| Category | | Title |
|---|---|---|
| **NFR:** | **A4bi** | |
| **SNAP:** | | |
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| **Version** | Guidebook 2023 | |

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# Contents

# 1 Overview

Annex X of EMEP/EEA Emission Inventory Guidebook 2023 is intended for guidance to improve the accuracy of emission inventories on residential wood combustion in European countries.

The annex provides an explanation on issues impacting real life emission levels and how to take these into account in the quantification of emission levels. The description of residential wood combustion technologies has been revised to make it easier to identify technologies and their features impacting emission levels.

The proposed text based on measurements and expert work at Fine Particle and Aerosol Technology Laboratory at the University of Eastern Finland and on expert work at Finnish Environment Institute SYKE, international literature, Finnish guidelines for residential combustion and projects carried out under Nordic Council of Ministers.

**The Annex covers the following topics on Residential wood combustion**

Chapter 1 Real Life Emissions

Chapter 2 Issues impacting emission levels in residential wood combustion

Chapter 3 The impact of user-dependent factors on emission levels in residential combustion

Chapter 4 How to include factors impacting emission levels into emissions inventories?

Chapter 5 Residential Wood Combustion Technologies and Emission Levels

Chapter 6 Collection of Activity Data

# 2 Residential combustion – Wood Combustion

## 2.1 Real life emissions

Small-scale wood combustion processes are not steady because combustion conditions vary depending on the appliance type, the technological level and maintenance, the phase of the combustion process and the air supply, quality and quantity of the fuel, and, specifically on operational practices.

**Complete combustion and efficiency**

The completeness of combustion depends on combustion temperature, mixing of combustion gases and air, and the time available for chemical reactions. Good combustion conditions decrease emissions and keeps the appliances cleaner as less particulate matter is generated on the surfaces of the combustion chamber and channels. The combustion in residential appliances is always at least partially incomplete. When there is incomplete combustion, the fuel is not fully utilized, which causes higher emissions per energy unit. The efficiency of an appliance describes how much of the energy contained in the fuel is utilized in space heating. The efficiency and the emission levels of an appliance do not directly correlate because the efficiency depends mainly on the air to fuel ratio and the flue gas temperature.

It should be noted that even advanced appliances can be operated in a way that generate unnecessary high emissions. In general, modern stoves with automated controls are easier to operate, have lower emission levels due to better air staging systems, firebox insulation and easier control of the valves and may even have automation to control combustion parameters and thus the emissions. In older appliances emission levels may have wider variability due to operational practices. However, when correctly operated, certain older appliances such as heat storing stoves, may have quite low emissions and high efficiency and thus lower wood consumption. In manually operated appliances the user has a significant impact on the completeness of combustion and therefore on the emissions levels.

**Figure 2-1 The intensity of combustion ($CO_2$) and the related emission levels in batch combustion.**

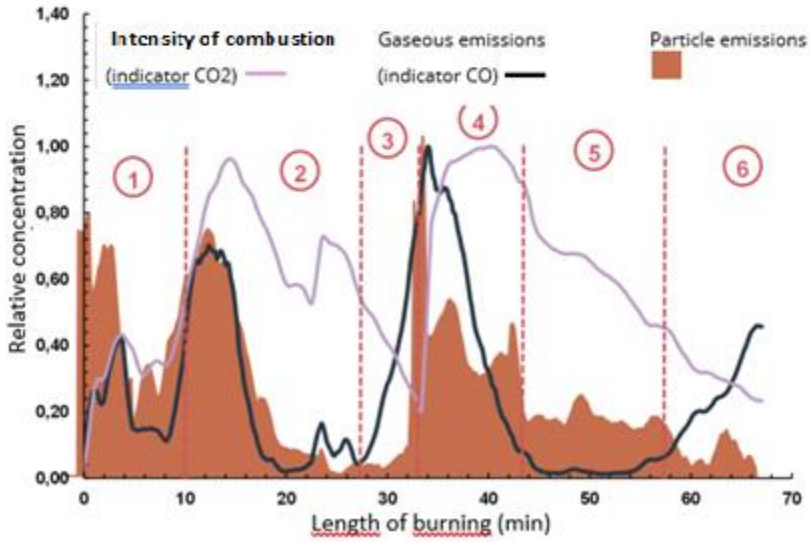


**Figure 2-1. The intensity of combustion (CO2) and the related emission levels in batch combustion.** Emission levels vary between the batch phases: 1. ignition, 2. combustion of first batch, 3. ember of first batch, 4. strong gasification of second batch, 5. combustion of second batch, 6. ember of second batch (MoE, 2022)

**Real-life emissions**

The term "real-life emissions" is used to describe emissions generated under the varying conditions of manual combustion over the whole combustion period from ignition to the glowing embers phase, as described in Figure 2-1

Real-life emissions may be different from emission levels reported for CE marked appliances and may vary considerably between the same appliance type due to the different operational practices of the users. Factors that influence real life emissions and ways to include these in the emission inventories are discussed in Chapter 1.2.

## 2.2 Issues impacting emission levels in residential wood combustion

Information presented in Table 1 describes the various factors related to fuel quality and quantity, combustion conditions and appliance maintenance that impact emission levels. Table 2-1provide a mapping to assess the magnitude of user-dependent factors on emission levels.

**Table 2-1 Issues impacting emission levels in residential wood combustion**

| |
|---|
| Fuel quality |
| *Moisture content* of wood is identified as the most important wood quality factor that impacts the emissions. Wood moisture content should be reduced from around 50% when cut to below 20% before combustion. To maximize heat production and to minimize emission levels, only dry wood of moisture content 12-20 weight-% should be used. If the moisture content is above 20 w-%, the wood is hard to ignite as the produced heat is needed to evaporate moisture and the temperature will not rise sufficiently high to enable complete combustion of the pyrolysis gases. The measured particle and carbon monoxide emissions from moist wood are several times higher compared to dry wood, but depend also on the appliance and wood species. On the other hand, over-dried firewood (< 10 w-%) and extremely dry fuel, e.g. waste wood from industrial manufacture of windows or floors, is too dry to burn properly and results in excessive particle emissions. Wood that is stored in open air should be protected from rain and snow and air circulation should be arranged in the pile. Wood should be taken indoors some days before the use to decrease the moisture, and in cold climate, to also adjust the temperature of wood.<br><br>*Only dry and clean wood should be combusted.* Contaminants in painted or impregnated wood as well as waste containing chlorine result in high POP and heavy metal emissions. |
| Fuel quantity |
| *The optimal batch size* is appliance specific and is typically described in operational instructions by manufacturer. As a rule of thumb, 1 kg of wood per 100 kg of appliance mass can be burned in a heat storing stove. Batch sizes in modern stoves are optimized for moderate to low heat generation and the capacity of the air system is typically downsized. Overloading leads to a lack of combustion air and to higher emissions. Batch sizes that are too small may lead to lower efficiency due to incomplete mixing of fuel and combustion air. The secondary air flow passes by the batch without reaction but, instead cools the batch resulting to e.g. higher carbon monoxide levels.<br><br>*The optimal log size* should follow equipment specific instructions. In general, greater surface area increases heat transfer velocity and thus pyrolysis, thus a smaller log size is preferred to be used for ignition.<br><br>*Arrangement of logs* in manually fed appliances should be loose when ignited and after that compact in order to optimize gasification of wood. An upright (campfire type) arrangement of logs has been identified to increase emissions compared to horizontal arrangement in most stoves. Use of several logs instead of one or two is favourable. |
| Combustion conditions |
| *Ignition and start-up phase* – The duration of the ignition phase impacts the emissions. A short ignition time means lower emissions than a longer ignition period. Ignition from the top has been identified to create less emissions than ignition from the bottom. Ignition from bottom can lead to a situation where part of gasified wood is not combusted. During the ignition phase emissions may be significantly higher than during steady burning. Also, when the fuel is added to the fire, organic compounds are released from the added fuel if the wood would not ignite properly .<br><br>*Combustion phase (see Figure 1)*<br>Control of the air supply can be done (1) automatically or (2) through in-built constructions or (3) by the user.<br>(1) Automatic optimization uses on-line measurements, e.g. of carbon monoxide, air-to-fuel ratio or temperature levels.<br>(2) In the inbuilt constructions the feed of secondary air helps to control emissions. As natural draught is impacted by the pressure difference of the combustion chamber and the chimney, the height of the chimney needs to be optimized for the building and the combustion appliance. In some cases where an excessively high flue draft is a permanent problem, it can be dealt with by installing a flue draft regulator in the chimney. Conversely, if the flue draft is generally too low, it can be dealt with by installing a flue gas fan on the top of the chimney.<br>(3) In manual combustion operation, the user needs to follow the appliance specific instructions for control of air supply by operating the air settings correctly. The draught can be improved by adjusting the ventilation in the room by e.g. turning room ventilation device into "fireplace mode", when such a mode is available, shutting off kitchen hoods or by opening windows in the room. Smoldering (very incomplete) combustion conditions occur if the air valve is throttled while there is still unburnt firewood. Note that the color of the flue gas can indicate high levels of emissions. During normal combustion visible smoke occurs momentarily only during ignition and addition of wood. In the case of incomplete |

| |
|---|
| combustion more smoke can be seen and the color is dark grey or black. However, in all cases emissions are generated although no smoke is visible.<br>*At the end phase (*glowing ember phase) efficiency of burning is lower due to the high air/fuel ratio. The ember remaining towards the end of a firing cycle burns slowly if the fire is left to die and extinguish naturally by itself. In cold climate the duration of the end phase should be minimized to avoid excess heat losses through the chimney. Secondary air inlets and the lid can be closed and only the flow of primary air allowed. When the ember is finished, air flow to the chimney can be closed, however, the remaining ember should not include any unburnt wood. |
| Maintenance |
| Sweeping of the combustion chamber, channels and chimney is needed to maintain an even efficiency in combustion because dust and particulate matter deteriorate the heat transfer from the flue gas to the structure of the appliance. In addition, ash in the combustion chamber may clog the combustion air flow routes and increase emissions. For boilers, sweeping is optimally carried out twice a month as impurities on the chamber surface deteriorate heat transfer. In modern boilers, automatic sweeping is arranged in the convection space of the boiler. In stoves and fireplaces, regular removal of ashes from the grate is necessary to ensure the optimal operation of the appliance. Chimney sweeping should in all cases be carried out regularly, depending on local regulations ~~how often the stove is used. If the stove is only used occasionally, on sweeping a year is sufficient~~. Even when dry wood is used, soot is generated on the surfaces of combustion chamber and channels.<br>Repair or replacement is needed for damages to constructions or equipment, e.g. gaskets and firebox insulation material deteriorates or leakages may appear due to tear and wear and needs replacement. |

## 2.3 impact of user-dependent factors on emission levels in residential combustion

To prepare an emissions inventory that sufficiently reflects real life emissions, information is needed on factors explained above. Technical and practical aspects related to fuel quality and technologies as well as to user practices and skills have different levels of significance to the emission levels and may also have interdependencies. Therefore, the impacts of relevant factors should be assessed at regional or country level using, for example, studies or surveys, interviewing chimney sweepers, or simply by making expert judgements. Such an approach can take into account occurrence of those factors that have significant local impacts. Also, the shares of total wood combusted in the different types of appliances can best be assessed on country level. Examples of appliance and user-dependent factors that impact emission levels are presented in Table 2-2 (MoE 2022).

**Table 2-2 User-dependent factors that impact emission levels in boilers**

| Appliance | Issues that have an impact on emission levels | Detail of the issue |
|---|---|---|
| Overfire boiler | Boiler without accumulator/ small size accumulator<br>●●● (significant) | In these appliances the limited air supply leads to smoldering combustion at partial load. Wood should be combusted in small batches. |
| Double nest boiler | Boiler with small size accumulator in dual nest boilers<br>●●● (significant) | |
| Pellet/chip boiler | Combustion using continuous pilot-flame or at low power e.g. due to warm outdoor temperature to warm up water in pellet or chip boilers<br>●● (moderate) | The appliance controls drive the combustion into partial load. During warm periods/in warm climate an alternative water heating method should be used. |
| Modern / Advanced boiler | Automated controls are not functioning<br>●●● (significant) | Air inlets are stuck. |
| Maintenance | Lack of maintenance<br>●● (moderate) | If the ash box is full or regular sweeping is neglected, the operation is not optimal. |

**Table 2-3 User-dependent factors that impact emission levels in manually operated stoves**

| Issue type | Issues that have an impact on emission levels | Detail of the issue |
|---|---|---|
| Fuel | Contaminated wood, waste or peat<br>●●● (significant) | The appliances are designed for combustion of clean wood only. Thus, the use of other fuels increases emissions. For instance, ashes clog air supply channels, chlorine containing fuel generates POP emissions, and heavy metal content increases heavy metals. |
| | Moist > 20 w-%<br>●●● (significant) | Combustion temperature remains low until moisture is evaporated thus increasing emissions, e.g. PM, VOC, PAH emissions to 2-3 fold. Wood needs to be stored prior to combustion and the storage needs to be protected from rain/snow. Note that ~30 w-% is hard to ignite and 50 w-% corresponds to fresh cut wood. Dry wood (6-10 w-%) may also generate excessive particulate emissions. |
| | Arrangement of wood<br>● (mild) | In manually operated stoves the arrangement of wood logs impact emissions. Appliance specific instructions should be followed. |
| Maintenance | Neglect of removal of ashes, sweeping and maintenance<br>●● (moderate) | The appliance does not function correctly. Particle emissions are increased due to a full ash pit or the combustion channels and chimney are not clean. Also, possible structural damages may have different impacts on emission levels. Removal of ashes and chimney sweeping should be carried out regularly. |
| Operation | Ignition<br>● (mild) | If ignited from below, wood gasifies but the gases are not combusted at the beginning. Ignition should be carried out on the top of the pile using dry wood.<br>Too slow ignition occurs when wood is not properly ignited and thus the combustion temperature remains too low. Dry small size wood should be used to ignite. |
| **Issue type** | **Issues that have an impact on emission levels** | **Detail of the issue** |
| | Batch size<br>●●● (significant) | Over- or underloading increases emissions and is appliance specific. Large batch size increases gasification to a too high level. The appliance specific instructions should be adhered to. |
| | Log size<br>● (mild) | Small log size is better at the beginning of the combustion cycle or when using moist wood; large log size is better to use in the last batches or when the wood is dry. |
| | Addition of wood<br>●● (moderate) | Wood added too early, i.e. to a strongly flaming batch will be gasified too strongly and thus increase emissions.<br>Wood added too late, i.e. to glowing embers does not ignite the logs immediately leading to increased emissions. Wood should be added just before the ember phase. |
| | Too low or too high power<br>●●● (significant) | Low power, i.e. limited air supply, generates smoldering combustion conditions where the temperature remains low and emission levels increase. In case of a hot firebox, no combustion air is left.<br>High power, i.e. high air supply with large batch size /small logs, contributes to a too high level of gasification, no combustion air is left and gases are not combusted, thus emission levels increase.<br>In both cases the decrease of the batch size and use of bigger log size helps. Adherence to appliance specific instructions. |
| Draught | Too low or too high draught<br>● (mild) | Too low draught causes combustion temperature to remain low. This can be corrected by using dry wood only and warming up the chimney before use.<br>Too high draught either decreases or increases combustion. Limiting the air supply corrects the situation. Both cases increase emission levels. |

**Table 2-4 User-dependant factor that impact emission levels in outdoor appliances**

| Issues that have an impact on emission levels | Detail of the issue |
|---|---|
| Open fireplace, camp stove etc. ●●● (significant) | In case of a cold firebox and a longstanding combustion period dry small size logs should be used to avoid excess emissions. |

## 2.4 How to include factors impacting emission levels into emissions inventories?

There are several options to estimate emission levels during “bad combustion” periods. One simple method presented in Equation 1 (Savolahti 2016) is to use the share of total wood (preferably by appliance types) that is combusted under “bad” combustion conditions, out of the total wood use (preferably of the specific appliance type) and a coefficient that describes the increase of emissions from normal combustion conditions to the “bad” combustion conditions (e.g. 10 fold during “bad combustion” compared to normal combustion).

**Equation 1 An example on how to include emissions from wood combusted under “bad” combustion conditions to the inventory**

$$E_{ApplianceX} = AD_{ApplianceX}*(1-S_{ApplianceX})*EF_{ApplianceX}+ AD*S_{ApplianceX} * EF_{ApplianceX}*C_{ApplianceX}$$

where
E “real life” emissions from a given appliance (incl. normal and bad combustion periods)
AD amount of wood (kJ) combusted in the given appliance during the calendar year
S share of wood (combusted in the appliance type) to be combusted under “bad” circumstances (this could be
appliance type specific or just a general value estimated for all appliances)
EF emission factor for “normal” combustion conditions
C coefficient to multiply the “normal combustion” EF to represent emission level under bad combustion period

The share of wood combusted under bad combustion conditions (for example 10-20% of total wood used) needs to be estimated according to regional conditions. Some examples of typical bad combustion coefficients for particles, black carbon, carbon monoxide, polyaromatic hydrocarbons and ammonia are proposed in Table 2-5[1]. Note that these figures are only approximate and depend on issues listed in Table 2 and therefore need to be adjusted according to regional conditions. Note that the ratio may be likely higher for low emitting appliances than for higher emitting appliances. Optimal conditions are required for low emitting appliances to operate correctly and due to the sensitivity of combustion conditions, even small deviations from the appliance specific optimum change the emission profile. As the emission factors are low, even small changes in absolute emissions can multiply the emission factors.

For sulphur and nitrogen oxides, heavy metals and other persistent organic pollutants than PAHs no coefficients for bad combustion are provided as the emissions depend rather on the fuel properties (content of sulphur, heavy metals, chlorine etc.) and gasification (combustion) temperature (i.e. more

[1] The presented ratio "bad:normal combustion" and "bad combustion factors" are used in Finland's small scale wood combustion emissions inventory. To apply in other regions, it is encouraged to carry out studies for local appliances and combustion practices.

and more fine ash constituents are volatilized, when temperature increases) than the combustion conditions generally.

For more information regarding bad combustion, please see for example Tissari et al. 2008a and Schmidl et al 2011.

**Table 2-5 Examples of typical "bad combustion good combustion" ratios for different small scales wood combustion technologies**

Note that the ratio depends on issues listed in Table 2-5 and needs to be adjusted to regional conditions.

| | | TSP, $PM_{10}$, $PM_{2.5}$ | BC | CO | VOC | PAHs | NH3 |
|---|---|---|---|---|---|---|---|
| Boilers (wood log) | conventional | 1 | 1 | 5 | 10 | 20 | 5 |
| Boilers (wood log, pellet, chip) | modern | 1 | 1 | 5 | 1 | 3-20 | 5 |
| Stoves -slow heat releasing appliances and room heaters | conventional | 2-6 | 3 | 5 | 4 | 9 | 5 |
| | modern | 2-6 | 3 | 5 | 4 | 9 | 5 |
| Stoves (inserts, cookers, sauna, open fireplace) | conventional | 2-3 | 2 | 5 | 4 | 3 | 5 |
| | modern | 2-3 | 2 | 5 | 4 | 10 | 5 |
| Outdoor appliances | | 2 | 2 | 5 | 4 | 3 | 5 |

## 2.5 Residential Wood Combustion Technologies

**General**

Typical small scale wood combustion appliances used in European countries are categorized in Table 2-5 into *(1) Boilers, (2) Stoves and (3) Outdoor appliances*. Note that same stove technology may include *conventional, modern* or *advanced* versions between which the emissions levels may differ significantly as the evolution generally includes features. The last column of the table includes the related EN standard, if available. Work to update the EN standards was underway during the preparation of this guidance.

Information on appliance-specific emission levels and technology specific emission factors are provided in the tables below the category descriptions.

**Table 2-6 Residential wood combustion appliances: Boilers, stoves and outdoor appliances**

| Category | Appliance | Type | Examples of appliances | Approximate efficiencies | EN Standard |
|---|---|---|---|---|---|
| Boilers (≤ 50 kW output) | Wood log | Conventional | Over-fire<br>Under-fire | Over-fire 50-65%<br>Under-fire 60-70% | EN 12809 Manually and mechanically stoked solid fuel boilers<br>EN303-5 Manually and mechanically stoked solid fuel boilers |
| | | Modern | Under-fire<br>Reverse fire<br>Double nest<br>Downdraught | Improved air staging 80-85% | |
| | | Advanced | | around 90% | |
| | Pellet | One type | | 75-90% | |
| | Wood chip | Modern/advanced | Grate | 75% to above 90% | |
| | | | Over-fire<br>Stoker burner | | |
| Stoves | Slow heat releasing appliances | Conventional | Masonry stove<br>Masonry oven<br>Ceramic oven | 75-85% | EN 15250 Manually-stoked closed freestanding room |

**Table 2-6 Residential wood combustion appliances: Boilers, stoves and outdoor appliances**

| Category | Appliance | Type | Examples of appliances | Approximate efficiencies | EN Standard |
|---|---|---|---|---|---|
| | | Modern | Masonry stove<br>Masonry oven<br>Ceramic oven<br>Stove with water-circulating heat exchanger | 75-85% | heaters (stoves) with thermal storage capacity. |
| | | Advanced | Masonry stove<br>Masonry oven<br>Ceramic oven | 80- 90% | |
| | Room heaters | Conventional | Wood stove | 40-50% | EN 13229 Manually-stoked closed freestanding room heaters (stoves).<br>EN 13240 Manually-stoked open freestanding room heaters (stoves) designed to be mounted within a fireplace recess or integrated into a building. |
| | | Modern | Wood stove<br>Pellet stove | 60-75% | |
| | | Advanced | Ecolabelled (e.g. Blue Angel, Nordic Swan)<br>Pellet stove<br>High-efficiency conventional stove (incl. catalytic combuster stove) | 80% | |
| Stoves | Inserts | | Stand alone insert<br>Closed fireplace | 50-80% | EN 14785 Pellet stove/ insert<br>EN 13240 Manually-stoked open and closed insert room heaters designed to be mounted within a fireplace recess or integrated into a building. |
| | Cookers | Conventional | Kitchen range | 45-70% | EN 12815<br>Manually-stoked cookers (incl. cookers providing space heating or with boilers. |
| | | Modern | Kitchen range | >80% | |
| | | Advanced | Kitchen range<br>Pellet cooker | >80% | |
| | Sauna stoves | Conventional | Sauna stove | 45-70% | EN 15821<br>Manually-stoked sauna stoves. |
| | | Modern | | > 60% | |
| | | Advanced | | > 75% | |
| | Open fireplaces | Conventional only | Radiating stove | <30% | |
| Outdoor appliances | Bath tubes | Conventional, simple | Stove outside/ under the bath tube | | |
| | Cooking ovens | | Cooking oven | | |
| | Outdoor heaters | | Cooking stove<br>Bake/pizza etc. ovens<br>Camp/tent stove | | |
| | Open fire | | Camp fire | | |

### *A Boilers - Features in Conventional, Modern and Advanced Appliances*

Residential boilers in most European countries have an indicative capacity below 50 kW output. Especially in temperate regions of Europe, small boilers with a nominal output 12-50 kW are used for primary heating in buildings not connected to district heating network or not using e.g. electricity or geothermal energy for heating. Residential wood boilers are batch-fired or continuous load type (pellet, chips) and the heat can be stored in a water tank. Wood logs, pellets or chips are used as fuel. Examples of typical appliances are illustrated in Figure 2-2

Conventional boilers used for central heating in residential buildings may be of simple design and mainly primary air supply only.

- Wood log boilers are manually fed and the air supply is generated by natural draught. The combustion process is typically not optimal and results in significant emissions, especially particles, CO, VOCs and PAHs due to incomplete combustion if the appliance is operated at low load.
- *In over-fire boilers* the combustion process resembles that in stoves.
- *Wood chip boilers* have usually water circulation -based systems and a separate grate burner. The primary air supply is adjusted with fans. Emissions are generally low due to the smooth burning process and are mainly impacted by the quality of wood chips.

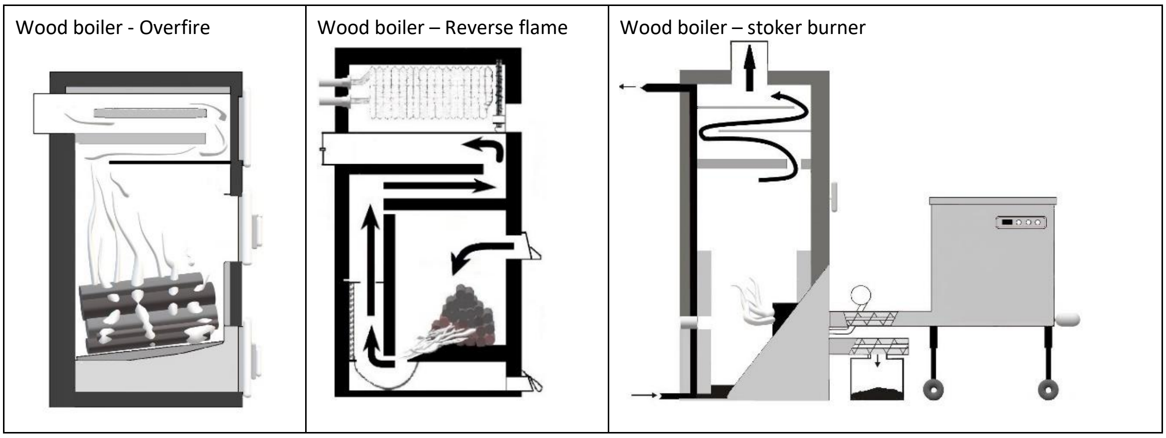
Modern wood boilers have improved air staging systems compared to conventional boilers, both primary and secondary air supply, which allow better control of combustion conditions and thus lower emissions and have automated controls for combustion conditions.

- *In under-fire/reverse boilers* combustion is more stable than in over-fire boilers, due to continuous gravity feed of fuel onto the fire bed resulting in higher energy efficiency and lower emissions.
- *Pellet boilers* are characterised by a high efficiency and the emissions are comparable to those of liquid fuel boilers. However, due to the simpler design of combustion process automation, emissions of CO and VOC are higher in comparison to larger boilers and industrial installations. Central heating boilers have water-circulation based systems and are operated manually or by an automatic system from a larger chamber storage.
- *Wood chip boilers have* over-fire or stoker burners or are based on gasification.

Advanced boilers have automated control and adjustment systems and may also have separate flue gas cleaning technologies (e.g. an ESP).

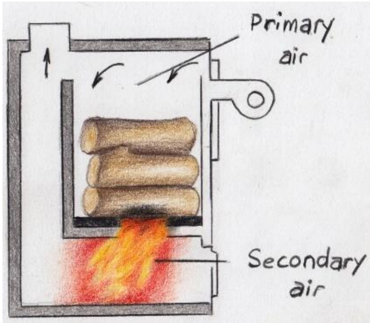
- *Wood chip boilers* have fully automated controls, ashes are removed by sweeping and the boiler can be operated remotely.
- Advanced appliances may not yet be available for all boiler types and may not yet be common but are emerging on the market.

**Figure 2-2 Examples of wood log boilers used in Europe**

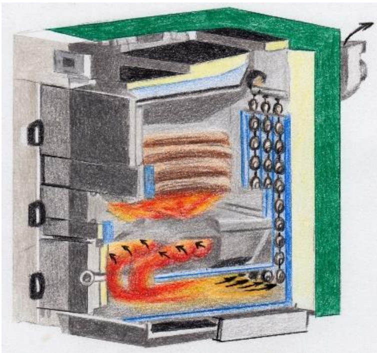


Wood boiler – Under-fire

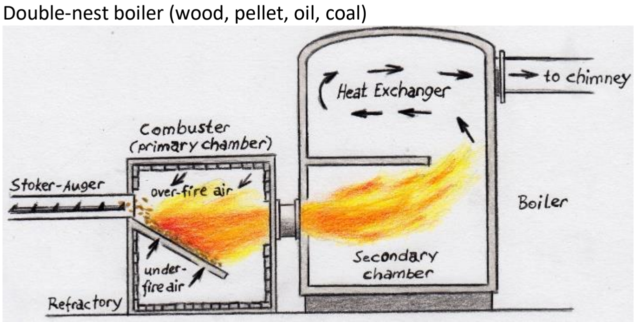
Wood boiler - Downdraught




Wood boiler – Modern, automatic



Double-nest boiler (wood, pellet, oil, coal)




## *B. Stoves*

**STOVES – Stoves, features of conventional, modern and advanced appliances**

Stoves are manually operated enclosed appliances where wood is added in batches. Heat is transmitted to the surroundings by either radiation or convection through heat storing or accumulation. The same stove technology may include *conventional, modern* or *advanced* versions between which the emission levels may differ significantly as the evolution generally includes features described below. Examples of typical stoves are illustrated in Figure 3.

*Slow heat releasing stoves and ovens* are mainly assembled on site and accumulate heat through storing capacity in their construction mass. They can release heat through convection for days after the fire has burnt out. The construction varies depending on country and region, and is based on brick, stone, ceramics or a combination (masonry stoves and ovens). The combustion chamber can be equipped with horizontal strips or inclined, perpendicular baffles made of steel or fireproof material, which improve combustion quality and efficiency. Masonry ovens are masonry stoves equipped with a bake oven.

*Room heaters* are light weight and made as prefabricated iron or steel appliances that provide heat directly to the room space using down- or upburning principle. Stoves equipped with hot-plate zones are used also for cooking and some include a tank to prepare hot water.

*Inserts* are prefabricated equipment with closable front doors and can be installed as stand-alone units or as fireplace inserts in open fireplaces. Combustion air is distributed to primary (grate) and secondary routes (panels) and discharge exhaust gases. Due to their construction, these appliances resemble the emission profiles of room heaters.

*Cookers* are usually made of iron or steel while the combustion chamber is covered with fire bricks. A kitchen stove has a cooktop and may also contain an oven. A cooktop and an oven combined into one appliance is called kitchen range. Cookers may provide hot water for indirect heating of a dwelling.

*Sauna stoves* are common in Scandinavia, wood-fired sauna stoves are typically light weight and made as prefabricated iron or steel appliances. In a sauna room the heating need is temporarily very high, so the stoves operate with a higher combustion rate as e.g. roomheaters. Several models of sauna stoves are available. The stoves have a pile of heat-storing stones on top or around of the firebox and can also incorporate a water heater.

*Open fireplaces* can be found in older buildings or in areas of fuel or energy poverty. In Europe open fireplaces are used more for recreational than heating purposes and provide heat directly to the room air by radiation. Open fireplace combustion chamber is directly connected to the chimney. Some designs may have dampers above the open fire-bed to limit the room air intake. Due to the open firebox there is non-adjustable excess of combustion air leading to low efficiency and high emissions. Up to 90% of heat released during combustion is lost through the chimney. In cases where combustion is poor, especially when outside air is cold or if the fire is allowed to smoulder and thus draw outside air into the room, a net heat loss may occur when using an open fireplace. Some fireplaces equipped with back water jackets provide hot water.

Partly closed fireplaces are equipped with louvers and glass doors to reduce the intake of combustion air. Distribution of the combustion air is not arranged or regulated and for that reason combustion conditions are not improved compared with open fireplaces detailed above. Open fireplaces can be upgraded to partially heat storing by installing a fireplace insert, see above under “Inserts”

<u>Conventional stoves</u> generally have primary air supply only (possible with airwash). The combustion process is typically not optimal and result in significant emissions, especially particles, CO, VOC and PAHs due to incomplete combustion.

<u>Modern stoves</u> have both primary and secondary/tertiary air supply which allow better control of combustion conditions and thus lower emission levels.

<u>Advanced stoves</u> have automated control and adjustment systems such as multiple air inlets and pre-heating of secondary combustion air, and some of them may also have separate flue gas cleaning technologies (e.g. catalyst or ESP).

- Pellet stoves have an active control system for supply of combustion air and provide proper air/fuel mixture leading to low emissions.
- Advanced wood stoves (including ecolabelled stoves) have multiple air inlets and pre-heating of secondary combustion air, which result in increased efficiency and reduced emissions in comparison with conventional stoves.
- Cookers may use wood pellets and have fully automated operation leading to similar emission levels as pellet stoves.
- Note that advanced appliances may not yet be common but are emerging on the market.

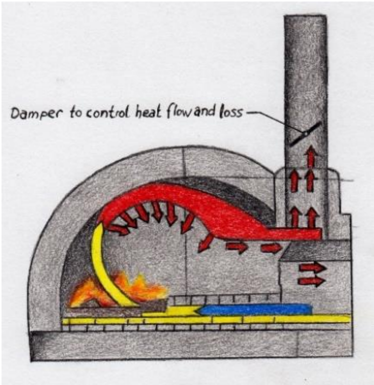
**Figure 2-3 Examples of stoves used in Europe**


## C. Outdoor appliances

While outdoor cooking and bake appliances, wood-fired pizza ovens, chimeneas and other stoves or ovens are traditionally common in Southern Europe, outdoor heating has increased also in some other countries in the recent years through the use of patio heaters, heated bath tubes and similar devices. All these appliances have limited control of emissions.

In addition, traditional campfires, fire pits and chimenea appliances are relevant in European countries. 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. Regarding the operation, these are very similar to an open fire.

**Figure 2-4** **Examples of outdoor appliances (to be completed)**

| Chimenea | Bathtub | Camp stove |
|---|---|---|
|  |  |  |



## 2.6 Activity Data

Residential wood combustion is a key category for several air pollutants in most countries. It is therefore recommended to use at least a Tier 2 method to quantify the emissions.

*National Data Collection*

National data collection on residential wood use ensures representative inventories compared to the country-specific conditions and enables accurate follow-up of the time series development. If the current national statistics does not provide the detailed data needed in the inventory, regular surveys or research are needed. The surveys need to be based on a representative sample in terms of location and housing. Reference literature to consider when preparing and conducting surveys of residential wood consumption include e.g. Broderick & Houck (2003), Eastern Research Group (2000) and Eurostat's manual for statistics on energy consumption in households (2013).

The institution responsible for national energy statistics to report the fuel consumption should make efforts to create an adequate sectoral disaggregation for the below 50 $MW_{th}$ wood use as part of their regular activity in developing annual statistical data. When this is not the case, sources listed below are useful to collect data on residential wood combustion:

- information from wood suppliers
- surveys to households and commercial/institutional and agriculture sector entrepreneurs to collect information on wood use
- surveys and research to cover wood acquired directly from the forest
- energy demand modelling to estimate the energy demand for space heating and the share of wooden fuels use

Note that

(1) Households and other small users of wood are not necessarily able to answer questions without support to quantification of consumed wood, therefore special care needs to be exercised in planning of the questions and some guidance provided in the questionnaire to assist the task.

(2) Care needs to be exercised also when asking stove type and its age, and preferably a selection of options to choose from could be provided. For instance, pictures of typical appliances can be provided or options of time periods that are relevant to construct the age distribution of appliances.

*Activity data for emission inventories*

Information on residential wood use is the key data to develop emission inventories. In addition, information on wood combustion appliances typically used in the country is relevant to enable understanding the characteristics of emissions. This information includes shares of wood of the total consumption that are combusted in boilers and stoves and outdoors, specifically in the different appliance technologies and their age distribution over the time series. That information helps to quantify e.g. the proportion of wood combusted in traditional low technology appliances, as these usually generate significant emission levels of most pollutants, and to follow up the development of emissions over the timeseries.

To collect data on residential wood combustion appliances the following data sources can be used

- information from appliance producers and sellers
- surveys to households and commercial/institutional and agriculture sector entrepreneurs

In case this data cannot be reached, surrogate data sources could be used, as long as the quality and national applicability of the data sets are well understood:

- information from chimney sweeper organizations
- housing statistics and data from housing registers which often include information of primary/secondary heating source and the construction year of the dwelling
- energy conservation/climate change mitigation studies for relevant sectors
- energy demand modelling

When developing the inventory, 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. Also, when data on fuel consumption are provided at an appropriate level of sectoral split, these sources can be used to check for possible anomalies.

**Additional Information**

Comparing wood consumption in residential heating between countries is not straightforward as the construction (e.g. different insulation solutions) and outside temperature impact the consumption.  Therefore it is always recommended to establish national surveys and models to be able to use representative data for the national conditions.

External information sources that can be used for comparison and verification presented in Table 2-7 temporarily be used in cases where national data collection has not yet been completed.

**Table 2-7 Energy consumption for residential space heating in selected European countries (Odyssee-Mure project, the Odyssee database (2012)**

| Party | Heat consumption for residential space heating *, MJ/m² |
|---|---|
| European Union average | 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. Thus, affordable district heating decreases wood consumption compared to those that heat with direct electricity. 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. Price levels, accessibility and consumer behavior all affect the choice of heating source, thus 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. Note that country specific shares should be used instead, as both heating supply and demand vary significantly between countries. Also, the recreational use of wood is not included in the shares below. In addition, the share might be higher in countries or regions with large forest areas if wood might be easily accessible.

**Table 2-8 Residential wood combustion (RWC), share of heating demand**

| 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 |

**B - Default factors to split your total fuel consumption over the various appliance types**

Default factors to split total fuel consumption between some common appliance types are presented in Table 2-9. 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 splits are estimated by dividing the energy balances 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). For countries not included, it is good practice to select a country resembling closely to the national circumstances. For the years in between the provided years, interpolation/extrapolation may be used to estimate the appliance type contributions.

**Table 2-9 Appliance types distinguished in the IIASA GAINS model**

| Abbreviation | Appliance types in the IIASA GAINS model | Abbreviation | Appliance types in the IIASA GAINS model |
|---|---|---|---|
| FPLACE | Fireplace | SHB_M | Single house boiler, manual feed |
| STOVE | Heating stove* | MB_A | Medium boiler, automatic feed (between 1 – 50 MWth) |
| SHB_A | Single house boiler, automatic feed | MB_M | Medium boiler, manual feed |

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

**Table 2-10a Appliance type split according to IIASA GAINS model for the year 2000 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 2-11b Appliance type split according to IIASA GAINS model for the year 2000 Year: 2000**

| 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 2-10c 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% |

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