oil, No. 1 fuel oil and light fuel oil). As all EFs are missing appropriate references in the Guidebook, all values are updated.

EFs for main pollutants and PMs are updated to values for combustion in stoves provided by UBA (2008). The new values are in the same range as the old values. Except for CO all the new values are lower than the values in the present version of the guidebook. For NMVOC and PMs the new values are below the lower limit of the present 95 % confidence interval. The new values are in line with the interval of EFs in the reviews literature and are chosen as UBA (2008) includes separate values for stoves and boilers/heaters, respectively.

EFs for HMs are updated according to the HM concentrations in diesel sold in Europe provided in van der Gon & Kuenen (2009). In correspondence with the Revised 1996 IPCC Guidelines, a calorific value of 43.33 TJ/Gg is used to calculate the EFs.

The PAH EFs are updated to values from Berdowski et al. (1995) for residential oil combustion. The new values are considerably lower than the present values.

The dioxin EF is maintained unchanged.

Table 3-21 Residential stoves burning liquid fuels

Table 3-21

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Liquid fuels				
SNAP (if applicable)				020205				
Technologies/Practices				Stoves				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	50	30	80	34	g/GJ			UBA, 2008
CO	100	40	120	111	g/GJ			UBA, 2008
NMVOC	20	15	30	1.2	g/GJ			UBA, 2008
SO2	140	25	168	60	g/GJ			UBA, 2008
NH3								
TSP	15	5	18	2.2	g/GJ			UBA, 2008
PM10	10	3	12	2.2	g/GJ			UBA, 2008
PM2.5	10	3	12	2.2	g/GJ			UBA, 2008
Pb	5	3	24	0.012	mg/GJ			van der Gon & Kuenen, 2009
Cd	0.3	0.2	2.4	0.0010	mg/GJ		0.0010	van der Gon & Kuenen, 2009
Hg	0.03	0.024	0.036	0.12	mg/GJ		0.12	van der Gon & Kuenen, 2009
As	0.5	0.3	1.2	0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Cr	5	3	24	0.20	mg/GJ			van der Gon & Kuenen, 2009
Cu	3	1.5	12	0.13	mg/GJ			van der Gon & Kuenen, 2009
Ni	100	80	350	0.0050	mg/GJ			van der Gon & Kuenen, 2009
Se				0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Zn	5	3	12	0.42	mg/GJ			van der Gon & Kuenen, 2009
PCDD/F	10	8	12	10	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	50000	10000	60000	80	ug/GJ			Berdowski et al, 1995
Benzo(b)fluoranthene	60000	11000	75000	40	ug/GJ			Berdowski et al, 1995
Benzo(k)fluoranthene	30000	5000	40000	70	ug/GJ			Berdowski et al, 1995
Indeno(1,2,3-cd)pyrene	40000	4000	50000	160	ug/GJ			Berdowski et al, 1995

It is assumed that the main liquid fuel used in residential appliances is gas oil (including diesel oil, distillate oil, No. 2 fuel oil, No 1 fuel oil and light fuel oil). As all EFs are missing appropriate references in the Guidebook, all values are updated.

EFs for main pollutants and PMs are updated to values from Italian measurement results for combustion of heating oil in small boilers provided by the Italian Ministry for the Environment (2005). Except for the NO_x EF the new values are lower than the values in the present version of the guidebook. And further, except for the SO_2 EF, the values are below the lower limit of the present 95 % confidence interval. The Italian Ministry for the Environment (2005) does not include EFs for PM_{10} and $PM_{2.5}$I. It is assumed that all particles have an aerodynamic diameter less than 2.5 µm. The Italian Ministry for the Environment (2005) does not include an EF for NMVOC, but the VOC EF are found applicable as it is lower than the NMVOC EF in UBA (2008), and is therefore not assumed to lead to an over estimation. UBA (2008) also include corresponding EFs for boilers and burners, of which SO_2 and NO_x are of the same size, while EFs for NMVOC and CO are around 10 and three times higher. The reason for using The Italian Ministry for the Environment (2005) rather than UBA (2008) is, that the former is based on Italian measurements, while the latter focus on literature review.

EFs for HMs are updated according to the HM concentrations in diesel sold in Europe provided in van der Gon & Kuenen (2009). In correspondence with the Revised 1996 IPCC Guidelines, a calorific value of 43.33 TJ/Gg is used to calculate the EFs.

The dioxin EF is updated to the average of the seven values for old and new appliances provided by Pfeiffer et al. (2000). The values are recalculated according to Pfeiffer et al. (2000) using NVC = 42.8 MJ/kg.

The PAH EFs are updated to values from Berdowski et al. (1995) for residential oil combustion. The new values are considerably lower than the present values.

Table 3-22 Residential small boiler (single house scale, capacity <= 50 kWh) burning liquid fuels

Table 3-22

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.b.i	Residential plants			
Fuel				Liquid fuels				
SNAP (if applicable)								
Technologies/Practices				Small boiler (single household scale, capacity <= 50 kWh)				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	95 % confidence int		Value	Unit	% confidence inte		Reference
		Old Lowe	Old Uppe			Lower	Upper	
NOx	70	50	80	69	g/GJ			Italian Ministry for the Environment, 2005
CO	40	30	120	4	g/GJ			Italian Ministry for the Environment, 2005
NMVOC	15	10	30	0.2	g/GJ			Italian Ministry for the Environment, 2005
SO2	140	25	168	79	g/GJ			Italian Ministry for the Environment, 2005
NH3					g/GJ			
TSP	5	3	18	1.53	g/GJ			Italian Ministry for the Environment, 2005
PM10	3	2	12	1.53	g/GJ			assumption: EF PM10 = EF TSP
PM2.5	3	2	12	1.53	g/GJ			assumption: EF PM2.5 = EF TSP
Pb	20	5	24	0.012	mg/GJ			van der Gon & Kuenen, 2009
Cd	2	0.3	2.4	0.0010	mg/GJ		0.0010	van der Gon & Kuenen, 2009
Hg	0.03	0.024	0.036	0.12	mg/GJ		0.12	van der Gon & Kuenen, 2009
As	1	0.5	1.2	0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Cr	20	5	24	0.20	mg/GJ			van der Gon & Kuenen, 2009
Cu	10	3	12	0.13	mg/GJ			van der Gon & Kuenen, 2009
Ni	300	100	350	0.0050	mg/GJ			van der Gon & Kuenen, 2009
Se				0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Zn	10	5	12	0.42	mg/GJ			van der Gon & Kuenen, 2009
PCDD/F	10	8	12	1.8	ng I-TEQ/GJ			Pfeiffer et al, 2000
Benzo(a)pyrene	10000	5000	60000	80	ug/GJ			Berdowski et al, 1995
Benzo(b)fluoranthene	11000	5000	75000	40	ug/GJ			Berdowski et al, 1995
Benzo(k)fluoranthene	5000	3000	40000	70	ug/GJ			Berdowski et al, 1995
Indeno(1,2,3-cd)pyrene	4000	2000	50000	160	ug/GJ			Berdowski et al, 1995

B. Other small combustion plants

List of EF tables for non-residential combustion in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology
Table 3-7	1	Coal	Non-residential	
Table 3-8	1	Gaseous fuels	Non-residential	
Table 3-9	1	Liquid fuels	Non-residential	
Table 3-10	1	Biomass	Non-residential	
Table 3-27	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-28	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-29	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-30	2	Coal	Non-residential	Automatic boilers < 1MW
Table 3-31	2	Wood	Non-residential	Manual boilers < 1 MW
Table 3-32	2	Wood	Non-residential	Automatic boilers < 1MW
Table 3-33	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-34	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-35	2	Natural gas	Non-residential	Gas turbines
Table 3-36	2	Gas oil	Non-residential	Gas turbines
Table 3-37	2	Gaseous fuels	Non-residential	Gas engines
Table 3-38	2	Gas oil	Non-residential	Gas engines

Biomass combustion

Emission factors in the GB 2009 include one tier 1 emission factor table and two tier 2 emission factor tables. In general, data are insufficient for the current technology disaggregation between advanced manual boilers and advanced automatic boilers. The technology label for the tier 2 table 3-32 will be changed from “Advanced wood combustion techniques < 1 MW – Automatic boilers” to “Wood combustion < 1 MW, automatic boilers”. Similarly “Advanced wood combustion techniques < 1 MW – Manual boilers” will be changed to “Wood combustion < 1 MW, manual boilers”.

In general, the emission factors in the 2010 update of the guidebook refer to the 2007 update of the guidebook. Emission factors have all been updated and references added.

If the emission factors in the literature survey are in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

Most emission factors have been rounded off to one or two significant digits.

In general, the Tier 1 emission factors for biomass have been based on the emission factors for manual boilers combusting wood.

Emission factors have to some degree been based on comparison with similar emission factors for (1) District heating boilers in 1A1[13] and (2) revised emission factors for residential plants.

[13] Chapter 1A1 Energy industries, Table 3-9 and Table 3-15.

List of EF tables for non-residential biomass combustion in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology
Table 3-10	1	Biomass	Non-residential	
Table 3-31	2	Wood	Non-residential	Manual boilers < 1 MW
Table 3-32	2	Wood	Non-residential	Automatic boilers < 1MW

NO_x

The GB 2009 emission factor for NO_x is 150 g/GJ for all three technologies. This value is equal to the Austrian limit value. The emission data collected in the 2009 update of the Guidebook however indicate an emission factor below 100 g/GJ. Lundgren et al. (2003) states 91 g/GJ and this reference will be applied for all three technologies.

List NO_x emission factor (g/GJ) references for non-residential biomass combustion.

Reference	NO_x
Austrian emission limit for boilers < 300 kW	150
German emission limit	- 2)
Danish emission limit 120 kW- 1 MW (Luftvejledningen)	- 1)
Lundgren et al. (2004), Larger combustion chamber, 350 kW	91
Van Loo (2002)*Stoker boiler automatic, 320 kW	116
Pfeiffer et al. (2000)*, Small consumers, wood	78
BLT (1999)*, Wood chips, boiler 500 kW, 100% capacity	123
Christensen et al. (1997)	55-120 3)
Struschka et al. (2008) (Table 5.5a, GHD Holzbrennstoffe)	88
Naturvårdsverket, Sweden	80 4) / 65 5)

* As refered in the 2009 update of the Guidebook

1) 143 g/GJ for units > 1 MW
2) 263 g/GJ for units > 1 MW (TA Luft)
3) Only wood included
4) Boilers, logs and chips
5) Boilers, pellets

CO

The GB 2009 emission factor for CO is 300 g/GJ for automatic boilers and 3000 g/GJ for manual boilers. The emission factor for automatic boilers will not be changed but a reference will be added to (1) the German test standard for 500 kW – 1 MW boilers (330 g/GJ) and (2) the Danish emission limit (239 g/GJ). The emission factor for manual boilers will be changed to EN 303-5 class 3 boilers for biomass. The standard only covers boilers up to 300 kW.

List CO emission factor (g/GJ) references for non-residential biomass combustion.

Reference	CO
Austrian emission limit for boilers < 300 kW	1100[4)] / 500[5)]-750[6)]
German emission limit	330-1300
Danish emission limit 120 kW- 1 MW (Luftvejledningen)	239
Lundgren et al. (2004), Larger combustion chamber, 350 kW	5
Van Loo (2002)*Stoker boiler automatic, 320 kW	19
Pfeiffer et al. (2000)*, Small consumers, wood	2752
BLT (1999)*, Wood chips, boiler 500 kW, 100% capacity	16
Christensen et al. (1997)	80-800[3)]
Struschka et al. (2008) (Table 5.5a, GHD Holzbrennstoffe)	2228
Naturvårdsverket, Sweden	4000[7)] / 1000[8)] / 300[9)]
EN 303 class 5 boilers, 150-300 kW (1200 mg/m_n^3 at 10 % O_2)	570

* As refered in the 2009 update of the Guidebook

1) 143 g/GJ for units > 1 MW
2) -
3) Only wood included
4) Manual boilers
5) Automatic boilers full load
6) Automatic boilers 30 % load
7) Wood logs
8) Wood chips
9) Pellets

NMVOC

The GB 2009 emission factor for NMVOC is 250 g/GJ for manual boilers and 20 g/GJ for automatic boilers. The emission factor for automatic boilers will be changed to 12 g/GJ referring to Johansson et al. (2004), data for modern boilers. These emission measurements are however based on small boilers. The emission factor for manual boilers will be changed to 300 g/GJ referring to Naturvårdsverket. The tier 1 emission factor will be equal to the value for manual boilers.

List NMVOC emission factor (g/GJ) references for non-residential biomass combustion.

Reference	NMVOC
Lundgren et al. (2004), Larger combustion chamber, 350 kW	<1
Christensen et al. (1997)	45-55[1)]
Struschka et al. (2008) (Table 5.5a, GHD Holzbrennstoffe)	99
Naturvårdsverket, Sweden	300[2)] / 150[3)] / 6[4)]
Johansson et al. (2004). Modern wood boilers (average)	12

1) Only wood included
2) Boilers, wood logs
3) Boilers, chips
4) Boilers, pellets

SO_2

The GB 2009 emission factors are in the range 20-38.4 g/GJ. US EPA (1996), AP-42 chapter 1.9 states the emission factor 11 g/GJ. Fuel analysis from several European studies (Johansson et al. (2003); Fernandes et al. (2011); Goncalves et al. (2010); Boman et al. (2004)) confirms that the emission level assuming full oxidation is in the range 8-40 g/GJ . The AP-42 emission factor will be applied.

NH_3

Roe et al. (2004) provides NH_3 emission factors for different wood combustion technologies, these EFs are summarised in the table below. Wood combustion in non-residential plants have been assumed equal to low emitting non-catalytic woodstoves, 37 g/GJ.

List NH_3 emission factor (g/GJ) references for non-residential biomass combustion.

	EF - lb/ton	EF - kg/ton	EF - g/GJ[1]
Residential; Wood; Fireplaces	1.8	0.9	74.4
Residential; Wood; Non-catalytic Woodstoves: Conventional	1.7	0.85	70.2
Residential; Wood; Non-catalytic Woodstoves: Low Emitting	0.9	0.45	37.2
Residential; Wood; Non-catalytic Woodstoves: Pellet Fired	0.3	0.15	12.4
Residential; Wood; Boilers and Furnaces	1.8	0.9	74.4
Residential; Wood; Outdoor Equipment	1.8	0.9	74.4

[1] Converted using a NCV of 12.1 GJ/ton as an average of freshly cut and air-dried wood (OECD/IEA, 2005)

PM

The GB 2009 emission factors for TSP are 80 g/GJ for manual boilers and 70 g/GJ for automatic boilers. The emission factor from Johansson et al. (2004) is in agreement with emission factors for residential boilers and boilers in district heating plants as well as the collected references. The emission factor for automatic boilers will be changed to 36 g/GJ referring to Johansson et al. (2004). The emission factor for manual boilers will be changed to 150 g/GJ referring to Naturvårdsverket.

As for residential plants the PM_{10} emission factor is estimated as 95 % of TSP and the $PM_{2.5}$ is estimated as 93 % of TSP. This is assumptions based on Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

List PM emission factor (g/GJ) references for non-residential biomass combustion.

Reference	PM
Struschka et al. (2008) (Table 5.5a, GHD Holzbrennstoffe)	74
Naturvårdsverket, Sweden	150[1)] / 100[2)] / 30[3)]
Johansson et al. (2004). Modern wood boilers (average)	36

1) Boilers, wood logs
2) Boilers, chips
3) Boilers, pellets

HMs

All emission factors have been assumed equal to the HM emission factors for residential wood combustion.

PCB

The emission factor for tier 1 and for manual boilers have been assumed equal to conventional boilers < 50 kW and the emission factor for automatic boilers have been assumed equal to advanced/ecolabelled stoves and boilers. The unit have been changed from mg/GJ to µg/GJ.

PCDD/F

Emission factors for all categories have been assumed equal to emission factors for advanced / ecolabelled stoves and boilers and pellet boilers.

PAHs

Emission factors for all categories have been assumed equal to emission factors for advanced / ecolabelled stoves and boilers and pellet boilers.

HCB

The emission factor for residential plants have been applied.

Tables for non-residential wood combustion

Table 3-10 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using biomass

Tier 1 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel				Biomass				
SNAP (if applicable)				020100 020300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices				NA				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	150	90	300	91	g/GJ	20	120	Lundgren et al. (2004) [1]
CO	1600	200	4500	570	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 kW
NMVOC	146	10	450	300	g/GJ	5	500	Naturvårdsverket, Sweden
SO2	38.4	20	50	11	g/GJ	8	40	US EPA, AP-42 chapter 1.9
NH3	-	-	-	37	g/GJ	18	74	Roe et al. (2004) [2]
TSP	156	60	250	150	g/GJ	75	300	Naturvårdsverket, Sweden
PM10	150	50	240	143	g/GJ	71	285	Naturvårdsverket, Sweden [3]
PM2.5	149	50	240	140	g/GJ	70	279	Naturvårdsverket, Sweden [3]
Pb	24.8	5	30	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	1.8	0.1	3	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.7	0.4	1.5	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	1.4	0.25	2	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	6.5	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	4.6	1	5	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	0.1	300	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.1	2	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	114	1	150	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.06	µg/GJ	0.006	0.6	Hedman et al. (2006)
PCDD/F	326	30	500	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	44.6	10	100	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	64.9	10	120	16	mg/GJ	8	32	
Benzo(k)fluoranthene	23.4	5	40	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	22.3	2	60	4	mg/GJ	2	8	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Larger combustion chamber, 350 kW
2) Assumed equal to low emitting wood stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

Table 3-30 Tier 2 emission factors for non-residential sources, automatic boilers burning wood

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel				Wood				
SNAP (if applicable)				020100 020300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices				Wood combustion <1MW - Manual Boilers				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	150	90	200	91	g/GJ	20	120	Lundgren et al. (2004) [1]
CO	3000	300	5000	570	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 kW
NMVOC	250	20	500	300	g/GJ	5	500	Naturvårdsverket, Sweden
SO2	20	15	50	11	g/GJ	8	40	US EPA, AP-42 chapter 1.9
NH3	-	-	-	37	g/GJ	18	74	Roe et al. (2004) [1]
TSP	80	70	250	150	g/GJ	75	300	Naturvårdsverket, Sweden
PM10	76	66	240	143	g/GJ	71	285	Naturvårdsverket, Sweden [2]
PM2.5	76	65	240	140	g/GJ	70	279	Naturvårdsverket, Sweden [2]
Pb	10	5	30	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	0.3	0.1	2	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.5	0.4	0.8	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	1	0.25	2	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	2	1	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	3	1	5	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	200	0.1	250	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.1	2	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	5	1	150	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.06	μg/GJ	0.006	0.6	Hedman et al. (2006)
PCDD/F	300	30	500	100	ng I-TEQ/GJ	30	500	Hedman et al. (2006)
Benzo(a)pyrene	50	12	150	10	mg/GJ	5	20	Boman et al. (2011);

Benzo(b)fluoranthene	60	14	120	16	mg/GJ	8	32	Johansson et al. (2004)
Benzo(k)fluoranthene	20	8	50	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	20	6	80	4	mg/GJ	2	8	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Assumed equal to low emitting wood stoves

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

Table 3-31 Tier 2 emission factors for non-residential sources, automatic boilers burning wood

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.c.i 1.A.5.a	Commercial / institutional: stationary Stationary Other, stationary (including military)			
Fuel				Wood				
SNAP (if applicable)				020100 020300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices				Wood combustion <1MW - Automatic Boilers				
Region or regional conditions				NA				
Abatement technologies				NA				
Not applicable								
Not estimated								
Pollutant	Former value	Former interval		Value	Unit	95 % confidence interval		Reference
						Lower	Upper	
NOx	150	90	200	91	g/GJ	20	120	Lundgren et al. (2004) [1]
CO	300	200	5000	300	g/GJ	50	4000	German test standard for 500 kW-1MW boilers; Danish legislation (Luftvejledningen)
NMVOC	20	10	500	12	g/GJ	5	300	Johansson et al. (2004) [1]
SO2	20	15	50	11	g/GJ	8	40	US EPA, AP-42 chapter 1.9
NH3	-	-	-	37	g/GJ	18	74	Roe et al. (2004) [2]
TSP	70	60	250	36	g/GJ	18	72	Johansson et al. (2004)
PM10	66	50	240	34	g/GJ	17	68	Johansson et al. (2004) [3]
PM2.5	66	50	240	33	g/GJ	17	67	Johansson et al. (2004) [3]
Pb	20	10	30	27	mg/GJ	0.5	118	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Cd	0.5	0.3	2	13	mg/GJ	0.5	87	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Hg	0.6	0.4	0.8	0.56	mg/GJ	0.2	1	Struschka et al. (2008)
As	0.5	0.25	2	0.19	mg/GJ	0.05	12	Struschka et al. (2008)
Cr	4	2	10	23	mg/GJ	1	100	Hedberg et al. (2002) , Struschka et al. (2008)
Cu	2	1	5	6	mg/GJ	4	89	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
Ni	2	0.1	200	2	mg/GJ	0.5	16	Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011)
Se	0.5	0.1	2	0.5	mg/GJ	0.25	1.1	Hedberg et al. (2002)
Zn	80	5	150	512	mg/GJ	80	1300	Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011)
PCBs	0.06 mg/GJ	0.012	0.3	0.007	µg/GJ	0.0007	0.07	Hedman et al. (2006)
PCDD/F	30	20	500	100	ng I-	30	500	Hedman et al. (2006)

					TEQ/GJ			
Benzo(a)pyrene	12	10	150	10	mg/GJ	5	20	Boman et al. (2011); Johansson et al. (2004)
Benzo(b)fluoranthene	14	10	120	16	mg/GJ	8	32	
Benzo(k)fluoranthene	8	5	50	5	mg/GJ	2	10	
Indeno(1,2,3-cd)pyrene	6	2	80	4	mg/GJ	2	8	
HCB	6	3	9	5	µg/GJ	0.1	30	Syc et al. (2011)

1) Data for modern boilers
2) Assumed equal to low emitting wood stoves
3) PM_{10} estimated as 95 % of TSP, $PM_{2.5}$ estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.

Solid fuel combustion

For non-residential small scale coal combustion there is a tier 1 EF table and four tier 2 EF tables in the GB 2009. It is not completely clear what the distinction is between the EFs in the GB 2009 Table 3-27 and table 3-29.

	Tier	Fuel	Sector	Technology
Table 3-7	1	Coal	Non-residential	
Table 3-27	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-28	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-29	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-30	2	Coal	Non-residential	Automatic boilers < 1MW

The table below shows the EFs available in the GB 2009.

	Tier 1	Boilers 50 kW to 1 MW	Boilers 1-50 MW	Manual boilers < 1 MW	Automatic boilers < 1MW
NOx	173	160	180	200	200
CO	931	2000	200	1500	400
NMVOC	88.8	200	20	100	20
SO2	900	900	900	450	450
TSP	124	200	80	150	80
PM10	117	190	76	140	76
PM25	108	170	72	130	72
Pb	134	200	100	150	80
Cd	1.8	3	1	2	2
Hg	7.9	7	9	6	8
As	4	5	4	4	0.5
Cr	13.5	15	15	10	1
Cu	17.5	30	10	15	8
Ni	13	20	10	15	2
Se	1.8	2	2	2	0.5
Zn	200	300	150	200	100
PCBs	170	170	170	170	170
PCDD/F	203	400	100	200	40
Benzo(a)	45.5	100	13	90	17
Benzo(b)	58.9	130	17	110	18
Benzo(k)	23.7	50	9	50	8
Indeno	18.5	40	6	40	7
HCB	0.62	0.62	0.62	0.62	0.62

It is not clear how the tier 1 EFs have been derived, but it seems to some kind of average of the tier 2 EFs. There are some strange inconsistencies, e.g. that the HM EFs for boilers > 1 MW is higher than the EFs for automatic boilers < 1MW despite the PM EFs being identical. Also, the SO_2 EFs seem inconsistent.

As for residential plants there is few data available for the small scale boilers included in this sector. For small automatic boilers EFs have been compared with the EFs for underfeed stokers in the US EPA, measurements reported by Thistlethwaite (2001) for a 500 kW boiler with an underfeed stoker and no abatement and data from Germany reported by Struschka et al. (2008).

The comparison is shown in the table below.

	Automatic boilers < 1MW	US EPA	Thistlethwaite, 2001	Struschka et al., 2008
NOx	200	165		111
CO	400	191	350	408
NMVOC	20	23		1
SO2	450			204
TSP	80	261	82	18
PM10	76	108		17.1
PM25	72	66		15.3
Pb	80	229	167	230
Cd	2	28	1	4
Hg	8	7	16	3.6
As	0.5	178	46	3.2
Cr	1	284	6	2.3
Cu	8		192	3.1
Ni	2	467	37	
Se	0.5		17	
Zn	100		201	11
PCBs	170			
PCDD/F	40			16.3
Benzo(a)	17		0.079	
Benzo(b)	18		1.244	
Benzo(k)	8		0.845	
Indeno	7		0.617	
HCB	0.62			

The CO and TSP EFs reported by Thistlethwaite (2001) are very close to the values in the 2009 GB. The HM EFs reported by Thistlethwaite (2001) are sometimes close to the GB 2009 EFs and sometimes very different. It is of course clear that the HM content of coal can very significantly. For PAH the EFs reported by Thistlethwaite (2001) are much lower than the 2009 GB EFs. For Cu and Zn the EFs reported by Thistlethwaite (2001) are much higher than those reported by Struschka et al. (2008).

The EFs in the GB are updated to Thistlethwaite (2001), where available. For NO_x and NMVOC the EFs are changed to US EPA. Regarding the particle size distribution the distribution reported by Struschka et al. (2008) is used.

There are not sufficient data available to update the other EF tables. Therefore, these EF tables are maintained as previous.

Other fuel combustion

	Tier	Fuel	Sector	Technology
Table 3-8	1	Gaseous fuels	Non-residential	
Table 3-9	1	Liquid fuels	Non-residential	
Table 3-33	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-34	2	Natural gas	Non-residential	Boiler 1 MW to 50 MW
Table 3-35	2	Natural gas	Non-residential	Gas turbines
Table 3-36	2	Gas oil	Non-residential	Gas turbines
Table 3-37	2	Gaseous fuels	Non-residential	Gas engines
Table 3-38	2	Gas oil	Non-residential	Gas engines

EFs for main pollutants and PMs are updated to values from Italian measurement results for combustion of natural gas in heating boilers provided by the Italian Ministry for the Environment (2005) except for the NMVOC EF which are updated to the average value for gas combustion from UBA (2008). The NO_x and SO_2 EFs are higher than the present values, and the EFs for CO, NMVOC and PMs are lower. As The Italian Ministry for the Environment (2005) does not include EFs for PM_{10} and $PM_{2.5}$ it is assumed that all particles have an aerodynamic diameter less than 2.5 µm. UBA (2008) also include EFs for all main pollutants and PMs, all being lower than the EF from The Italian Ministry for the Environment (2005). The reason for using The Italian Ministry for the Environment (2005) rather than UBA (2008) is that the former is based on measurements, while the latter focus on literature review.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

The EF for PCDD/F is changed to 0.5 ng I-TEQ/GJ as provided by UNEP (2005) for power plants. The value in the present guidebook version is larger and is for residential stoves, which are assumed to have a larger emission than boilers.

EFs for PAHs are maintained.

Table 3-33 Commercial/institutional medium size boilers (> 50 kWh and <= 1 MWh) burning natural gas

Table 3-33

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.c.i	Commercial/institutional Residential plants			
Fuel				Natural gas				
SNAP (if applicable)								
Technologies/Practices				Medium size boilers (< 50 kWh - <= 1 MWh)				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	70	35	200	73	g/GJ			Italian Ministry for the Environment, 2005
CO	30	18	42	24	g/GJ			Italian Ministry for the Environment, 2005
NMVOC	3	1.8	4.2	0.4	g/GJ			UBA (2008)
SO2	0.5	0.05	1	1.4	g/GJ			Italian Ministry for the Environment, 2005
NH3								
TSP	0.5	0.3	0.7	0.45	g/GJ			Italian Ministry for the Environment, 2005
PM10	0.5	0.3	0.7	0.45	g/GJ			assumption: EF PM10 = EF TSP
PM2.5	0.5	0.3	0.7	0.45	g/GJ			assumption: EF PM2.5 = EF TSP
Pb	0.98	0.492	1.97	0.00150	mg/GJ			Nielsen et al, 2012
Cd	0.52	0.172	1.55	0.00025	mg/GJ			Nielsen et al, 2012
Hg	0.23	0.0781	0.703	0.68	mg/GJ			Nielsen et al, 2012
As	0.094	0.0312	0.281	0.12	mg/GJ			Nielsen et al, 2012
Cr	0.66	0.219	1.97	0.00076	mg/GJ			Nielsen et al, 2012
Cu	0.4	0.199	0.796	0.000076	mg/GJ			Nielsen et al, 2012
Ni	0.984	0.492	1.97	0.00051	mg/GJ			Nielsen et al, 2012
Se	0.011	0.00375	0.0337	0.011	mg/GJ		0.011	USEPA 1998, chapter 1.4
Zn	13.6	4.53	40.7	0.0015	mg/GJ			Nielsen et al, 2012
PCDD/F	2	0.9	2.1	0.5	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	0.562	0.187	0.561	0.56	ug/GJ		0.56	USEPA 1998, chapter 1.4
Benzo(b)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Benzo(k)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Indeno(1,2,3-cd)pyrene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4

EFs for main pollutants are updated to values from DGC (2009) for forced draught burners. Except for the new CO EF, which is higher than the upper limit of the old 95 % confidence interval, all new values are in the same range as the old values.

EFs for PMs are updated to values for all natural gas heating boilers provided by the Italian Ministry for the Environment (2005). The new values are similar to the EFs in the present version of the guidebook, which lacks a proper reference.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

The EF for PCDD/F is changed to 0.5 ng I-TEQ/GJ as provided by UNEP (2005) for power plants. The value in the present guidebook version is larger and is for residential stoves, which are assumed to have a larger emission than boilers.

EFs for PAHs are maintained.

Table 3-34 Commercial/institutional medium size boilers (> 1 MWh and <= 50 MWh) burning natural gas

Table 3-34

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.c.i	Commercial/institutional Residential plants			
Fuel				Natural gas				
SNAP (if applicable)								
Technologies/Practices				Medium size boilers (< 1 MWh - <= 50 MWh)				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	70	35	200	40	g/GJ	30	55	DGC, 2009
CO	20	12	28	30	g/GJ		30	DGC, 2009
NMVOC	2	1.2	2.8	2	g/GJ			DGC, 2009
SO2	0.5	0.05	1	0.3	g/GJ			DGC, 2009
NH3								
TSP	0.5	0.3	0.7	0.45	g/GJ			Italian Ministry for the Environment, 2005
PM10	0.5	0.3	0.7	0.45	g/GJ			assumption: EF PM10 = EF TSP
PM2.5	0.5	0.3	0.7	0.45	g/GJ			assumption: EF PM2.5 = EF TSP
Pb	0.98	0.492	1.97	0.00150	mg/GJ			Nielsen et al, 2012
Cd	0.52	0.172	1.55	0.00025	mg/GJ			Nielsen et al, 2012
Hg	0.23	0.0781	0.703	0.68	mg/GJ			Nielsen et al, 2012
As	0.094	0.0312	0.281	0.12	mg/GJ			Nielsen et al, 2012
Cr	0.66	0.219	1.97	0.00076	mg/GJ			Nielsen et al, 2012
Cu	0.4	0.199	0.796	0.000076	mg/GJ			Nielsen et al, 2012
Ni	0.984	0.492	1.97	0.00051	mg/GJ			Nielsen et al, 2012
Se	0.011	0.00375	0.0337	0.011	mg/GJ		0.011	USEPA 1998, chapter 1.4
Zn	13.6	4.53	40.7	0.0015	mg/GJ			Nielsen et al, 2012
PCDD/F	2	0.9	2.1	0.5	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	0.562	0.187	0.562	0.56	ug/GJ		0.56	USEPA 1998, chapter 1.4
Benzo(b)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Benzo(k)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Indeno(1,2,3-cd)pyrene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4

EFs for NO_x, CO and NMVOC are updated to values from Nielsen et al. (2010) based on an extensive Danish measurement campaign including accredited measurements for Danish gas turbines burning natural gas from the North Sea. The updated values for NO_x and CO are lower than the lower limit of the old 95 % confidence interval.

The PM EFs are updated to values for gas turbines provided by BUWAL (2001) which are also lower than the lower limit of the old 95 % confidence interval. It is assumed that EF $PM_{2.5}$ = EF PM_{10} as is the case for natural gas combustion in UBA (2008) for gas-fired appliances.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

The EF for PCDD/F is changed to 0.5 ng I-TEQ/GJ as provided by UNEP (2005) for power plants. The value in the present guidebook version is larger and is for residential stoves, which are assumed to have a larger emission than boilers.

EFs for PAHs are maintained.

Table 3-35 Commercial/institutional gas turbines burning natural gas

Table 3-35

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.b.i	Commercial/institutional Residential plants			
Fuel				Natural gas				
SNAP (if applicable)								
Technologies/Practices				Gas turbine				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	153	92	245	48	g/GJ			Nielsen et al, 2010
CO	39.2	24		4.8	g/GJ			Nielsen et al, 2010
NMVOC	1	0.3		1.6	g/GJ			Nielsen et al, 2010
SO2	0.281	0.169		0.5	g/GJ			BUWAL, 2001
NH3								
TSP	0.908	0.454		0.2	g/GJ			BUWAL, 2001
PM10	0.908	0.454		0.2	g/GJ			BUWAL, 2001
PM2.5	0.908	0.454		0.2	g/GJ			assumption: EF PM2.5 = EF PM10
Pb	0.234	0.0781	1.97	0.00150	mg/GJ			Nielsen et al, 2012
Cd	0.515	0.172	1.55	0.00025	mg/GJ			Nielsen et al, 2012
Hg	0.1	0.05	0.15	0.68	mg/GJ			Nielsen et al, 2012
As	0.0937	0.0312	0.281	0.12	mg/GJ			Nielsen et al, 2012
Cr	0.656	0.219	1.97	0.00076	mg/GJ			Nielsen et al, 2012
Cu	0.398	0.199	0.796	0.000076	mg/GJ			Nielsen et al, 2012
Ni	0.984	0.492	1.97	0.00051	mg/GJ			Nielsen et al, 2012
Se	0.0112	0.00375	0.0337	0.011	mg/GJ		0.011	USEPA 1998, chapter 1.4
Zn	13.6	4.53	40.7	0.0015	mg/GJ			Nielsen et al, 2012
PCDD/F				0.5	ng I-TEQ/GJ			UNEP, 2005
Benzo(a)pyrene	0.562	0.187	0.562	0.56	ug/GJ		0.56	USEPA 1998, chapter 1.4
Benzo(b)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Benzo(k)fluoranthene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4
Indeno(1,2,3-cd)pyrene	0.843	0.281	0.843	0.84	ug/GJ		0.84	USEPA 1998, chapter 1.4

The EFs for NO_x and CO are updated to values from Nielsen et al. (2010), which is based on an extensive Danish measurement campaign including accredited measurements for Danish gas turbines burning gas oil. The EF for TSP for gas oil fueled steam turbines provided by Nielsen et al. (2010) are applied for all particle fractions, as it is assumed that all particles have aerodynamic diameters less than 2.5 µm. NMVOC was not part of the measurement program in Nielsen et al. (2010), and the EF from US EPA (2000) is maintained. The updated EF for NO_x is lower than the present values while the updated EFs for CO and PMs are higher.

EFs for HMs are updated according to the HM concentrations in diesel sold in Europe provided in van der Gon & Kuenen (2009). In correspondence with the Revised 1996 IPCC Guidelines, a calorific value of 43.33 TJ/Gg is used to calculate the EFs. The updated EFs for Pb, Cd, Hg and Cr are lower than the present values. EFs have been applied for the HMs missing EFs in the present version of the guidebook.

The dioxin EF is updated to the average of the seven values for old and new appliances provided by Pfeiffer et al. (2000). The values are recalculated according to Pfeiffer et al. (2000) using NVC = 42.8 MJ/kg.

No PAH EFs for gas turbines burning gas oil are identified. The PAH emissions are assumed very limited/negliable and it is proposed to apply PAH to the list of NEs.

Table 3-36 Commercial/institutional gas turbines burning gas oil

Table 3-36

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.b.i	Commercial/institutional residential plants			
Fuel				Gas oil				
SNAP (if applicable)				020104				
Technologies/Practices				Gas turbines				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence inte		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	398	239	557	83	g/GJ			Nielsen et al, 2010
CO	1.49	0.89	2.09	2.6	g/GJ			Nielsen et al, 2010
NMVOC	0.19	0.11	0.26	0.18	g/GJ			US EPA, chapter 3.1
SO2	46.1	4.61	460	46	g/GJ			1)
NH3								
TSP	3	1.5	6	9.5	g/GJ			Nielsen et al, 2010
PM10	3	1.5	6	9.5	g/GJ			assumption: EF PM10 = EF TSP
PM2.5	3	1.5	6	9.5	g/GJ			assumption: EF PM2.5 = EF TSP
Pb	6.34	2.11	19	0.012	mg/GJ			van der Gon & Kuenen, 2009
Cd	2.17	0.723	6.51	0.0010	mg/GJ		0.0010	van der Gon & Kuenen, 2009
Hg	0.543	0.181	1.63	0.12	mg/GJ		0.12	van der Gon & Kuenen, 2009
As				0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Cr	4.98	1.66	14.9	0.20	mg/GJ			van der Gon & Kuenen, 2009
Cu				0.13	mg/GJ			van der Gon & Kuenen, 2009
Ni				0.0050	mg/GJ			van der Gon & Kuenen, 2009
Se				0.0020	mg/GJ		0.0020	van der Gon & Kuenen, 2009
Zn				0.42	mg/GJ			van der Gon & Kuenen, 2009
PCDD/F				1.84	ng I-TEQ/GJ			Pfeiffer et al, 2000
Benzo(a)pyrene					ug/GJ			
Benzo(b)fluoranthene					ug/GJ			
Benzo(k)fluoranthene					ug/GJ			
Indeno(1,2,3-cd)pyrene					ug/GJ			

1) estimate based on 0.1 % S and LHV = 43.33 TJ/1000 tonnes

The EFs for main pollutants and HMs are updated to values from Nielsen et al. (2010), which is based on an extensive Danish measurement campaign including accredited measurements for Danish gas engines. The new values are considerable lower than the old EFs and for the major part below the lower limit of the old 95 % confidence interval. It must be noticed that measurements in Nielsen et al. (2010) are carried out for engines burning only natural gas and does not cover dual-fuel engines. The values are applied anyway as they result from a large and new measurement program in Denmark, and as the values are assumed to be applicable for European conditions.

The PM EFs are updated to values for gas turbines from BUWAL (2001) which are also lower than the lower limit of the old 95 % confidence interval. It is assumed that EF $PM_{2.5}$ = EF PM_{10}.

EFs for HMs are updated to Nielsen et al. (2013) that include EFs based on the HM content of Danish natural gas. The new values are considerably lower than the old values. It is expected that the HM EFs should be very low as the content of metals in natural gas is very limited. As Se is not included in the Nielsen et al. (2013), the present Se EF is maintained.

EFs for PAHs are updated to values provided by Nielsen et al. (2010) for reciprocating engines. The new values are lower than the old values from US EPA (1998).

A dioxin EF for natural gas fired engines is applied (Nielsen et al., 2010).

Table 3-37 Commercial/institutional stationary reciprocating engines burning gas (including dual-fuel)

Table 3-37

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.b.i	Commercial/institutional Residential plants			
Fuel				Gas fuels (includes dual fuel 95% gas + 5% oil)				
SNAP (if applicable)								
Technologies/Practices				Stationary reciprocating engines - gas-fired, includes dual fuel				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	d 95 % confidence inter		Value	Unit	% confidence int		Reference
		Old Lower	Old Upper			Lower	Upper	
NOx	1420	708	2120	135	g/GJ			Nielsen et al, 2010
CO	407	204	611	56	g/GJ			Nielsen et al, 2010
NMVOC	46	23	69	89	g/GJ			Nielsen et al, 2010
SO2	0.281	0.169	0.393	0.5	g/GJ			BUWAL, 2001
NH3								
TSP	1.5	0.01	20	2	g/GJ			BUWAL, 2001
PM10	1.5	0.01	20	2	g/GJ			BUWAL, 2001
PM2.5	1.5	0.01	20	2	g/GJ			assumption: EF PM2.5 = EF PM10
Pb	0.234	0.0781	0.703	0.040	mg/GJ			Nielsen et al, 2010
Cd	0.515	0.172	1.55	0.0030	mg/GJ		0.003	Nielsen et al, 2010
Hg	0.1	0.05	0.15	0.10	mg/GJ		0.1	Nielsen et al, 2010
As	0.0937	0.0312	0.281	0.050	mg/GJ		0.05	Nielsen et al, 2010
Cr	0.656	0.219	1.97	0.050	mg/GJ			Nielsen et al, 2010
Cu	0.398	0.199	0.796	0.010	mg/GJ			Nielsen et al, 2010
Ni	0.984	0.492	1.97	0.050	mg/GJ			Nielsen et al, 2010
Se	0.0112	0.00375	0.0337	0.20	mg/GJ		0.2	Nielsen et al, 2010
Zn	13.6	4.53	40.7	2.91	mg/GJ			Nielsen et al, 2010
PCDD/F				0.57	ng I-TEQ/GJ			Nielsen et al, 2010
Benzo(a)pyrene	2.7	1.35	4.05	1.2	ug/GJ			Nielsen et al, 2010
Benzo(b)fluoranthene	18	9	27	9.0	ug/GJ			Nielsen et al, 2010
Benzo(k)fluoranthene	2	1	3	1.7	ug/GJ			Nielsen et al, 2010
Indeno(1,2,3-cd)pyrene	4.7	2.35	7.05	1.8	ug/GJ			Nielsen et al, 2010

The EFs for NO_x, CO, HMs, PAHs and dioxin are updated to values from Nielsen et al. (2010), which is based on an extensive Danish measurement campaign including accredited measurements for Danish gas engines. Except for Zn and the PAHs, the new EFs are considerably lower than the values in the present version of the guidebook. NMVOC was not part of the measurement program in Nielsen et al. (2010) and no EFs are available for SO_2 and PMs. These EFs are updated according to BUWAL (2001). As no $PM_{2.5}$ EF is included in BUWAL (2001) it is assumed that EF PM2.5 = EF PM_{10}. Values from BUWAL (2001) are of the same size as the present values.

It must be noticed that measurements in Nielsen et al. (2010) are carried out for engines burning only natural gas and does not cover dual-fuel engines. The values are applied anyway as they result from a large and new measurement program in Denmark, and as the values are assumed to be applicable for European conditions.

EFs for PAHs provided by Nielsen et al. (2010) are applied. The new values are considerably lower than the present values provided in US EPA (1998).

EFs for HCB and PCB provided by Nielsen et al. (2010) are applied.

Table 3-38 Commercial/institutional reciprocating engines burning gas oil

Table 3-38

Tier 2 emission factors								
				Code	Name			
NFR source category				1.A.4.a.i 1.A.4.b.i	Commercial/institutional residential plants			
Fuel				Gas oil				
SNAP (if applicable)				020105				
Technologies/Practices				Reciprocating engines				
Region or regional conditions								
Abatement technologies								
Not applicable								
Not estimated								
Pollutant	Old value	95 % confidence int		Value	Unit	% confidence inte		Reference
		Old Lowe	Old Uppe			Lower	Upper	
NOx	1450	680	2050	942	g/GJ			Nielsen et al, 2010
CO	385	193	578	130	g/GJ			Nielsen et al, 2010
NMVOC	37.1	18.5	55.6	50	g/GJ			BUWAL, 2001
SO2	46.1	4.61	461	48	g/GJ			BUWAL, 2001
NH3								
TSP	28.1	14.1	56.2	30	g/GJ			BUWAL, 2001
PM10	22.4	11.2	44.8	30	g/GJ			BUWAL, 2001
PM2.5	21.7	10.8	43.4	30	g/GJ			assumption: EF PM2.5 = EF PM10
Pb	4.07	0.41	40.7	0.15	mg/GJ			Nielsen et al, 2010
Cd	1.36	0.14	13.6	0.010	mg/GJ			Nielsen et al, 2010
Hg	1.36	0.14	13.6	0.11	mg/GJ			Nielsen et al, 2010
As	1.81	0.18	18.1	0.060	mg/GJ			Nielsen et al, 2010
Cr	1.36	0.14	13.6	0.20	mg/GJ			Nielsen et al, 2010
Cu	2.72	0.27	27.1	0.30	mg/GJ			Nielsen et al, 2010
Ni	1.36	0.14	13.6	0.010	mg/GJ			Nielsen et al, 2010
Se	6.79	0.68	67.9	0.22	mg/GJ			Nielsen et al, 2010
Zn	1.81	0.18	18.1	58	mg/GJ			Nielsen et al, 2010
PCDD/F				0.99	ng I-TEQ/GJ			Nielsen et al, 2010
Benzo(a)pyrene	116	58.2	116	1.9	ug/GJ		1.9	Nielsen et al, 2010
Benzo(b)fluoranthene	502	251	754	15	ug/GJ		15	Nielsen et al, 2010
Benzo(k)fluoranthene	987	49.3	98.7	1.7	ug/GJ		1.7	Nielsen et al, 2010
Indeno(1,2,3-cd)pyrene	187	93.7	187	1.5	ug/GJ		1.5	Nielsen et al, 2010
HCB				0.22	ug/GJ		0.22	Nielsen et al, 2010
PCB				0.13	ng/GJ		0.13	Nielsen et al, 2010

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Appendix E Black carbon methodology for Small combustion (1A4)

Nielsen, O.-K., Plejdrup, M.S. & Nielsen, M. (2012)

This appendix covers a review of the available data for BC emissions from small combustion. Furthermore, separate discussion papers are dedicated to a review of the GB 2009 emission factors (EFs) and to discuss different methods for allocating fuel consumption data to different technologies as well as bottom-up methods for estimating fuel consumption for small combustion installations.

Residential plants

The 2009 EMEP/EEA Guidebook (GB) contained four tier 1 EF tables and a larger number of tier 2 EF tables as presented in the table below. In the 2009 version, there was no match between the technological descriptions in section 2.2 and the EFs provided in section 3 of the chapter.

List of EF tables for residential plants in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology
Table 3-3	1	Coal	Residential	
Table 3-4	1	Natural gas	Residential	
Table 3-5	1	Other liquid fuels	Residential	
Table 3-6	1	Biomass	Residential	
Table 3-12	2	Solid fuels	Residential	Fireplaces
Table 3-13	2	Gaseous fuels	Residential	Fireplaces
Table 3-14	2	Wood	Residential	Fireplaces
Table 3-15	2	Solid fuels	Residential	Stoves
Table 3-16	2	Solid fuels	Residential	Boilers < 50 kW
Table 3-17	2	Wood	Residential	Stoves
Table 3-18	2	Wood	Residential	Boilers < 50 kW
Table 3-19	2	Natural gas	Residential	Stoves
Table 3-20	2	Natural gas	Residential	Boilers < 50 kW
Table 3-21	2	Liquid fuels	Residential	Stoves
Table 3-22	2	Liquid fuels	Residential	Boilers < 50 kW
Table 3-23	2	Coal	Residential	Advanced stoves
Table 3-24	2	Wood	Residential	Advanced fireplaces
Table 3-25	2	Wood	Residential	Advanced stoves
Table 3-26	2	Wood	Residential	Pellet stoves

Biomass combustion

Emission factors are included in one tier 1 emission factor table and 6 tier 2 emission factor tables in the 2009 GB. As mentioned above the technology description in chapter 2.2 does not match the tier 2 emission factor tables. Suggested new technology names and the link to the technology description in chapter 2.2 are shown below. The emission factor table for advanced fireplaces will be deleted and replaced by an emission factor table for energy efficient stoves.

List of EF tables for residential plants in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology	New technology name	Chapter 2.2 technology name
Table 3-6	1	Biomass	Residential		-	-
Table 3-14	2	Wood	Residential	Fireplaces	Open fireplaces	Open and partly closed fireplace
Table 3-17	2	Wood	Residential	Stoves	Conventional stoves	Closed fireplace, conventional traditional stoves, domestic cooking
Table 3-18	2	Wood	Residential	Boilers < 50 kW	Conventional boilers < 50 kW	Conventional biomass boilers
Table 3-24	2	Wood	Residential	Advanced fireplaces	Energy efficient stoves	Energy efficient conventional stoves
Table 3-25	2	Wood	Residential	Advanced stoves	Advanced/ecolabelled stoves and boilers	Advanced combustion stoves, masonry heat accumulating stoves[14], catalytic combustor stoves, advanced combustion boilers
Table 3-26	2	Wood	Residential	Pellet stoves	Pellet stoves and boilers	Modern pellet stoves, automatic wood boilers (pellets / chips)

BC and OC fractions of PM depend of both technology, wood type and PM emission level. For open fireplaces the OC fraction is high whereas a more complete combustion in advanced stoves results in a lower OC fraction.

It has not been possible to distinguish between elemental carbon and black carbon. Most references state data for elemental carbon.

In most recent European literature PM and BC measurement data are based on dilution sampling and BC fractions related to $PM_{2.5}$.

Residential wood combustion (tier 1)

The revised emission factor for $PM_{2.5}$ is 740 g/GJ (370-1480). The tier 1 emission factor for $PM_{2.5}$ follows the emission factor for conventional stoves. The BC fraction for stoves (10 %) will be applied.

Fireplaces

The revised emission factor for $PM_{2.5}$ from fireplaces is 820 (410-1640) g/GJ.

The BC fraction 7 % of $PM_{2.5}$ that is an average of the listed references will be applied. The average OC fraction is 43 %.

[14] This technology can be included in the category Energy efficient stoves instead dependent on the most common technology applied for masonry heat accumulating stoves in the country.

List of BC references for open fireplaces.

Reference	Country	Plant	PM [g/GJ]	EC or BC	OC
Alves et al. 2011	Portugal	Brick open fireplace, wood logs	$PM_{2.5}$: 550-1122	4.7 % (2.2-7.5 %)	43.2-53 %
Alves et al. 2011	Portugal	Brick open fireplace, briquettes	$PM_{2.5}$: 850	5.4 %	47.7 %
Goncalves et al. 2011	Portugal	Brick open fireplace	$PM_{2.5}$: 47-1611	1.1[15]-17 %	20-48 %
Fernandes et al. 2011	Portugal	Brick open fireplace, wood logs	$PM_{2.5}$: 700 (374-1026)	2-12 %	-
Fernandes et al. 2011	Portugal	Brick open fireplace, briquettes	$PM_{2.5}$: 692	2,98 %	45 %
Fine et al. 2002	USA	Open fireplace, hardwood	$PM_{2.5}$: 183-378	1.2-6.4 %	74.2-84.9 %
Fine et al. 2002	USA	Open fireplace, softwood	$PM_{2.5}$: 89-206	14.2-17.9 %	~100 %
Bølling et al., 2009	-	Open fireplace	$PM_{2.5}$: 160-910		
Kupiainen & Klimont 2004 (IIASA)	-	Open fireplace	-	10 %	50 %

Conventional stoves

The revised emission factor and interval for $PM_{2.5}$ from conventional stoves is 740 (370-1480) g/GJ..

The BC fraction 10 % of $PM_{2.5}$ that is an average of the listed references will be applied. Some of the BC fractions are however based on TSP. The average OC fraction is 45 %[16].

List of BC references for conventional stoves.

Reference	Country	Plant	PM [g/GJ]	EC or BC	OC
Alves et al. 2011	Portugal	Cast iron woodstove, split logs	$PM_{2.5}$: 557 (344-906)	1.9 - 7.7 %	45.6 - 53.6 %
Alves et al. 2011	Portugal	Cast iron woodstove, briquettes	233	3,9 %	47.1 %
Goncalves et al. 2011	Portugal	Cast iron woodstove, wood logs and briquetts	$PM_{2.5}$: 92 - 1433	0.82 - 9.3 %	30- 50 %
Fernandes et al. 2011	Portugal	Cast iron woodstove, wood logs	$PM_{2.5}$: 447 (278-617)	3-12 %	-
Fernandes et al. 2011	Portugal	Cast iron woodstove, briquettes	$PM_{2.5}$: 396	3.62 %	40.27 %
Bølling et al. 2009	-	Conventional wood stoves	50-2100	-[17]	-
US EPA (SPECIATE), 2002 (IIASA)	USA	Stoves, woodlogs, hardwood	-	14 % of TSP	42 % of TSP
US EPA (SPECIATE), 2002 (IIASA)	USA	Stoves, woodlogs, softwood	-	20 % of TSP	39 % of TSP
Rau, 1989 (IIASA)		Stoves, woodlogs, hardwood	-	5-16 % of TSP	14-57 % of TSP
Rau, 1989 (IIASA)		Stoves, woodlogs, softwood	-	5-38 % of TSP	20-51 % of TSP

[15] Briquettes
[16] Not including Fine et al. (2002)
[17] EC data only related to TC

Conventional boilers < 50 kW

The revised emission factor level and interval for $PM_{2.5}$ from conventional boilers is 470 (235-945) g/GJ.

BC emission factors have been reported by Kupiainen & Klimont (2007). Based on the default $PM_{2.5}$ emission factor 475 g/GJ the BC fraction 16 % have been estimated.

List of BC references for conventional boilers.

Reference	Country	Plant	PM [g/GJ]	EC or BC	OC
Bølling et al. 2009	-	Conventional wood boilers and masonry heaters	$PM_{2.5}$: 50-2000	10 %-35 % of TC	
Kupiainen & Klimont 2007	-	Boilers < 50 kWth	-	75 mg/MJ[1)]	
Johansson et al. 2004		Old-type boilers	TSP: 87-2200 g/GJ	-	

1) Corresponding to 16 % of the default emission factor 475 g/GJ

Energy efficient stoves

The plant category is new. The emission factor for $PM_{2.5}$ is 370 (285-740) g/GJ. The same BC fraction as for conventional boilers will be applied.

Advanced/ecolabelled stoves and boilers

The revisedemission factor level and interval for $PM_{2.5}$ from advanced/ecolabelled stoves and boilers is 93 (19-233) g/GJ.

The category includes the chimney type stove[18].

The BC fraction 28 % of $PM_{2.5}$ that is an average of the listed references will be applied. The average OC fraction is 31 %.

List of BC references for advanced / ecolabelled stoves and boilers.

Reference	Country	Plant	PM [g/GJ]	EC or BC	OC
Goncalves et al. 2010	Portugal	Chimney type (tiled stove)	PM_{10}: 62-161	11.3-37.1 %	19.7-42.8 %
Fernandes et al. 2011	Portugal	Chimney type (tiled stove)	PM_{10}: 101 (50-152)	11-37 %	
Schmidl et al. 2011	Austria	Chimney type (tiled stove) 6.5 kW	PM_{10}: 54-78	24.2-38.7 %	26.8-38.8 %
Schmidl et al. 2011	Austria	Advanced tiled stove 6kW	PM_{10}: 58-66	29.8-37.6 %	22.2-35.6 %

Pellet stoves and boilers

The revised emission factor level for $PM_{2.5}$ from pellet stoves is 29 (9-47) g/GJ.

[18] The chimney type stove are iron stoves with chamotte lining (Schmidl et al. 2011).

The BC fraction 15 % of PM_{10} referring to Schmidl et al. (2011) will be applied. The average OC fraction is 13 %.

List of BC references for pellet stoves and boilers.

Reference	Country	Plant	PM	EC or BC	OC
Schmidl et al. 2011	Austria	Automatically fed pellet stove, 6 kW	PM_{10}: 2-7 g/GJ	13.7-15.87 %	4.7-5.3 %, 22 % in the start-up phase
Schmidl et al. 2011	Austria	Automatically fed boiler 40 kW moving grate	PM_{10}: 6-26 g/GJ	0.2-45.2 %	2-38.2 %
Bølling et al. 2009	?	Pellet stoves and boilers	$PM_{2.5}$: 10-50 g/GJ	6 %	-
Verma et al., 2011	Belgium	Five different pellet boilers (15-35 kW)	1-11 g/GJ[19]	0-38.8 %	-
Sippula et al., 2007	Finland	Pellet boiler	PM_1: 58 g/GJ	1.5 %	6.6 %

Overview of BC emission factors for residential wood combustion

The list below gives an overview of the BC fractions for residential wood combustion and the resulting BC emission factor if the default emission factor for $PM_{2.5}$ is applied. The resulting BC emission factors are compared to the emission factor intervals from Kupiainen & Klimont (2007).

List of EF tables for residential plants in the GB chapter on small combustion.

	Tier	Fuel	Sector	New technology name	$PM_{2.5}$	BC fraction	BC [g/GJ]	Kupiainen & Klimont 2007
Table 3-6	1	Biomass	Residential	-	740[20]	10%	74	0.83-105
Table 3-14	2	Wood	Residential	Open fireplaces	820	7%	57	75-100
Table 3-17	2	Wood	Residential	Conventional stoves	740	10%	74	75-105
Table 3-18	2	Wood	Residential	Conventional boilers < 50 kW	470	16 %	75[21]	75
Table 3-24	2	Wood	Residential	Energy efficient stoves	370	16 %	59	56-79
Table 3-25	2	Wood	Residential	Advanced/ecolabelled stoves and boilers	93	28%	26	56-79
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	29	15%	4	0.83

An overview of BC and OC fractions is shown below. In general, the BC fraction increases with improved combustion technology. However, the fraction for pellet stoves and boilers is lower than for advanced / ecolabelled stoves and boilers. The OC fraction decrease with improved combustion technology.

[19] Not diluted
[20] Not estimated yet. Assumed that the emission factor for conventional stoves will be applied.
[21] Refers to Kupiainen & Klimont (2007)

List of BC and OC fractions for residential wood combustion.

	Tier	Fuel	Sector	New technology name	$PM_{2.5}$	BC fraction	OC fraction
Table 3-6	1	Biomass	Residential	-	740	10%	-
Table 3-14	2	Wood	Residential	Open fireplaces	820	7%	43%
Table 3-17	2	Wood	Residential	Conventional stoves	740	10%	45%
Table 3-18	2	Wood	Residential	Conventional boilers < 50 kW	470	16 %	-
Table 3-24	2	Wood	Residential	Energy efficient stoves	370[22]	16 %	-
Table 3-25	2	Wood	Residential	Advanced/ecolabelled stoves and boilers	93	28%	31%
Table 3-26	2	Wood	Residential	Pellet stoves and boilers	29	15%	13%

Solid fuel combustion

There are five EF tables in the 2009 GB for solid fuels in residential plants. One of the EF tables is for tier 1, while the remaining four tables is tier 2 EF tables for fireplaces, stoves, small boilers and advanced stoves.

	Tier	Fuel	Sector	Technology
Table 3-3	1	Coal	Residential	
Table 3-12	2	Solid fuels	Residential	Fireplaces
Table 3-15	2	Solid fuels	Residential	Stoves
Table 3-16	2	Solid fuels	Residential	Boilers < 50 kW
Table 3-23	2	Coal	Residential	Advanced stoves

Some data are available for BC emission shares from small scale coal combustion. However, it has not been possible to find specific data for all technologies. Most data are available for stoves, with no data being available for advanced stoves and small boilers (< 50 kW).

Engelbrecht et al. (2002) reports source profiles for residential coal combustion in South Africa. Engelbrecht et al. (2002) presents data for stoves and braziers (assumed comparable to fireplaces) for bituminous coal and for low smoke fuels. The data reported are shown in the table below.

	Stove	Fireplace	Stove	Stove
% of $PM_{2.5}$	Bituminous coal	Bituminous coal	Low-smoke coal	Low-smoke coal
EC	9.5167	9.839	18.9857	6.8002
OC	70.8	78.268	56.3225	73.6005

Very similar results are obtained for stoves and fireplaces combusting bituminous coal. The EC shares of $PM_{2.5}$ for the low-smoke coal are differing slightly more, but are still comparable to the data for bituminous coal.

[22] Not estimated yet

Pinto et al. (1998) reports EC and OC shares of $PM_{2.5}$ from residential combustion of lignite in hand-fired stoves. The analysis was done for particles collected during the smouldering phase as well as during the active phase. The data are included in the table below.

% of $PM_{2.5}$	Residential coal combustion, smouldering	Residential coal combustion, active
EC	6.2	10
OC	68	62

Watson et al. (2001) presents data for a composite of two stoves and two fireplaces. The reported EC share of $PM_{2.5}$ is 26.08 % and the OC share is reported as 69.49 %. The four datasets are not included in the original reference but is included in the SPECIATE database. The four single datasets are shown in the table below.

% of $PM_{2.5}$	EC	OC
Stove burning coal from Trapper Mine.	6.7953	65.4335
Stove burning coal from Trapper Mine.	33.2055	45.4365
Fireplace and stove burning coal from Seneca Mine.	21.2664	75.9568
Fireplace and stove burning coal from Seneca Mine.	43.0381	91.1323

Bond et al. (2004) reports EC fractions of 0.5 to 0.6 for residential coal combustion in stoves based on unpublished data. It has not been possible to find any later publication where these measurement data have been described in more detail.

Zhang et al. (2012) reports EC and OC shares of $PM_{2.5}$ based on five measurements in China. The EC share is reported as 6.4 % ± 2.3 %-point. The OC share is reported as 48.7 % ± 19.1 %-point.

In the table below is a summary of the available data concerning EC.

Technology	Engelbrecht et al., 2002	Engelbrecht et al., 2002	Pinto et al., 1998	Watson et al., 2001	Bond et al., 2004	Zhang et al., 2012
	% of $PM_{2.5}$	% of $PM_{2.5}$	% of $PM_{2.5}$	% of $PM_{2.5}$		% of $PM_{2.5}$
Fireplaces	9.839					
Stoves	9.5167	18.9857; 6.8002	2; 6.2	26.08	50	6.4

The data reported by Watson et al. (2001) and Bond et al. (2004) seem like outliers compared to the remaining datasets. One of the measurements by Watson et al. (2004) (6.8 %) was close to the other data sources but the remaining three data points differed significantly. The data for low-smoke fuels from Engelbrecht et al. (2002), the data by Pinto et al. (1998) and the data from Zhang et al. (2012) is thought to be the best data set for stoves. The value for low-smoke fuel (AFC) reported by Engelbrect et al. (2002) of 6.8 % is in close agreement with the percentage of 6.4 reported by Zhang et al. (2012). Pinto et al. (1998) reports a share of 6.2 % for the smoldering phase and only 2 % for the active phase. Considering these datasets and noting that the other available data are higher, it is recommended that data from Zhang et al., (2012) are used as BC share for coal stoves. For fireplaces the share reported by Engelbrecht et al. (2002) is the only source and is therefore included. No information has been found in the literature neither for advanced coal stoves nor for small coal boilers. Since there is no information available to suggest that the composition of particles for these technologies are different than for coal stoves, it is recommended to use Zhang et al. (2012) as the reference for the BC EF.

	Tier	Fuel	Sector	Technology	BC share of $PM_{2.5}$	Reference
Table 3-3	1	Coal	Residential		6.4	Zhang et al., 2012
Table 3-12	2	Solid fuels	Residential	Fireplaces	9.839	Engelbrecht et al., 2002
Table 3-15	2	Solid fuels	Residential	Stoves	6.4	Zhang et al., 2012
Table 3-16	2	Solid fuels	Residential	Boilers < 50 kW	6.4	Zhang et al., 2012
Table 3-23	2	Coal	Residential	Advanced stoves	6.4	Zhang et al., 2012

Other fuel combustion

The 2009 guidebook includes seven tables for residential combustion of gaseous and liquid fuels. Two of the tables cover Tier 1 for natural gas and liquid fuels, respectively. The three tier 2 tables for gaseous fuels cover fireplaces, stoves and boiler, while the two tables for liquid fuels cover stoves and boilers. The technology for table 3-13 is changed from fireplaces to cooking appliances, as the use of gaseous fuels in fireplaces to be of limited relevance.

A literature study has been carried out and a short description of the most important references is given in the following;

Hildemann et al, 1991: Presents EFs for natural gas combustion in home appliances based on measurements of emissions from a residential natural gas fired space heater and a water heater;

EC = 6.7 % of $PM_{2.5}$
OC = 84.9 % of $PM_{2.5}$

Muhlbaier, 1981: Present EFs for residential gas fired appliances, based on measurements for three furnaces and one hot water heater;

EC = 4 % of $PM_{2.5}$
OC = 8 % of $PM_{2.5}$

Reff et al, 2009: In order to make an inventory of $PM_{2.5}$ trace elements in the United States, Reff et al has set up a list of 84 source categories based on CSSs from NEI and profiles from SPECIATE. SPECIATE profile #92156 gives Reff et al as reference, and according to the notes in SPECIATE the EFs are based on the EFs given in Hildemann et al. Reff et al (supp. Info.) has scaled OC down as the sum of species > 100 % of $PM_{2.5}$ in the original reference because Hildemann et al did not correct for artifacts. The following EFs are presented in the article for residential natural gas combustion;

EC = 6.7 % of $PM_{2.5}$
OC = 84.9 % of $PM_{2.5}$

Bond et al, 2004: together with a global BC inventory EFs for BC and OC applicable for small combustion appliances are presented;

	Kerosene, residential	LPG*, residential	Natural gas, All	Heavy fuel oil, All
Ratio to	PM_1	PM_1	PM_1	PM_1
BC, %	13	13	6	8
OC, %	10	10	50	3

*Bond et al assumes the same EFs as for kerosene

A summary of EC and OC emission factors from the reviewed literature is given in the table below.

Reference	**Hildemann et al., 1991**	**Muhlbaier, 1981**	**Battye and Boyer**	**Reff et al., 2009**	**Bond et al, 2004**	**Bond et al, 2004**	**SPECIATE 4.3**
Source	residential	residential	residential	Residential	Residential	Residential	Residential
Technology		Furnaces and water heater					oil boiler
Fuel	natural gas	Natural gas	natural gas	natural gas	LPG	Kerosene	distillate oil
Ratio to	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	**PM_1*****	**PM_1*****	$PM_{2.5}$
BC, %	6.7	4	6.7	6.7	**13**	**13**	3.898
OC, %	84.9*	8		49.0**	**10**	**10**	1.765
Note			high estimate = 15				EFs not found in the reference (Hays et al, 2008)

*Also refered in Chow et al., 2011

**Down-scaled values from Hildemann et al

*** Bond et al, 2004 reference mention that PM_1 make up 100 % of TSP

Hildemann et al, 1991, Reff et al. 2009 and Muhlbaier, 1981 are assumed to be the best sources for BC and OC EFs for residential appliances. The remaining references seem to use the EFs by Hildemann et al. An average of the EFs from Hildemann et al and Muhlbaier are **proposed for residential natural gas combustion** (for OC an average of Muhlbaier and Reff et al are proposed as the EF_{OC} in Reff et al are a scaled value based on Hildemann et al.).

The most appropriate reference to emission factors for LPG and kerosene combustion in residential stoves are Bond et al, 2004. For liquid fuel combustion in residential boilers only one emission factor has been observed, and the EF has not been found in the original reference (Hays et al, 2008) but only in SPECIATE 4.3. Still, this EF is proposed for application in the guidebook.

The following table resumes the proposed EFs for the guidebook:

	Tier	**Fuel**	**Sector**	**Technology**	**BC**	**OC**	**Reference**
Table 3-4	1	Natural gas	Residential		5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-5	1	Other liquid fuels	Residential		3.898	1.765	SPECIATE 4.3
Table 3-13	2	Gaseous fuels	Residential	Fireplaces	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981

Table 3-19	2	Natural gas	Residential	Stoves	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-20	2	Natural gas	Residential	Boilers < 50 kW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-21	2	Liquid fuels	Residential	Stoves	13	10	Bond et al, 2004
Table 3-22	2	Liquid fuels	Residential	Boilers < 50 kW	3.898	1.765	SPECIATE 4.3

Other small combustion plants

Other small combustion plants refer to plants typically in the commercial/institutional sector but the EFs are generally applicable to plants smaller than 50 MW. The chapter contains tier 1 EFs for the main fuel groups and tier 2 EFs for different technologies for coal, wood, natural gas and oil. The list of GB 2009 EF tables is presented in the table below.

List of EF tables for non-residential combustion in the GB chapter on small combustion.

	Tier	Fuel	Sector	Technology
Table 3-7	1	Coal	Non-residential	
Table 3-8	1	Gaseous fuels	Non-residential	
Table 3-9	1	Liquid fuels	Non-residential	
Table 3-10	1	Biomass	Non-residential	
Table 3-27	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-28	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-29	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-30	2	Coal	Non-residential	Automatic boilers < 1MW
Table 3-31	2	Wood	Non-residential	Manual boilers < 1 MW
Table 3-32	2	Wood	Non-residential	Automatic boilers < 1MW
Table 3-33	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-34	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-35	2	Natural gas	Non-residential	Gas turbines
Table 3-36	2	Gas oil	Non-residential	Gas turbines
Table 3-37	2	Gaseous fuels	Non-residential	Gas engines
Table 3-38	2	Gas oil	Non-residential	Gas engines

Biomass combustion

Three emission factor tables are relevant for biomass combustion in non-residential plants.

The $PM_{2.5}$ emission factor for non-residential combustion of biomass is 140 g/GJ. The BC fraction for advanced/ecolabelled boilers will be applied.

The $PM_{2.5}$ emission factor for non-residential manual boilers combusting wood is 140 g/GJ. For automatic boilers the emission factor is 33 g/GJ. For manual boilers the BC fraction for advanced/ecolabelled residential stoves and boilers will be applied. For automatic boilers the BC fraction for residential pellet boilers will be applied.

	Tier	Fuel	Sector	Technology	$PM_{2.5}$ [g/GJ]	BC fraction	BC [g/GJ]	Kupiainen & Klimont (2007)
Table 3-10	1	Biomass	Non-residential		140	28 %	39	-
Table 3-31	2	Wood	Non-residential	Manual boilers < 1 MW	140	28 %	39	35
Table 3-32	2	Wood	Non-residential	Automatic boilers < 1MW	33	15 %	5	-

Solid fuel combustion

There are five EF tables in the 2009 GB for solid fuels in small-scale non-residential plants. One of the EF tables is for tier 1, while the remaining four tables are tier 2 EF tables for boilers.

	Tier	Fuel	Sector	Technology
Table 3-7	1	Coal	Non-residential	
Table 3-27	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-28	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-29	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-30	2	Coal	Non-residential	Automatic boilers < 1MW

It is not clear from the 2009 GB, what is the distinction between EF table 3-27 and either table 3-29 or 3-30. Table 3-27 should presumably be the same as either 3-29 or 3-30.

It has not been possible to find in the literature detailed EC (or BC) measurements on this level of detail regarding the combustion technology. Therefore, the same BC share is used for small boilers (< 1 MW) as the one for domestic boilers, while medium sized boilers are assumed to have the same share as large boilers (see chapter 1A1).

Other fuel combustion

The 2009 guidebook includes eight tables for non-residential combustion of gaseous and liquid fuels. Two of the tables cover Tier 1 for gaseous fuels and liquid fuels, respectively. The tier 2 tables cover natural gas combustion in boilers 50kW-1MW and 1MW-50MW, natural gas and liquid fuel combustion in turbines and in engines.

A literature study has been carried out and a short description of the most important references is given in the following text;

Mugica et al, 2008: Include emission factors for a smaller industrial LP gas steam boiler (1 m^3 capacity);

EC = 5.353 % of $PM_{2.5}$ (± 0.35)
OC = 71.32 % of $PM_{2.5}$ (± 5.04)

England et al, 2007: Present data from eight gas-fired units, here among a dual-fuel institutional boiler and a diesel powered electricity generator. The profile presented by England et al for gas-fired boilers include EFs for BC and OC;

BC = 13 %
OC = 61 %

Bond et al, 2004: together with a global BC inventory EFs for BC and OC applicable for small combustion appliances are presented;

	Kerosene, residential	LPG*, residential	Natural gas, All	Heavy fuel oil, All
Ratio to	PM_1	PM_1	PM_1	PM_1
BC, %	13	13	6	8
OC, %	10	10	50	3

*Bond et al assumes the same EFs as for kerosene

Mazzera et al, 2001: Measurements from McMurdo station, Antarctica, for e.g. diesel-fueled heating appliances for space heating are used as basis for the presented EFs for EC and OC;

	Diesel, non-residential	Diesel, non-residential Recalculated*
Ratio to	PM_{10}	$PM_{2.5}$
BC, %	4.4916; 7.3929	5.85; 9.63
OC, %	54.3207; 72.0403	70.78; 93.87

*recalculated according to the current size distribution for PM in the guidebook (TSP = 27.5 g/GJ, PM_{10} = 21.5 g/GJ, $PM_{2.5}$ = 16.5 g/GJ)

Battye et al, 2002: It is not clear which sources the EFs are based on, but they are included here as they refer to combustion in commercial appliances;

	Petroleum, commercial	Natural gas commercial
Ratio to	$PM_{2.5}$	$PM_{2.5}$
BC, %	7.4	6.7

Cooper et al, 1987: Presents a number of PM species profiles for combustion. The profile for oil boiler, Cubatao, T<15 are assumed applicable for small non-residential appliances;

BC = 8.69 % of $PM_{2.5}$
OC = 8.96 % of $PM_{2.5}$

A summary of EC and OC emission factors from the reviewed literature is given in the tables below.

Gaseous fuels

Reference	Battye and Boyer	Bond et al, 2004	England et al, 2007
Source	commercial	All	All
Technology			Boiler
Fuel	natural gas	natural gas	Gaseous fuels
Ratio to	$PM_{2.5}$	PM_1*	PM_{10}
BC, %	6.7	6	13
OC, %		50	61
Note	high estimate = 15		

* Bond et al, 2004 reference mention that PM_1 make up 100 % of TSP

Liquid fuels

Reference	SPECIATE 4.3	Battye and Boyer	Mugica et al, 2008	Cooper et al, 1987	Bond et al, 2004	Mazzera et al, 2001	Mazzera et al, 2001
Source	Commercial and institutional	Commercial			All	Non-residential	Non-residential
Technology	boilers		boiler	boiler		(Air heating)	Steam-heating boiler
Fuel	residual oil	petroleum	LPG	Oil	Heavy fuel oil	Diesel	Diesel
Ratio to	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_1*	$PM_{2.5}$**	$PM_{2.5}$**
BC, %	2.42	7.4	5.353	8.69	8	5.85**	9.63**
OC, %	7.8		71.32	8.96	3	70.78**	93.87**
Note	Average of 8 samples from schools, hospitals, apartments, and industrial boilers EFs not found in the reference (Watson, 1979)	high estimate = 13	Smaller industrial boiler	included in SPECIATE (13504*)	From SPECIATE 3.1		

* Bond et al, 2004 reference mention that PM_1 make up 100 % of TSP

** Recalculated shares according to the current size distribution in the guidebook

The guidebook only includes Tier 1 emission factors for liquid fuel combustion in small appliances. None of the seven BC emission factors stand out as more applicable than the others. Therefore it is proposed to apply the average of the seven EF values to the guidebook. The OC emission factors show more variation than the BC emissions factors and further investigation might be useful to find the most appropriate emission factor. Here the average of the six EFs is given with the corresponding BC EF.

The following EFs have been included for combustion of liquid and gaseous fuels in small appliances. For combustion in non-residential turbines and engines EFs proposed for turbines and engines in sector 1A1 have been applied:

	Tier	Fuel	Sector	Technology	BC	OC	Reference
Table 3-8	1	Gaseous fuels	Non-residential		5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-9	1	Liquid fuels	Non-residential		6	36	See text
Table 3-33	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-34	2	Natural gas	Non-residential	Boiler 1 MW to 50 MW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-35	2	Natural gas	Non-residential	Gas turbines	2.5		*
Table 3-36	2	Gas oil	Non-residential	Gas turbines	2.5		*
Table 3-37	2	Gaseous fuels	Non-residential	Gas engines	2.5		*
Table 3-38	2	Gas oil	Non-residential	Gas engines	2.5		*

* Average of EFs from England et al. (2004), Wien et al. (2004) and US EPA (2011). For further description, please refer to "Discussion paper – BC methodologies for Energy Industries (1A1)".

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