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	Commercial/institutional plants
	020103	Commercial/institutional — Combustion plants < 50 MW
	020104	Stationary gas turbines
	020105	Stationary engines
	020106	Other stationary equipment
	020200	Residential plants
	020202	Residential — Combustion plants < 50 MW
	020203	Stationary gas turbines
	020204	Stationary engines
	020205	Residential — Other stationary equipment (Stoves, fireplaces, cooking)
	020300	Plants in agriculture, forestry and aquaculture
	020302	Combustion plants < 50 MW
	020303	Stationary gas turbines
	020304	Stationary engines
ISIC		
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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.i — Commercial/institutional;
- 1.A.4.b.i — Residential;
- 1.A.4.c.i — Agriculture/forestry; and
- 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}	$PM_{2.5}$	Black Carbon (BC)	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	X	
Residential plants	X	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	X	

2 Description of sources

2.1 Process description

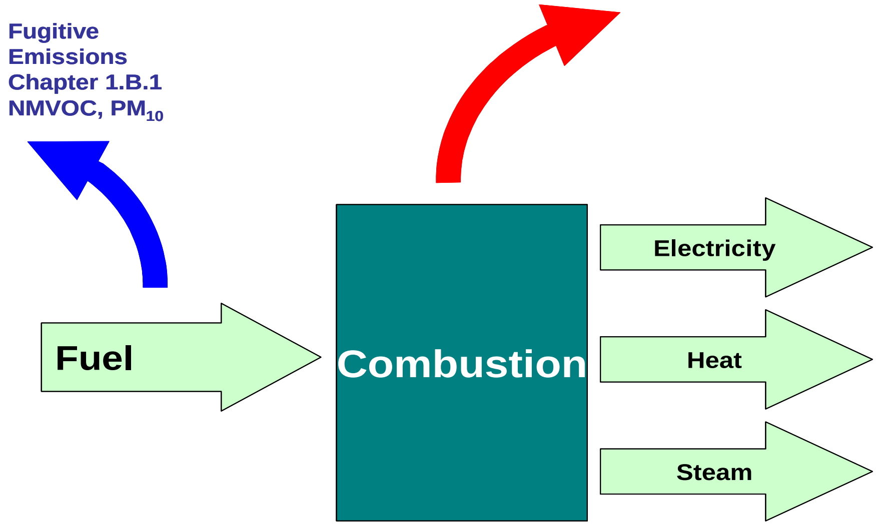
The small combustion installations included in this chapter are mainly intended for heating and provision of hot water in residential and commercial/institutional sectors. Secondary activities extend to the use of appliances within residential and commercial sectors for cooking. In the agricultural sector 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, space heaters (> 50 kW),
    - smaller-scale combined heat and power generation (CHP).

The disaggregation in the emission factor tables for non-residential applications includes size classes for technologies which potentially have appliances with capacities of >50KWth but less than 1MWth, and greater than 1MWth and less than 50MWth. 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)

General

Small combustion appliances are used to provide thermal energy for heating and cooking. 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 fuel size varying from a few mm to 300 mm. More detailed descriptions of techniques can be found in Kubica, et al., (2004). It can be helpful to consider residential combustion equipment in terms of appliances (manufactured products) and more basic equipment such as 'traditional' solid fuel fireplaces.

- Basic equipment – traditional solid fuel fireplaces, chimeneas, barbecues: such equipment is distinguished by being 'open' and consequently have no or very limited air controls. In addition, due to relatively low replacement rates (of buildings and equipment), solid fuel open fireplaces can be a significant part of residential heating stock. Although there may be oil and gas fired devices for which a 'basic equipment' label might be applicable, it is considered more appropriate to treat these as appliances.
- Appliances – providing a range of functions including room heaters (stoves, inset appliances and slow heat release stoves), cookers, central heating boilers, water heaters with a wide range of performance and emission characteristics depending on fuel, age, technology and mode of use. At one extreme, older stoves and open inset appliances may have very limited controls and provide only modest improvement in efficiency and emission performance compared to basic equipment. However, modern wood log stoves and automatic appliances provide better management of the combustion process with improvement in emissions and efficiency. Similarly, modern gas and oil-fired appliances offer improved combustion management and associated emission benefits.

Within Europe, there is a range of regulatory instruments in place which provide a regulatory framework for gas appliances, construction products (solid fuel and liquid fuel appliances), boiler efficiency (gas and liquid fuel appliances) and also for ecodesign of energy-related products. These instruments have led to development of a range of appliance Standards for solid, gaseous and, to an extent, liquid fuel small combustion appliances

The following harmonised EN Standards cover solid fuel heating appliances:

EN Standard	Standard Description	Scope
EN 13229	Inset appliances including open fires fired by solid fuels – requirements and test methods	Manually-stoked open freestanding roomheaters (stoves) and, open and closed inset roomheaters which are designed to be mounted within a fireplace recess or integrated into a building. Also includes roomheaters with boilers.
EN 13240	Roomheaters fired by solid fuels – requirements and test methods	Manually-stoked closed freestanding roomheaters (stoves). Also includes roomheaters with boilers.
EN 14785	Residential space heating appliances fired by wood pellets – requirements and test methods	Mechanically-stoked closed freestanding roomheaters (stoves) or closed inset roomheaters. Also includes roomheaters with boilers.
EN 15250	Slow heat release appliances fired by solid fuels – requirements and test methods	Manually-stoked closed freestanding roomheaters (stoves) with thermal storage capacity.
EN 15821	Multi-firing sauna stoves fired by natural wood logs – requirements and test methods	Manually-stoked sauna stoves.
EN 12815	Residential cookers fired by solid fuels – requirements and test methods	Manually-stoked cookers (also providing space heating and includes cookers with boilers.
EN 12809	Residential independent boilers fired by solid fuels – Nominal heat output up to 50 kW - requirements and test methods	Manual and mechanically-stoked solid fuel boilers (also providing space-heating).
EN303-5	Heating boilers - Part 5 : heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW – Terminology, requirements, testing and marking	Manual and mechanically-stoked solid fuel boilers.

Basic equipment

Solid fuel open fireplaces are the simplest combustion devices, and are often used or retained as supplemental heating appliances primarily for aesthetic reasons in residential dwellings. Many older buildings retain solid fuel open fireplaces and open fireplaces are commonly used in areas of fuel or energy poverty.

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 the fireplace is not being used. The heat energy is transferred to the dwelling mainly by radiation.

Open fireplaces are characterised by high, non-adjustable excess of the combustion air, which influences their efficiency and emissions. In open masonry fireplaces 80-90% of heat released during combustion is lost through the chimney (Artjushenko, 1985). In cases where combustion is poor, where the outside air is cold, or where the fire is allowed to smoulder (thus drawing outside air into a residence without producing appreciable radiant heat energy), a net heat loss may occur in a residence using a fireplace.

Some fireplaces are equipped with back water jackets (Crowther, 1997). These can give thermal outputs of up to 12KW$_{th}$ and thus can provide central heating from low cost living-room equipment.

Open fireplaces are usually of masonry type and have very low efficiency while having significant emissions of total suspended particulates (TSP), Carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and polycyclic aromatic hydrocarbons (PAH) resulting from the incomplete combustion of the fuels.

Fuels for solid fuel open fireplaces include wood (logs), coal, anthracite and manufactured solid fuels. An open fire for wood logs may include a fire basket or grate to retain the fuel but commonly the fuel will be burnt directly on the hearth. A mineral fuel appliance will typically include a grate to support the fire bed above an ash container and allow an air supply to the underside of the fire bed.

Chimeneas and barbecues are outdoor appliances which burn wood and charcoal solid fuels. They are little different from an open fire in operation. Other types of outdoor solid fuel appliances include wood-fired pizza and other ovens which also tend to have very limited controls.

The emission factors associated with the equipment detailed here can be found in Table 3-12 for solid fuels excluding biomass and in Table 3-39 for wood fuels in open fireplaces.

Appliances

Fireplace appliances (insert and free standing)

Solid fuel fireplaces are manually-fired fixed bed combustion appliances. They differ from the open fire places detailed in above (under "Basic equipment") in that they are defined appliances, whereas open fire places typically come as part of the overall construction of the property. Insert fireplaces fitted within a chimney aperture are appliances covered under EN standard EN 13229. The user intermittently adds solid fuels to the fire by hand. They can be distinguished into the following.

Partly-closed fireplaces

Equipped with louvers and glass doors to reduce the intake of combustion air. Distribution of the combustion air is not especially arranged or regulated and for that reason combustion conditions are not improved significantly compared with open fire places detailed above (under "Basic equipment"). Some masonry fireplaces are designed or retrofitted in that way in order to improve their overall efficiency.

The technologies described in this sub-section are covered by emission factors found in Table 3-12 for solid fuels excluding biomass and Table 3-39 for wood fuelled fireplaces.

Closed fireplaces

These fireplaces are equipped with front doors and have air flow control systems, which includes the distribution of combustion air to primary routes (grate) and secondary routes (panels), as well as a system to discharge the exhaust gases. In closed fireplaces combustion temperatures can increase up to 400^{o}C or more, and the retention time of the gases in the combustion zone is longer compared with open fireplaces. 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 %, but can be as high as 80% depending on specific appliance.

Because the combustion mechanics of closed fireplaces are more efficient than open and partly closed fireplaces, they more closely resemble the emission profiles of stoves. It is therefore more appropriate to use the emission factors listed in Table 3-14 for solid fuels other than wood, and Table 3-40 for wood-based fuels used in closed fireplaces.

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. The technology described here are covered by emission factors found in Table 3-13 for gaseous fuelled fireplaces.

Stoves

Stoves are enclosed appliances in which hand supplied fuels are combusted to provide useful heat, which is transmitted to the surroundings by either radiation or convection. They can vary widely due to fuel type, application, design and construction materials, and also combustion process organisation. Due to the fuel properties they can be divided into the following subgroups:

- Solid fuels;
- Liquid fuels; and
- Gas fuels.

The stoves utilizing solid fuels are usually used for space heating of 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 only.

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 (air flow under-fire, down-burning combustion) and downdraught (air flow from over-fire, up-burning combustion).

Downburning stoves (which make up the majority of older stoves) have higher emissions compared to upburning stoves. This is because the devolatised products of fuels are less completely combusted in low temperatures present in the reaction zone (between 400 – 600ºC). On the contrary, in upburning techniques for solid fuels combustion the combustible gases are passing through a burning fuel bed with temperatures in excess of 600ºC and thus are more completely oxidised. Variations on the down/up draught process include “S-draught” and “Cross-draught” processes; these variants allow a greater residence time of gases within the combustion zone so will also typically have lower pollutant emissions than the downburning stoves. 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.

Solid fuel stoves are divided into two main subgroups for mode of heat transfer, radiating stoves and convection stoves which work through heat storing or heat accumulation. Radiating stoves are usually made as prefabricated iron or steel appliances; some of them provide water heating, indirect heating (boilers) and some are used as cooking stoves. Convection stoves may include masonry stoves, which are usually assembled on site with bricks, stone or ceramic materials. Under the EN standards stoves are covered by EN 13240 for conventional room heating typically covered by radiating stoves and EN 15250 for slow heat release appliances typically covered by convection appliances. Additionally, the standard EN 14785 applies to residential space heating stoves which make use of wood pellet fuels.

Conventional, radiating stoves

Radiating stoves can be divided into coal and wood-based fuel types. For coal fired stoves the appliance usually functions around the downburning methodology. For wood fired stoves both downburning and upburning methods are used. These appliances typically 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.

The emission factors associated with this type of technology are covered within Table 3-14 for coal-based fuel types and Table 3-40 for wood-based fuel types.

Masonry stoves (heat accumulating- convection methodology)

The construction of masonry stoves varies depending on country and region, but will be based on bricks, stones, or a combination of both together with fireproof materials such as ceramic (e.g. volcanic rocks as seen in Finnish stoves for example). Sometimes these devices can come as prefabricated units. Because of the large thermal capacity of masonry materials they keep a room warm for many hours (8-12) or days (1-2) after the fire has burnt out, that is why they are called heat accumulating or heat storing stoves. Their combustion chamber can be equipped with horizontal strips or inclined, perpendicular baffles made of steel or fireproof material, which improve combustion quality and efficiency. Because of the increased residence time of fuels in the combustion zone there is a decrease in pollutant emissions compared to conventional radiating stoves. Their combustion efficiency ranges from 60 to 80 % and their autonomy from 8 to 12 hours (CITEPA, 2003). These stoves can be further divided into two sub-categories:

- Room heating stoves; some more advanced appliances employ counter flow systems for heat transfer and/or down draught combustion principles
- Heat accumulating cooking stoves can be divided further again into simple residential cooking and boiler cooking stoves. The former are equipped with a combustion chamber and hot plate zones for food preparation and room heating; the latter are simultaneously used as kitchen stoves, room heating and preparation of sanitary hot water (e.g. Russian Stoves).

The emission factors associated with this type of technology are covered within Table 3-14 for coal-based fuel types and Table 3-40 for wood based fuel types.

The conventional radiating stoves detailed are characterised by high emissions. The further development of their design has resulted in new more advanced technologies which have better efficiencies and lower pollutant emission releases. The technologies detailed below represent the more advanced technologies which extend beyond the conventional radiating stoves that may be in use.

High-efficiency conventional stoves (including catalytic combuster stoves)

These appliances essentially cover 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.

As a sub-category of high-efficiency stoves, it is possible to equip stoves with a catalytic converter in order to reduce emissions caused by incomplete combustion, this is particularly the case for wood fuel-based stoves. The catalytic converter (a cellular or honeycomb, ceramic substrate monolith covered with a very thin layer of platinum, rhodium, or combination of these) is usually placed inside the flue gas channel beyond the main combustion chamber. The catalyst efficiency of emission reduction depends on catalyst material, its construction – active surface area, and the conditions of flue gas flow inside the converter. Due to more complete oxidation of the fuels, energy efficiency also increases. However, the catalyst will need frequent cleaning in order to maintain performance. Catalytic combustors are not common for coal and wood stoves.

The emission factors which cover this type of appliance can be found in Table 3-41 covering the combustion of wood-based fuels in high-efficiency stoves.

Advanced combustion stoves (including ecolabelling for wood 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.

Ecolabelling schemes for wood and biofuel-based stoves are intended to earmark a set standard for improved efficiency and lower emissions, with a number of schemes in place such as Nordic swan (in Norway), Blue Angel (in Germany), and Flammerverte (in France). These schemes all set in place criteria for the ecolabelling with performances better than Ecodesign requirements.

The emission factors which cover this type of appliance can be found in Table 3-19 covering the combustion of solid fuels other than biomass in advanced boilers, and Table 3-42 for ecolabelled stoves burning wood based fuels.

Pellet stoves

This is a type of advanced stove using an automatic feed for 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.

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.

The emission factors which cover this type of appliance can be found in Table 3-17 which covers the combustion of liquid/gas fuels in stoves.

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. Boilers that meet these descriptions are covered by the EN standards EN12809 for residential independent boilers with capacity up to 50KWth and EN303-5 for manually and mechanically stoked boilers with capacity up to 500KWth.

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: over-fire boiler (overfeed burning — over-fire and under-fire — down-burning) and under-fire 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. Over-fire burning in fixed bed is characterized by the relative low temperature (400 – 800°C) of the volatile matter in the oxidizing zone, by a local lack of oxygen as a result of poor mixing (Kubica, 2003). 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 (such as PM, CO, NMVOC and PAH) resulting from incomplete combustion of fuel may be very high particularly if they are operated at low load, this is often at the end or beginning of the heating seasons such as spring and autumn.

The emission factors which cover this type of appliance can be found in Table 3-15 which covers the combustion of coal in conventional boilers and Table 3-43 which covers the combustion of wood in conventional boilers.

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.

Over-fire and under-fire boilers use all types of solid fuels except pellets, wood chips and fine grain coal. For both techniques, if an upgraded coal fuel such as briquettes replaces raw coal the emission in particular of the products of incomplete combustion are reduced by about 30% and even by as much as 90% (except for CO) for smokeless fuel and coke (Karcz et al, 1996, Kubica et al 1994 and Kubica et al 1997).

The emission factors which cover this type of appliance can be found in Table 3-15 which covers the combustion of coal in conventional boilers and Table 3-43 which covers the combustion of wood in conventional boilers.

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%). Some of these boiler types use pre-heated combustion air, which is usually cool outdoor air. The emissions of pollutants due to incomplete combustion processes are decreased in comparison with conventional boilers.

The emission factors which cover this type of appliance can be found in Table 3-19 which covers the combustion of coal in advanced stoves, but will also be expected to be representative for advanced boilers.

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. Drowndraught wood boilers use a combination air fan and flue gas fan. The secondary combustion air is partly introduced in the grate and partly the secondary chamber. 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. Some of these boiler types employ lambda control probes to measure flue gas oxygen concentration and have precise combustion air control as well as staged-air combustion. Owing to the optimised combustion process, emissions due to incomplete combustion are low.

The emission factors which cover this type of appliance can be found in Table 3-42 which covers the combustion of wood in advanced stoves and boilers including ecolabelled appliances.

Stoker coal burners

For coal and wood, techniques referred to sometimes as 'clean coal/biomass combustion' are used. In this appliance the underfeed denotes that raw fuel is fed from below the plane of fuel ignition. Before the fuel reaches the plane of ignition the moisture is evaporated and some of the volatile matter is evolved. These gases then pass through the burning fuel bed where temperature is about 1100°C. The organic matter formed within the devolatization process is almost completely oxidised. 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. Primary air is supplied through the retort grate. The stoker boiler is characterized by higher efficiency, usually above 80 %. The advantage of stoker boilers 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.

The emission factors which cover this type of appliance can be found in Table 3-19 which covers the combustion of coal in advanced stoves, and is also expected to be representative for advanced boilers.

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 (beneath the grate) and secondary (into the gas oxidation zone) air supplies. The boilers are equipped with a smaller pellet storage, which is fuelled manually or by an automatic system from a larger chamber storage. The operation of wood pellet boilers is similar to the function of wood pellet stoves; the pellets are introduced by screw into the burner. The burners can have different design such as underfeed burners, horizontally fed burners and overfed burners. These boilers are characterised by a high efficiency (usually above 80 %) and their emissions are comparable to those of liquid fuel boilers.

The emission factors which cover this type of appliance can be found in Table 3-44 which covers the combustion of wood pellets in modern wood pellet stoves and boilers.

Liquid/gas-fuelled small boilers

Gas/liquid boilers will typically have two functions, being used for hot water preparation and for heat generation for the central heating systems. 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 C) with open combustion chamber are usually applied in small combustion installations, which operate in the residential sector. These devices can be made of cast iron or steel. In respect of emissions, a principal distinction can be made between burners with and without a pre-mixing of fuel and combustion air: pre-mixing burners are characterized by homogenous short flames and a high conversion rate of fuel bounded nitrogen; non-premixing burners are characterized by heterogenous flames with under-stoichiometric reaction zones and a lower conversion rate of fuel bounded nitrogen. This latter type is characteristic for old combustion installations below 50KWth. For this reason emissions of NO_X from non-pre-mixing appliances have lower NO_x emissions in comparison to new designs, which use burners with air pre-mixing systems, which gives a greater oxidation and breaking of bonds to increase NO_X emissions. 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 loses, with flue gases discharged at temperatures above 200ºC, and the inlet/return water temperature usually above 60ºC. Due to the 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.

The emission factors which cover this type of appliance can be found in Table 3-16 which covers the combustion of natural gas in boilers and Table 3-18 which covers the combustion of gas-oil in boilers.

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 %. Therefore, less flue is used and emissions are lower. The inlet/return water temperature is below 55ºC to ensure the moisture in the flue gas will condense, which aids the high efficiency. In this case a two-function option of boiler operation (combination of water heating and surroundings heating) is preferred as this lowers the average inlet temperature. Condensation requires use of a corrosion-proof stainless-steel heat exchanger. The condensate, which contains sulphuric and nitric acids, is drained off into wastewater systems where it is diluted sufficiently so as not to cause corrosion. The efficiency can be furthermore increased due to modification of design enabling preheating of combustion air with flue gases. Condensing boilers are mainly used by gaseous fuels, but oil-firing boilers are also available.

The emission factors which cover this type of appliance can be found in Table 3-16 which covers the combustion of natural gas in boilers and Table 3-18 which covers the combustion of gas-oil in boilers.

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. These appliances are also required to meet the standards set down within EN 12815 which covers residential cookers using solid fuels. Their autonomy is a few hours. Wood pellet oven appliances are a recent development. 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. Pellet ovens offer fully automatic operation and should provide similar emission levels to pellet stoves.

Outdoor pizza ovens and other oven devices are used in some countries. Solid fuel barbecues (outdoor cooking including ‘disposable’ single use barbecue packs) are used seasonally.

The emission factors which cover this type of appliance can be found in Table 3-14 which covers the combustion of solid fuels other than biomass within stoves, which can also be used for cooking. Table 3-40 covers emission factors for wood fired stoves, which can also be used for cooking.

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). Emission factors for this kind of technology are not currently well defined in the guidebook. The best suited emission factors to use will be provided within Table 3-16 for gas fired residential boilers.

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 chimenea devices are also relevant.

Combustion appliances are used to heat stones used in saunas in Scandinavia (EN 15821 covers sauna stoves).

The emission factors which cover this type of appliance can be found in Table 3-13 which covers the combustion of natural gas within fire places, but can also be used to cover gas fired outdoor heating devices.

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

Overview

A general allocation of non-residential technologies and sizes is provided in the following table. For emission inventory purposes it is important to understand that the broad function/technology descriptions cover a range of combustion technologies and abatement technologies (in particular for solid fuels) with wide ranges in associated emission. The fuel descriptions also cover a wide range of fuel quality/properties. Note that where activity data is available (for example EU ETS data for energy installations >20MWth) it may be possible to disaggregate activity data to other size ranges.

Fuels	<1MW$_{th}$	>1MW$_{th}$	Function/ technology	Coverage	Comments
Hard coal and brown coal	Y	Y	Boilers	Firetube boilers, smallest boilers likely use a fixed grate with underfeed or overfeed stoking, boilers will often have moving grate stokers of various types	Hot water boilers >1MWth for district or community heating
	y	Y	Steam boiler	Firetube and watertube boilers, moving grate, fluid bed or pulverised fuel stoking	<1 MWth steam boilers likely to be rare.
(Solid) biomass	Y	-	Hot water boiler	Firetube boilers, smallest boilers likely fixed grate with underfeed or overfeed toking, boilers will often have moving grate stokers of various types	Machines >1MWth for district or community heating. Fuels either wood chip or wood pellet but a range of residues also burned.
	-	Y	Steam boiler	Firetube and watertube boilers, moving grate, fluid bed or pulverised fuel stoking	Fuels either wood chip or wood pellet but a range of residues also burned.
	Y	N	Ovens	Typically pizza or bread ovens, fairly simple devices	Restaurant ovens typically burn wood logs or wood briquettes
	Y	N	Barbecue/grill	Charcoal grills/barbecues, fairly simple devices	Charcoal fuel

Fuels	<1MW$_{th}$	>1MW$_{th}$	Function/ technology	Coverage	Comments
Liquid fuel	Y	-	Hot water boiler	Firetube boilers with one of more oil burners	Typically burn gas oil. Some condensing oil-fired boilers on market but typically non-condensing
	Y	Y	Steam boiler	Firetube and watertube boilers with one of more oil burners	Larger machines can burn heavy or medium fuel oil.
	Y	N	Air (space) heater	Including portable/movable units for spaceheating.	Smaller portable units may burn kerosene fuels.
	Y	Y	Reciprocating engine	Typically providing electricity generation but also CHP.	Gas oil the main fuel. Larger units may burn higher sulphur fuels.
	-	Y	Gas turbine	Typically providing electricity generation but also fluid pumping/compression	Gas oil the main fuel. Larger units may burn higher sulphur liquid fuels. There are gas turbines smaller than 1 MWth but are comparatively rare.
Gaseous fuels	Y	-	Hot water boiler	Firetube boilers with one of more oil burners	
	-	Y	Steam boiler	Firetube (watertube on larger machines) boilers with one of more oil burners	
	Y	-	Air (space) heater	Including portable/movable units for spaceheating.	Smaller portable units may burn bottled gas.
	Y	Y	Reciprocating engine	Typically providing CHP but also electricity generation and gas compression/fluidpumping.	
	-	Y	Gas turbine	Typically providing CHP but also electricity generation and gas compression/fluidpumping.	There are gas turbines smaller than 1 MWth but are comparatively rare.
	Y	-	Ovens (Cooking)	Covers very small hotel/restaurant kitchens to larger commercial bakeries	
	Y	N	Hobs (Cooking)	Typically hotel/restaurant other kitchens	
	Y	Y	Drying/heating furnaces	Industrial (re)heat furnaces, curing furnaces, drying	Some industrial activity and emissions may be covered under

Fuels	<1MW$_{th}$	>1MW$_{th}$	Function/ technology	Coverage	Comments
					industry reporting codes

Boilers with indicative capacity up to 50 MW$_{th}$

Boilers of such a capacity are used for heating in multi-dwelling residential buildings, office, school, hospital and apartment blocks and are commonly found small sources in commercial and institutional sector as well as in agriculture. The largest units are likely to be associated with other NFR sectors but are included. In this guidance, boilers have been distinguished into two groups (<1MWth and 1-50MWth) which provides a convenient but arbitrary separation between smaller 'products' and larger 'bespoke' equipment.

As noted below, 1MWth is a realistic threshold for manual stoking (although a manually—stoked modern non-residential boilers would be extremely unusual). In addition, typically, boilers <1MWth provide hot water and larger boilers provide steam. However, this should not be considered a definitive boundary; there are many hot water boilers >1MWth (for example in community or district heating plant) and small steam boilers are not uncommon in industry. The following technology descriptions provide some indication of the range of technologies that are applied.

Solid fuel boilers

Fixed and moving grate combustion technologies are commonly used for combustion of solid fuels in this capacity range. This is a well-established technology, and a great variety of fixed-grate and moving grate boilers are in use. Fixed grate technology is associated with the <1MWth size range.

In addition to fixed grate combustion, fluidised bed combustion boilers are in use in this capacity range, frequently for biomass combustion. Pulverised fuel or wood dust burners can also be present.

Installations can also be differentiated by stoking arrangement:

- manually fuelled; usually with a capacity lower than 1MWth;
- automatically fuelled; all sizes; and
- Some smaller boilers can be considered semi-automatic in that they have manually-fed hoppers (for coal fuels or wood pellets) or magazines (wood logs) however these are generally associated with single dwelling residential appliances (<50 kW) and the largest appliances are usually smaller than 150 kW output.
- As a standard approach to inventory compilation for Tier 2, the emission factors are presented thus:Table 3-20 and Table 3-21 provide data on combustion of coal fired boilers for <1MWth and >1MWth - <50MWth respectively.
- Table 3-45 and Table 3-46 provide data on combustion of wood fired boilers for 1-50 MWth and 50 kWth – 1 MWth, respectively.

As a further step to disaggregating the emission estimates a higher Tier of data is provided for the <1MWth appliances. This reflects the difference in emissions between manual feed and automatic feed boilers. For inventory compilation dependent on available activity data the standard emission factor tables should be used for basic Tier 2 inventory compilation. Where available activity data allows the advanced tables may be used for <1MWth, these additional emission factor tables are presented thus:

- Table 3-22 and Table 3-23 provide data on combustion of coal fired boilers for <1MWth disaggregated between manual feed and automatic feed respectively.
- Table 3-45 and Table 3-46 provide data on combustion of wood fired boilers for <1MWth disaggregated between manual feed and automatic feed respectively.

Manual feed boilers

Coal boilers

Manually fed boilers in this capacity range apply two combustion techniques, under-fire and upper-fire, similar to the residential boilers of lower capacity range.

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 tend to have better organisation of the combustion air compared with the ones used in single households.

Biomass/straw boilers

Manual stoking is usually associated with wood log boilers and 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 MW_{th}. They are popular in the agricultural regions due to their relatively low costs and simple maintenance.

Automatic feed boilers

Most modern 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.

Fixed grate combustion is commonly used in the smaller appliances but moving grate combustion is commonly adopted for larger machines. Fuel is fed to the grate using as spreader stokers, overfeed stokers, and underfeed stokers.

Coal of smaller granulation or fine wood (wood pellet, chips or sawdust/residues) is charged on a mechanical moving grate. The combustion temperatures are between 1 000 °C and 1 300 °C. General applications are aimed at production of hot water, and/or low-pressure steam for commercial and institutional users, in particular for 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 fuel is fed into the combustion chamber through a screw conveyor (augur) 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 including process residues and wastes.

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 can be classified according to burner type, 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 ≤ 100 °C, medium-temperature > 100 °C to ≤ 115 °C, high-temperature > 115 °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).

Emission factor tables covering the use of liquid fuels for commercial boilers are covered by Table 3-24 and Table 3-25, which detail the use of liquid fuels for <1MWth and >1MWth – 50MWth appliances respectively.

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 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.

Condensing boilers

Recover some of the latent heat of the water vapour in the flue gases to improve energy efficiency – commonly applied to small (<1MWth) gas-fired boilers but condensing technology has also been applied to small gas oil and wood pellet boilers.

Non-residential cooking

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 artisan bakeries and traditional wood-fired pizza ovens in restaurants. In addition, there is growing use of charcoal barbecues/grills by restaurants and catering/event hospitality organisations.

Emission factor tables for these sources are covered by Table 3-20 and Table 3-46 which detail emission factors for coal and wood, respectively, for the <1MWth sized appliances. Additionally, Table 3-22, and Table 3-23 (coal), Table 3-47 and Table 3-48 (wood) provide further disaggregation for <1MWth appliances between those that are manual feed and automatic feed respectively.

Cooking using gas

Gas-fired units are widely used in hotels, the commercial restaurants and non-commercial sectors (for example schools and hospitals). These comprise hobs (including heating rings for pots) and ovens.

The Ecodesign Lot 22 study (Mudgal et al, 2011) estimated annual natural gas use in various cooking uses as:

Cooking use	EU natural gas use, kWh per oven per year
Domestic oven	183.7

Restaurant ovens	11,887
Bakery convection ovens	61,402
Bakery rack ovens	78,345

Outdoor cooking for catering/event hospitality uses bottled gas (LPG).

Emission estimation for cooking with natural gas should make use of the emission factors presented within Table 3-26 which covers gas boilers <1MWth, but can be used for cooking with gas as a proxy.

Non-residential 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.

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 work spaces, 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.

Gas turbines

'Micro' turbines are available providing small scale generation (typically 15-500 kWe) and provide gas turbine technology in the <1MWth size range. The technology is attractive for cogeneration and applicable to natural gas, produced fuel gas, biogases and liquid fuels. However, emission data for the technology are limited – particularly for pollutants other than NO_X and CO. Consequently, Tier 2 factors for this technology <1MWth are not included in the guidebook. Manufacturers' information and scientific literature indicate that low-NO_X combustion technology can achieve NO_X emissions comparable to levels achieved on larger gas turbines.

Gas turbines can utilise a range of gaseous fuels, such as natural gas or in some instances, process gases or gasification products. Liquid fuels are also used, such as light distillates (e.g. naphtha, kerosene or gas oil) but, in general, use of liquid fuels is limited to specific applications or as a standby fuel. Gas turbines are aero-derivative designs (i.e. based on multiple shaft engines derived from aircraft engine types) or industrial heavy-duty gas turbines (based on single shaft designs). Gas turbines for electricity generation can be open (simple) cycle units but are often installed as a part of a combined cycle gas turbine (CCGT). In a CCGT installation, a heat recovery steam generator (HRSG) is used to recover waste heat from the combustion gases providing steam to power a steam turbine which drives an alternator providing more electricity. The net rated efficiency of a modern CCGT is in excess of 50 %. Gas turbines are often found in co-generation plant, the gas turbine directly coupled to an electricity generator and the energy from hot exhaust gases recovered in a suitable HRSG (boiler) or used directly (for example drying). Supplementary burners are commonly used to provide additional heat input to the exhaust gases. Integrated coal gasification combined cycle gas turbine (IGCC) plants use fuel gas derived from coal. Note that for IGCC plants, the only emission relevant unit considered here is the gas turbine. Gas turbines are also used for gas compression/fluid transfer.

Emission factor tables for gas turbines can be found in Table 3-28 and Table 3-29 which cover the use of natural gas and gas oil respectively.

Reciprocating engines

Stationary engines are spark-ignition engines and compression-ignition engines (2- and 4-stroke) with electrical outputs ranging from less than 100 kW to over 20 MW. Both types represent relevant emission sources. Such units are common as island generators (away from a supply grid), small combined heat and power CHP units, or for cogeneration and standby or emergency uses.

Engines can utilise a range of gaseous fuels, such as natural gas or in some instances, process gases or gasification products. Gas engines are typically spark-ignition engines. Liquid fuel types are more commonly compression ignition types. Emission factor tables for reciprocating engines can be found in Table 3-30 and Table 3-31 which cover the use of natural gas and gas oil respectively.

Cogeneration and 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' NO_X burner technology is available for gas combustion in larger appliances. In general, natural gas fuels have far lower potential for emission of sulphur and metal compounds than oils and solid fuels because natural gas contains lower quantities of such components – this also applies to NO_X emissions as natural gas does not contain significant quantities of compounds with bound nitrogen.

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. However, natural gas is a simpler fuel (principally methane with other low molecular weight hydrocarbons) and the potential for emission of complex organic compounds (PAH and PCDD/F) is limited compared to oils and solid fuels.

Note that the inventory methodologies for Greenhouse gas emissions (carbon dioxide, methane and nitrous oxide) are not included – refer to IPCC guidance (IPCC, 2006).

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).

As described above, small combustion activities can have a wide range of particulate emissions and, this emission may be partitioned between filterable and condensable fractions. The proportions are variable and determination of particulate fraction emissions is highly dependent on the measurement approach.

However, 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. A range of filterable PM measurement methods are applied around the world typically with filter temperatures of 70-160°C (the temperature is set by the test method). The condensable fraction can be determined directly by recovering condensed material from chilled impinger systems downstream of a filter – note that this is condensation without dilution and can require additional processing to remove sampling artefacts. Another approach for total PM includes dilution where sampled flue or exhaust gases are mixed with ambient air (either using a dilution tunnel or dilution sampling systems) and the filterable and condensable components are collected on a filter at lower temperatures (but depending on the method this can be 15-52°C). The use of dilution methods, however, may be limited due to practical constraints with weight and/or size of the equipment.

A wide range of PM measurement techniques have been applied for particulate measurements including type approval standards defined to address national emission regulations. Methods used in research projects can differ significantly from type approval methods. The methodologies applied can be split into dilution methods (including use of dilution tunnels or systems applying dilution after sampling) and direct sampling methods. The latter methods include conventional industrial stack emission test methods such EN13284-1 and ISO 9096 and national methods applied in (for example) Sweden and Germany for small and large-scale combustion plant.

The dilution methods (NS3058/9, BS3841, USEPA 5G, AS/NZS 4012/3) tend to be used on residential appliances to collect the filterable and condensable PM fractions which are associated with the relatively poor combustion conditions associated with solid fuel, batch-fed, manually-controlled appliances operating under natural draught.

USEPA Method 5H is designed to assess wood-burning stoves and provides a direct sampling method coupled with collection of the condensable fraction by chilling the sampled flue gases downstream of the filter.

There are key differences in the test protocols adopted for type approval of residential and other small appliances (multiple tests at single output, multiple tests at multiple outputs and single tests at multiple outputs). Other key differences include use of natural wood logs or a standard wood crib, constant or natural draught and ignition processes. None of the type approval methods assess emissions during ignition from cold.

The characteristics of the measurement methodologies, and hence PM collected, mean that it can be difficult to compare reported emission data. A comparative study (Nussbaumer et al., 2008/1) of the different sampling methods for small-scale biomass appliances 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 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).

The PM emission factors (for TSP, PM_{10} and $PM_{2.5}$) can represent the total primary PM emission, or the filterable PM fraction. The basis of the emission factor is described (see individual emission factor tables).

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. Furthermore, it should be noted that the BC percentages depend on whether condensables are taken into account in the $PM_{2.5}$ emission factor, since the BC or EC is only present in the solid (filterable) part and not in the gases that form particles upon cooling (the condensables).

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 NO_X is generally in the form of nitric oxide (NO) with a small proportion present as nitrogen dioxide (NO_2). Although emissions of NO_X 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.

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 NO_X), 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; and
- 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; and
- 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 in the ≤50 MW_{th} range, but are likely to be excessive for smaller facilities.
- FBC furnaces can incorporate lime injection into the combustion bed to capture SO_2

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 catalyst 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.

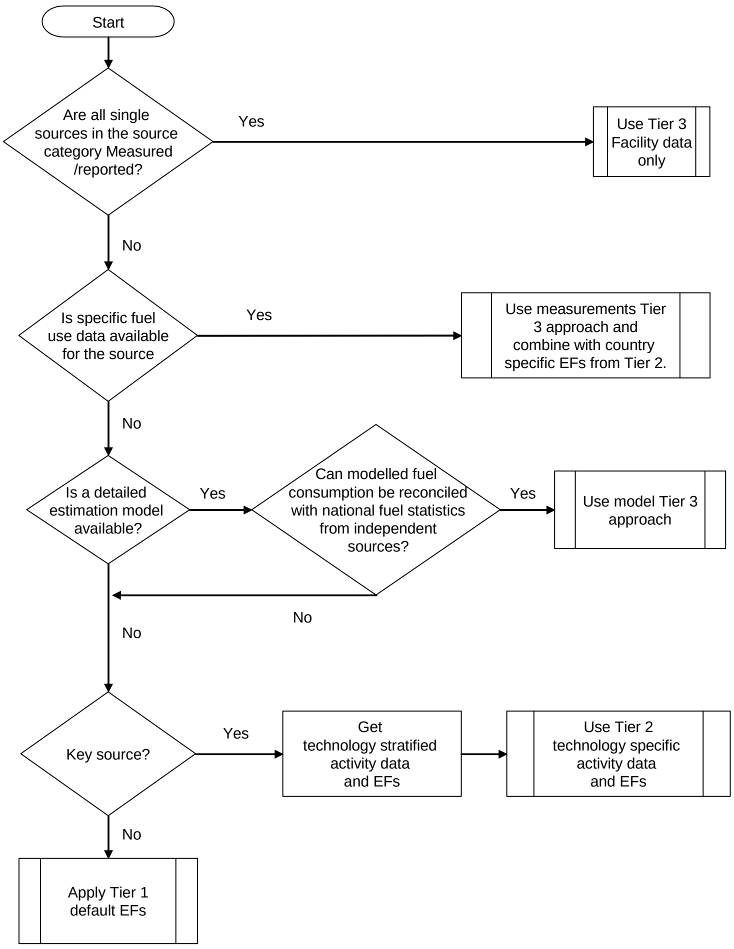
3 Methods

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 idea behind the decision tree is to use detailed information whenever it is available. If detailed information (e.g. in the form of measurements or modelling tools) is available, this should be used as much as possible.

If the source category is a key source, a Tier 2 or better method must be applied and detailed input data must be collected. Small combustion is likely to be a key source for multiple pollutants. 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.

Despite this source being a key source for multiple pollutants, many Parties apply Tier 1 approaches in the absence of the data and information needed for a Tier 2 approach. Especially for biomass this is an issue, since PM emissions from small combustion of solid biomass are the largest source of primary $PM_{2.5}$ emissions in Europe. To overcome this, a specific Tier 2 approach for solid biomass has been developed, which is accompanied by default information on how to split between technologies/appliances. This is provided to encourage each Party to report their emissions from small combustion of solid biomass using the Tier 2 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:

$$E_{pollutant} = AR_{fuelconsumption} \times EF_{pollutant} \tag{1}$$

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. This distinction is an economical one and is made following the split which is typically available in the energy statistics. For the Tier 1 approach, it is assumed that the residential plants are typically of a size < 50 kWth, while non-residential plants are typically between 50 kWth – 50 MWth. However, it should be noted that this is not always hold in practice. For the Tier 1 approach however, which is only to be applied for non-key sources, this simplification can be made.

Table 3-1 Summary of Tier 1 emission factor categories

Activity	Description
1.A.4.b.i Residential combustion	Small stationary combustion installations for heating and cooking in residential applications.
1.A.4.a.i, 1.A.4.c.i, 1.A.5.a Non-residential (institutional/commercial plants, plants in agriculture/forestry/aquaculture and other stationary plants (including military))	Small combustion installations applied in stationary institutional/commercial plants, stationary plants in agriculture/forestry/aquaculture and other stationary applications

The general Tier 1 fuel types are provided in Table 3-2. Different hard and brown coal fuels 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 also treated as one fuel type in the Tier 1 approach.

Where 'Guidebook 2006' is referenced in the tables, the emission 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, liquified natural gas, liquefied petroleum gas,
Liquid fuels	Residual fuel oil, refinery feedstock, petroleum coke, Orimulsion, bitumen, gas oil, kerosene, naphtha, shale oil
Biomass	Wood, wood pellets, charcoal, vegetable (agricultural) waste

Default Tier 1 emission factors are provided in Table 3-3 to Table 3-10. For PM, the footnotes below the table explain what part of the PM emission is contained in the emission factor (based on filterable component only, or total PM including the condensable component). For the fossil fuels, this is not always clear however from the references, as indicated in the footnotes. For biomass (wood), all emission factors in Tier 1 and Tier 2 are based on a total PM only approach.

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

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					
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	110	g/GJ	36	200	EMEP/EEA (2006) chapter B216
CO	4600	g/GJ	3000	7000	EMEP/EEA (2006) chapter B216
NMVOC	484	g/GJ	250	840	EMEP/EEA (2006) chapter B216
SOx	900	g/GJ	300	1000	EMEP/EEA (2006) chapter B216
NH_3	0.3	g/GJ	0.1	7	EMEP/EEA (2006) chapter B216
TSP	444	g/GJ	80	600	EMEP/EEA (2006) chapter B216
PM_{10}	404	g/GJ	76	480	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	398	g/GJ	72	480	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	130	mg/GJ	100	200	EMEP/EEA (2006) chapter B216
Cd	1.5	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Hg	5.1	mg/GJ	3	6	EMEP/EEA (2006) chapter B216
As	2.5	mg/GJ	1.5	5	EMEP/EEA (2006) chapter B216
Cr	11.2	mg/GJ	10	15	EMEP/EEA (2006) chapter B216
Cu	22.3	mg/GJ	20	30	EMEP/EEA (2006) chapter B216
Ni	12.7	mg/GJ	10	20	EMEP/EEA (2006) chapter B216
Se	120	mg/GJ	60	240	EMEP/EEA (2006) chapter B216
Zn	220	mg/GJ	120	300	EMEP/EEA (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	800	ng I-TEQ/GJ	300	1200	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	230	mg/GJ	60	300	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	330	mg/GJ	102	480	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	130	mg/GJ	60	180	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	110	mg/GJ	48	144	EMEP/EEA (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	EMEP/EEA (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.
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

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	PCDD/F, PCB, HCB, PAH, NH3				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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	*
PM_{10}	1.2	g/GJ	0.7	1.7	*
$PM_{2.5}$	1.2	g/GJ	0.7	1.7	*
BC	5.4	% of $PM_{2.5}$	2.7	11	*
Pb	<0.0015	mg/GJ	<0.0008	<0.003	*
Cd	<0.00025	mg/GJ	<0.0001	<0.0005	*
Hg	<0.1	mg/GJ	<0.0013	0.68	*
As	0.033	mg/GJ	<0.027	0.0656	DBI 2014
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	*

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

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Most of heavy metal measurements are below the limit of quantification which are marked with “<”. Values with the “<” sign can be used directly for calculations.

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					
Not estimated	HCB, PCB, NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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	*
PM_{10}	1.9	g/GJ	1.1	2.6	*
$PM_{2.5}$	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
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
HCB, PCB and NH3 are not relevant for light heating oil

Table 3-6 Tier 1 emission factors for NFR source category 1.A.4.b, using biomass [4) 5)]

Tier 1 default emission factors					
	Code	Name			
NFR source category	1.A.4.b.i	Residential plants			
Fuel	Solid biomass				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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)
SO_X	11	g/GJ	8	40	US EPA (1996b)
NH_3	8	g/GJ	2	19	DBFZ (2023)
TSP (total particles)	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM_{10} (total particles)	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) [1)]
$PM_{2.5}$ (total particles)	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) [1)]
BC (based on total particles) [2)]	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) [3)]
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. PM is estimated as total particles (including condensable material).
2. The value of 10% BC is only valid for total particles. Since the condensable component is not expected to include any BC, in case a filterable only approach is used an EF of 10% * 740 = 74 g/GJ can be assumed for BC.
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.
5. The emission factors for solid biomass combustion in the Tier 1 approach are identical to the Tier 2 emission factors for conventional stoves, in view of the fact that stoves are the key contributor to (PM) emissions from biomass.

Commercial/institutional, agricultural and other stationary 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 Agriculture / forestry / fishing: Stationary Other, stationary (including military)			
Fuel	Hard Coal and Brown Coal				
Not applicable					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	173	g/GJ	150	200	EMEP/EEA (2006) chapter B216
CO	931	g/GJ	150	2000	EMEP/EEA (2006) chapter B216
NMVOC	88.8	g/GJ	10	300	EMEP/EEA (2006) chapter B216
SOx	900	g/GJ	450	1000	EMEP/EEA (2006) chapter B216
TSP	124	g/GJ	70	250	EMEP/EEA (2006) chapter B216
PM_{10}	117	g/GJ	60	240	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	108	g/GJ	60	220	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	See Note
Pb	134	mg/GJ	50	300	EMEP/EEA (2006) chapter B216
Cd	1.8	mg/GJ	0.2	5	EMEP/EEA (2006) chapter B216
Hg	7.9	mg/GJ	5	10	EMEP/EEA (2006) chapter B216
As	4	mg/GJ	0.2	8	EMEP/EEA (2006) chapter B216
Cr	13.5	mg/GJ	0.5	20	EMEP/EEA (2006) chapter B216
Cu	17.5	mg/GJ	5	50	EMEP/EEA (2006) chapter B216
Ni	13	mg/GJ	0.5	30	EMEP/EEA (2006) chapter B216
Se	1.8	mg/GJ	0.2	3	EMEP/EEA (2006) chapter B216
Zn	200	mg/GJ	50	500	EMEP/EEA (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	203	ng I-TEQ/GJ	40	500	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	45.5	mg/GJ	10	150	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	58.9	mg/GJ	10	180	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	23.7	mg/GJ	8	100	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	18.5	mg/GJ	5	80	EMEP/EEA (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	EMEP/EEA (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).
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

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 Agriculture / forestry / fishing: Stationary Other, stationary (including military)			
Fuel	Gaseous Fuels				
Not applicable	PCDD/F, PCB, HCB, PAH, NH3				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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	*
PM_{10}	0.78	g/GJ	0.47	1.09	*
$PM_{2.5}$	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	0.1	mg/GJ	0.007	0.54	*
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	*

* average of Tier 2 EFs for commercial/institutional gaseous fuel combustion for all technologies
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
Most of the heavy metal measurements are below the limit of quantification which are marked with “<”. Values with the sign “<” can be used directly for calculations.

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 Agriculture / forestry / fishing: Stationary Other, stationary (including military)			
Fuel	Liquid Fuels				
Not applicable					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	306	g/GJ	50	1319	*
CO	93	g/GJ	2	200	*
NMVOC	20	g/GJ	0.018	70	*
SOx	94	g/GJ	28	140	*
TSP	21	g/GJ	6	42	*
PM_{10}	21	g/GJ	0.75	80	*
$PM_{2.5}$	18	g/GJ	0.75	60	*
BC	56	% of $PM_{2.5}$	20	100	*
Pb	8	mg/GJ	0.006	40	*
Cd	0.15	mg/GJ	0.00025	0.6	*
Hg	0.1	mg/GJ	0.025	0.22	*
As	0.5	mg/GJ	0.0005	2	*
Cr	10	mg/GJ	0.1	40	*
Cu	3	mg/GJ	0.065	20	*
Ni	125	mg/GJ	0.0025	600	*
Se	0.1	mg/GJ	0.0005	0.44	*
Zn	18	mg/GJ	0.21	116	*
PCDD/F	6	*ng I-TEQ/GJ*	0.2	20	*
Benzo(a)pyrene	1.9	µg/GJ	0.19	1.9	Nielsen et al. (2010)
Benzo(b)fluoranthene	15	µg/GJ	1.5	15	Nielsen et al. (2010)
Benzo(k)fluoranthene	1.7	µg/GJ	0.17	1.7	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	1.5	µg/GJ	0.15	1.5	Nielsen et al. (2010)
HCB	0.22	µg/GJ	0.022	1.5	Nielsen et al. (2010)
PCB	0.13	ng/GJ	0.013	0.22	Nielsen et al. (2010)

* average of Tier 2 EFs for commercial/institutional liquid fuel combustion for all technologies (gas oil and fuel oil), where the TSP EF has been set to the PM_{10} EF to ensure consistency in PM emission factors

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

NH3 is relevant for if SNCR/SCR is applied.

Table 3-10 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using solid biomass [6)]

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 Agriculture / forestry / fishing: Stationary Other, stationary (including military)			
Fuel	Solid biomass				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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_x	11	g/GJ	8	40	US EPA (1996b)
NH_3	1	g/GJ	0.1	8	DBFZ (2023)
TSP	170	g/GJ	95	320	Denier van der Gon (2015) applied on Naturvårdsverket, Sweden
PM_{10}	163	g/GJ	91	305	Denier van der Gon (2015) applied on Naturvårdsverket, Sweden [3)]
$PM_{2.5}$	160	g/GJ	90	299	Denier van der Gon (2015) applied on Naturvårdsverket, Sweden [3)]
BC	28	% of $PM_{2.5}$	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) [4) 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	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. 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. Emission factors have been recalculated to represent total particles (including condensable component) by assuming condensables represent 12% of the total PM mass for PM2.5 (average of automatic and medium sized boilers from Denier van der Gon et al., 2015).
3. The value of 28% BC is only valid for total particles. Since the condensable component is not expected to include any BC, in case a filterable only approach is used an EF of 28% * 160 = 45 g/GJ can be assumed for BC.
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, from the Eurostat energy balances or the International Energy Agency (IEA). These usually distinguish between residential fuel consumption and commercial/institution/agricultural fuel consumption, and are therefore easily combined with the emission factors presented for residential and non-residential fuel use.

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

3.3 Tier 2 technology-specific approach for non-biomass fuels

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.

Please note that this section does NOT contain the Tier 2 methodology for solid biomass combustion, for the Tier 2 method for small combustion of solid biomass fuels please refer to Section 3.4.

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

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

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; and
- 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 for plants < 50 kWth and for plants >50 kWth in particular. These classifications are chosen to reflect the different emission characteristics for smaller and larger plants, respectively. In general the smaller plants (<50 kWth) are mostly residential plants and the larger plants (50 kWth – 50 MWth) are mostly non-residential, however it should be noted that this assumption does not always hold.

An overview of the Tier 2 emission factor tables and a link to the technology description 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.

For these fossil fuel emission factors, the PM emission factors represent either filterable only or total PM (including condensable component), as indicated in the footnotes below the tables. In some cases however, the origin of the emission factors is unclear at the moment.

Table 3-11 Tier 2 emission factor tables

	Tier	Fuel	Sector	Technology name	Chapter 2.2 technology name
Table 3-12	2	Solid fuels (excluding biomass)	Small size (<50 kWth)	Open fireplaces	Basic equipment – open fireplaces
Table 3-13	2	Gaseous fuels	Small size (<50 kWth)	Partly closed/closed fireplaces	Appliances – Fireplaces
Table 3-14	2	Solid fuels (excluding biomass)	Small size (<50 kWth)	Conventional stoves	Conventional radiating stoves burning solid fuels excluding biomass
Table 3-15	2	Solid fuels (excluding biomass)	Small size (<50 kWth)	Conventional boilers <50kW	Conventional under-fire boilers burning solid fuels excluding biomass
Table 3-16	2	Gaseous fuels	Small size (<50 kWth)	Conventional boilers < 50 kW	Standard domestic boilers including condensing boilers
Table 3-17	2	Gas oil	Small size (<50 kWth)	Conventional stoves	Conventional stoves burning liquid/gas fuels
Table 3-18	2	Gas oil	Small size (<50 kWth)	Conventional boilers < 50 kW	Standard domestic boilers including condensing boilers

	Tier	Fuel	Sector	Technology name	Chapter 2.2 technology name
Table 3-19	2	Coal	Small size (<50 kWth)	Advanced stoves	Advanced and ecolabelled stoves
Table 3-20	2	Coal	Medium size (50 kWth – 50 MWth)	Standard boilers >50KWth <1MWth	Standard boilers including fixed and moving grate technologies
Table 3-21	2	Coal	Medium size (50 kWth – 50 MWth)	Standard boilers >1MWth <50MWth	Standard boilers including fixed and moving grate technologies
Table 3-22	2	Coal	Medium size (50 kWth – 50 MWth)	Boilers <1MWth – manual feed technology	Advanced Tier inventory compilation for manual feed <1MWth
Table 3-23	2	Coal	Medium size (50 kWth – 50 MWth)	Boilers <1MWth – automatic feed technology	Advanced Tier inventory compilation for automatic feed <1MWth
Table 3-24	2	Fuel oil	Medium size (50 kWth – 50 MWth)	Standard boilers >50KWth <1MWth	Standard boilers using liquid based fuels
Table 3-25	2	Fuel oil	Medium size (50 kWth – 50 MWth)	Standard boilers >1MWth <50MWth	Standard boilers using liquid based fuels
Table 3-26	2	Gaseousl gas	Medium size (50 kWth – 50 MWth)	Standard boilers >50KWth <1MWth	Gas fired boilers
Table 3-27	2	Gaseous fuel	Medium size (50 kWth – 50 MWth)	Standard boilers >1MWth <50MWth	Gas fired boilers
Table 3-28	2	Gaseous fuel	Medium size (50 kWth – 50 MWth)	Gas turbines	Gas turbines
Table 3-29	2	Gas oil	Medium size (50 kWth – 50 MWth)	Gas turbines	Gas turbines
Table 3-30	2	Gaseous fuel	Medium size (50 kWth – 50 MWth)	Stationary reciprocating engines	Stationary reciprocating engines
Table 3-31	2	Gas oil	Medium size (50 kWth – 50 MWth)	Stationary reciprocating engines	Stationary reciprocating engines

Small-size (<50 kWth) combustion installations, mostly applied in residential heating technologies (1.A.4.b.i)

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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Fireplaces, Saunas and Outdoor Heaters				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	60	g/GJ	36	84	EMEP/EEA (2006) chapter B216
CO	5000	g/GJ	3000	7000	EMEP/EEA (2006) chapter B216
NMVOC	600	g/GJ	360	840	EMEP/EEA (2006) chapter B216
SOx	500	g/GJ	300	700	EMEP/EEA (2006) chapter B216
NH_3	5	g/GJ	3	7	EMEP/EEA (2006) chapter B216
TSP	350	g/GJ	210	490	EMEP/EEA (2006) chapter B216
PM_{10}	330	g/GJ	198	462	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	330	g/GJ	198	462	EMEP/EEA (2006) chapter B216
BC	9.839	% of $PM_{2.5}$	3	30	Engelbrecht et al., 2002
Pb	100	mg/GJ	60	140	EMEP/EEA (2006) chapter B216
Cd	0.5	mg/GJ	0.3	0.7	EMEP/EEA (2006) chapter B216
Hg	3	mg/GJ	1.8	4.2	EMEP/EEA (2006) chapter B216
As	1.5	mg/GJ	0.9	2.1	EMEP/EEA (2006) chapter B216
Cr	10	mg/GJ	6	14	EMEP/EEA (2006) chapter B216
Cu	20	mg/GJ	12	28	EMEP/EEA (2006) chapter B216
Ni	10	mg/GJ	6	14	EMEP/EEA (2006) chapter B216
Se	1	mg/GJ	0.6	1.4	EMEP/EEA (2006) chapter B216
Zn	200	mg/GJ	120	280	EMEP/EEA (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	300	700	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	100	mg/GJ	60	140	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	170	mg/GJ	102	238	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	60	140	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	80	mg/GJ	48	112	EMEP/EEA (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	EMEP/EEA (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.
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves, Fireplaces, Saunas and Outdoor Heaters				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	PCDD/F, PCB, HCB, PAH, NH3				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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)
PM_{10}	2.2	g/GJ	1.3	3.1	*
$PM_{2.5}$	2.2	g/GJ	1.3	3.1	*
BC	5.4	% of $PM_{2.5}$	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)

* assumption: EF(TSP) = EF(PM_{10}) = EF($PM_{2.5}$). The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM

** average of EFs from the listed references

Most of heavy metal measurements are below the limit of quantification which are marked with “<”. Values with the sign “<” can be used directly for calculation.

Table 3-14 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	100	g/GJ	60	150	EMEP/EEA (2006) chapter B216
CO	5000	g/GJ	3000	7000	EMEP/EEA (2006) chapter B216
NMVOC	600	g/GJ	360	840	EMEP/EEA (2006) chapter B216
SOx	900	g/GJ	540	1000	EMEP/EEA (2006) chapter B216
TSP	500	g/GJ	240	600	EMEP/EEA (2006) chapter B216
PM_{10}	450	g/GJ	228	480	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	450	g/GJ	216	480	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	60	240	EMEP/EEA (2006) chapter B216
Cd	1	mg/GJ	0.6	3.6	EMEP/EEA (2006) chapter B216
Hg	5	mg/GJ	3	7.2	EMEP/EEA (2006) chapter B216
As	1.5	mg/GJ	0.9	6	EMEP/EEA (2006) chapter B216
Cr	10	mg/GJ	6	18	EMEP/EEA (2006) chapter B216
Cu	20	mg/GJ	12	36	EMEP/EEA (2006) chapter B216
Ni	10	mg/GJ	6	24	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	1.2	2.4	EMEP/EEA (2006) chapter B216
Zn	200	mg/GJ	120	360	EMEP/EEA (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	1000	ng I-TEQ/GJ	300	1200	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	250	mg/GJ	150	324	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	400	mg/GJ	150	480	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	150	mg/GJ	60	180	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	120	mg/GJ	54	144	EMEP/EEA (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	EMEP/EEA (2006) chapter B216

Note: The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
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 3-15 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					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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	EMEP/EEA (2006) chapter B216
TSP	261	g/GJ	130	400	US EPA, 1998
PM_{10}	225	g/GJ	113	338	Tivari et al., 2012
$PM_{2.5}$	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	EMEP/EEA (2006) chapter B216
Cd	3	mg/GJ	0.6	3.6	EMEP/EEA (2006) chapter B216
Hg	6	mg/GJ	3	7.2	EMEP/EEA (2006) chapter B216
As	5	mg/GJ	0.9	6	EMEP/EEA (2006) chapter B216
Cr	15	mg/GJ	6	18	EMEP/EEA (2006) chapter B216
Cu	30	mg/GJ	12	36	EMEP/EEA (2006) chapter B216
Ni	20	mg/GJ	6	24	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	1.2	2.4	EMEP/EEA (2006) chapter B216
Zn	300	mg/GJ	120	360	EMEP/EEA (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	300	1200	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	270	mg/GJ	150	324	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	250	mg/GJ	150	480	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	60	180	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	90	mg/GJ	54	144	EMEP/EEA (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	EMEP/EEA (2006) chapter B216

The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM emissions

Table 3-16 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	PCDD/F, PCB, HCB, PAH, NH3				
Not estimated					
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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)
PM_{10}	0.20	g/GJ	0.12	0.28	BUWAL (2001)
$PM_{2.5}$	0.20	g/GJ	0.12	0.28	*
BC	5.4	% of $PM_{2.5}$	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)

* assumption: EF(PM_{10}) = EF($PM_{2.5}$). The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
** average of EFs from the listed references

Table 3-17 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	PCB, HCB, NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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)
SO_x	60	g/GJ	36	84	UBA (2008)
TSP	2.2	g/GJ	1.3	3.1	UBA (2008)
PM_{10}	2.2	g/GJ	1.3	3.1	UBA (2008)
$PM_{2.5}$	2.2	g/GJ	1.3	3.1	UBA (2008)
BC	13	% of $PM_{2.5}$	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)

Note: SOx: light fuel oil with a sulphur content of 1000 mg/kg, NCV of 42.8 MJ/kg = emission factor of 46.7 g/GJ
Low sulphur light fuel oil with a sulphur content of 50 mg/kg, NCV of 42.8 MJ/kg = emission factor of 2.3 g/GJ
The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3-18 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					
Not estimated	PCB, HCB, NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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)
SO_X	79	g/GJ	47	111	Italian Ministry for the Environment (2005)
TSP	1.5	g/GJ	1	2	Italian Ministry for the Environment (2005)
PM_{10}	1.5	g/GJ	1	2	*
$PM_{2.5}$	1.5	g/GJ	1	2	*
BC	3.9	% of $PM_{2.5}$	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)

Note: * assumption: EF(TSP) = EF(PM_{10}) = EF($PM_{2.5}$)
SOx: light fuel oil with a sulphur content of 1000 mg/kg, NCV of 42.8 MJ/kg = emission factor of 46.7 g/GJ
Low sulphur light fuel oil with a sulphur content of 50 mg/kg, NCV of 42.8 MJ/kg = emission factor of 2.3 g/GJ
The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM emissions

Table 3-19 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Advanced coal combustion techniques <1MWth - Advanced stove				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	150	g/GJ	50	200	EMEP/EEA (2006) chapter B216
CO	2000	g/GJ	200	3000	EMEP/EEA (2006) chapter B216
NMVOC	300	g/GJ	20	400	EMEP/EEA (2006) chapter B216
SOx	450	g/GJ	300	900	EMEP/EEA (2006) chapter B216
TSP	250	g/GJ	80	260	EMEP/EEA (2006) chapter B216
PM_{10}	240	g/GJ	76	250	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	220	g/GJ	72	230	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	80	200	EMEP/EEA (2006) chapter B216
Cd	1	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Hg	5	mg/GJ	3	9	EMEP/EEA (2006) chapter B216
As	1.5	mg/GJ	1	5	EMEP/EEA (2006) chapter B216
Cr	10	mg/GJ	5	15	EMEP/EEA (2006) chapter B216
Cu	15	mg/GJ	10	30	EMEP/EEA (2006) chapter B216
Ni	10	mg/GJ	5	20	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	1	2.4	EMEP/EEA (2006) chapter B216
Zn	200	mg/GJ	120	300	EMEP/EEA (2006) chapter B216
PCB	170	µg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	500	ng I-TEQ/GJ	40	600	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	150	mg/GJ	13	180	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	180	mg/GJ	17	200	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	100	mg/GJ	8	150	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	80	mg/GJ	6	100	EMEP/EEA (2006) chapter B216
HCB	0.62	µg/GJ	0.31	1.2	EMEP/EEA (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.
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Medium size (50 kWth – 50 MWth) combustion installations, mostly used in non-residential applications (1.A.4.a.i, 1.A.4.c.i, 1.A.5.a)

Table 3-20 Tier 2 emission factors for small non-residential sources (> 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 Agriculture / forestry / fishing: 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					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	160	g/GJ	150	200	EMEP/EEA (2006) chapter B216
CO	2000	g/GJ	200	3000	EMEP/EEA (2006) chapter B216
NMVOC	200	g/GJ	20	300	EMEP/EEA (2006) chapter B216
SOx	900	g/GJ	450	1000	EMEP/EEA (2006) chapter B216
TSP	200	g/GJ	80	250	EMEP/EEA (2006) chapter B216
PM_{10}	190	g/GJ	76	240	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	170	g/GJ	72	220	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	200	mg/GJ	80	300	EMEP/EEA (2006) chapter B216
Cd	3	mg/GJ	1	5	EMEP/EEA (2006) chapter B216
Hg	7	mg/GJ	5	9	EMEP/EEA (2006) chapter B216
As	5	mg/GJ	0.5	8	EMEP/EEA (2006) chapter B216
Cr	15	mg/GJ	1	20	EMEP/EEA (2006) chapter B216
Cu	30	mg/GJ	8	50	EMEP/EEA (2006) chapter B216
Ni	20	mg/GJ	2	30	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Zn	300	mg/GJ	100	500	EMEP/EEA (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	400	ng I-TEQ/GJ	40	500	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	100	mg/GJ	13	150	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	130	mg/GJ	17	180	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	50	mg/GJ	8	100	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	40	mg/GJ	6	80	EMEP/EEA (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	EMEP/EEA (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.
The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3-21 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 Agriculture / forestry / fishing: 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					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	180	g/GJ	150	200	EMEP/EEA (2006) chapter B216
CO	200	g/GJ	150	3000	EMEP/EEA (2006) chapter B216
NMVOC	20	g/GJ	10	300	EMEP/EEA (2006) chapter B216
SOx	900	g/GJ	450	1000	EMEP/EEA (2006) chapter B216
TSP	80	g/GJ	70	250	EMEP/EEA (2006) chapter B216
PM_{10}	76	g/GJ	60	240	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	72	g/GJ	60	220	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	100	mg/GJ	80	200	EMEP/EEA (2006) chapter B216
Cd	1	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Hg	9	mg/GJ	5	10	EMEP/EEA (2006) chapter B216
As	4	mg/GJ	0.5	5	EMEP/EEA (2006) chapter B216
Cr	15	mg/GJ	1	20	EMEP/EEA (2006) chapter B216
Cu	10	mg/GJ	8	30	EMEP/EEA (2006) chapter B216
Ni	10	mg/GJ	2	20	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Zn	150	mg/GJ	100	300	EMEP/EEA (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	100	ng I-TEQ/GJ	40	500	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	13	mg/GJ	10	150	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	17	mg/GJ	10	180	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	9	mg/GJ	8	100	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	6	mg/GJ	5	80	EMEP/EEA (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	EMEP/EEA (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.
The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3-22 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 Agriculture / forestry / fishing: 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					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	200	g/GJ	150	300	EMEP/EEA (2006) chapter B216
CO	1500	g/GJ	200	3000	EMEP/EEA (2006) chapter B216
NMVOC	100	g/GJ	20	300	EMEP/EEA (2006) chapter B216
SOx	450	g/GJ	300	900	EMEP/EEA (2006) chapter B216
TSP	150	g/GJ	80	250	EMEP/EEA (2006) chapter B216
PM_{10}	140	g/GJ	76	240	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	130	g/GJ	72	220	EMEP/EEA (2006) chapter B216
BC	6.4	% of $PM_{2.5}$	2	26	Zhang et al., 2012
Pb	150	mg/GJ	80	200	EMEP/EEA (2006) chapter B216
Cd	2	mg/GJ	1	3	EMEP/EEA (2006) chapter B216
Hg	6	mg/GJ	5	9	EMEP/EEA (2006) chapter B216
As	4	mg/GJ	0.5	5	EMEP/EEA (2006) chapter B216
Cr	10	mg/GJ	1	15	EMEP/EEA (2006) chapter B216
Cu	15	mg/GJ	8	30	EMEP/EEA (2006) chapter B216
Ni	15	mg/GJ	2	20	EMEP/EEA (2006) chapter B216
Se	2	mg/GJ	0.5	3	EMEP/EEA (2006) chapter B216
Zn	200	mg/GJ	100	300	EMEP/EEA (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et al. (2004)
PCDD/F	200	ng I-TEQ/GJ	40	500	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	90	mg/GJ	13	150	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	110	mg/GJ	17	180	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	50	mg/GJ	8	100	EMEP/EEA (2006) chapter B216
Indeno(1,2,3-cd)pyrene	40	mg/GJ	6	80	EMEP/EEA (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.2	EMEP/EEA (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.

The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3-23 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 Agriculture / forestry / fishing: 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					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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	EMEP/EEA (2006) chapter B216
TSP	82	g/GJ	41	164	Thistlethwaite, 2001
PM_{10}	78	g/GJ	39	156	Struschka et al., 2008
$PM_{2.5}$	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	EMEP/EEA (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	EMEP/EEA (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.
The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM emissions

Table 3-24 Tier 2 emission factors for non-residential sources, medium-sized (> 50 kWth to ≤ 1 MWth) boilers liquid 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	Fuel oil (Distillate fuel oil)				
SNAP (if applicable)	20100 20300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices	Fuel oil (Distillate fuel oil) combustion in boilers ≤ 1MW				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable	Se				
Not estimated	NH_3, TSP, BC, PCB , HCB				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	100	g/GJ	50	150	EMEP/EEA (2006) chapter B216
CO	40	g/GJ	24	40	EMEP/EEA (2006) chapter B216
NMVOC	15	g/GJ	9	15	EMEP/EEA (2006) chapter B216
SO_x	140	g/GJ	84	140	EMEP/EEA (2006) chapter B216
PM_{10}	3	g/GJ	0.75	6	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	3	g/GJ	0.75	6	EMEP/EEA (2006) chapter B216
Pb	20	mg/GJ	5	40	EMEP/EEA (2006) chapter B216
Cd	0.3	mg/GJ	0.075	0.6	EMEP/EEA (2006) chapter B216
Hg	0.1	mg/GJ	0.025	0.2	EMEP/EEA (2006) chapter B216
As	1	mg/GJ	0.25	2	EMEP/EEA (2006) chapter B216
Cr	20	mg/GJ	5	40	EMEP/EEA (2006) chapter B216
Cu	10	mg/GJ	2.5	20	EMEP/EEA (2006) chapter B216
Ni	300	mg/GJ	75	600	EMEP/EEA (2006) chapter B216
Zn	10	mg/GJ	2.5	20	EMEP/EEA (2006) chapter B216
PCDD/F	10	I-TEQng/GJ	2.5	20	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	8	mg/GJ	2	16	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	9	mg/GJ	2.25	18	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	6	mg/GJ	1.5	12	EMEP/EEA (2006) chapter B216
Indeno (1,2,3-cd)pyrene	3	mg/GJ	0.75	6	EMEP/EEA (2006) chapter B216

Note:
140 g/GJ of of SOx as sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use appropriate equation to adjust value.

Table 3-25 Tier 2 emission factors for non-residential sources, medium sized (> 1 MWth to ≤ 50 MWth) boilers liquid 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	Fuel oil (Residual fuel oil)				
SNAP (if applicable)	20100 20300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices	Fuel oil (Residual oil) combustion in boilers > 1MW				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	NH_3, TSP, BC, PCB, HCB				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	100	g/GJ	50	150	EMEP/EEA (2006) chapter B216
CO	40	g/GJ	20	80	EMEP/EEA (2006) chapter B216
NMVOC	5	g/GJ	2	15	EMEP/EEA (2006) chapter B216
SO_x	140	g/GJ	84	140	EMEP/EEA (2006) chapter B216
PM_{10}	40	g/GJ	10	80	EMEP/EEA (2006) chapter B216
$PM_{2.5}$	30	g/GJ	7.5	60	EMEP/EEA (2006) chapter B216
Pb	10	mg/GJ	2.5	20	EMEP/EEA (2006) chapter B216
Cd	0.3	mg/GJ	0.075	0.6	EMEP/EEA (2006) chapter B216
Hg	0.1	mg/GJ	0.025	0.2	EMEP/EEA (2006) chapter B216
As	1	mg/GJ	0.25	2	EMEP/EEA (2006) chapter B216
Cr	20	mg/GJ	5	40	EMEP/EEA (2006) chapter B216
Cu	3	mg/GJ	0.75	6	EMEP/EEA (2006) chapter B216
Ni	200	mg/GJ	50	400	EMEP/EEA (2006) chapter B216
Zn	5	mg/GJ	1.25	10	EMEP/EEA (2006) chapter B216
PCDD/F	10	I-TEQ ng/GJ	2.5	20	EMEP/EEA (2006) chapter B216
Benzo(a)pyrene	1	mg/GJ	0.5	2	EMEP/EEA (2006) chapter B216
Benzo(b)fluoranthene	2	mg/GJ	1	4	EMEP/EEA (2006) chapter B216
Benzo(k)fluoranthene	1	mg/GJ	0.5	2	EMEP/EEA (2006) chapter B216
Indeno (1,2,3-cd)pyrene	1	mg/GJ	0.5	2	EMEP/EEA (2006) chapter B216

Note:
140 g/GJ of SOx as sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use appropriate equation to adjust value.
NH3 is only relevant in the case of using SCR or SNCR

Table 3-26 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 Agriculture / forestry / fishing: 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	PCDD/F, PCB, HCB, PAH				
Not estimated	NH_3				
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)
PM_{10}	0.45	g/GJ	0.27	0.63	*
$PM_{2.5}$	0.45	g/GJ	0.27	0.63	*
BC	5.4	% of $PM_{2.5}$	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)

* assumption: EF(TSP) = EF(PM_{10}) = EF($PM_{2.5}$). The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM emissions

** average of EFs from the listed references

Note: NH_3 is only relevant in the case of using SCR, SNCR

Most of heavy metal measurements are below the limit of quantification which are marked with "<". Values with the sign "<" can be used directly for calculation.

Table 3-27 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 Agriculture / forestry / fishing: 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	PCDD/F, PCB, HCB, PAH				
Not estimated	NH_3				
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)
PM_{10}	0.45	g/GJ	0.27	0.63	*
$PM_{2.5}$	0.45	g/GJ	0.27	0.63	*
BC	5.4	% of $PM_{2.5}$	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)

* assumption: EF(TSP) = EF(PM_{10}) = EF($PM_{2.5}$). The TSP, PM_{10} and $PM_{2.5}$ emission factors represent filterable PM emissions

** average of EFs from the listed references

Note: NH3 is only relevant in the case of using SCR, SNCR

Most of heavy metal measurements are below the limit of quantification which are marked with "<". Values with the sign "<" can be used directly for calculation.

Table 3-28 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 Agriculture / forestry / fishing: 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	PCDD/F, PCB, HCB, PAH				
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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 $PM_{2.5}$	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)

* assumption: EF(PM10) = EF(PM2.5). The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
NH3 is only relevant in the case of using SCR, SNCR
Most of heavy metal measurements are below the limit of quantification which are marked with “<”. Values with the sign “<” can be used directly for calculation.

Table 3-29 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 Agriculture / forestry / fishing: 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					
Not estimated	PCB, HCB, NH_3, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
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)
SOx	46	g/GJ			*
TSP	9.5	g/GJ	6	13	Nielsen et al. (2010)
PM_{10}	9.5	g/GJ	6	13	**
$PM_{2.5}$	9.5	g/GJ	6	13	**
BC	33.5	% of $PM_{2.5}$	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(PM_{10}) = EF($PM_{2.5}$).
The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
NH3 is only relevant in the case of using SCR or SNCR

Table 3-30 Tier 2 emission factors for non-residential sources, reciprocating engines 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 plants Residential Agriculture / forestry / fishing: 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	PCB, HCB				
Not estimated	NH_3				
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)
SOx	0.5	g/GJ	0.05	1	BUWAL (2001)
TSP	2	g/GJ	1	3	BUWAL (2001)
PM_{10}	2	g/GJ	1	3	BUWAL (2001)
$PM_{2.5}$	2	g/GJ	1	3	*
BC	2.5	% of $PM_{2.5}$	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	µg/GJ	0.24	6	Nielsen et al. (2010)
Benzo(b)fluoranthene	9	µg/GJ	1.8	45	Nielsen et al. (2010)
Benzo(k)fluoranthene	1.7	µg/GJ	0.34	8.5	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	1.8	µg/GJ	0.36	9	Nielsen et al. (2010)

* assumption: $EF(PM_{10}) = EF(PM_{2.5})$.

The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

NH3 is only relevant in the case of using SCR or SNCR

PCDD/F, PCB, HCB and the larger part of NMVOC emissions are from lubricant use but not from natural gas combustion

Table 3-31 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 plants Residential Agriculture / forestry / fishing: 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					
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)
SOx	48	g/GJ	29	67	BUWAL (2001)
TSP	30	g/GJ	18	42	BUWAL (2001)
PM_{10}	30	g/GJ	18	42	BUWAL (2001)
$PM_{2.5}$	30	g/GJ	18	42	*
BC	78	% of $PM_{2.5}$	47	100	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	µg/GJ	0.19	1.9	Nielsen et al. (2010)
Benzo(b)fluoranthene	15	µg/GJ	1.5	15	Nielsen et al. (2010)
Benzo(k)fluoranthene	1.7	µg/GJ	0.17	1.7	Nielsen et al. (2010)
Indeno(1,2,3-cd)pyrene	1.5	µg/GJ	0.15	1.5	Nielsen et al. (2010)
HCB	0.22	µg/GJ	0.022	0.22	Nielsen et al. (2010)

Note: SOx: light fuel oil with a sulphur content of 1000 mg/kg, NCV of 42.8 MJ/kg = emission factor of 46.7 g/GJ
Low sulphur light fuel oil with a sulphur content of 50 mg/kg, NCV of 42.8 MJ/kg = emission factor of 2.3 g/GJ
* assumption: EF(PM_{10}) = EF($PM_{2.5}$).
The TSP, PM_{10} and $PM_{2.5}$ emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions
NH3 is only relevant in the case of using SCR or SNCR

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:

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

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

Advancement of inventory approach from Tier 1 to Tier 2 requires the further disaggregation of fuel use from national totals down into fuel use by specific technology types. Information on fuel use at this level of aggregation is expected to be more limited and would likely require additional surveying/research by the inventory agency to help derive the data needed for further disaggregation. It is recommended to use country specific information on the split of these technology types. This section provides guidance on how to split the Tier 1 activity data (which is typically available from statistics) into different technologies for Tier 2.

Default datasets (in case no country specific information is available)

Table 3-42 provides a default split for residential and commercial/institutional fuel use covering the main technology types for this sector (fire places, boilers and stoves) for solid fuels except biomass. This data has been derived from the the Greenhouse gas and Air pollution Interactions and Synergies (GAINS) model based on data for 2010 recorded as petajoules of energy and represents a weighted average of the EU28 Member States. For ease of use this has been converted into percentage splits by fuel and technology to allow inventory compilers to disaggregate national totals of data. In developing the ratios for the EU it is recognised that the likely ratios will vary geographically dependent on available fuels and local climatic / cultural variations for the residential sector. Therefore, if solid fuels are important for small combustion in your country, it is good practiceto consult the GAINS model (http://gains.iiasa.ac.at/models/index.html) for country specific appliance type splits.

Table 3-32 Disaggregation of residential solid fuel use (excl. biomass) across main technology types based on GAINS model

Fuel type	Technology Type	EU28 Average ratios of fuel splits
Brown coal/lignite	Fire places	0%
	Residential boilers (automatic feed)	0%
	Residential boilers (manual feed)	75%
	Stoves	25%
Hard coal	Fire places	0%
	Residential boilers (automatic feed)	1%
	Residential boilers (manual feed)	51%
	Stoves	48%
Derived coal (coke)	Fire places	0%
	Residential boilers (automatic feed)	0%
	Residential boilers (manual feed)	70%
	Stoves	30%

Alternatively, Table 3-33 provides data for non-residential fuel use covering the sectoral split of energy usage, energy usage by different size energy classes, and number of plants in operation. The data in Table 3-33 has been based on a study completed by contractor (Grebot et al, 2014) on behalf of the European Commission to look at control options for emissions from appliances below 50MWth. The data within the table was derived based on surveys sent out to Member State Competent Authorities in 2012/2013 and extrapolation to cover gaps where they existed in order to develop a complete data-set. The study focussed upon the size range 1MWth to 50MWth and also included data held within the (GAINS) model managed by the International Institute for Applied Systems Analysis (IIASA). The study did not include the 50kWth – 1MWth appliances within the survey element as the scope was defined by the Medium Combustion Plant Directive (MCPD). Table 3-33 includes data for this size class based on trend analysis and extrapolation of data for the other size classes quoted within the table.

Table 3-33 can be used alongside national energy statistics to help further disaggregate data into a format for usage with the emission factor tables covered within the Guidebook on the 50kWth – 1MWth and 1MWth – 50MWth categories. However, care is required noting the high level of uncertainty for data within Table 3-33 and the fact that this presents an EU average for 27 Member States. Any regional or national variation is not be captured within the table and Inventory Agencies are also recommended to make use of the methods detailed in section 0 in developing estimates at Tier 2 approach.

Table 3-33 Summary of EU27 data-set taken from the European Commission study on 'Analysis of the impacts of various options to control emissions from combustion of fuels in installations with a total rated thermal input below 50MW (2014)'

Datum	$50Kw_{th}$ - $1MW_{th}$	1-5 MW_{th}	5-20 MW_{th}	20-50 MW_{th}
Number of plants	569,045	113,809	23,868	5,309
Percentage of plants based on total	80%	16%	3%	1%
Sectoral distribution[1]				
Public electricity generation	11%	11%	8%	16%
Public heat generation	23%	25%	29%	40%
Tertiary (i.e. non-residential)	13%	5%	2%	0%
Hospitals	6%	6%	1%	2%
Greenhouses	13%	13%	40%	4%
Food industry	4%	4%	3%	6%
Industry	18%	18%	14%	28%
Others (University)	5%	5%	0%	1%
Others (CHP)	1%	1%	0%	0%
Others	6%	11%	3%	3%
Technology type[2]				
Boilers	80%	80%	82%	81%
Engines / turbines / others	20%	20%	18%	19%
Capacity of plants (GW_{th})	300,000	273,714	232,367	177,099
Fuel consumption:				
Biomass (PJ)	168	163	160	182
Other solid fuel (PJ)	56	49	46	74
Liquid fuel (PJ)	236	213	290	206
Natural gas (PJ)	1,272	1,268	1,704	844
Other gaseous fuel (PJ)	169	277	125	104
Total fuel consumption (PJ)	1,902	1,971	2,325	1,410
Fuel consumption as percentage:				
Biomass (%)	9%	8%	7%	13%
Other solid fuel (%)	3%	2%	2%	5%
Liquid Fuel (%)	12%	11%	12%	14%
Natural gas (%)	67%	64%	73%	60%
Other gaseous consumption (%)	9%	15%	6%	8%
SO_2 emissions (kt)	-	103	130	68
NO_X emissions (kt)	-	210	227	117
Dust emissions (kt)	-	17	20	16

Note 1: The sectoral distribution is a weighted average derived from a small sample of Member States which reported this information.

Note 2: The technology type split is significantly influenced by the 80:20 assumption which has been used to fill the majority of Member States, for which this information was not available.

Other methodologies for further disaggegation of activity data for more advanced calculation (Tier 2 and Tier 3 approaches)

Development of emission estimates following a Tier 1 approach will only require data on national levels of fuel consumption. The advancement to Tier 2 and Tier 3 approach requires more detailed information disaggregated to technology type. This kind of information is expected to be more limited. While Table 3-32 and Table 3-33 provide a useful breakdown of the appliances on the EU market prior to 2014 (noting the accession of Croatia to form the EU28), additional methodologies can be used to help inventory agencies develop the necessary activity data for Tier 2 and Tier 3 level approach. This includes gathering data by collecting:

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

Equally 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 which could include energy classes for the below 50MWth category.

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.

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 statistical 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; and
- 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. It can also be beneficial to include drawings in the survey to assist both respondents and surveyors. Section 3.5.1 provides further discussion on the use of biomass within residential and non-residential settings. This includes discussion around emissions and the affect that operational settings and maintenance can have on emissions. It also highlights the importance around the nature of the fuel itself, different types of wood with varying organic, moisture and oil content will affect the emissions produced, as will the nature of the wood (logs vs pellets) burnt within appliances.

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; and
- 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 3-34 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/m^2
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 complicated further, as firing is not only used for meeting heating demand in dwellings but also for creating domestic comfort. 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 2 technology-specific approach for solid biomass fuels

3.4.1 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.

This section provides guidance for estimating emissions from the combustion of solid biomass. Given the importance of this source to (specifically) PM emission in most countries, a specific methodology has been elaborated. This methodology is a Tier 2 methodology, but in addition to the regular Tier 2 methodologies this method provides default technology splits that Parties may use to apply the Tier 2 approach. The thought behind this idea is that they will therefore be able to provide a more accurate estimate compared to the earlier Tier 1 approach for residential biomass combustion.

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

$$E_i = \sum_{j,k} EF_{i,j,k} \cdot A_{j,k} \, , \tag{1}$$

where

E_i = annual emission of pollutant *i*,

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

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

In order to use this inventory, data must be available on:

- The total annual consumption of solid biomass
- How this solid biomass is split over the various fuels *k* (e.g. different wood types)
- How the use of solid biomass is split over the different appliance types *i*

Ideally, this information should be available from national statistics or national studies, reflecting the specific situation in the country. However, in case this information is not available, this Tier 2 methodology provides default information on how to split the technologies used for the combustion of solid biomass over the different appliance types and fuel types.

This methodology splits the small combustion of wood in several appliance and fuel types as explained in the next sections.

3.4.2 Appliance type split factors

This section provides default factors to split your total fuel consumption over the various appliance types. The split is based on the appliance types given by Klimont et al. (2002) and Kupiainen and Klimont (2007), for which data are also available from the IIASA GAINS model for various years.

The appliance types are explained in the table below.

Table 3-35 Appliance types distinguished in the IIASA GAINS model

Abbreviation	Appliance type	Corresponding EF table(s)
FPLACE	Fireplace	Table 3-39
STOVE	Heating stove*	Table 3-40, Table 3-41, Table 3-42
SHB_A	Single house boiler, automatic feed	Table 3-44
SHB_M	Single house boiler, manual feed	Table 3-43
MB_A	Medium boiler, automatic feed (between 1 – 50 MWth)	Table 3-45, Table 3-48
MB_M	Medium boiler, manual feed	Table 3-47

* Generally, the use of biomass stoves for cooking can be considered negligible in Europe.

This information is to be used only if no data from the country itself is available on the split of different appliance types. The split is estimated by taking the energy balances as a starting point to split between residential, commercial/institutional and other sectors. The allocation to stoves and boilers were proposed by IIASA and discussed with countries in the country consultations. More information on the estimation of these fractions is available in Klimont et al. (2016).

Most countries in the UNECE domain are included in the split factors provided in Table 3-36 to Table 3-38 (for years 2000, 2005 and 2010, respectively). For countries not included, it is good practice to select a country most resembling the countries listed. For the years in between the provided years, interpolation/extrapolation may be used to estimate the appliance type contributions in the other years.

In addition, GAINS also contains these split for projected future years, therefore it can also be used for the most reporting of emissions from the most recent years as well as projections reporting.

Table 3-36 Appliance type split according to IIASA GAINS model for the year 2000

Year: 2000	FPLACE	MB_A	MB_M	SHB_A	SHB_M	STOVE
Albania	0%	1%	6%	0%	2%	91%
Austria	1%	6%	0%	4%	62%	27%
Belarus	0%	1%	14%	0%	2%	83%
Belgium	8%	0%	0%	4%	4%	85%
Bosnia-Herzegovina	0%	0%	0%	0%	2%	98%
Bulgaria	0%	0%	2%	0%	2%	96%
Croatia	6%	0%	0%	0%	25%	69%
Cyprus	8%	0%	0%	25%	33%	33%
Czech Republic	1%	3%	0%	0%	36%	59%
Denmark	1%	6%	8%	8%	34%	43%
Estonia	6%	1%	1%	0%	25%	67%
Finland	5%	13%	2%	3%	19%	58%
France	6%	4%	0%	0%	11%	79%
Germany	8%	0%	0%	25%	33%	33%
Greece	6%	0%	0%	6%	25%	62%
Hungary	0%	9%	0%	0%	46%	46%
Iceland	-	-	-	-	-	-
Ireland	20%	0%	0%	0%	5%	75%
Italy	62%	0%	0%	0%	9%	29%
Kosovo	-	-	-	-	-	-
Latvia	6%	5%	5%	0%	15%	68%
Lithuania	8%	4%	4%	0%	38%	47%
Luxembourg	6%	3%	1%	6%	24%	60%
FYR of Macedonia	0%	1%	9%	0%	2%	88%
Malta	-	-	-	-	-	-
Moldova	0%	1%	10%	0%	2%	87%
Montenegro	-	-	-	-	-	-
Netherlands	77%	3%	0%	0%	0%	19%
Norway	5%	0%	0%	0%	1%	94%
Poland	4%	1%	8%	0%	12%	75%
Portugal	21%	0%	0%	7%	17%	55%
Romania	0%	0%	1%	0%	2%	96%
Russian Federation	1%	0%	2%	0%	11%	85%
Serbia	0%	0%	0%	0%	2%	98%
Slovakia	5%	0%	0%	0%	15%	80%
Slovenia	0%	0%	0%	2%	89%	9%
Spain	6%	2%	1%	6%	24%	61%
Sweden	6%	4%	2%	7%	65%	15%
Switzerland	1%	27%	0%	8%	42%	21%
Turkey	0%	0%	0%	1%	11%	87%
Ukraine	0%	1%	12%	1%	10%	76%
United Kingdom	7%	29%	4%	36%	10%	14%

Table 3-37 Appliance type split according to IIASA GAINS model for the year 2005

Year: 2005	FPLACE	MB_A	MB_M	SHB_A	SHB_M	STOVE
Albania	0%	0%	4%	0%	2%	93%
Austria	1%	9%	0%	7%	58%	25%
Belarus	0%	2%	17%	0%	2%	80%
Belgium	7%	2%	1%	4%	4%	82%
Bosnia-Herzegovina	0%	0%	0%	0%	2%	98%
Bulgaria	0%	0%	2%	0%	2%	96%
Croatia	6%	0%	0%	0%	29%	65%
Cyprus	8%	0%	0%	42%	17%	33%
Czech Republic	1%	5%	0%	1%	37%	55%
Denmark	1%	4%	5%	20%	26%	44%
Estonia	6%	4%	2%	0%	24%	65%
Finland	5%	13%	2%	3%	19%	58%
France	6%	7%	0%	0%	10%	77%
Germany	8%	0%	0%	42%	17%	33%
Greece	6%	0%	0%	6%	25%	62%
Hungary	1%	9%	0%	1%	41%	48%
Iceland	-	-	-	-	-	-
Ireland	19%	1%	0%	0%	5%	75%
Italy	60%	0%	0%	0%	9%	31%
Kosovo	0%	0%	0%	0%	2%	98%
Latvia	6%	7%	6%	2%	13%	67%
Lithuania	7%	3%	2%	2%	39%	47%
Luxembourg	6%	4%	1%	6%	24%	59%
FYR of Macedonia	0%	0%	3%	0%	2%	94%
Malta	-	-	-	-	-	-
Moldova	0%	1%	10%	0%	2%	87%
Montenegro	0%	0%	0%	0%	2%	98%
Netherlands	78%	3%	0%	0%	0%	19%
Norway	4%	0%	0%	0%	0%	94%
Poland	4%	2%	5%	0%	12%	77%
Portugal	21%	0%	0%	14%	14%	52%
Romania	0%	1%	6%	0%	2%	91%
Russian Federation	1%	5%	27%	0%	8%	59%
Serbia	0%	0%	0%	0%	2%	98%
Slovakia	5%	0%	0%	0%	15%	80%
Slovenia	0%	0%	0%	5%	86%	8%
Spain	6%	2%	1%	6%	24%	61%
Sweden	6%	7%	2%	14%	58%	12%
Switzerland	1%	28%	0%	11%	39%	21%
Turkey	0%	0%	0%	1%	11%	87%
Ukraine	0%	1%	12%	1%	10%	76%
United Kingdom	8%	25%	4%	38%	11%	15%

Table 3-38 Appliance type split according to IIASA GAINS model for the year 2010

Year: 2010	FPLACE	MB_A	MB_M	SHB_A	SHB_M	STOVE
Albania	0%	1%	3%	1%	4%	91%
Austria	1%	9%	0%	10%	57%	24%
Belarus	0%	3%	15%	1%	4%	77%
Belgium	8%	1%	1%	4%	4%	83%
Bosnia-Herzegovina	0%	0%	0%	1%	5%	94%
Bulgaria	0%	0%	1%	1%	4%	93%
Croatia	6%	0%	0%	0%	27%	67%
Cyprus	5%	45%	0%	32%	5%	14%
Czech Republic	2%	5%	0%	8%	32%	53%
Denmark	1%	3%	2%	25%	23%	45%
Estonia	6%	3%	1%	0%	24%	66%
Finland	5%	13%	2%	3%	19%	58%
France	6%	7%	0%	0%	10%	77%
Germany	8%	0%	0%	58%	8%	25%
Greece	6%	0%	0%	12%	19%	62%
Hungary	2%	15%	0%	5%	37%	41%
Iceland	-	-	-	-	-	-
Ireland	17%	2%	0%	1%	4%	76%
Italy	59%	0%	0%	0%	7%	34%
Kosovo	0%	0%	0%	1%	5%	94%
Latvia	7%	6%	4%	3%	12%	67%
Lithuania	7%	4%	2%	3%	38%	47%
Luxembourg	6%	7%	0%	12%	17%	58%
FYR of Macedonia	0%	1%	4%	1%	4%	89%
Malta	-	-	-	-	-	-
Moldova	0%	2%	10%	1%	4%	83%
Montenegro	0%	0%	0%	1%	5%	94%
Netherlands	78%	2%	0%	0%	0%	20%
Norway	4%	1%	0%	0%	0%	94%
Poland	4%	3%	5%	1%	10%	77%
Portugal	20%	1%	0%	14%	14%	51%
Romania	0%	1%	3%	1%	4%	91%
Russian Federation	1%	5%	20%	1%	9%	65%
Serbia	0%	0%	0%	1%	5%	94%
Slovakia	4%	2%	1%	0%	11%	82%
Slovenia	0%	0%	0%	8%	84%	7%
Spain	6%	4%	0%	12%	18%	60%
Sweden	5%	7%	1%	16%	58%	12%
Switzerland	1%	28%	0%	16%	35%	20%
Turkey	0%	0%	0%	2%	11%	86%
Ukraine	0%	10%	54%	1%	4%	31%
United Kingdom	7%	31%	0%	38%	10%	14%

3.4.3 Fuel type split factors and combustion practices

Different solid biomass types

Apart from the appliance types, also the type of biomass is an important parameter to consider in the estimation of emissions from small combustion of wood. For example, soft and hard wood, wood from different tree types will all have different emission characteristics. Some specific emission factors are available and presented in the Tier 3 section of this chapter. However, it should be recognized that especially activity data are difficult to collect. Therefore, in the absence of any information it may be assumed that the emission factors provided in Section 3.4.4 provide an average of the wood types/conditions available.

In the case of pellets however, the situation is different. Pellet stoves have very different emission characteristics, therefore it is important to investigate the share of pellets in the overall wood consumption for small combustion. In some cases this information may be available from national statistics. In case no country specific information is available, it is good practice to assume the appliance types SHB_A (automatic feed single house boilers) are fuelled by wood pellets. Specific emission factors for small boilers fuelled by pellet stoves are available in the following section.

Impact of different combustion and operating practices

In small scale wood burning most the majority of the PM emissions consist of volatized and either partially or unburned high molecular tarry components coming from the fuel because of heat. Highest particulate emissions occur when the fire is hot enough to release these tarry components from the wood but still too cool for these components to burn. Besides a low temperature, burning of released tarry components can also be inhibited under oxygen-starved conditions.

The main conditions determining the release of particles are:

- **Start-up phase:** During the start-up phase that takes place during the time between ignition and full steady burning, PM, CO and NMVOC emission can be very high, for above discussed reasons. Any means of operation that extends start-up phase usually increases emission and any means of operation that maximizes full steady burning period decreases emissions. During the start-up phase emissions can be the 10-fold of emission during steady burning. Conditions during start-up may be repeated when fresh fuel is added to the fire. Tarry components are released from the added fuel but the fire is not yet hot enough to fully burn these components. According to Nussbaumer et al. (2008/2) the start-up phase accounts for roughly 50% of the total PM emissions, keeping in mind this fraction can variate significantly depending on the conditions.
- **Shutdown phase:** Another phase critical for emissions is the final phase of the fire when no fresh fuel is added anymore and the temperature and burning rate of the fire is decreasing. In this phase wood smouldering can occur, which causes very high emissions again, far exceeding the emission during steady full burning. Smouldering conditions can be very prolonged if the fire is left to die and extinguish naturally by itself. Similar conditions occur when the fire is regulated downwards or extinguished by decreasing or completely eliminating the oxygen supply. Under oxygen starved conditions the components released from the fuel because of heat can then no longer fully combust and emissions strongly increase when the fire is subdued

in this way. Almost full elimination of the oxygen supply results in prolonged smouldering, and volatile components are still released from the fuel but can no longer burn, resulting in high emissions of particles.

- **Way of operating:** ignition of the fire from the top results in 50-80% lower emissions than ignition from the bottom, since when the fuel is ignited from the bottom there can be a lack of oxygen and therefore incomplete combustion, while the flames are initially cooled from the logs lying on top of the fire (Nussbaumer et al., 2008/2). If a one-stage fuel chamber is used and the fuel chamber is filled with wood logs for more than 50%, PM emissions may be 5-10 times larger compared to ideal conditions, while for two-stage fuel chambers the performance is much better (Nussbaumer et al. 2008/2).
- **Impact of fire temperature**: As a general rule, the higher the temperature the lower the emission. As mentioned above, emissions can be very high when the fire is no longer hot enough the to let the released volatile components spontaneously catch fire and combust, yet still so hot that the release rate of these components from the fuel is still high. Fire temperature is partially determined by the type of appliance but is strongly influenced by operating conditions as well. Any practice that reduces fire temperature below the temperature needed for spontaneous combustion of volatile components, either resulting in local “cool zones” or in a cooler fire altogether (e.g. by letting the fire become too spread-out) has the potential to increase emissions by orders of magnitude.
- **Water content of the fuel:** A factor that is considered under operating conditions is the wood moisture content. A high moisture content (e.g. above 20%) will significantly prolongue the start-up phase, as evaporating moisture may keep the fire too cool to fully burn the released volatile tarry components. Evaporation of moisture present in the fuel also promotes steam stripping of tarry components from the wood. Steam stripping results in an increased release of these components and in combination with a cooler fire results in significantly higher emission as well (Simoneit, 2002).

The effect of above discussed operating practices is particularly strong for smaller appliances (e.g. below 50 kW_{th}) for which tarry and other semi-volatile matter dominates particulate emission. In larger appliances the fire temperature is often significantly higher so that these components released from the fuel fully combust anyway. Also air supply is much more optimized compared to conventional small appliances, and the flue gasses are better mixed because of the higher turbulence of the flame, which prevent cool partially burned parts of the flue gas to escape. The fire is usually regulated by the supply rate of the fuel rather then the oxygen supply. In larger appliances particulate emissions as a result from ash suspension due to the higher flame turbulence (which does usually not occur in smaller appliances) may surpass the emission due to the release of partially or unburned volatile components from the fuel. For these larger appliances many of the operation conditions discussed above may have much less effect, or may even have an opposite effect (e.g. fuel moisture). For instance, US EPA (1989) reports that reducing wood moisture increased the particulate emission factor. Also US EPA AP42 chapter on wood residue combustion in boilers reports higher value for dry than wet wood for Filterable (17.5% for TSP, 19.5% for PM10 and 25% for PM2.5). This is likely related to the fact that if there is more water, there is less wood per kg which, if burning the same, will generate less PM per kg of wood combusted.

Another important observation is that stoves that have been in use for several years emit more particulates than brand new stoves. SINTEF Energy Research (Seljeskog et al., 2013) reports that wood stove testing in Norway has shown that, depending on the quality of each specific stove type and each stove specific technical solution themselves, normal use over several years might lead to increased air leakage with the inherent result of higher particle emissions. Leakage means that air is introduced into the stove in wrong places, and not at the secondary air inlet area where it is supposed to mix with hot flue gases and burnout the remaining particle matter. Here leakages cool down parts of the combustion zone and prevent particle burnout. Further studies are needed to quantify such effects in more detail.

3.4.4 Technology-specific emission factors for solid biomass combustion

This section provides the emission factors for the combustion of solid biomass in 4 different appliance type categories. These match with the appliance type splits provided in Section 3.4.2. For the boilers, the appliance type split factors distinguish between automatic feed and manual feed. This split is not available in the emission factor tables

An important notice is that this Tier 2 methodology only provides total PM emission factors (including condensables) for all PM related pollutants (TSP, PM10 and PM2.5). As explained, the measured PM emissions highly depends on the measurement technique used (Nussbaumer et al., 2008/1):

1. Solid particles only: this refers to sampling of particles on a heated filter, through a probe, from undiluted flue gas in the chimney at a fixed gas temperature. Using this technique, the PM formed due to cooling and dilution of hot flue gases (the condensable fraction) is not taken into account.
2. Total particles: this refers to sampling of filterable particles in a dilution tunnel with a filter holder gas temperature < 35°C (e.g. Norwegian standard NS 3058-2). Due to the cooling and dilution, condensable organic material in the hot flue gas condenses on the filter. Therefore, when PM is measured using this technique both the filterable and condensable PM are included.

The BC fraction provided in the EF tables is also based on an EF for PM2.5 which includes the condensable fraction. This is an important note, since the fraction of BC in PM2.5 depends strongly on the measurement technique used for PM2.5 (BC is typically not present in the condensable fraction).

For reporting, an approach with reporting PM emissions based on total particles is strongly encouraged, therefore all EF tables for small scale biomass combustion include only emission factors for total PM emissions (including condensable component). In any case, a Party should use a consistent approach for all small combustion emissions and clearly report in the IIR if the condensable fraction in PM from small combustion is (or is not) included. For reference, the emission factors representing solid particles only (so excluding the condensable component) are shown in Table 3-49.

Fireplaces

This section provides the default emission factors for wood burning in fireplaces

Table 3-39 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Open fireplaces				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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)
SO_x	11	g/GJ	8	40	US EPA (1996/1)
NH_3	8	g/GJ	2	19	DBFZ (2023)
TSP (total particles)	880	g/GJ	440	1760	Alves et al. (2011) [2)]
PM_{10} (total particles)	840	g/GJ	420	1680	Alves et al. (2011) [2)]
$PM_{2.5}$ (total particles)	820	g/GJ	410	1640	Alves et al. (2011) [2)]
BC (based on total particles)	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 (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) PM10 estimated as 95 % of TSP, PM2.5 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.

Stoves

This section provides the default emission factors for wood (and similar wood waste) burning in stoves. The emission factors presented here provide an average for a typical solid biomass fraction. Different stoves are distinguished:

- Conventional stoves
- High-efficiency stoves
- Advanced / ecolabelled stoves and boilers

These 3 stove types are described in more detail in Section 2.2.1.

The split between conventional, high-efficiency and ecolabelled stoves should be made based on country specific information. The Guidebook does not contain specific information on a country basis for this split. Generally it is assumed that most stoves in Europe are still conventional, given the relatively long lifetime of stoves. In some European regions however, particularly in Germany and Scandinavian countries, a significant share of the stoves is likely similar to ecolabelled stoves with the associated emission factors. For instance in Denmark, new stoves have to meet stringent regulations. At European level, the Ecodesign Directive includes specific elements aimed to significantly particulate emissions from wood stoves, but this legislation was implemented in January 2022.

If no information is available on the split between different types of stoves, it is good practice to assume all stoves are conventional stoves.

Emission factors for pellet boilers/stoves are provided in the section on "Single house boilers" in Table 3-44.

Table 3-40 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Conventional stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**

			Lower	Upper	
NO_X	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)
SO_X	11	g/GJ	8	40	US EPA (1996/2)
NH_3	8	g/GJ	2	19	DBFZ (2023)
TSP (total particles)	800	g/GJ	400	1600	Alves et al. (2011) and Glasius et al. (2005) [1)]
PM_{10} (total particles)	760	g/GJ	380	1520	Alves et al. (2011) and Glasius et al. (2005) [1)]
$PM_{2.5}$ (total particles)	740	g/GJ	370	1480	Alves et al. (2011) and Glasius et al. (2005) [1)]
BC (based on total particles)	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 3-41 Tier 2 emission factors for source category 1.A.4.b.i, high-efficiency 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	High-efficiency stoves				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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)]
SO_x	11	g/GJ	8	40	US EPA (1996b)
NH_3	8	g/GJ	1	19	DBFZ (2023)
TSP (total particles)	400	g/GJ	200	800	Glasius et al. (2005) [4) 5)]
PM_{10} (total particles)	380	g/GJ	290	760	Glasius et al. (2005) [4) 5)]
$PM_{2.5}$ (total particles)	370	g/GJ	285	740	Glasius et al. (2005) [4) 5)]
BC (based on total particles)	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.
7) Emission factors for solid particles are calculated from the total particulate EFs by assuming the $PM_{2.5}$ solid particle EF is equal to those for conventional stoves (i.e. the emission reduction by using high-efficiency stoves is fully achieved in the condensable fraction). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3-42 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Advanced / ecolabelled stoves and boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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	EMEP/EEA (2009)
SO_x	11	g/GJ	8	40	US EPA (1996/2)
NH_3	4	g/GJ	1	10	DBFZ (2023)
TSP (total particles)	100	g/GJ	20	250	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
PM_{10} (total particles)	95	g/GJ	19	238	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
$PM_{2.5}$ (total particles)	93	g/GJ	19	233	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) [2)]
BC (based on total particles)	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.

Single house boilers (<50 kWth)

This section provides default emission factors for single house boilers, defined as boilers with a thermal capacity below 50 kW. If a dinstiction between manual and automatic feed is made, it is good practice to apply the EFs for conventional boilers (Table 3-43) for manual feed single house boilers, and apply the EFs for pellet stoves (Table 3-44) for automatic feed single house boilers.

Table 3-43 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					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	

NO_X	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)]
SO_X	11	g/GJ	8	40	US EPA (2003)
NH_3	8	g/GJ	1	19	DBFZ (2023)
TSP (total particles)	500	g/GJ	250	1000	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM10 (total particles)	480	g/GJ	240	960	Winther (2008) [3)] and Johansson et al. (2003) [4)]
PM2.5 (total particles)	470	g/GJ	235	940	Winther (2008) [3)] and Johansson et al. (2003) [4)]
BC (based on total particles)	16	% of PM2.5	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) PM10 estimated as 95 % of TSP, PM2.5 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 PM2.5 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.
7) Emission factors for solid particles are calculated from the total particulate EFs by applying the ratio of emission factors for solid / total particles reported in Denier van der Gon et al. (2015). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5μm, and does not contain any BC.

Table 3-44 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 equipment (stoves, fireplaces, cooking,...)			
Technologies/Practices	Pellet stoves and boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated					
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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)
SO_X	11	g/GJ	8	40	US EPA (1996/2)
NH_3	1	g/GJ	0.02	5	DBFZ (2023)
TSP (total particles)	62	g/GJ	31	124	Denier van der Gon et al. (2015)
PM_{10} (total particles)	60	g/GJ	30	120	Denier van der Gon et al. (2015)
$PM_{2.5}$ (total particles)	60	g/GJ	30	120	Denier van der Gon et al. (2015)
BC (based on total particles)	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)
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.

Medium boilers (>50 kWth)

This section provides default emission factors for medium boilers, defined as boilers with a thermal capacity between 50 kW and 50 MW. To apply the emission factors, the fuel consumption needs to be split between 2 capacity ranges: 50 kWth – 1 MWth and 1 MWth – 50 MWth. If no information is available on the split between these two size ranges, it is good practice to assume all medium size boilers are in the size range 50 kWth – 1 MWth.

For the > 1 MWth size range, all boilers are assumed to be automatic feed and EFs are provided in . For the size range 50 kW – 1 MW, a split between manual feed (MB_M) and automatic feed (MB_A). Default split factors on a per country basis are available in Table 3-36 to Table 3-38. Emission factors for manual and automatic feed medium-sized boilers are available in Table 3-47 and Table 3-48, respectively.

If country specific information is used on the share of medium boilers and no split between manual and automatic feed is available, there is also an emission factor table with averaged EFs (Table 3-46). For emissions of PM and NMVOC, the emission factor suggested is the average of the manual and automatic boilers in this size range (50 kWth – 1 MWth) presented in Table 3-47 and Table 3-48.

Table 3-45 Tier 2 emission factors for non-residential sources, medium sized (>1 MWth to ≤ 50 MWth) boilers 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)	20100 20300	Commercial and institutional plants Plants in agriculture, forestry and aquaculture			
Technologies/Practices	Wood combustion >1MW – Boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	NH_3				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	210	g/GJ	50	300	US EPA (2003)
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)]
SO_X	11	g/GJ	8	40	US EPA (2003)
TSP (total particles)	40	g/GJ	20	80	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [5)]
PM10 (total particles)	38	g/GJ	19	76	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [3)] [5)]
PM2.5 (total particles)	37	g/GJ	18	74	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [3)] [5)]
BC (based on total particles)	15	% of PM2.5	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) 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.
5) Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized automatic boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5μm, and does not contain any BC.
6) NH_3 is only relevant in the case of using SCR or SNCR

Table 3-46 Tier 2 emission factors for non-residential sources, medium sized (>50KWth to ≤ 1 MWth) boilers wood (in the absence of information on manual/automatic feed)

Tier 2 emission factors					
	Code	Name			
NFR source category	1.A.4.a.i	Commercial / institutional: stationary			
	1.A.4.c.i	Stationary			
	1.A.5.a	Other, stationary (including military)			
Fuel	Wood				
SNAP (if applicable)	20100	Commercial and institutional plants			
	20300	Plants in agriculture, forestry and aquaculture			
Technologies/Practices	Wood combustion <1MW – Boilers				
Region or regional conditions	NA				
Abatement technologies	NA				
Not applicable					
Not estimated	NH_3				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO_x	91	g/GJ	20	120	Lundgren et al. (2004) 1)
CO	435	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 Kw, German test standard for 500 kW-1MW boilers
NMVOC	156	g/GJ	5	400	Aggregate of Table 3-47 and Table 3-48

SO_X	11	g/GJ	8	40	US EPA (2003)
TSP (total particles)	105	g/GJ	41.5	166	Average of Table 3-47 and Table 3-48
PM10 (total particles)	100.5	g/GJ	39.5	158	Average of Table 3-47 and Table 3-48
PM2.5 (total particles)	98.5	g/GJ	38.5	154	Average of Table 3-47 and Table 3-48
BC (based on total particles)	26	% of PM2.5	8.5	39	Average of Table 3-47 and Table 3-48
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	0.006	0.3	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) Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized manual boilers (there is very little difference between automatic and medium sized boilers concerning the solid and condensable fractions in total PM according to this paper). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5μm, and does not contain any BC.
5) NH_3 is only relevant in the case of using SCR or SNCR

Table 3-47 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 Agriculture / forestry / fishing: 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	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_X	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_X	11	g/GJ	8	40	US EPA (2003)
NH_3	1	g/GJ	0.1	8	DBFZ (2023)
TSP (total particles)	170	g/GJ	85	340	Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden [5)]
PM10 (total particles)	163	g/GJ	81	326	Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden [2) 5)]
PM2.5 (total particles)	160	g/GJ	80	320	Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden [2) 5)]
BC (based on total particles)	28	% of PM2.5	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) [3) 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)
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) PM10 estimated as 95 % of TSP, PM2.5 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.
5) Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized manual boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3-48 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 Agriculture / forestry / fishing: 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	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	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)]
SO_x	11	g/GJ	8	40	US EPA (2003)
NH_3	1	g/GJ	0.1	8	DBFZ (2023)
TSP (total particles)	40	g/GJ	20	80	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [6)]
PM10 (total particles)	38	g/GJ	19	76	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [3) 6)]
PM2.5 (total particles)	37	g/GJ	18	74	Denier van der Gon et al. (2015) applied on Johansson et al. (2004) [3) 6)]
BC (based on total particles)	15	% of PM2.5	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) PM10 estimated as 95 % of TSP, PM2.5 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 residential pellet 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.
5) Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized automatic boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5μm, and does not contain any BC.

Table 3-49 presents the emission factors for solid particles only, for each of the technologies provided in this section for biomass combustion. These are fully consistent with the emission factors provided for total particles in the emission factor Tables above. For reporting purposes, Parties are strongly recommended to use the emission factors for total PM (thus including the condensable component) as provided in the emission factor tables above.

Table 3-49 Emission factors for PM based on solid particles only (for reference)

Technology		TSP	PM_{10}	$PM_{2.5}$	BC (%) 1)	References
Residential	Open fireplaces	270	260	240	24	Denier van der Gon et al. (2015) applied on Efs in Table 3.39
	Conventional stoves	200	160	140	53	Denier van der Gon et al. (2015) applied on Efs in Table 3.40
	High-efficiency stoves	170	150	140	43	Denier van der Gon et al. (2015) applied on Efs in Table 3.41
	Advanced/ecolabelled stoves and boilers	54	49	47	55	Denier van der Gon et al. (2015) applied on Efs in Table 3.42
	Conventional boilers < 50 kW	170	150	140	54	Denier van der Gon et al. (2015) applied on Efs in Table 3.43
	Pellet stoves and boilers (burning pellets)	32	30	30	30	Denier van der Gon et al. (2015), for BC applied on Schmidl et al. (2011)
Non-residential	Medium sized (1-50 MW) boilers	36	34	33	17	Johansson et al. (2004), for BC Denier van der Gon et al. (2015) applied on Schmidl et al. (2011)
	Medium sized (50 kW - 1 MW) boilers	93	88.5	86.5	29	Average of Medium Sized 50kW-1MW for automatic & manual feed
	Manual boilers (<1 MW), manual feed	150	143	140	32	Naturvårdsverket, Sweden, for BC Denier van der Gon et al. (2015) applied on Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011)
	Manual boilers (<1 MW), automatic feed	36	34	33	17	Johansson et al. (2004), for BC Denier van der Gon et al. (2015) applied on Schmidl et al. (2011)

1) Also the BC fraction in this table is only valid for emission factors based on filterable only approach

3.4.5 Activity data

General approach for collecting activity data

The Tier 2 approach for biomass relies on information on the fuel consumption of biomass for different appliance type and separately for wood and pellets. Ideally, data for pellet consumption and other biomass should be available from national data or statistics. However, if this information is not available, a first approximation suggested is to assume that the automatic single house boilers (SHB_A) are using pellets, while all other appliance types use non-pellet solid biomass.

The first prerequisite is the total amount of biomass combustion. This data is commonly available from statistics, e.g. from national statistics, from Eurostat and from the energy balances of the International Energy Agency. It should be recognised that especially for solid biomass, these numbers may be uncertain. 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 could be an underestimation. Consultation with the forestry experts and/or energy demand modelling is recommended to verify and/or adjust the energy consumption figures from statistics. However, some countries do include this aspect in their national statistics on energy consumption. Therefore, without any better information it is good practice to adopt the energy consumption figures available in national or international statistics.

The heating values (net and gross calorific values NCV and GCV) of wood is primarily dependent on the moisture and ash content. At 0% ash and water ("daf") the NCV and GCV of fuel wood are about 19 and 20 MJ/kg, respectively. Ash is inert during combustion and an increase in ash content results in a proportional decrease in heating value. According to (FAO, 2015) ash contents in biomass fuels usually range from 0.5 to 10%, for fuel wood usually between 0.5 and 2% and for other herbaceous agricultural waste lying between 5 and 10% (e.g. straw = 6%). The NCV and GCV of fuel wood at water content W (H(W) in MJ/kg) can be calculated according to $H(W) = (H_{dm}*(100\text{-}W)\text{-}2.44*W)/100$, with H_{dm} being the heating value of the wood in dry (anhydrous) state (NCV or GCV in MJ/kg), W the wood water content (% water on wet basis) and 2.44 the evaporation heat of water at 25°C (MJ/kg). Note that water content is not the same as moisture content (humidity), the difference being that moisture content is expressed on a dry basis while water content is expressed on a wet basis.

Fuel wood water content may vary widely as used, primarily depending on species, drying time and climatic conditions during drying. Newly chopped fresh wood is made up half by water and half by wood substance. Once it has been dried in ambient air, the typical water content is reduced to 15-20% (FAO, 2015). If water content is unknown 20% may be assumed by default. When wood (waste) is processed into pellets the water content decreases to below 10% (e.g. 8%). The water content of oven-dry and torrefied wood may be even lower but the use of oven-dried and torrefied wood in small combustion appliances will likely be small, since this treatment is typically done to strengthen the wood and make it fit for use e.g. as building material. FAO (2015) estimates the following typical NCVs:

Table 3-50 Net Calorific Values for fuel woods with different moisture contents and 1% ash

Type of solid biomass	Water content (%)	NCV (MJ/kg)
Oven-dry wood	5%	18.5
Pellets	8%	17.1
Fuel wood (fully air dried)	15	15.6
Fuel wood (partially air dried)	20%	14.6
Wood chips and surface dry wood	30%	12.4

In addition, advancement of inventory approach from Tier 1 to Tier 2 requires the further disaggregation of fuel use from national totals down into fuel use by specific technology types. Information on fuel use at this level of aggregation is expected to be more limited and would likely require additional surveying/research by the inventory agency to help derive the data needed for further disaggregation. If this information is available or can be collected, it is good practice to use this national data source. However, when this information is not available, this Tier 2 methodology provides default information to stratify the solid biomass consumption according to different appliance types on a per country basis.

More information on activity data is provided in Section 3.3.4 on non-biomass fuels.

Independent estimates of biomass consumption

As mentioned above, some statistical estimates of solid biomass consumption in especially the residential sector may be underestimating the actual use in households. Since wood combustion is a key source of especially particulate emissions, reliable activity data are of crucial importance.

For an independent estimate, several methods exist. Options are to use information on energy demand in space heating (see e.g. Table 3-34) and combine this with statistics on the total surface area (in m^2) in the residential sector. However, it should be noted that a distinction needs to be made between the various fuel types that may be used for space heating (e.g. gas or electricity). Another option is to start from the total energy demand in the residential sector, express this in GJ/person and compare different countries. The latter approach was used by Denier van der Gon et al. (2015), where total wood use for UNECE-Europe by country was estimated by starting from the specific residential wood use per person (GJ / capita), in this case adopted from the GAINS model. The data from the GAINS model show that higher wood consumption occurs in countries with higher wood availability, and based on combining population data with land cover for woodlands a relation between these was derived. Using this, for several countries corrections were introduced. Resulting wood consumption data for the year 2010 are shown in Table 3-50 Net Calorific Values for fuel woods with different moisture contents and 1% ash

Table 3-51 Per capita wood consumption for 2010 estimated by Denier van der Gon et al. (2015)

Country	Per capita wood use (GJ)	Country	Per capita wood use (GJ)
Albania	2.5	Hungary	3.3
Armenia	2.5	Ireland	0.5
Austria	10.0	Italy	2.5
Azerbaijan	1.5	Lithuania	8.2
Belgium	2.4	Luxembourg	2.0
Bulgaria	4.1	Latvia	16.4
Bosnia and Herzegovina	8.2	Moldova	2.6
Belarus	2.6	Macedonia (FYROM)	6.2
Switzerland	2.3	Malta	0.8
Cyprus	0.8	Netherlands	1.1
Czech Republic	5.1	Norway	6.1
Germany	3.2	Poland	3.8
Denmark	8.0	Portugal	2.9
Spain	2.0	Romania	7.5
Estonia	14.0	Russia	4.1
Finland	13.1	Slovakia	4.6
France	5.8	Slovenia	9.5
United Kingdom	0.4	Sweden	4.7
Georgia	1.7	Turkey	2.6
Greece	2.3	Ukraine	3.0
Croatia	6.3	Serbia, Montenegro and Kosovo	7.1

3.5 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.

3.5.1 Use of biomass fuels within small combustion plant (<50MWth)

The Tier 1 inventory approach to produce emission estimates for small combustion plant is based on quantities of fuel types consumed by the small combustion sector (<50MWth). Advancement to the Tier 2 inventory approach level provides the opportunity to refine estimates based on technology types which span both residential and commercial combustion; with technologies detailed in section 2.2 of this guidebook chapter. The further refinement and advancement to Tier 3 inventory approach should assess the impact on emissions that performance issues and age of fleet can have for the small combustion sector. This approach should not be based on an installation-specific emission estimate, but would be suited to proportional analysis of the total number of appliances in use.

Biomass based fuels will typically have greater variation than other fuel types used within the small combustion sector. This is due in part to the evolution and range of wood and biomass appliances that might be in use, but also due to the variation in the nature of the fuel itself which can have significant impacts on the resulting emissions.

In terms of performance for wood based small combustion plant, particularly within the residential sector, Morrin et al (2015), discuss the impacts of setting the equipment in use correctly. For stoves and boilers where the fuel mixture is too rich (ratio of fuel to oxygen favours fuel) combustion is more limited meaning that the carbon is retained in the monoxide form. Emissions for 'rich' operating conditions will increase the amount of carbon monoxide and particulate matter (as soot) generated, while NO_X is reduced due to lack of available oxygen. In lean operating conditions (ratio of fuel to oxygen overly favours oxygen) the performance output of the stove/boiler is reduced, with emission outputs reducing the amount of CO and particulate matter generated but increasing NO_X significantly.

Maintenance and correct setting of equipment in use are likely to have impacts on the quantity and nature of emissions generated from small combustion plant. The Morrin et al (2015) study conducted by the Ireland Environmental Protection Agency, included sampling and analysis of boiler equipment with laboratory trial conditions as well as field sampling for in-use equipment. Table 3-52 provides details of the results of this study for NO_X in particular and highlighting the potential wider variation for wood pellet-based fuels compared to fuel oil and gas equivalents.

The University of Aveiro in Portugal conducted studies as part of the AIRUSE (2014) project to assess the impact that different types of wood have on the resulting emissions to air. This takes into account the fact that different types of wood will vary in terms of oil content, quantity of carbon, and moisture which affect the combustion mechanics. It can also be assumed that the physical nature of the material (wood logs versus wood pellet) would have impact on how completely the wood burns and thus the resulting emissions.

Table 3-52 Sampling and analysis results for boilers within laboratory trials and in-use equipment. Data referenced from Irish EPA Research, Report 149: Improved Emissions Inventories for NOX and Particulate Matter from Transport and Small Scale Combustion Installations in Ireland', 2015

Appliance type	Fuel Type	Number of appliances sampled	Laboratory trials	Field survey of in-use equipment	NO_X	Units
Residential Boiler	Fuel Oil	6	√		42	g/GJ
Residential Boiler	Fuel Oil	23		√	36.6	g/GJ
Commercial Boiler[1]	Fuel Oil	4		√	32-36	g/GJ
Residential Boiler	Gas	4	√		25.8	g/GJ
Residential Boiler	Gas	6		√	48.3	g/GJ
Commercial Boiler[1]	Gas	5		√	19	g/GJ
Residential Boiler	Wood Pellet	3	√		44 – 57	g/GJ
Residential Boiler	Wood Pellet	2		√	75	g/GJ

Commercial Boiler[2]	Wood Pellet	1		√	81	g/GJ

1) Sampling based on appliances used to service offices and schools
2) Sampling based on one 400kw wood pellet boiler.

Table 3-53 and Table 3-54 provide the results of the AIRUSE project with sampling across a variety of different wood types for fireplaces, traditional stoves, and modern ecolabelled stoves. For Fireplaces this illustrated that CO ranged from 2762 – 6258 mg/MJ (equivalent to g/GJ) with black poplar producing the greatest emissions and pellets fuels producing 3151 mg/MJ. For $PM_{2.5}$ the range is from 373 – 1135 mg/MJ with the greatest emissions coming from olive and pellet fuels producing 649 mg/MJ. Traditional stoves showed similar ranges with CO emissions from 2054 – 5362 mg/MJ with cork oak producing the highest emissions, and pellet-based fuels producing 3400 mg/MJ. For PM2.5 emissions range from 150 – 721 mg/MJ with pyrenean oak producing the highest emissions, and pellet-based fuels producing 384 mg/MJ.

The results presented in Table 3-53 and Table 3-54 illustrate potential emissions can be broad with maximum emission values more than double the minimum values. In developing emission estimates to Tier 3 level to account for the broad range in variation for emissions generated by wood fuel-based appliances in the small combustion sector a set of practical steps need to be taken to assess the available activity data and the fleet of appliances in use.

Firstly there is a requirement to better understand the type of wood fuels used within a reporting nation. This information may be available in part from trade associations representing wood/wood pellet sales. However, this will only provide commercially acquired wood stocks. As a second stage use of public surveys to better understand the type and age of appliance, maintenance patterns and frequency of wood use from non-commercial sources can be used to corroborate and develop further nationally held data.

These stages will provide such information as should be needed to help typify the existing in-use fleet of appliances on the market. This should include proportional (percentage) breakdown of the typical types of wood (oak, spruce, pine, etc) and nature of equipment in use (age, well maintained vs poorly maintained). This information should then further be used to help guide in selection of appropriate emission factors for different categories of appliance.

Table 3-53 Emission Factors from traditional appliances (fireplace versus wood stove) – reprinted from AIRUSE 'Emission profiles for biomass burning' March 2014 (units as mg/MJ)

EF [$mg.MJ^{-1}$]														
			CO_2		CO		$PM_{2.5}$		PM_{10}		OC		EC	
	Ref	Fuel	av.	std.	av.	std.	av.	std.	av.	std.	av.	std.	av.	std.
Fireplace	[1]	Maritime pine	93784	7135	2762.16	372.43	372.97	194.59			156.76	70.27	33.51	26.49
		Golden wattle	91730	3714	3340.54	204.86	421.62	335.14			189.19	167.57	18.38	14.05
		Holm oak	90541	7946	3340.54	441.62	702.70	448.65			389.19	216.22	16.22	5.95
		Eucalypt	85676	3930	4264.86	397.30	648.65	410.81			275.68	210.81	19.46	19.46
		Olive	94216	10432	4378.38	433.51	1135.14	540.54			491.89	308.11	21.08	8.65
		Cork oak	89838	16595	4261.62	1183.78	972.97	540.54			540.54	281.08	36.76	21.62
		Portugese oak	88703	2200	4243.24	951.35	756.76	524.32			329.73	183.78	17.30	10.81
		Briquettes/Pellets	91405	2946	3151.35	913.35	648.65	416.22			318.92	227.03	15.68	13.51
	[2]	European beech	94545	4966	4021.15	361.96	311.89	68.11			210.81	49.73	23.24	12.43
		Pyrenean oak	87466	4482	4651.15	761.31	675.68	220.54			487.57	163.78	32.43	4.86
		Black poplar	95406	9667	6258.36	634.20	757.30	275.14			568.11	182.16	42.70	10.27
	[3]	Maritime pine			3243.24	486.49	0.00	0.00	722.42	235.96	431.88	150.08	81.86	41.46
		Eucalypt			4540.54	156.76	0.00	0.00	1093.70	154.10	630.05	90.17	20.88	2.12
		Cork oak			4702.70	551.35	0.00	0.00	744.86	154.13	450.14	103.50	32.45	8.17
Woodstove	[1]	Maritime pine	90270	13568	3086.49	1027.03	281.08	232.43			135.14	135.14	32.97	23.24
		Golden wattle	85622	22324	5216.22	1297.30	427.03	232.43			221.62	143.24	15.68	9.73
		Holm oak	88216	17027	3443.24	1005.41	313.51	210.81			162.16	113.51	12.43	5.41
		Eucalypt	83676	14000	3654.05	772.97	540.54	362.16			281.08	216.22	20.00	16.22
		Olive	93243	17297	3508.11	848.65	470.27	243.24			248.65	118.92	24.86	12.97
		Cork oak	86703	22378	5362.16	1664.86	448.65	329.73			259.46	183.78	22.70	17.84
		Portugese oak	85027	10811	4643.24	691.89	702.70	448.65			335.14	248.65	17.30	8.11
		Briquettes/Pellets	88432	14108	3400.00	854.05	383.78	259.46			200.00	162.16	9.73	6.49
	[2]	European beech	94484	3176	2966.25	209.70	149.73	39.46			86.49	27.03	23.24	7.03
		Pyrenean oak	76477	7369	5166.89	419.34	721.08	203.78			494.05	144.86	48.65	10.81
		Black poplar	101586	1544	4544.21	262.23	236.76	75.68			154.59	59.46	47.57	2.70
	[3]	Maritime pine			2054.05	43.24			256.09	127.43	107.00	32.15	89.80	60.59
		Eucalypt			2540.54	227.03			411.50	132.78	224.35	73.05	32.28	11.85
		Cork oak			2918.92	508.11			300.73	155.00	160.53	99.00	26.80	1.55
	[4]	Maritime pine	87756	1639	3357.38	672.80			351.19	85.80	165.18	112.34	101.61	38.35
		European beech	88298	7781	2569.00	473.58			338.19	3.33	142.95	6.30	67.29	11.90

1) GONÇALVES, C.; ALVES, C.; PIO, C. - Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment. 50 (2012) 297–306. doi: 10.1016/j.atmosenv.2011.12.013.

2) MARTINS, V. I. F. - Emissões de carbono particulado durante a queima doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2012

3) DUARTE, M. A. C. - Emissões de compostos carbonosos pela queima doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2011

4) Vicente, E. A. D. - Medidas para mitigar as emissões da combustão doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2013

Table 3-54 Emission Factors from Modern Ecolabelled stoves – reprinted from AIRUSE 'Emission profiles for biomass burning' March 2014

			EF [mg.MJ^{-1}]									
			CO_2		CO		PM_{10}		OC		EC	
		Fuel	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**
Eco-labelled woodstove	[5]	Maritime pine	88649	525	1485.95	144.86	60.54	13.51	15.68	6.49	23.78	12.97
		Golden wattle	89730	3819	2505.95	120.54	65.95	10.27	12.97	5.41	15.68	5.41
		Eucalyptus	85405	461	2188.11	484.86	111.89	45.95	35.68	16.76	14.59	10.27
		Cork oak	88541	525	3489.73	346.49	156.22	48.65	67.03	13.51	17.84	9.73

			EF [mg.MJ^{-1}]						%PM_{10}				EF [mg.MJ^{-1}]			
			CO_2		CO		PM_{10}		OC		EC		OC		EC	
		Fuel	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**	**av.**	**std.**
Eco-labelled woodstove	**[6]**	Briquettes			939.33		72.77		37.60		33.10		27.36		24.09	
		Beech			1680.96		89.28		37.00		35.60		33.04		31.79	
		Oak			1813.66		71.86		29.80		22.20		21.41		15.95	
		Spruce			1339.82		79.55		32.90		28.30		26.17		22.51	

1) FERNANDES, A. P. et al. - Emission factors from residential combustion appliances burning Portuguese biomass fuels. Journal of environmental monitoring: JEM. 13:11 (2011) 3196–206. doi: 10.1039/c1em10500k.
2) SCHMIDL, C. et al. - Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment. ISSN 13522310. 45:39 (2011) 7443–7454. doi: 10.1016/j.atmosenv.2011.05.006.

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	
Low sulphur light fuel oil	Post 1.1.2008	50 mg/kg	2.3	Calculation with NCV of 42.8 MJ/kg

4.3.3 Residential and small (< 500 kW output) non residential solid fuel boilers

EN303 pt5 is a harmonised EN Standard covering solid fuel central heating hot water boilers up to 500kW output which incorporates emission 'classes' for CO, OGC (volatile organic compounds) and filterable PM. The emission factors associated with the emission concentrations are provided in Table 4-2 and are calculated based on stoichiometric specific flue gas volume of 253 m^3/GJ net fuel input for biomass and 258 m^3/GJ net fuel input for bituminous coal (see Stewart R, 2012 and Appendix B).

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 NO_X emissions.

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

Fuel	Fuel	Appliance	Emission concentration, mg m^{-3} at STP (0 °C, 101.3 kPa), dry and 10 % O_2								
feed	**type**	**output**	**CO**			**'OGC' (VOC)**			**PM**		
type		**kW**	**Class 3**	**Class 4**	**Class 5**	**Class 3**	**Class 4**	**Class 5**	**Class 3**	**Class 4**	**Class 5**
Manual	biogenic	≤50	5 000	1 200	700	150	50	30	150	75	60
		>50≤150	2 500			100			150		
		>150≤500	1 200			100			150		
	fossil	≤50	5 000			150			125		
		>50≤150	2 500			100			125		
		>150≤500	1 200			100			125		
Automatic	biogenic	≤50	3 000	1 000	500	100	30	20	150	60	40
		>50≤150	2 500			80			150		
		>150≤500	1 200			80			150		
	fossil	≤50	3 000			100			125		
		>50≤150	2 500			80			125		
		>150≤500	1 200			80			125		
			Emission factors, g.GJ^{-1} (net thermal input)								
Manual	biogenic	≤50	2 426	582	340	73	24	15	73	36	29
		>50≤150	1 213			49			73		
		>150≤500	582			49			73		
	fossil	≤50	2 470	593	346	73	25	15	61	37	30
		>50≤150	1 235			49			61		
		>150≤500	593			49			61		
Automatic	biogenic	≤50	1 455	485	243	49	15	10	73	29	19
		>50≤150	1 213			39			73		
		>150≤500	582			39			73		
	fossil	≤50	1 482	593	346	49	15	10	61	30	20
		>50≤150	1 235			39			61		
		>150≤500	593			39			61		

Notes:
PM is filterable PM. OGC expressed as Carbon

4.3.4 Ecodesign regulations for small combustion installations

In the EU, several Regulations define minimum requirements (including air emissions) under the Ecodesign Directive. The Directive provides a framework for setting minimum requirements which are given legal force through implementing Regulations.

Implementing regulations have been produced for:

- Space heaters and combination heaters (central heating boilers ≤ 400 kW output gas, oil, electric) and small cogeneration units ≤ 50 kW electrical output;
- Water heaters (≤ 400 kW output gas, oil, electric);
- Solid fuel central heating boilers (≤ 500 kW output, biomass or mineral fuels) and small cogeneration units ≤ 50 kW electrical output;
- Domestic local space heaters ≤ 50 kW output (gas, liquid, electric);
- Commercial local space heaters ≤ 120 kW output (gas, liquid, electric); and
- Solid fuel local space heaters ≤ 50 kW output.

Details of emission limit values are provided at Appendix C, note that whilst emission limit values reflect current controls in some countries, the minimum requirements defined in the Regulations come into effect in the period 2018-2022 (implementation dates are set in the Regulations).

4.3.5 Medium Combustion Plant directive

The EU Directive 2015/2193 on the limitation of emissions of certain pollutants into the air from Medium Combustion Plant (MCP) known as the Medium Combustion Plant Directive (MCPD) regulates pollutant emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 Megawatt thermal (MWth), and less than 50 MWth. The MCPD regulates emissions of SO_2, NOX and dust to air. It also requires monitoring of carbon monoxide (CO) emissions. The emission limit values set in the MCPD apply from 20 December 2018 for new plants and 2025 or 2030 for existing plants, depending on their size.

4.3.6 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	NO_X		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 'Aggregate' 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

6 References

AIRUSE (2014) 'Emission profiles for biomass burning', study by University de Aveiro on behalf of AIRUSE and LIFE+ programme reference

Alves, C., Goncalves, C., Fernandes, A.P., Tarelho, L. & Pio, C., 2011: Fireplace and woodstove fine particle emissions from combustion of western Medeterranean wood types. Atmospheric Research, 2011, 101.

Artjushenko (1985) 'Heating of Private Houses" (1985); Kiev, 178 p. 1985 (in Russian)

Australian Government (2011) 'National Pollutant Inventory Emission estimation technique manual For Combustion in boilers', Version 3.6.

Bäfver, L.S., 2008: Particles from biomass combustion – Characteristics and influence of additives. Chalmers University of Technology.

Berdowski, J.J.M., Veldt, C., Baas, J., Bloos, J.P.J & Klein, A.E., 1995: Technical paper to the OSPARCOM-HELCOM-UNECE emission inventory of heavy metals and persistent organic pollutants. Umweltbundesamt, Berlin, Germany.

Boman Ch., Nordin A., Boström D., and Öhman M. (2004). 'Characterization of Inorganic Particulate Matter from Residential Combustion of Pelletized Biomass Fuels'. Energy&Fuels 18, pp. 338–348, 2004.

Boman C., Nordin A., Öhman M., Boström D. (2005). 'Emissions from small-scale combustion of biomass fuels — Extensive quantification and characterization'. Energy Technology and Thermal Process Chemistry Umeå University, STEM-BHM (P12648-1 and P21906-1), Umeå, February 2005.

Boman, C., Pettersson, E., Westerholm, R., Boström, D. & Nordin, A., 2011: Stove Performance and Emission Characteristics in Residential Wood Log and Pellet Combustion, Part 1: Pellet Stoves. Enery Fuels 2011, 25.

Bryczkowski A., Kubica R. (2002): Inżynieria i Aparatura Chemiczna, 41, nr 4, 14, 2002 (Polish).

Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J-H & Klimont, Z., 2004: A Technology-based Global Inventory of Black and Organic Carbon Emissions from Combustion. Journal of Geophysical Research 109, D14203, doi:10.1029/2003JD003697

Bond, T.C., Wehner, B., Plewka, A., Wiedensohler, A., Heintzenberg, J. & Charlson, R.J., 2006: Climate-relevant properties of primary particulate emissions from oil and natural gas combustion. Atmospheric Environment 40 (2006) 3574–3587.

Broderick, D.R. & Houck, J.E. (2003): Emissions Inventory Improvement Program (EIIP) Residential Wood Combustion Coordination Project. Prepared for Mid-Atlantic Regional Air Management Association

BUWAL 2001: Massnahmen zur Reduktion der PM_{10}-Emissionen. Umwelt-Materialen Nr. 136, Luft. Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern (in German).

Bølling, A.K., Pagels, J., Yttri, K.E., Barregard, L., Sallsten, G., Schwarze, P.E. & Boman, C. (2009). Health effects of residential wood smoke particles: the importance of combustion conditions and physicochemical particle properties. Particle and Fibre Toxicology 2009, 6:29.

CEPMEIP (2004). Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004. 'Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP)'. In: P. Dilara et. al (eds.), *Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004*. EUR 21302 EN, JRC, pp 163–174.

CITEPA, (2003). 'Wood Combustion in Domestic Appliances'. Final background document on the sector, 30.06.2003.

Crowther (1997) 'CRE Group LTD., "Scoping study for the transfer of clean coal technology in the domestic and small industrial markets"; ETSU for DTI, Crown Copyright 1997

DBFZ (2023): Deutsches Biomasseforschungszentrum; NH3- und N2O-Emissionen aus Messungen an fünf Kaminöfen des Projektes Evaluierung der 1. BImSchV von 2010 (UFOKFA), use of the CO and NH3 measurement data (which were measured simultaneously) for calculating the NH3/CO ratio of 0.19% which is generally used for the calculation of the NH3 emission factors for wood combustionDBI 2014, DBI Gas- und Umwelttechnik GmbH 2014, Udo Lubenau, Stefan Schütz, Messungen der Erdgasqualität an verschiedenen Stellen im Netz zur Ableitung bzw. Verifizierung von durchschnittlichen Emissionsfaktoren und Heizwerten von Erdgas

DGC, 2009: Energi- og Miljødata – 2009 opdatering (in Danish).

Denier van der Gon, H. A. C., Bergström, R., Fountoukis, C., Johansson, C., Pandis, S. N., Simpson, D., and Visschedijk, A. J. H. (2015), 'Particulate emissions from residential wood combustion in Europe – revised estimates and an evaluation', Atmos. Chem. Phys., 15, 6503-6519, doi:10.5194/acp-15-6503-2015.

DUKES 2007. Digest of UK Energy Statistics 2007, published by BERR and available here http://stats.berr.gov.uk/energystats/dukesa_1-a_3.xls

Eastern Research Group (2000): Conducting Surveys for Area Source Inventories. Prepared for: Area Source Committee Emission Inventory Improvement Program (EIIP)

EC SCOLF 1999/2005. Sulphur Content of Liquid Fuels Directive 1999/32/EC and 2005/33/EC Marine oil amendment.

Ehrlich et al 2007. Ehrlich C, Noll G, Kalkoff W-D, Baumbach G, Dreiselder A. 'PM_{10} , $PM_{2.5}$ and $PM_{1.0}$ Emissions from industrial plants — Results from measurement programmes in Germany', *Atmospheric Environment* Vol. 41, No 29 (2007) pp. 6236–6254.

EMEP/EEA, 2009, *EMEP/EEA Air pollutant emission inventory guidebook 2009,* European Environment Agency, Technical report No. 9/2009, (https://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009), accessed 19 July 2019.

Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. & Egami, R.T., 2002: The comparison of source contributions from residential coal and low-smoke fuels, using CMB modeling, in South Africa. Environmental Science and Policy 5 (2), 157–167.

England, G.C., Watson, J.G., Chow, J.C., Zielinska, B., Chang, M.-C.O., Loos, K.R. & Hidy, G.M., 2007: Dilution-based emissions sampling from stationary sources: Part 2. Gas-fired combustors compared with other fuel-fired systems. Journal of the Air & Waste Management Association 57 (1), 79-93.

Fernandes, A.P., Alves, C.A., Goncalves, C., Tarelho, L., Pio, C., Schmidl, C. & Bauer, H. (2011): Emission facgtors from residential combustion appliances burning Portuguese biomass fuels. Journal of Environmental Monitoring, 2011, 13, 3196.

Fine, P.M., Cass, G.R. & Simoneit, B.R.T. (2002): Chemical Characterization of Fine Particle Emissions from the Fireplace Combustion of Woods Grown in the Southern United States. Environmental Science & Technology, vol. 36, No. 7, 2002.

Glasius, M., Vikelsøe, J., Bossi, R., Andersen, H.V., Holst, J., Johansen, E. & Schleicher, O. 2005: Dioxin, PAH og partikler fra brændeovne. Danmarks Miljøundersøgelser. 27s –Arbejdsrapport fra DMU nr. 212. http://arbejdsrapport.dmu.dk

Glasius, M., Konggaard, P., Stubkjær, J., Bossi, R., Hertel, O., Ketzel, M., Wåhlin, P., Schleicher,

O. & Palmgren, F., 2007: Partikler og organiske forbindelser fra træfyring – nye undersøgelser af udslip og koncentrationer. Danmarks Miljøundersøgelser. 42s.- Arbejdsrapport fra DMU, nr. 235, http//www.dmu.dk/Pub/AR235.pdf (In Danish)

Goncalves, C., Alves, C., Evtyugina, M., Mirante, F., Pio, C., Caseiro, A., Schmidl, C., Bauer, H. & Carvalho, F., 2010: Characterisation of PM_{10} emissions from woodstove combustion of common woods grown in Portugal. Atmospheric Environment, 2010, 44.

Goncalves, C., Alves, C., Fernandes, A.P., Monteriro, C. Tarelho, L., Evtyugina, M., Pio, C. (2011): Organic compounds in $PM_{2.5}$ emitted from fireplace and woodstove combustion of typical Portuguese wood species. Atmospheric Environment 45 (2011), pages 4533-4545.

Goncalves, C., Alves, C. & Pio, C., (2012): Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 2012

Grebot B. et al (2014) 'Analysis of the impacts of various options to control emissions from combustion of fuels in installations with a total rated thermal input below 50MW', Study on behalf of the European Commission

Gustavsson, L., Johansson, L, Leckner, B, Cooper, D, Tullin, C, Potter, A. 2004 b. 'Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets', *Atmospheric Environment* Vol. 38, Issue 24, pp. 4183–4195, (2004).

EMEP/EEA (2006). EMEP/CORINAIR Emission Inventory Guidebook, version 4 (2006 edition), published by the European Environmental Agency. Technical report No 11/2006. Aavailable via http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html. Generally chapter B216.

Hays M.D., Smith N.D., Kinsey J., Dongb Y., Kariherb P. (2003). 'Polycyclic aromatic hydrocarbon size distributions in aerosols from appliances of residential wood combustion as determined by direct thermal desorption — GC/MS', *Aerosol Science*, 34, pp. 1061–1084, 2003.

Hedberg, E., Kristensson, A., Ohlsson, M., Johansson, C., Johansson, P.-Å., Swietlicki, E., Vesely, V., Wideqvist, U. & Westerholm, R., 2002: Chemical and physical characterization of emissions from birch wood combustion in a wood stove. Atmospheric Environment, 2002, 36

Hedman B., Näslund, M. & Marklund, S., 2006: Emission of PCDD/F, PCB and HCB from Combustion of Firewood and Pellets in Residential Stoves and Boilers, Environmental Science & Technology, 2006, 40

Hernandez, D., Nguyen, Q. & England, G.C., 2004: Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas Fired Combustion Systems. Topical Report: Test Results for a Diesel-Fired Compression Ignition Reciprocating Engine with a Diesel Particulate Filter at Site Foxtrot; Prepared for the U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA; the Gas Research Institute: Des Plains, IL; and the American Petroleum Institute: Washington, DC, 2004.

Hildemann, L.M., Markowski, G.R. & Cass, G.R., 1991: Chemical Composition of Emissions from Urban Sources of Fine Organic Aerosol. Environmental Science & Technology 25(4), 744-759.

Hübner, C., Boos, R. & Prey, T., 2005: In-field measurements of PCDD/F emissions from domestic heating appliances for solid fuels. Chemosphere, 2005, 58.

Hustad J. E., Skreiberg Ø., and Sønju O. K., (1995).'Biomass Combustion Research and Utilisation in IEA Countries, Biomass and Bioenergy', Vol. 9, Nos 1–5, 1995.

Johansson, L.S., Tullin, C., Leckner, B. & Sjövall, P., 2003: Particle emissions from biomass combustion in small combusters. Biomass and Bioenergy, 2003, 25 (435-446).

Johansson, L.S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. & Potter, A., 2004: Emissions characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Atmospheric Environment, 2004, 38.

Johansson, L., Persson H., Johansson, M., Tullin, C., Gustavsson, L., Sjödin, Å., Cooper, D., Potter, A., Paulrud, S., Lundén, E.B., Padban, N., Nyquist, L. & Becker, A., 2006: Fältstudie av metan och andra viktiga komponenter från vedpannor. Etapp 1. 2005. Slut-rapport för Energimyndighetsprojekt nr 21826-1.

Kakareka S., Kukharchyk T., Khomich V. (2004). Research for HCB and PCB Emission Inventory Improvement in the CIS Countries (on an Example of Belarus) / Belarusian Contribution to EMEP. Annual report 2003. Minsk, 2004.

Kakareka, S., Kukharchyk, T., 2006: PCB and HCB emission Sources Chapters in the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook.

Karasek F., Dickson L., (1987). Science, 237, 1987.

Karcz A. et al (1996) 'Fuel coke — an environment friendly alternative to coal. II CUSTNET Conference on Coal Research a Development through Collaboration in Europe"; Ostrawa, Republika Czeska, 2–4.09.1996

Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., Borken-Kleefeld, J., and Schöpp, W.: Global anthropogenic emissions of particulate matter including black carbon, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-880, in review, 2016.

Kubica K. (1994) "'Correlation of coal properties to char, briquette, and utilization characteristics"; Int. Conf. "Production and Utilization of Ecological Fuels from East Central European Coals", Praga, Republika Czeska, 31.10-1.11.1994

Kubica K. (1997) "*Influence of „biofuel" addition on emission of pollutants from fine coal combustion*", Proc. 4th Polish-Danish Workshop on Biofuels, Starbieniewo, 12-14 czerwca 1997

Kubica K. (2002/3). 'Low emission coal boilers as alternative for oil and gas boilers for residential and communal sectors; Coal hasn't to contaminate' Katalog ochrony środowiska — Ekoprofit nr 1 (61)/2002, Katowice, 2002 (Polish).

Kubica K. (2003/3). 'Zagrożenia trwałymi zanieczyszczeniami, zwłaszcza dioksynami i furanami z indywidualnych palenisk domowych i kierunki działań dla ich ograniczenia' ('Threats caused by persistent pollutants, particularly by dioxins and furans from residential heating and the directions of protection actions aiming at their emission reduction'). Project: GF/POL/01/004 — Enabling activities to facilitate early action on the implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs Convention), Warszawa, 2004; http://ks.ios.edu.pl/gef/doc/gf-pol-nip-r1.pdf.

Kubica K. (2004/5). 'Spalanie i współspalanie paliw stałych w miastach' ('Combustion and co-combustion of solid fuels'). Rozdział w monografii 'Zarządzanie energią w miastach' ('Management of energy in the town'). red. R. Zarzycki; ISBN 83-86492-26-0; Polska Akademia Nauk Oddział w Łodzi, Łódź 2004 s. 102–140.

Kubica K., (1997/1). 'Distribution of PAH generated in domestic fuels boilers'. Proc. of the ninth International Conference on Coal Science, Essen, Niemcy, 7–12.9.1997.

Kubica K., (2002/1). 'Emission of Pollutants during Combustion of Solid Fuels and Biomass in Small Appliances'. UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: 'Emissions from Small and Medium Combustion Plants', Ispra, April 2002, Procc. No I.02.87.

Kubica K., (2003/1). 'Environment Pollutants from Thermal Processing of Fuels and Biomass', and 'Thermochemical Transformation of Coal and Biomass' in Termochemical Processing of Coal and Biomass, pp. 145–232, ISBN 83-913434-1-3. Publication, copyright by IChPW and IGSMiE PAN, Zabrze-Kraków, 2003 (Polish).

Kubica K., J. Rańczak J. (2003/3). 'Co-firing of coal and biomass in mechanical great boilers'; Procc., of Int., Conf., Combustion of alternative fuels in power and cement industry, 20–21.2.2003, Opole, Poland, pp. 81–97.

Kubica K., Paradiz B., Dilara (2004/4). 'Toxic emissions from Solid Fuel Combustion in Small Residential Appliances'. Procc. sixth International Conference on Emission Monitoring CEM-2004, 9–11.6.2004, Milano Italy; www.cem2004.it.

Kubica K., Paradiz B., Dilara P., (2004). 'Small combustion installations — Techniques, emissions and measurements', Ispra, EUR report 2004.

Kubica, K., Raińczak, J., Rzepa, S., Ściążko, M., (1997/2). 'Influence of 'biofuel' addition on emission of pollutants from fine coal combustion', Proc. fourth Polish-Danish Workshop on Biofuels, Starbieniewo, 12–14 czerwca 1997/2.

Kupiainen, K., Klimont, Z., (2004). 'Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control', IIASA Interim Report IR-04-079, www.iiasa.ac.at/rains/reports.html

Kupiainen, K. & Klimont, Z. (2007): Primary emissions of fine carbonaceous particles in Europe. Atmospheric Environment 41 (2007), 2156-2170.

Lamberg, H., Nuutinen, K., Tissari, J., Ruusunen, J., Yli-Pirilä, P., Sippula, O., Tapanainen, M., Jalava, P., Makkonen, U., Teinilä, K., Saarnio, K., Hillamo, R., Hirvonen, J.-R. & Jokiniemi, 2011: Physicochemical characterization of fine particles from small-scale wood combustion. Atmospheric Environment, 2011, 45.

Li, V.S., 2006: Conventional Woodstove Emission Factor Study, Environment Canada

Lundgren J. , R. Hermansson, J. Dahl, 2004: Experimental studies of a biomass boiler suitable for small district heating systems, Biomass and Bioenergy, Volume 26, Issue 5, May 2004, Pages 443-453, ISSN 0961-9534, http://dx.doi.org/10.1016/j.biombioe.2003.09.001.

McDonald, J.D., Zielinska, B., Fujita, E.M., Sagebiel, J.C., Chow, J.C. & Watson, J.G, 2000: Fine Particle and Gaseous Emission Rates from Residential Wood Combustion

Muhlbaier, J.L., 1981: Participate and gaseous emissions from natural gas furnaces and water heaters. Journal of the air pollution control association, 31:12, pp. 1268-1273

Naturvårdsverket: Emission factors and emissions from residential biomass combustion in Sweden.

Nielsen, M., Nielsen, O-K. & Hoffmann, L., 2013: Improved inventory for heavy metal emissions from stationary combustion plants – 1990-2009 (in prep.).

Nielsen, M., Nielsen, O-K. & Thomsen, M., 2010: Emissions from decentralized CHP plants 2007 – Energinet.dk environmental project No. 07/1882.

Nussbaumer T., Czasch C., Klippel N., Johansson L. and Tullin C.. (2008/1) 'Particulate emissions from biomass combustion in IEA countries, survey on measurements and emission factors', report for the International Energy Agency (IEA) Bioenergy Task 32, Zurich.

Nussbaumer T., Doberer A., Klippel N., Bühler R. and Vock W. (2008/2), ‚Influence of ignition and operating type on particle emissions from residential wood combustion', 16th European Biomass Conference and Exhibition, 2–6 June 2008, Valencia, Spain.

Morrin et al, (2015) 'Improved emission inventories for NO_X and particulate matter from transport and small scale combustion installations in Ireland' report by the Ireland Environmental Protection Agency reference: ETASCI Report 149

Mudgal S. Et al, (2011) 'Lot 22 Domestic and commercial ovens including when incoporated in ovens', Prepatory studies for Ecodesign requirements of EuPs (III)' reference: TREN/D3/91-2007/-Lot-22-SI2.521661

Pacyna J.M., Munthe J. (2004). 'Summary of research of projects on mercury funded by EC DG Research'. Workshop on Mercury Needs for further International Environmental Agreements, Brussels, 29–30.3.2004.

Paulrud, S., Petersson; K., Steen, E., Potter, A., Johansson, L., Persson, H., Gustafsson, K., Johansson, M., Österberg, S. & Munkhammar, I., 2006: Användningsmöster och emissioner från vedeldade lokaleldstäder I Sverige (in Swedish)

Perry R.H., Green D.W., (1997). Chemical Engineers Handbook, Ed.7, Mc Grow-Hill, London, 1997.

Pettersson, E., Boman, C., Westerholm, R., Boström, D. & Nordin, A., 2011: Stove Performance and Emission Characteristics in Residential Wood Log and Pellet Combustion, Part 2: Wood Stove. Fuels Energy, 2011, 25

Pfeiffer, F., Struschka, M., Baumbach, G., Hagenmaier, H. & Hein, K.R.G., 2000: PCDD/PCDF emissions from small firing systems in households. Chemosphere 40 (2000) 225-232.

Pulles, T., van der Gon, H.D., Appelman, W. & Verheul, M. (2012): Emission factors for heavy metals from diesel and petrol used in European vehicles. Atmospheric Environment. Accepted, in press.

Pye S., Jones G., Stewart R., Woodfield M., Kubica K., Kubica R., Pacyna J. (2005/1). 'Costs and environmental effectiveness of options for reducing mercury emissions to air from small-scale combustion installations', AEAT/ED48706/Final report v2, December 2005.

Pye S., Thistlethwaite G., Adams M., Woodfield M., Goodwin J., Forster D., Holland M. (2004). Study Contract on the Cost and Environmental Effectiveness of Reducing Air Pollution from Small-scale Combustion Installations' (EC reference ENV.C.1/SER/2003/0099r), http://europa.eu.int/comm/environment/air/cafe/

Quass U., Fermann M., Bröker G.; (2000). 'The European Dioxin Emission Inventory — Stage II Desktop studies and case studies'. Final report 31.12.2000, Vol. 2, pp. 115–120, North Rhine Westphalia State Environment Agency.

Rau, J.A. 1989. Composition and Size Distribution of Residential Wood Smoke Particles. Aerosol Science and Technology 10, 181-192. As cited in Kupiainen & Klimont (2002).

Roe S.M., Spivey, M.D., Lindquist, H.C., Kirstin B. Thesing, K.B., Randy P. Strait, R.P & Pechan, E.H. & Associates, Inc, 2004: Estimating Ammonia Emissions from Anthropogenic Non-Agricultural Sources. Draft Final Report. April 2004.

Schmidl, C., Luisser, M., Padouvas, E., Lasselsberger, L., Rzaca, M., Cruz, C.R.-S., Handler, M., Peng, G., Bauer, H. & Puzbaum, H., 2011: Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment, 2011, 45.

Syc, M., Horak, J., Hopan, F., Krpec, K., Tomsej, T., Ocelka, T. & Pekarek, V., 2011: Effect of Fuels and Domestic Heating Appliance Types on Emission Factors of Selected Organic Pollutants. Environmental Science & Technology, 2011.

Simoneit, Bernd R.T., 2002: Biomass burning — a review of organic tracers for smoke from incomplete combustion, Applied Geochemistry, Volume 17, Issue 3, March 2002, Pages 129-162, ISSN 0883-2927, http://dx.doi.org/10.1016/S0883-2927(01)00061-0.Skreiberg, Ø., 1994. 'Advanced techniques for Wood Log Combustion'. Procc. from Comett Expert Workshop on Biomass Combustion May 1994.

Stewart R, (2012) 'Conversion of biomass boiler emission concentration data for comparison with Renewable Heat Incentive emission criteria', Report for Defra. Reference: AEA/R/ED46626/AEA/R/3296.

Struschka, M., Kilgus, D., Springmann, M. & Baumbach, G., 2008: Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung, 44/08, Umwelt Bundes Amt, Universität Stuttgart, Institut für Verfahrenstechnid und Dampfkesselwesen (IVD)

The Italian Ministry for the Environment, 2005: Experimental study on atmospheric pollutant emissions from heating systems, in Italy. Promoted by the Italian Ministry for the Environment, in cooperation with: The Lombardy Region, the Piedmont Region, the Italian Oil Union, Assopetroli, ENEA, CTI, SSC, IPASS.

Tissari, J., Hytönen, K., Lyyränen, J. & Jokiniemi, J., 2007: A novel field measurement method for determining fine particle and gas emissions from residential wood combustion. Atmospheric Environment, 2007, 41.

UNEP, 2005: Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. United Nations Environment Programme.

US EPA (1989): Effect of burn rate, wood species, moisture content and weight of wood loaded on woodstove emissions, Project summary, EPA/600/S2-89/025, December 1989.

US EPA(1996/1): US EPA AP-42, chapter 1.9, Residential Fireplaces

US EPA(1996/2): US EPA AP-42, chapter 1.10, Residential Wood Stoves

US EPA, 1998: Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors. Chapter 1.4: Natural gas combustion.

US EPA, 2000: Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors. Chapter 3.1: stationary gas turbines.

US EPA, 2003: Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors. Chapter 1.6: Wood residue combustion in boilers.

US EPA, 2011: SPECIATE Version 4.3

Wien, S., England, G. & Chang, M., 2004b: Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas Fired Combustion Systems. Topical Report: Test Results for a Combined Cycle Power Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Bravo; Prepared for the U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA; the Gas Research Institute: Des Plains, IL; and the American Petroleum Institute: Washington, DC, 2004.

Winther, K., 2008: Vurdering af brændekedlers partikelemission til luft i Danmark (in Danish)

Zhang, J., Smith, K.R., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.K., Rasmussen, R.A. & Thorneloe, S.A., 2000: Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. Atmospheric Environment 34 (2000) 4537-4549.

Zhang, H., Wang, S., Hao, J., Wan, L., Jiang, J., Zhang, M., Mestl, H.E.S., Alnes, L.W.H., Aunan, K. & Mellouki, A.W., 2012: Chemical and size characterization of particles emitted from the burning of coal and wood in rural households in Guizhou, China. Atmospheric Environment 51 (2012) 94-99

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 CH_4 or C_3H_8 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:

1) No information about NMVOC and VOC standard reference — usually CH_4 or C_3H_8 are used.

2) Original data in g/kg.
3) 10 kW open fire, smokeless coal brands.
4) Stoves, charcoal and char briquettes, 12.5 kW roomheater, coke and manuf. briq.
5) UNECE TFEIP: Dutch fig. for coke use.
6) UNECE TFEIP: Sweden, pellet boilers, 1.8–2 MW.
7) As THC.
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	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
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
NO_X 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 Aggregate 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 Aggregates 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. (°C)	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 $10 m^3/kg$ 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 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 Aggregate 130	-	-	-
NO_X (as NO_2) [2)]	17–22 Aggregate 20	-	-	-	35–55 Aggregate 40	-	-	-
CO [2)]	7–12 Aggregate 9	-	-	-	10–12 Aggregate 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) 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
	Aggregate	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
	Aggregate	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
	Aggregate	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
	Aggregate	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, NO_X 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
	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

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_X (as NO_2)	CO
	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
Boman et al., 2005	Pellet stove 4.8 kW (high load)	n.d.	31–36; Aggregate 33	52–100; Aggregate 88
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	29–33; Aggregate 31	243–383; Aggregate 299
	Natural-draft wood stove, 9 kW; birch pine spruce	n.d.	37–71; Aggregate 50	1 200–7 700; Aggregate 3 800
	Pellet stove, 4–9.5 kW; pine and spruce (high load)	n.d.	57–65; Aggregate 61	110–170; Aggregate 140
	Pellet stove, 4- 9,5 kW; pine and spruce (low load 30 %)	n.d.	52–57; Aggregate 54	320–810; Aggregate 580
Kubica, 2004/2	Pellet boilers			
Kubica at al., 2005/4	Automatic-fuelled coal boilers - stocker; pea coal (qualified size)	120–450; Aggregate 260	96–260; Aggregate 190	90–850 Aggregate 280
	Automatic-fuelled coal boilers; fine coal (qualified coal size)	355–600 Aggregate 420	70–200 Aggregate 145	60–800 Aggregate 450
Kubica K.; 2004/1	Conventional stove 5 kW	253	81	2 272
	Boiler, stocker; wood pellets	n.d.	n.d.	300–500

Source	Installation/fuel	Pollutants (g/GJ)		
		SO_2	NO_X (as NO_2)	CO
Kubica, 2004/2	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
Kubica at al., 2005/23)	Automatic-fuelled coal boiler — stocker, ≤ 25 kW (120 pieces); pea coal	n.d.	67–207; Aggregate 161	104–320; Aggregate 150
	Automatic-fuelled coal boiler, ≤ 35 kW (68 pieces); fine coal,	155–496 Aggregate 252	64–208; Aggregate 122	119–435; Aggregate 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)]

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
	Domestic closed stove; CRE; < 10 kW, smokeless coal brands	n.d.	42-50 [2)]	n.d.
	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 Aggregate 78
	Automatic-fuelled coal boiler, fine coal, 25 and 35 kW (68 pieces)	n.d.	n.d.	70–380 Aggregate 187
Kubica et al., 2005/3	Hard coal; stoves and boilers < 1 MW	25-100 Aggregate 65	25-1050 aver.270	30-1,200 Aggregate 360
	Hard coal; boilers > 1 MW < 50 MW	70-122 Aggregate 70	90-250 Aggregate 110	25-735 Aggregate 140

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
	Brown coal Residential/commercial/institutional/	140	260	350
	Coke Residential/commercial/institutional/	30 -80 Aggregat e 80	96-108 Aggregate 90	14-133 Aggregate 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
	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	$PM_{2.5}$	PM_{10}	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

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
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
	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

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
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
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

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
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; Aggregate 380
	Woodstove	n.d.	n.d.	140–450; Aggregate 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
	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 Aggregate 240
	Pellet burner boilers 10–15 kW, horizontal feeding of the fuel; sawdust, logging residues and bark	n.d.	n.d.	57-157 Aggregate 95

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Pellet burner boilers 10–15 kW, underfeeding of the fuel; sawdust, logging residues and bark	n.d.	n.d.	64-192 Aggregate 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.	Aggregate 590
	All factory-built fireplaces with open door, cordwood	n.d.	n.d.	Aggregate 840
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

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	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 Aggregate 15
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	n.d.	32–81 Aggregate 51
	Natural-draft wood stove, 9 kW; birch pine spruce	n.d.	n.d.	37–350 Aggregate 160
	Pellet stove, 4–9,5 kW; pine and spruce (high load)	n.d.	n.d.	15–17; Aggregate 16
	Pellet stove, 4–9,5 kW; pine and spruce (low load 30 %)	n.d.	n.d.	21–43 Aggregate 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

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
	Automatic-fuelled coal boiler, wood chips	n.d.	n.d.	60
Kubica et al., 2005/3	Residential/commercial/institutional/	9–698 Aggregate 450	10–713 Aggregate 490	17–4 000 Aggregate 520
	Boilers > 1MW < 50 MW	9–170 Aggregate 80	60–214 Aggregate 80	20–500 Aggregate 100
Hedberg et al., 2002 [2)]	Commercial soapstone stove, birch logs	6–163 Aggregate 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
	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.

Source	Installation type	$PM_{2.5}$	PM_{10}	TSP
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.

Technology-specific references for Appendix A

APEG (The Airborne Particle Expert Group) (1999). 'Source apportionment of airborne particulate matter in the United Kingdom'. Prepared on behalf of the Department of the Environment, Transport and the Regions, the Welsh Office, the Scottish Office and the Department of the Environment (Northern Ireland).

Baart A., Berdowski J., van Jaarsveld J. and Wulffraat K., (1995). 'Calculation of atmospheric deposition of contaminants on the North Sea', TNO-MEP-R 95/138, Delft, The Netherlands.

Bartle K.D., Ściążko M., Kubica K. (1996). 'Clean Coal — Derived Solid Fuels for Domestic and power Plant Combustion'. Report 1996, contract CIPA-CT92-3009, 1996.

Baumbach G., Zuberbühler U., Struschka M., Straub D., Hein K.R.G. (1999). 'Feinstaubuntersuchungen an Holzfeuerunge', Teil 1: Bereich Hausbrand und Kleingewerbe. Institut für Verfahrenstechnik und Dampfkesselwesen, Report No 44–1999, Universtät Stuttgart. Juli 1999.

Berdowski J.J.M., Bass J., Bloos J.P.J., Visschedijk A.J.H., Zandveld P.Y.J., (1997). 'The European Atmospheric Emission Inventory for Heavy Metals and Persistent Organic Pollutants', Umweltforschungsplan des Bundesministers fur Umwelt, Naturchutz und Raktorsicherheit. Luftreinhaltung. Forschunbericht 104 02 672/03. TNO, Apeldorn, The Netherlands, 1997.

BLT (Various 1999–2005). BLT — Biomass Logistics Technology Francisco Josephinum, Wieselburg, Austria. Reports are available at this link: http://blt.josephinum.at/index.php?id=653

Boman C., Nordin A., Öhman M., Boström D. (2005). 'Emissions from small-scale combustion of biomass fuels — Extensive quantification and characterization', Energy Technology and Thermal Process Chemistry Umeå University, STEM-BHM (P12648-1 and P21906-1), Umeå, February 2005.

Boman Ch., Nordin A., Boström D., and Öhman M. (2004). 'Characterization of Inorganic Particulate Matter from Residential Combustion of Pelletized Biomass Fuels', Energy&Fuels 18, pp. 338–348, 2004

Bostrom Curt-Ake, (2002). 'Emission Factors for Small Scale Combustors (Bio-Fuels). IVL, Sweden', UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: 'Emissions from Small and Medium Combustion Plants', Ispra, April 2002, Procc. No. I.02.87.

Broderick D.R., Houck J.E. (2005). 'Development of a Fireplace Baseline Particulate Emission Factor Database', OMNI Consulting Services, Inc. www.omni-test.com/publications/baselinepaper1.pdf

Bryczkowski A., Kubica R. (2002). 'Inżynieria i Aparatura Chemiczna', 41, No 4, 14, 2002 (Polish).

BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (1995). 'Emissionsfaktoren für Stationäre Quellen', BUWAL, Bern.

BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (2001). 'Massnahmen zur Reduktion von PM_{10}-Emissionnen', Schlussbericht, BUWAL Abteilung Luftreinhaltung und NIS, January, 2001.

Caserini S., Monguzzi A.M., Fracaroli A., Moretti M., Giudici A. (2003). Distribuzione delle emissioni di diossine in atmosfera in Lombardia: scenario attuale e trend per le principali sorgenti, 1 Convegno: Ingegneria e Chimica per l'Ambiente 'POP: diffusione nell'ambiente, loro controllo e tecnologie di abbattimento' Milano, 26–27.11.2003, www.aidic.it/POP/convegno%20novembre%202003.htm

Caserini Stefano, (2004). Private Communication, Technical University Milano.

CEC (2003). 'European energy and transport. Trends to 2030', KO-AC-02-001-EN-C, European Commission, Directorate General for Energy and Transport, Luxembourg.

CEPMEIP (2002). 'Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance', 2002, www.air.sk/tno/cepmeip/

Chapter Combustion Plants as Point Sources — B111, EMEP/Corinair Atmospheric Emission Inventory Guidebook.

CITEPA, (2003). 'Wood Combustion in Domestic Appliances'. Final background document on the sector, 30.6.2003.

Cofala J., Klimont, Z., Amann, M. (2006). 'The potential for further control of emissions of fine particulate matter in Europe', IIASA IR 06-011. www.iiasa.ac.at/rains/reports/wp-06-011.pdf

COM(2003). 423 final, 'Proposal for a Directive of the European Parliament and of the Council relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air', Brussels, 16.7.2003.

Compilation of Air Pollutant Emission Factors (AP-42) (1996). Volume 1: 'Stationery Point and Planning and Standards', Research triangle Park. North Carolina, 1996.

Czekalski B., Drodz W., (2003). 'Emission from oil and gas boilers — The results of investigation in Poland. Personal communication', EN-POL, Katowice, Poland, October 2003.

Davies M., Rantall, T.D., Stokes B.J., Williamson F., (1992). 'Characterisation of Trace Hydrocarbon Emissions from Coal Fired Appliances'. Final report on Ecsc. Project No 7220–ED821. Report No ENV/27.

Determination of Mean Emission Factors as Representative Figures for Emission of Stuttgart — IVD (1996, final report to P&D. Project 29546364/ Emission Factors, 1996.

Dreiseidler, A., Baumbach, G., Pregger, T., and Obermeier, A. (1999). 'Studie zur Korngrößenverteilung (< PM_{10} und $PM_{2.5}$) von Staubemissionen', Forschungsbericht 297 44 853, i. A. Des Umweltbundesamtes Berlin, Germany (different UBA sources, partly personal communication, cited in this study).

Ehrlich Ch., Noll G., Kalkoff W.-D. (2001). 'Overview of investigations on aerosols from combustion (including biomass) in Germany', pp. 50 in Aerosols from Biomass Combustion, ISBN 3-908705-00-2, International Seminar at 27.6.2001 in Zurich by IEA Bioenergy Task 32 and Swiss Federal Office of Energy, Verenum, Zurich 2001, www.ieabcc.nl/publications/aerosols.pdf.

Emission Factors Manual PARCOPM–ATMOS (1993). 'Emission Factors for Air Pollutants', final version — TNO report 92–233/112322-24285, 1992, 1993.

EPA (Environmental Protection Agency, 1996). 'Report on Revisions to fifth Edition AP-42 Section 1.10 Residential Wood Stoves', pp. 10/92, United States Environmental Protection Agency. Research Triangle Park, North Carolina, U.S.

EPA (Environmental Protection Agency, 1998a). 'Compilation of Air Pollutant Emission Factors', fifth edition, EPA AP-42, United States Environmental Protection Agency. Research Triangle Park, North Carolina.

EPA (Environmental Protection Agency, 1998b). 'Compilation of Air Pollutant Emission Factors, Section 7.1, Residential Wood Combustion', fifth edition, EPA AP-42. United States Environmental Protection Agency. Research Triangle Park, North Carolina, U.S.

Fine P.M., Cass G.R., Simoneit B.T. (2001). 'Chemical Characterization of Fine Particle Emissions from Fireplace Combustion of Woods Grown in the Northeastern United States', *Environmental, Science and Technology* 35, pp. 2665–2675, 2001.

Fine P.M., Cass G.R., Simoneit B.T. (2002). 'Chemical Characterization of Fine Particle Emissions from the Fireplace Combustion of Woods Grown in the Southern United States', *Environmental, Science and Technology* 36, pp. 1442–1451, 2002.

Gaegauf U.Ch., Wieser, Y. Macquat W.Y. (2001). 'Field investigation of nanoparticle emissions from various biomass combustion systems' pp. 80 in Aerosols from Biomass Combustion, ISBN 3-908705-00-2, International Seminar on 27.6.2001 in Zurich by IEA Bioenergy Task 32 and Swiss Federal Office of Energy, Verenum, Zurich 2001 www.ieabcc.nl/publications/aerosols.pdf

Geueke K.J., Gessner A., Hiester E., Quaß U., Bröker G., (2000). 'Elevated Emissions of Dioxin and Furans from Domestic Single Stove Coal Combustion', Organohalogen Compounds, Vol. 46, pp. 272–275, 2000.

Glasius, M, Vikelsoe, J, Bossi, R, Vibeke Andersson, H, Holst, J, Johansen, E and Schleicher, O. 2005. Dioxin, PAH og partikler fra braendeovne. Danmarks Miljöundersogelser, Miljöministeriet. DMU nr 212. (In Danish).

Grochowalski A, (2002). 'Ambient air concentration and emission of dioxins in Poland' and 'Results of dioxins emission measurements from thermal processes in Poland 1996–2002'. Proc., of JRC Workshop on the Determination of Dioxins in Industrial Emissions, Brno, Czech Republic, 16–19.4.2002, pp. 87.

Gulland J. (2003). 'Residential Wood Combustion, Overview of Appliance Categories', June 2003, updated September 2003.

Gullett B.K., Touati A., Hays M.D. (2003). 'PCDD/F, PCB, HxCBz, PAH, and PM Emission Factors for Fireplace and Woodstove Combustion in the San Francisco Bay Region', *Environmental, Science and Technology* 37, pp. 1758–1765, 2003.

Hays M.D., Smith N.D., Kinsey J., Dongb Y., Kariherb P. (2003). 'Polycyclic aromatic hydrocarbon size distributions in aerosols from appliances of residential wood combustion as determined by direct thermal desorption — GC/MS', *Aerosol Science*, 34, pp. 1061–1084, 2003.

Hedberg E., Kristensson A., Ohlsson M., Johansson C., Johansson P., Swietlicki E., Vesely V., Wideqvist U., Westerholm R. (2002). 'Chemical and physical characterization of emissions from birch wood combustion in a wood stove', *Atmospheric Environment* 36, pp. 4823–4837, 2002.

Heslinga D., (2002). 'Emission from stationary combustion sources smaller that 20 kW in the Netherlands: methodology and emission factors', UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: 'Emissions from Small and Medium Combustion Plants', Ispra, April 2002, Procc. No I.02.87.

Hlawiczka S., Fudala J. (2003). 'Distribution of Cd, Pb and Hg emissions among sectors of economy in Poland and the emission assessment for the years 1990–2000' in: Environmental Engineering Studies, Polish Research on the way to the EU. Kluwer Academic/Plenum Publishers, New York, 2003.

Hlawiczka S., Kubica K., Zielonka U., (2003). 'Partitioning factor of mercury during coal combustion in low capacity domestic heating appliances', *The Science of the Total Environment*, Elsevier, 312, pp. 261–265, 2003.

Hobson M., Thistlethwaite G., (2003). 'Emission factors programme Task 7 — Review of Residential and Small-Scale Commercial Combustion Sources', AEAT/ENV/R/1407, Issue 1.

Houck J.E., Broderick D.R. (2005). '$PM_{2.5}$ Emission Reduction Benefits of Replacing Conventional Uncertified Cordwood Stoves with Certified Cordwood Stoves or Modern Pellet Stoves', OMNI Environmental Services, Inc.. Prepared for Hearth, Patio and Barbecue Association, 26.5.2005, www.omni-test.com/publications/Emission_Reduction.pdf

Houck J.E., Crouch J., Huntley R.H. (2001). 'Review of Wood Heater and Fireplace Emission Factors', OMNI Consulting Services Inc., Hearth Products Association, U.S. EPA. www.omni-test.com/publications/ei.pdf

Houck J.E., Scott A.T., Purvis C.R., Kariher P.H., Crouch J. and Van Buren M.J. (2000). 'Low emission and high efficiency residential pellet-fired Heaters'. Proceedings of the Ninth Biennial Bioenergy Conference, Buffalo, NY, October 15–19, 2000, www.omni-test.com/Publications.htm

Houck J.E., Tiegs P., E., (1998). 'Residential Wood Combustion — $PM_{2.5}$ Emissions', Westar $PM_{2.5}$ Emission Inventory Workshop, Reno, Nevada, 22–23.7.1998.

Houck J.E., Tiegs P., E., (1998/1). 'Residential Wood Combustion Technology Review',. Vol. 1. Technical report, EPA-600/R-98-174a, December 1998.

Houck, J. and Tiegs, P.E. (1998). 'Residential Wood Combustion Technology Review' EPA-600/R-98-174 (Volumes 1 and 2).

Hübner C., Boos R., Prey T. (2005). 'In-field measurements of PCDD/F emissions from domestic heating appliances for solid fuels', Chemosphere 58, pp. 367–372, 2005.

Hustad J. E., Skreiberg Ø., and Sønju O. K., (1995).'Biomass Combustion Research and Utilisation in IEA Countries, Biomass and Bioenergy', Vol. 9, Nos 1–5, 1995.

IIASA (International Institute for Applied Systems Analysis), 2004. 'Results of the RAINS model developed at IIASA', Laxenburg, Austria, www.iiasa.ac.at/rains

Johansson L., TullinC., Leckner B. (2001). 'Particulate emissions from small-scale biomass combustion' pp. 87 in Aerosols from Biomass Combustion, ISBN 3-908705-00-2, international seminar on 27.6.2001 in Zurich by IEA Bioenergy Task 32 and Swiss Federal Office of Energy, Verenum, Zurich 2001 www.ieabcc.nl/publications/aerosols.pdf

Johansson, L et al. (2006). 'Fältmätningar av metan och andra viktiga komponenter från ved pannor' (Field measurements of methane and other parameters from wood log boilers). SP Swedish National Testing and Research Institute. Borås, Sweden 2006. STEM-BHM (21826-1, 21826-2, 5030403). In Swedish with English summary.

Johansson, L, Johansson, M, Tullin, C (2004a). 'Emissionsnivåer av komponenter som omfattas av miljömålet 'Frisk luft' vid P-märkning och miljöprovning av eldningsutrustning för villor' (Emission parameters within the Swedish environmental objective clean air to the emission levels obtained during the testing of domestic combustion devices for testing of emission limits and by the P-mark). SP Swedish National Testing and Research Institute. Borås, Sweden 2004. STEM-BHM (20710-1). In Swedish with English summary.

Johansson, L, Leckner, B, Gustavsson, L, Cooper, D, Tullin, C, Potter, A. 2004 b. 'Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets', *Atmospheric Environment* 38 (2004) pp. 4183–4195.

Kakareka S., Kukharchyk T., Khomisch V., (2003). 'Belarusian Contribution to EMEP'. Annual report 2002, Minsk-Moscow, January 2003.

Karasek F., Dickson L., (1987). *Science*, 237, 1987

Karcz A., Kubica K., Ściążko M.. 'Fuel coke — An environment friendly alternative to coal. II CUSTNET Conference on Coal Research a Development through Collaboration in Europe', Ostrawa, Republika Czeska, 2–4.09.1996.

Karvosenoja, N. (2000). 'Results of investigation in Finland. Personal communication'.

Klimont Z., Cofala J., Bertok I., Amann M., Heyes Ch., and Gyarfas F. (2002). 'Modelling Particulate Emissions in Europe: A Framework to Estimate Reduction Potential and Control Costs'. Interim report IR-02-076. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, www.iiasa.ac.at/rains/reports/ir-02-076.pdf

Krucki A., Juńczyk J. (2006). Private communication, Instytut Techniki Cieplnej w Lodzi, June 2006.

Kubica K. (2001/1). 'Combustion of biomass in small capacity appliances — Emission of pollutants', Międzynarodowa Konferencja nt. 'Odnawialne źródła energii u progu XXI wieku', s. 419, Warszawa 2001 (Polish, abstract in English).

Kubica K. (2002/3). 'Low emission coal boilers as alternative for oil and gas boilers for residential and communal sectors; Coal hasn't to contaminate' Katalog ochrony środowiska — Ekoprofit nr 1 (61)/2002, Katowice, 2002 (Polish).

Kubica K. (2003/3). 'Zagrożenia trwałymi zanieczyszczeniami, zwłaszcza dioksynami i furanami z indywidualnych palenisk domowych i kierunki działań dla ich ograniczenia' ('Threats caused by persistent pollutants, particularly by dioxine and phuranes from residential heating and the directions of protection actions aiming at their emission reduction'). Project: GF/POL/01/004 — Enabling activities to facilitate early action on the impementation of the Stockholm Convention on Persistent Organic Pollutants (POPs Convention). Warszawa, 2004, http://ks.ios.edu.pl/gef/doc/gf-pol-nip-r1.pdf

Kubica K. (2004/1). 'Toxic Pollutants Emission from either Combustion Process and Co-Combustion of Coal and Biomass', 'Ochrona Powietrza w Teorii i Praktyce', ISBN 83-921514-0-2 pp. 213–229, Zabrze, 2004 (in Polish, abstract in English).

Kubica K. (2004/2). 'Analiza wskaźników emisji zanieczyszczeń do powietrza — pyłów, wielopierścieniowych węglowodorów aromatycznych — ze spalania paliw'. Raport 30-011-BK-3086 dla IOS. Warszawa, 30 grudzień, 2004 (in Polish).

Kubica K. (2004/5). 'Spalanie i współspalanie paliw stałych w miastach' ('Combustion and co-combustion of solid fuels'), Rozdział w monografii 'Zarządzanie energią w miastach' ('Management of energy in the town'), red. R. Zarzycki, ISBN 83-86492-26-0, Polska Akademia Nauk Oddział w Łodzi, Łódź 2004. 102–140.

Kubica K. (2006/2). 'Występowanie metali ciężkich w biomasie drzewnej Gmin Zabrze i Bytom w aspekcie jej wykorzystania w energetyce i produkcji kompostu' ('Appearence of heavy metals in wood biomass of Zabrze and Bytom Communes owing to its use in energy and compost production'). Interim report, July 2006, WSEiA, Bytom.

Kubica K., (1997/1). 'Distribution of PAH generated in domestic fuels boilers'. Proc. of ninth International Conference on Coal Science, Essen, Niemcy, 7–12.09.1997.

Kubica K., (1998). 'The effect of coal combustion process in stable bed conditions on generation and distribution of PAHs'. Proc. of the II International Scientific Conference 'Air Protection in theory and Application', 339, Szczyrk, 2–4.6.1998.

Kubica K., (2002/1). 'Emission of Pollutants during Combustion of Solid Fuels and Biomass in Small Appliances', UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: 'Emissions from Small and Medium Combustion Plants', Ispra, April 2002, Procc. No.I.02.87 .

Kubica K., (2003/1). 'Environment Pollutants from Thermal Processing of Fuels and Biomass', and 'Thermochemical Transformation of Coal and Biomass' in Termochemical Processing of Coal and Biomass; pp. 145–232, ISBN 83-913434-1-3, publication. Copyright by IChPW and IGSMiE PAN, Zabrze-Kraków, 2003, (in Polish).

Kubica K., et al. (2002/2). 'Development of technologies for biomass utilization'. Report IChPW 1.3.2002 (in Polish).

Kubica K., Hlawiczka S., Cenowski M., Kubica R. (2005/3). 'Analiza zmian wskaźników emisji pyłu z wybranych procesów w okresie 1990–1999'. Raport dla IOS, Warszawa, wrzesień, 2005 (in Polish)

Kubica K., J. Rańczak J. (2003/3). 'Co-firing of coal and biomass in mechanical great boilers'. Procc., of Int., Conf., Combustion of alternative fuels in power and cement industry, 20–21.2.2003, Opole, Poland, pp. 81–97.

Kubica K., Kubica R., Pacyna J., Pye S., Woodfield M. (2006/1). 'Mercury emission from combustion of coal in SCIs', MEC3 — Mercury Emissions from Coal Third International Experts' Workshop, Katowice, Poland, 5–7.6.2006, www.nilu.pl/mec3/

Kubica K., Kubica R., Zawiejska Z., Szyrwińska I. (2005/2). 'Ocena efektów ekologicznych i społecznych programu obniżenia niskiej emisji, zrealizowanego w Tychach w latach 2002–2004 w dzielnicach obrzeżnych miasta'. Raport Nr 0433/05 z dnia 01-03-2005 NILU Polska Sp. z o.o., SOZOPROJEKT Sp. z o.o., Katowice, maj, 2005.

Kubica K., Misztal M., (1997/3). 'Promotion of Low Emission Coal Fired Boilers'. Report Thermie B Action DIS-0715-95-UK, IChPW, Zabrze, March 1997.

Kubica K., Paradiz B., Dilara (2004/4). 'Toxic emissions from Solid Fuel Combustion in Small Residential Appliances'. Procc. Sixth International Conference on Emission Monitoring CEM-2004, 9–11.6.2004, Milano Italy, www.cem2004.it

Kubica K., Paradiz B., Dilara P., (2004). 'Small combustion installations — Techniques, emissions and measurements', Ispra, EUR report 2004.

Kubica K., Ranczak J, Matuszek K., Hrycko P., Mosakowski S., Kordas T. 'Emission of Pollutants from Combustion of Coal and Biomass and Its Co-firing in Small and Medium Size Combustion Installation' (2003/2), fourth Joint UNECE Task Force and EIONET Workshop on Emission Inventories and Projections in Warsaw, Poland, 22–24.9.2003.

Kubica K., Ranczak J., Wilkosz K. (1999). Report ICHPW 2696/99 'Determination of non-metallic organic compounds emission factors for solid fuels (coal coke), gas and oil fire appliances', Zabrze, 31.5.99 (in Polish).

Kubica K., Sciążko M. (1994). 'Correlation of coal properties to char, briquette, and utilization characteristics'. International conference 'Production and Utilization of Ecological Fuels from East Central European Coals', Praga, Republika Czeska, 31.10–1.11.1994.

Kubica K., Zawistowski J., Rańczak J. (2005/1). 'Spalanie paliw stałych w instalacjach małej mocy — rozwój technik spalania węgla i biomasy'. Karbo, 50, p. 2, 2005 (in Polish, abstract in English).

Kubica, K., Raińczak, J., Rzepa, S., Ściążko, M., (1997/2002). 'Influence of 'biofuel' addition on emission of pollutants from fine coal combustion'. Proc. fourth Polish-Danish Workshop on Biofuels, Starbieniewo, 12–14 czerwca 1997/2002.

Kupiainen, K., Klimont, Z., (2004). 'Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control', IIASA IR 04-079, www.iiasa.ac.at/rains/reports.html

Lammi K., Lehtonen E. and Timonen T. (1993). 'Energiantuotannon hiukkaspäästöjen teknis-taloudelliset vähentämismahdollisuudet' ('Technical and economical alternatives to reduce particulate emissions from energy production)', Helsinki, Finland, Ministry of the Environment. Report 120, p. 64 (in Finnish with English summary).

Lee R.M., Coleman P., Jones J.L., Jones K.C., Lohmann R. (2005). 'Emission Factors and Importance of PCDD/Fs, PCBs, PCNs, PAHs and PM_{10} from the Domestic Burning of Coal and Wood in the UK', *Environmental, Science and Technology* 39, pp. 1436–1447, 2005.

Loibel W., Orthofer O., Winiwarter W. (1993). 'Spatially disaggregated emission inventory for antrophogenic NMVOC emissions in Austia', *Atmospheric Environment*, 27A, 16, pp. 2575–2590, 1993.

McDonald J.D., Zielinska B., Fujita E., Sagebie J.C., Chow J.C., and Watson J.G. (2000). 'Fine Particle and Gaseous Emission Rates from Residential Wood Combustion', *Environmental, Science and Technology*, 34, pp. 2080–2091, 2000.

Meier, E. and Bischoff, U. (1996). 'Alkalische Emisisonsfaktoren beim Einsatz ballastreicher Braunkohlen in Vebrennunganlagen', IfE Leipzig i.A des BMBF, Beitrag C2.2 des Verbundvorhabens SANA. In: Wissenschaftliches Begleitprogramm zur Sanierung der Atmmosphäre über den neuen Bundesländern, Abschlussbericht Band II.

Moritomi H., Fujiwara N. (2005). 'Mercury emission from coal combustion in Japan', Mercury Experts Conference 2, MEC2 — 25.5. 2005, Ottava, Canada.

Nielsen M., Illerup J.B., Kristensen P.G., Jensen J., Jacobsen H.H., Johansen L., P., (2002). 'Emission factors for CHP plants < 25 MWe', (2003), fourth Joint UNECE Task Force and EIONET Workshop on Emission Inventories and Projections in Warsaw, Poland, 22–24.9.2003.

Nussbaumer T. (2001). 'Relevance of aerosols for the air quality in Switzerland' pp. 1 in Aerosols from Biomass Combustion, ISBN 3-908705-00-2. International seminar on 27.6.2001, www.ieabcc.nl/publications/aerosols.pdf

NUTEK (1997). 'Environmentally — Adapted Local Energy Systems'. Report 4733, Swedish Environmental Agency, Stockholm.

Oanh N.T.K., Reutergårdh L.B., Dung N.T. (1999). 'Emission of Polycyclic Aromatic Hydrocarbons and Particulate Matter from Domestic Combustion of Selected Fuels', *Environmental, Science and Technology* 33, pp. 2703–2709, 1999.

Ohlström, M. (1998). 'Energiantuotannon pienhiukkaspäästöt Suomessa' ('The fine particle emissions of energy production in Finland'), Espoo, Finland, Technical Research Center of Finland, VTT Research Notes 1934, p. 114. (In Finnish with English summary).

Ohlström, Mikael, Tsupari, Eemeli, Lehtilä, Antti & Raunemaa, Taisto. Pienhiukkaspäästöt. (2005). Fine particle emissions and their reduction potentials in Finland. The effects of greenhouse gas emission reduction. Espoo 2005. VTT Tiedotteita Research Notes 2300. 91 s. + liitt. 1 s. Finland. (In Finnish with English summary).

Olendrzynski K., Fudala J., Hlawiczka S., Cenowski S., Kachniarz M., Kargulewicz I., Debski B. Skoskiewicz J.(2002). 'Emission Inventory of SO_2, NO_2, NH_3, CO, PM, HMs, NMVOCs and POPs in Poland 2000', UN-ECE – EMEP/Poland. Report/2002, IOS, Warszawa.

Pacyna J.M., Munthe J. (2004). 'Summary of research of projects on mercury funded by EC DG Research'. Workshop on Mercury Needs for further International Environmental Agreements, Brussels, 29–30.3.2004.

Pacyna J.M., Pacyna E.G., (2001). 'An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide', *Environ.Rev.*2001, No 9 pp. 269 – 298.

Paulrud, S et al. 2006. 'Användningsmönster och emissioner från vedeldade lokaleldstäder' ('The use of domestic wood burning and emissions from wood stoves'). IVL-report, Swedish Environmental Research Institute, Gothenburg, Sweden 2006 (In Swedish with English summary).

Perry R.H., Green D.W., (1997). Chemical Engineers Handbook, edition 7, Mc Grow-Hill, London, 1997.

Pfeiffer F., Struschka, M., Baumbach, G. (2000). 'Ermittlung der mittleren Emissionsfaktoren zur Darstellung der Emissiionsentwicklung aus Feuerungsanlagen im Bereich der Haushalte und Kleinverbraucher'. UBA-FB 295 46 36414/00, Umwelbundesamt, Berlin May 2000 (German, English abstract).

Pulles T., van Aardenne J., Tooly L., Rypdal K., (2001). 'Good Practice Guidance for CLRTAP (Convention on Long-Range Transboundary Air Pollution) Emission Inventories', European Topic Centre on Air and Climate Change (ETC/ACC), 7.11.2001, www.emep.int or on the Internet site of the European Environment Agency http://reports.eea.eu.int/EMEPCORINAR/en

Purvis, C. & Mccrills, R. 2000. 'Fine particulate matter (PM) and organic speciation of fireplace emissions', *Environmental, Science and Technology*, 34, pp. 1653–1658.

Purvis, C. & Mccrills, R. 2000. 'Fine particulate matter (PM) and organic speciation of fireplace emissions', *Environmental, Science and Technology*, 34, pp. 1653–1658.

Pye S. (2005/2). UK National atmospheric Emission Inventory (supplied by Pye S, UK, July 2005).

Pye S., Jones G., Stewart R., Woodfield M., Kubica K., Kubica R., Pacyna J. (2005/1). 'Costs and environmental effectiveness of options for reducing mercury emissions to air from small-scale combustion installations', AEAT/ED48706/Final report v2, December 2005.

Pye S., Thistlethwaite G., Adams M., Woodfield M., Goodwin J., Forster D., Holland M. (2004). 'Study Contract on the Cost and Environmental Effectiveness of Reducing Air Pollution from Small-scale Combustion Installations' (EC reference ENV.C.1/SER/2003/0099r), http://europa.eu.int/comm/environment/air/cafe/

Quass U., Fermann M., Bröker G.; (2000).'The European Dioxin Emission Inventory — Stage II' Desktop studies and case studies'. Final report 31.21.2000, Vol. 2, pp. 115–120, North Rhine Westphalia State Environment Agency.

Ross A.B., Jones J.M., Chaiklangmuang S., Pourkahanian M., Williams A., Kubica K., Andersson J.T., Kerst M., Danihelka P. i Bartle K.D. (2002). 'Measurement and prediction of the emission of pollutants from the combustion of coal and biomass in a fixed bed furnace', *Fuel* 81, 5, pp. 571, 2002.

Saanum et al, (1995). 'Emissions from Biomass Combustion', Norway Institute of Technology, 1995.

Schauer, J., Kleeman, M, Cass, G, Simoneit, B. 2001. 'Measurement of emissions from air pollution sources 3. C1-C29 organic compounds from fireplace combustion of wood', *Environmental, Science and Technology*, 35, pp. 1716–1728.

Senior C. (2004). 'Mercury Tutorial — Mercury Transformations'. Connie Senior (private presentation), Reaction Engineering International. The 29th International Technical Conference on Coal Utilization and Fuel Systems Clearwater, Florida, 18–22.4.2004 (on behalf of EPA).

Skreiberg, Ø., 1994. 'Advanced techniques for Wood Log Combustion'. Procc. from Comett Expert Workshop on Biomass Combustion, May 1994.

Smith, K.R. (1987). 'Biofuels, Air Pollution, and Health, A Global Review', Plenum Press, New York, p. 452.

Spitzer, J., Enzinger, P., Fankhauser, G., Fritz, W., Golja, F., Stiglbrunner, R. (1998). 'Emissionsfaktoren für Feste Brennstoffe'. Endbericht Nr.: IEF-B-07/98, Joanneum Research, Graz, December 1998, p. 50.

Strand, M. 2004. 'Particle Formation and Emission in Moving Grate Boilers Operating on Woody Biofuels'. Doctorial thesis. Department of Chemistry, TD, Växjö University, Sweden.

Struschka, M., Zuberbühler U., Dreiseidler A., Dreizler D., Baumbach, G. (2003). 'Ermittlung und Evaluierung der Feinstaubemissionen aus Kleinfeurungsanlagen im Bereich der Haushalte und Kleinverbraucher sovie Ableitung von geeingenten Maßnahmen zur Emissionminderung'. UBA-FB 299 44 140, Umwelbundesamt, Berlin Juli 2003 (German, English abstract).

Tan Y., Mortazavi R., Bob Dureau B., Mark A. Douglas M.A. (2004). 'An investigation of mercury distribution and speciation during coal combustion', *Fuel* 83 (2004), pp. 2229–2236.

Thanner G., Moche W., (2002). 'Emission von Dioxine, PCBs und PAHs aus Kleinfeuerungen', Umweltbundesamt, Federal Environment Agency, Austria, Monographien Band 153, Wien, 2002.

The Air Quality Strategy for UK; 2000. 'The Air Quality Strategy for England, Scotland, Wales and Northern Ireland', Working Together for Clean Air, Cm 4548 January, 2000.

Tullin C., Johansson L., Leckner B. (2000). 'Particulate emissions from small-scale biomass combustion', Nordic Seminar on Small Scale Wood Combustion, Nadendal, Finland, 2000.

UBA (Umweltbundesamt) (1989). 'Luftreinhaltung'88, Tendenzzen — Probleme — Lösungen', Federal Environmental Agency (Umweltbundesamt), Berlin, in Dreiseidler et al. 1999.

UBA (Umweltbundesamt) (1998). 'Schriftliche Mitteilung von Hr. Nöcker vom 01.09.1998, UBA II 4.6', Federal Environmental Agency (Umweltbundesamt), Berlin, in Dreiseidler et al. 1999.

UBA (Umweltbundesamt) (1998a). 'Schatzung der Staubemissionen in Deutschland (Industrieprozesse, Kraftwerke und Fernheizwerke, industriefeuereungen)'. Schriftliche Mitteilung von Hr.Remus vom 9.2000. Federal Environmental Agency (Umweltbundesamt), Berlin.

UBA (Umweltbundesamt) (1999a). 'Various estimates of particulate emission factors and particle size distributions' by Federal Environmental Agency (Umweltbundesamt), Berlin, in Dreiseidler et al., 1999.

UMEG (Gesellschaft für Umweltmessungen und Umwelterhebungen mbH) (1999). 'Feinstaubuntersuchungen an Holzfeuerungen, Teil 2: Bereich Industriefeuerungen > 1 MW', Institut für Verfahrenstechnik und Dampfkesselwesen, Report No 44-1999, Universtät Stuttgart, July, 1999.

UNEP Chemicals (2003). 'Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases', Geneva, Switzerland, first edition, May 2003.

Van der Most, P.F.J., Veldt, C. (1992). 'Emission Factors Manual PARCOM-ATMOS, Emission factors for air pollutants 1992, Final version'; TNO and Ministry of Housing, Physical Planning and the Environment, Air and Energy Directorate Ministry of Transport and Water Management: The Netherlands. Reference number 92–235, 1992.

Van Loo S., and Koppejan J. (2002). Handbook of Biomass Combustion and Co-firing., Twente University Press, Enschede, 2002.

Wierzbicka, A., Lillieblad, L., Pagels, J., Strand, M., Gudmundsson, A., Ghaibi, A., Swietlicli, M. Sanati, M., Bohgard, M. 'Particle emissions from district heating units operating on three commonly used biofuels', *Atmospheric Environment* 39 (2005), pp. 139–150.

Williams A., Kubica K., Anderson J., Bartle K.D., Danihelka P., (2001). INCO-Copernicus Contr. No ERB IC15-CT98-053: 'Influence of co-combustion of coal and biomass on the emission of pollutants in domestic appliances'. Final report 1999–2001.

Winiwarter, W., Trenker, Ch., Höflinger, W. (2001). 'Österreichische Emissionsinventur für Stau', A study for Austrian Environmental Agency (Umweltbundesamt). Final report, ARC Seibersdorf Research Report, ARC — S-0151, 121 p., September 2001.

Zhang J., Smith K., Ma Y., Ye S., Jiang S., Qi W., Liu P., Khalil M., Rasmussen R., Thorneloe S., (2000). 'Greenhouse gases and other airborne pollutants from household stoves in China: A database for emission factors', *Atmospheric Environment* 34 (2000) pp. 4537–4549.

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:

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

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.

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

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:

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

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:

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

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						
Fuel type	Fd 1)		Fw 1)		Fc 1)	
	dscm/J	dscf/10^6 Btu	wscm/J	wscf/10^6 Btu	scm/J	scf/10^6 Btu
Coal						
Anthracite 2	$2.71 \cdot 10^{-7}$	10100	$2.83 \cdot 10^{-7}$	10540	$0.530 \cdot 10^{-7}$	1970
Bituminus 2	$2.63 \cdot 10^{-7}$	9780	$2.86 \cdot 10^{-7}$	10640	$0.484 \cdot 10^{-7}$	1800
Lignite	$2.65 \cdot 10^{-7}$	9860	$3.21 \cdot 10^{-7}$	11950	$0.513 \cdot 10^{-7}$	1910
Oil 3)	$2.47 \cdot 10^{-7}$	9190	$2.77 \cdot 10^{-7}$	10320	$0.383 \cdot 10^{-7}$	1420
Gas						
Natural	$2.34 \cdot 10^{-7}$	8710	$2.85 \cdot 10^{-7}$	10610	$0.287 \cdot 10^{-7}$	1040
Propane	$2.34 \cdot 10^{-7}$	8710	$2.74 \cdot 10^{-7}$	10200	$0.321 \cdot 10^{-7}$	1190
Butane	$2.34 \cdot 10^{-7}$	8710	$2.79 \cdot 10^{-7}$	10390	$0.337 \cdot 10^{-7}$	1250
Wood	$2.48 \cdot 10^{-7}$	8710	-	-	$0.492 \cdot 10^{-7}$	1830
Wood bark	$2.58 \cdot 10^{-7}$	9240	-	-	$0.516 \cdot 10^{-7}$	1920
Municipal	$2.57 \cdot 10^{-7}$	9600	-	-	$0.488 \cdot 10^{-7}$	1820
Solid waste	-	9570				

Notes:

1) determined at standard conditions: 20°C (68°F) and 760mmHg (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 Gross and net fuel calorific ratios

Fuel	Ratio
Power stn coal	1.05
Industrial coal	1.05
Wood	1.08
HFO	1.05
Gas oil	1.05
Natural gas	1.11

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

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

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:

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

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.

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

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}

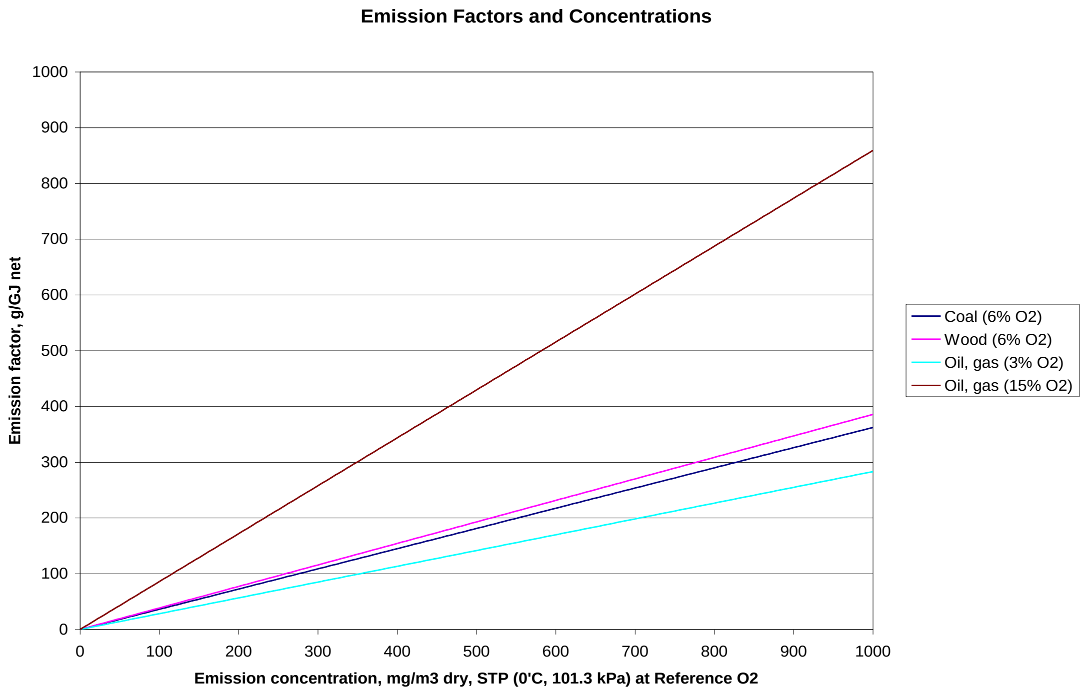
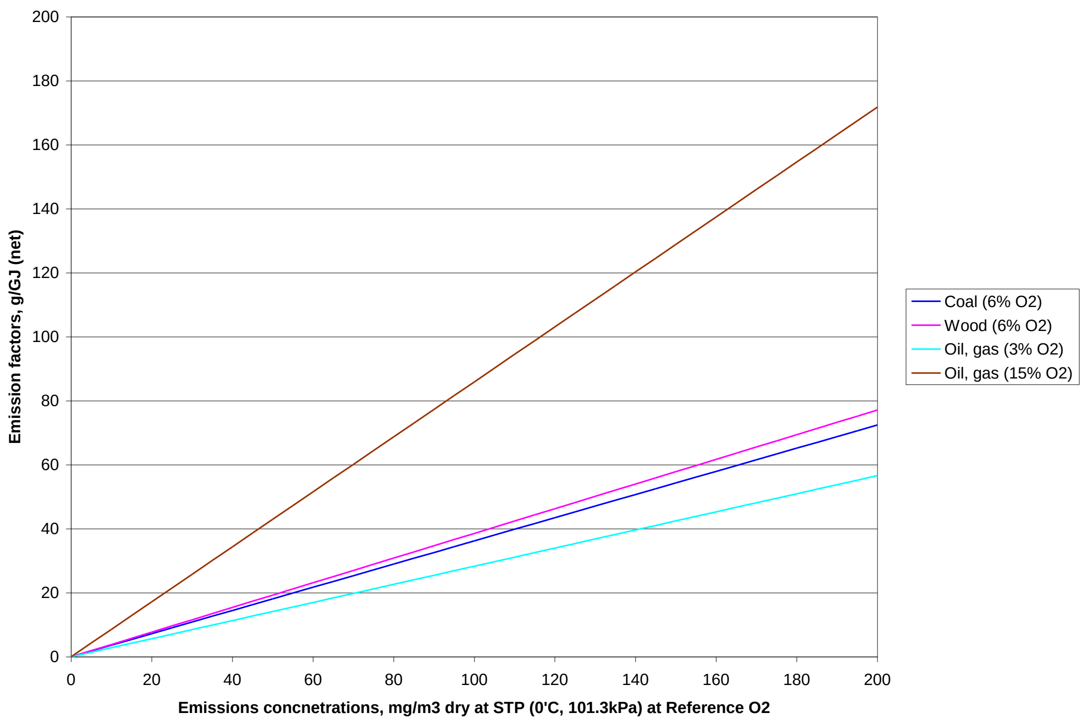


Figure B2 Emission factors — selected fuels and standardised concentrations up to 200 mg.m^{-3}



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

Table C1.1 Ecodesign NOx emission limits for boilers ≤400kW output, water heaters and LSH (gas and liquid fuel)

Type	Fuel :	ELV mg/kWh gross input		ELV, g/GJ net input	
		Gaseous	Liquid	Gaseous	Liquid
Boilers	Boilers	56	120	17	35
Heat pump/Cogen	External combustion	70	120	22	35
Heat pump/cogen	Internal combustion	240	420	74	123
Water htrs	Water htrs	54	120	17	35
Heat pump	External combustion	70	120	22	35
Heat pump	Internal combustion	240	420	74	123
LSH	Domestic	130	130	40	38
LSH	Commercia;	240	240	74	70

Emission limits drawn from EC Regulations 2015/1188, 2013/813 and 2013/814. Conversion from gross to net heat input based on conversions provided in Appendix B.

Table C1.2 Ecodesign emission limits for solid fuel boilers ≤500kW output

Type	Fuel	mg/m3 at 10% O_2 dry and STP (0°C, 101.3 kPa)				g/GJ net heat input			
		PM	CO	OGC	NO_X	PM	CO	OGC	NO_X
Manual	Biomass	40	500	20	200	19.4	243	9.7	97.0
Auto		60	700	30	200	29.1	340	14.6	97.0
Manual	fossil	40	500	20	350	19.8	247	9.9	173
Auto		60	700	30	350	29.6	346	14.8	173

PM emission limits based on filterable material only. All limits drawn from EC Regulation 2015/1189. Conversion from concentrations and emission factors assume a stoichiometric specific flue gas volume of 253 m^3/GJ net fuel input for biomass and 258 m^3/GJ net fuel input for bituminous coal (see AEA Technology 2012 and Appendix B).

Table C1.3 Ecodesign emission limits for solid fuel LSH

Type	Fuel	g/kg (dry matter)		mg/m³ at 13% O_2 dry and STP (0°C, 101.3 kPa)				g/GJ net heat input					
		PM(iii)	PM(ii)	PM(i)	CO	OGC	NO_X	PM(iii)	PM(ii)	PM(i)	CO	OGC	NO_X
open	Biomass	-	6	50	2000	120	200	-	347	33.5	1339	80.3	134
closed		2.4	5	40	1500	120	200	139	289	26.8	1004	80.3	134
pellet		1.2	2.5	20	300	60	200	69	145	13.4	201	40.2	134
cooker		2.4	5	40	1500	120	200	139	289	26.8	1004	80.3	134
open	fossil	-	6	50	2000	120	300	-	178	34.1	1363	81.8	204
closed		5	5	40	1500	120	300	149	149	27.3	1022	81.8	204
cooker		5	5	40	1500	120	300	149	149	27.3	1022	81.8	204

PM emission limits based on different methods applied in EU. All limits drawn from EC Regulation 2015/1185. Conversion from concentrations and emission factors assume a stoichiometric specific flue gas volume of 253 m³/GJ net fuel input for biomass and 258 m³/GJ net fuel input for bituminous coal (see AEA Technology 2012 and Appendix B and, calorific values of 17.3 GJ/tonne (dry biomass) and 33.6 GJ/tonne (dry bituminous coal).

Table C2.1 Proposed Medium Combustion Plant Directive emission limit values

Existing, new, small/large/engines/GTs

Table C3.1 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 C3.2 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:

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 C3.3 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

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. 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 %).
4. Germany distinguishes NO_X 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 C3.4 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 NO_X 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 C3.5 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)

A review of the emissions factors for small combustion was performed in 2013. Details of this can be found in Appendix D of the 2013 EMEP/EEA air polliutant emission inventory guidebook chapter for small combustion (1A4).

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	Boilers < 50 kW
Table 3-20	2	Liquid fuels	Residential	Stoves
Table 3-21	2	Liquid fuels	Residential	Boilers < 50 kW
Table 3-22	2	Coal	Residential	Advanced stoves
Table 3-23	2	Wood	Residential	High-efficiency stoves
Table 3-24	2	Wood	Residential	Advanced/ecolabelled stoves
Table 3-25	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 high-efficiency 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 stoves	Advanced/ecolabelled stoves and boilers	Advanced combustion stoves, masonry heat accumulating stoves[1], catalytic combustor stoves, advanced combustion boilers
Table 3-25	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 Aggregate of the listed references will be applied. The Aggregate OC fraction is 43 %.

[1] 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[2]-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 Aggregate of the listed references will be applied. Some of the BC fractions are however based on TSP. The Aggregate OC fraction is 45 %[3].

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	-[4]	-
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

[2] Briquettes
[3] Not including Fine et al. (2002)
[4] 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

High-efficiency 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[5].

The BC fraction 28 % of $PM_{2.5}$ that is an Aggregate of the listed references will be applied. The Aggregate 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.

The BC fraction 15 % of PM_{10} referring to Schmidl et al. (2011) will be applied. The Aggregate OC fraction is 13 %.

[5] The chimney type stove are iron stoves with chamotte lining (Schmidl et al. 2011).

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[6]	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[7]	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[8]	75
Table 3-23	2	Wood	Residential	High-efficiency stoves	370	16 %	59	56-79
Table 3-24	2	Wood	Residential	Advanced/ecolabelled stoves and boilers	93	28%	26	56-79
Table 3-25	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.

[6] Not diluted
[7] Not estimated yet. Assumed that the emission factor for conventional stoves will be applied.
[8] 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 3-23	2	Wood	Residential	High-efficiency stoves	370[9]	16 %	-
Table 3-24	2	Wood	Residential	Advanced/ecolabelled stoves and boilers	93	28%	31%
Table 3-25	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 3-22	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.

[9] 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 3-22	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 Aggregate of the EFs from Hildemann et al and Muhlbaier are **proposed for residential natural gas combustion** (for OC an Aggregate 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	Boilers < 50 kW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-20	2	Liquid fuels	Residential	Stoves	13	10	Bond et al, 2004
Table 3-21	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 3-26	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-27	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-28	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-29	2	Coal	Non-residential	Automatic boilers < 1MW
Table 3-30	2	Liquid fuels	Non-residential	Boilers 50 kW to 1MW
Table 3-31	2	Liquid fuels	Non-rediential	Boilers 1MW to 50MW
Table 3-32	2	Wood	Non-residential	Boilers 50 kW to 1MW
Table 3-33	2	Wood	Non-residential	Boilers 1MW to 50MW
Table 3-34	2	Wood	Non-residential	Manual boilers < 1 MW
Table 3-35	2	Wood	Non-residential	Automatic boilers < 1MW
Table 3-36	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-37	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW
Table 3-38	2	Natural gas	Non-residential	Gas turbines

Table 3-39	2	Gas oil	Non-residential	Gas turbines
Table 3-40	2	Gaseous fuels	Non-residential	Gas engines
Table 3-41	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 3-32	2	Wood	Non-residential	Boilers 50kW to 1MW	86.5*	21.5 %*	19*	-
Table 3-33	2	Wood	Non-residential	Boilers 1MW to 50 MW	33*	15 %*	5*	-
Table 3-34	2	Wood	Non-residential	Manual boilers < 1 MW	140	28 %	39	35
Table 3-35	2	Wood	Non-residential	Automatic boilers < 1MW	33	15 %	5	-

*Values for Tables 3-32 and 3-33 are based on the aggregated data for manual and automatic boilers <1MW and assumptions about technology type and performance for >1MW technologies.

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 3-26	2	Coal	Non-residential	Boilers 50 kW to 1 MW
Table 3-27	2	Coal	Non-residential	Boilers 1-50 MW
Table 3-28	2	Coal	Non-residential	Manual boilers < 1 MW
Table 3-29	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	Aggregate 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 Aggregate 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 Aggregate 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 3-30	2	Fuel oil	Non-residential	Boiler 50 kW to 1MW	No estimate	No estimate	-
Table 3-31	2	Fuel oil	Non-residential	Boiler 1 MW to 50 MW	No estimate	No estimate	-
Table 3-36	2	Natural gas	Non-residential	Boiler 50 kW to 1 MW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-37	2	Natural gas	Non-residential	Boiler 1 MW to 50 MW	5.35	28.5	Hildemann et al, 1991; Muhlbaier, 1981
Table 3-38	2	Natural gas	Non-residential	Gas turbines	2.5		*

Table 3-39	2	Gas oil	Non-residential	Gas turbines	2.5	*
Table 3-40	2	Gaseous fuels	Non-residential	Gas engines	2.5	*
Table 3-41	2	Gas oil	Non-residential	Gas engines	2.5	*

* Aggregate 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)".

References

Battye, W., Boyer, K. & Pace, T.G., 2002: Methods for improving global inventories of black carbon and organic carbon particulates. Change 2002

Bond, T.C., Streets, D.G., Yarber, K.F., Nelson, S.M., Woo, J-H & Klimont, Z., 2004: A Technology-based Global Inventory of Black and Organic Carbon Emissions from Combustion. Journal of Geophysical Research 109, D14203, doi:10.1029/2003JD003697

Chow, J.C., Watson, J.G., Kuhns, H.D., Etyemezian, V., Lowenthal, D.H., Crow, D.J., Kohl, S.D., Engelbrecht, J.P. & Green, M.C., 2004: Source profiles for industrial, mobile, and area sources in the Big Bend Regional Aerosol Visibility and Observational (BRAVO) Study. Chemosphere 54 (2), 185-208.

Cooper, J.A., Redline, D.C., Sherman, J.R., Valdovinos, L.M., Pollard, W.L., Scavone, L.C. & Badgett-West, C., 1987: PM_{10} Source Composition Library for the South Coast Air Basin, Volume II. Prepared for the South Coast Air Quality Management District, El Monte, CA.

Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. & Egami, R.T., 2002: The comparison of source contributions from residential coal and low-smoke fuels, using CMB modeling, in South Africa. Environmental Science and Policy 5 (2), 157–167.

England, G.C., Watson, J.G., Chow, J.C., Zielinska, B., Chang, M.-C.O., Loos, K.R. & Hidy, G.M., 2007: Dilution-based emissions sampling from stationary sources: Part 2. Gas-fired combustors compared with other fuel-fired systems. Journal of the Air & Waste Management Association 57 (1), 79-93.

Hildemann, L.M., Markowski, G.R. & Cass, G.R., 1991: Chemical Composition of Emissions from Urban Sources of Fine Organic Aerosol. Environmental Science & Technology 25(4), 744-759.

Mazzera, D.M., Lowenthal, D.H., Chow, J.C. & Watson J.G., 2001: Sources of PM_{10} and sulfate aerosol at McMurdo Station, Antarctica. Chemosphere 45 (2001) 347-356.

Mugica, V., Mugica, F.,Torres, M. & Figueroa J., 2008: $PM_{2.5}$ Emission Elemental Composition from Diverse Combustion Sources in the Metropolitan Area of Mexico City. The Scientific World Journal (2008) 8, 275–286.

Muhlbaier, J.L., 1981: Participate and gaseous emissions from natural gas furnaces and water heaters. Journal of the air pollution control association, 31:12, pp. 1268-1273

Pinto, J.P., Stevens, R.K., Willis, R.D., Kellogg, R., Mamane, Y., Novak, J., Šantroch, J., Beneš, I., Leniček, J. & Bureš, V., 1998: Czech Air Quality Monitoring and Receptor Modeling Study. Environmental Science & Technology 32(7), 843-854.

Reff, A., Bhave, P.V., Simon, H., Pace, T.G., Pouliot, G.A., Mobley, J.D. & Houyoux, M., 2009: Emissions inventory of $PM_{2.5}$ trace elements across the United States. Environ. Sci. Technol., 43, pp. 5790-5796

US EPA, 2011: SPECIATE Version 4.3

Watson, J.G., Chow, J.C. & Houck, J.E., 2001: $PM_{2.5}$ Chemical Source Profiles for Vehicle Exhaust, Vegetative Burning, Geological Material, and Coal Burning in Northwestern Colorado during 1995. Chemosphere 43, 1141-1151.

Zhang, H., Wang, S., Hao, J., Wan, L., Jiang, J., Zhang, M., Mestl, H.E.S., Alnes, L.W.H., Aunan, K. & Mellouki, A.W., 2012: Chemical and size characterization of particles emitted from the burning of coal and wood in rural households in Guizhou, China. Atmospheric Environment 51 (2012) 94-99

Alves, C., Goncalves, C., Fernandes, A.P., Tarelho, L. & Pio, C. (2011): Fireplace and woodstove fine particle emissions from combustion of western Mediterranean wood types. Atmospheric Research Volume: 101 (2011), pages: 692-700.

Bølling, A.K., Pagels, J., Yttri, K.E., Barregard, L., Sallsten, G., Schwarze, P.E. & Boman, C. (2009). Health effects of residential wood smoke particles: the importance of combustion conditions and physicochemical particle properties. Particle and Fibre Toxicology 2009, 6:29.

England, G.C., Wien, S., McGrath, T. & Hernandez, D., 2004: Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas Fired Combustion Systems. Topical Report: Test Results for a Combined Cycle Power Plant with Oxidation Catalyst and SCR at Site Echo; Prepared for the U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA; the Gas Research Institute: Des Plains, IL; and the American Petroleum Institute: Washington, DC, 2004.

Fernandes, A.P., Alves, C.A., Goncalves, C., Tarelho, L., Pio, C., Schmidl, C. & Bauer, H. (2011): Emission facgtors from residential combustion appliances burning Portuguese biomass fuels. Journal of Environmental Monitoring, 2011, 13, 3196.

Fine, P.M., Cass, G.R. & Simoneit, B.R.T. (2002): Chemical Characterization of Fine Particle Emissions from the Fireplace Combustion of Woods Grown in the Southern United States. Environmental Science & Technology, vol. 36, No. 7, 2002.

Goncalves, C., Alves, C., Evtyugina, M., Mirante, F., Pio, C., Caseiro, A., Schmidl, C., Bauer, H. & Carvalho, F. (2010): Characterisation of PM_{10} emissions from woodstove combustion of common woods grown in Portugal. Atmospheric Environment 44 (2010) 4474-4480.

Goncalves, C., Alves, C., Fernandes, A.P., Monteriro, C. Tarelho, L., Evtyugina, M., Pio, C. (2011): Organic compounds in $PM_{2.5}$ emitted from fireplace and woodstove combustion of typical Portuguese wood species. Atmospheric Environment 45 (2011), pages 4533-4545.

Johansson, L.S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. & Potter, A. (2004): Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Atmospheric Environment 38 (2004) 4183-4195.

Kupiainen K. & Klimont Z. (2002): Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control. IIASA Interim Report IR-04-079.

Kupiainen, K. & Klimont, Z. (2007): Primary emissions of fine carbonaceous particles in Europe. Atmospheric Environment 41 (2007), 2156-2170.

Schmidl, C., Luisser, M., Padouvas, E., Lasselberger, L., Rzaca, M., Cruz, C.R.-S., Handler, M., Peng, G., Bauer, H. & Puxbaum, H. (2011): Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment 45 (2011) 7443-7454.

Sippula, O., Kytönen, K., Tissari, J., Raunemaa, T. & Jokiniemi, J. (2007): Effect of Wood Fuel on the Emissions from a Top-Feed Pellet Stove. Energy and Fuels, 2007, 21, 1151-1160.

Struschka, M., Kilgus, D., Springmann, M. & Baumbach, G., 2008: Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung, 44/08, Umwelt Bundes Amt, Universität Stuttgart, Institut für Verfahrenstechnid und Dampfkesselwesen (IVD)

US EPA, 2011: SPECIATE Version 4.3

Verma, V.K., Bram, S., Vandendael, I., Laha, P., Hubin, A. & Ruyck, J.D. (2011): Residential pellet boilers in Belgium: Standard laboratory and real life performance with respect to European standard and quality labels. Applied Energy 88 (2011) 2628-2634.

Wien, S., England, G. & Chang, M., 2004: Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas Fired Combustion Systems. Topical Report: Test Results for a Combined Cycle Power Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Bravo; Prepared for the U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA; the Gas Research Institute: Des Plains, IL; and the American Petroleum Institute: Washington, DC, 2004.