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Improving the estimation of air pollutant emissions from small-scale combustion sector

The state-of-art, updates and improvements in EDGAR database for EU27

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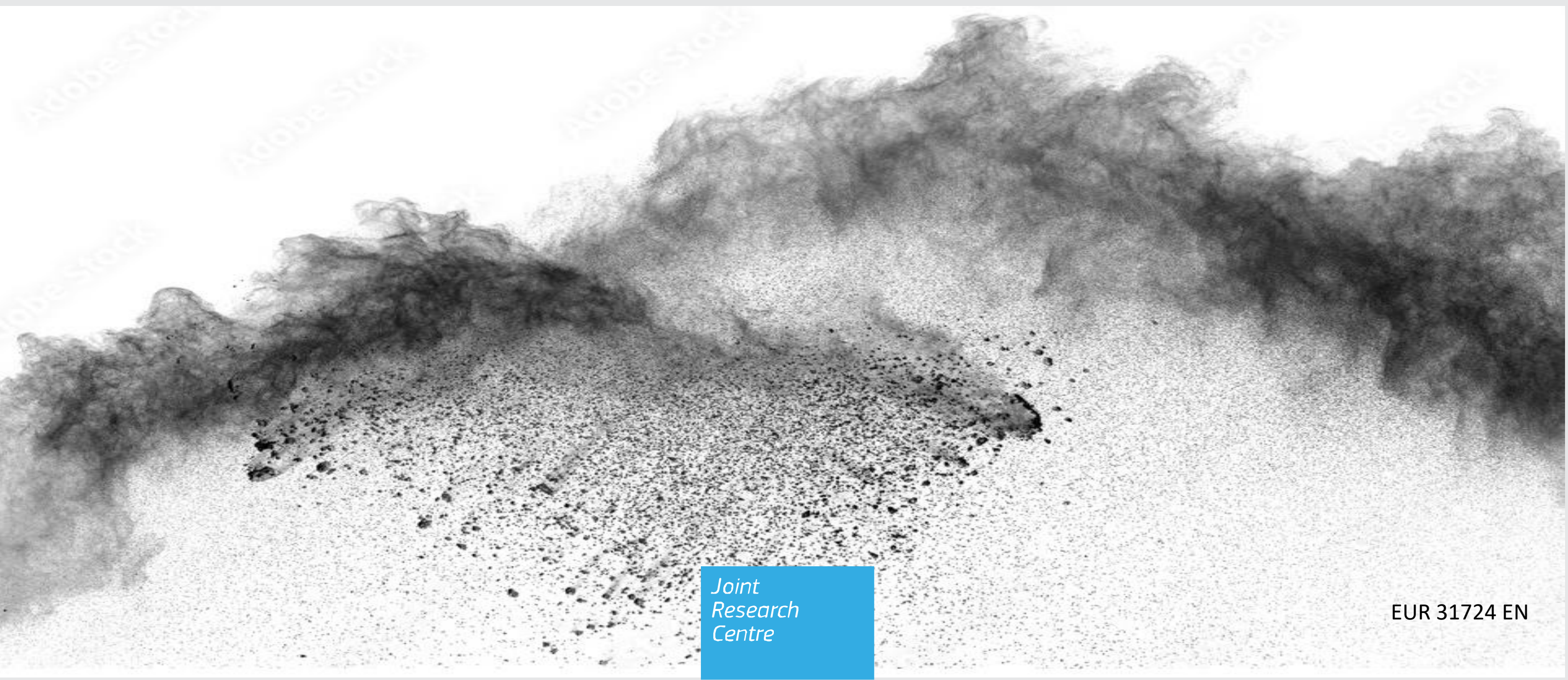

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Contents

Abstract

The small-scale combustion sector including residential heating and other small-scale combustion activities, can impact air quality and affect climate change.

The aim of this report is to provide insights on the EU27 small-scale combustion sector from the point of view of fuel consumption, air pollutant emissions as well as improvement done in the estimation of main air pollutants from this sector.

Enhancing the accuracy of air pollutant emission estimates from the small-scale combustion sector holds significant importance. This is not only due to the sector's impact on air quality and climate change, but also to gain insights into its relative contribution when compared to other activities like larger-scale energy production, transport, industrial processes, agriculture and waste management. Understanding this contribution is important for comprehensive environmental assessments and informed decision-making.

The work done will contribute to the improvement of independent estimation of air pollutant emission from small-scale combustion sector combining the relevant information provided by countries with that coming from modelling and from the international guidelines. As such, the estimation become more coherent in understanding the air pollution dynamics and supporting the policy development.

Acknowledgements

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Authors

Antoine Ebeling collected the latest data on air pollutant emissions for the small-scale combustion sector of each EU country, utilizing the information that EU27 Member States (hereafter MS) reported under the National Emissions reduction Commitments Directive (2016/2284/EU) (hereafter NECD). Documented the various methodologies employed by each EU country, collected data on the distribution of technologies, and country specific emission factors for the small-scale combustion sector of each MS. This dataset was then structured into a comprehensive database encompassing both technology shares and emission factors. Conducted data analysis and contributed to the report by providing insights within sections covering methodologies overview, policy measures, and the health impact, contributed in creating the inputs of new structure for the EDGAR database.

Manjola Banja is the overall responsible of the report defining the working methodology for data collection and analysis, the structure of the report, drafting the report, carried out data analysis, and prepared the graphical part of the report supervising the entire work done to improve the air pollutant emissions estimation for the small-scale combustion sector within EDGAR database.

1 Introduction

The small-scale combustion sector[1] refers to a broad range of energy-consuming activities and appliances at a smaller scale, typically in residential, commercial, and small-scale industrial settings. It includes various combustion processes used for heating, cooking, hot water production, and other energy needs.

This sector can contribute to local air pollution and greenhouse gas emissions if not properly managed. Across the EU MS, several policy measures have been implemented to address the environmental and health impacts of the small-scale combustion sector. These measures aim to promote cleaner and more efficient technologies, reduce emissions, and improve air quality.

The EU MS have established emission standards and regulations that set limits on air pollutant emissions from small-scale combustion appliances. These standards often include limits for particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and other pollutants. Compliance with these standards is mandatory for manufacturers and importers of appliances.

Eco-design Directive – the European Union's Eco-design Directive sets minimum energy efficiency and environmental performance standards for energy-related products, including small-scale combustion appliances. This directive aims to improve the overall environmental performance of appliances, including their energy efficiency and emissions (Directive 2009/125/EC, 2009).

Eco-design and Energy Labelling Standards – the Eco-design regulations and energy labelling requirements are implemented for various small-scale combustion appliances. These regulations ensure that appliances meet certain efficiency and emission criteria, and energy labels provide consumers with information about the energy efficiency and environmental performance of appliances (Directive 2009/125/EC, 2009), (Regulation (EU) 2017/1369 , 2017).

Incentive Programs – In Europe, small-scale combustion technologies are becoming increasingly popular. Many EU MS have implemented policies and incentives to promote the use of these technologies, particularly for residential heating. These incentives can encourage the replacement of old and inefficient appliances with newer, low-emission models as a way to reduce greenhouse gas and air pollutant emissions and improve energy efficiency. However, the scale effect also needs to be considered: a large increase in the overall number of stoves, even if recent and more efficient ones, can lead to an increase in overall emission of air pollutants due to the mere number of stoves installed.

In Germany, for example, the government provides financial incentives to households that replace old, inefficient heating systems with new, high efficiency systems, including small-scale biomass boilers. In Austria, the government has implemented a program to subsidize the installation of pellet stoves and boilers, aiming to replace old oil heating systems. Between 2001 and 2020, the share of new wood stoves and cooking stoves in households in Austria has been increased from 2.4% to 21.2% (AT, IIR 2022). Other EU MS as Denmark and Sweden, have a long tradition of using small-scale biomass heating systems and have developed advanced technologies and supply chains to support their use.

Support for Renewable Energy – the European countries promote the use of renewable energy sources, such as biomass, as a sustainable alternative to fossil fuels in the small-scale combustion sector. Incentives and support schemes are provided to encourage the use of biomass boilers and other renewable heating technologies. The Renewable Energy Directive (2018/2001/EU) sets a target for the European Union, requiring a minimum of 32% renewable energy by 2030 with a revision in 2023. In March 2023, an agreement was reached between the European Parliament and the Council to increase the EU's binding renewables target to at least 42.5% for 2030. The negotiations further aimed to achieve a 45% share of renewables by 2030, demonstrating a commitment to higher renewable energy adoption within the European Union (Council of the EU Press release, March 2023).

Bioeconomy and circular economy: Sustainable biomass management as a resource is a key concern in the EU. In recent years, the EU has developed specific policies and initiatives related to the bioeconomy and circular economy, such as the European Green Deal (EC, 2021) and the Circular Economy Action Plan (COM(2020) 98 final). Sustainability in biomass utilisation hinges on resource-efficiency, as driven by the principles of the bioeconomy and circular economy, with an emphasis on minimizing waste and maximizing the value of renewable biological resources (Monforti-Ferrario, F, Belis C, 2018).

([1]) Here after the activities in stationary residential, commercial/institutional and agriculture/fishing are considered as small-scale combustion activities.

Support for Energy Efficiency – The Energy Performance of Buildings Directive (2018/844/EC – amended) includes provisions for technologies in the small-scale combustion sector. It emphasizes the importance of improving energy efficiency in buildings by promoting the use of advanced and efficient technologies for heating and hot water production. The directive encourages the adoption of high-efficiency boilers, stoves, and other heating devices that meet specific energy performance requirements. It also promotes the use of renewable energy sources, such as biomass, where applicable, to reduce the environmental impact of small-scale combustion installations. Additionally, the directive encourages the regular maintenance and optimization of these technologies to ensure optimal energy efficiency and minimize emissions.

Awareness Campaigns and Education – Public awareness campaigns and educational programs are conducted to raise awareness about the environmental and health impacts of small-scale combustion appliances and to promote good practices for efficient and cleaner burning. These campaigns aim to inform consumers about the benefits of adopting cleaner technologies and provide guidance on proper appliance use and maintenance.

This technical report provides an overview of the small-scale combustion sector in the EU27 and the needs to improve the Emissions Database for Global Atmospheric Research (EDGAR) emission estimation for this sector.

The study begins with an overview of the small-scale combustion sector, encompassing main technology types, fuel usage patterns, and emissions in the EU27 providing information on this use for the MS. The main part of Chapter 2 is the methodological overview of emission estimation in the small-scale combustion sector in each MS. It also presents some info related to the health consequences of air pollution from fine particulate matter ($PM_{2.5}$) in the EU27 region and investigates the relationship between the changes on premature deaths from $PM_{2.5}$ and changes in the emissions of $PM_{2.5}$. A short overview of policy measures related to the reduction of air pollution from small-scale combustion sector is provided in section 2.5.

Subsequently, the report provides a short overview of the EDGAR database methodology for small-scale combustion sector assessment in Chapter 3, describing also the issues related to estimating air pollutants.

Moreover, it highlights the role of the EMEP/EEA (European Monitoring and Evaluation Programme/European Environment Agency) Guidebook 2019 and the International Institute for Applied System Analysis (IIASA) Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS) model, as benchmarks for technology split and fuel allocation in the improvement of estimation of air pollutant emissions from small-scale combustion.

The approach for EDGAR database updates in this sector is outlined, focusing on technology data and emission factors and on the key fuels used in this sector.

Some examples of improvements done following the selected approach are presented in Chapter 4, showing how the improvements are performed in these cases.

In the Annexes an overview on the inclusion of particulate matter condensable fraction in emission factors applied for residential and commercial subsectors is provided together with the relative changes since 2005 of main air pollutant emissions from each MS as wells as the GAINS model technology split for fuelwood in each MS residential subsector.

2 Overview of small-scale combustion sector in EU27

The small-scale combustion sector includes the small-scale stationary combustion in residential, commercial, and public services, agriculture, forestry, fisheries, and other sectors. Here are some key points regarding the small-scale combustion sector:

Residential Space Heating – includes heating systems used in individual homes and apartments, such as stoves and boilers fuelled with wood logs or pellets, fireplaces, gas heaters, and oil heaters. These appliances provide space heating and hot water for domestic use.

Cooking Appliances – include small-scale combustion devices for cooking purposes include traditional stoves, gas cooktops, electric cookers, and wood-fired cook stoves. These appliances are used for preparing meals in households and small-scale food establishments.

Residential Water Heating – includes electric water heaters, gas water heaters, and oil-fired water heaters. These appliances heat water for domestic use, including showers, sinks, and other applications.

Small-Scale Industrial Processes – encompasses heating processes for various applications, such as space heating in workshops, process heating in small manufacturing facilities, and heat generation for drying or other industrial processes.

Agriculture and Farming – combustion processes are employed in agricultural settings for purposes such as greenhouse heating, poultry and livestock heating, and grain drying.

Outdoor Applications – include outdoor combustion devices, such as outdoor fire pits, wood-fired ovens, and portable gas or charcoal grills used for cooking and recreational purposes.

Small-combustion technologies refer to heating systems, which typically have an output up to 50 kW and are used to heat homes, small businesses, and public buildings. These technologies include a wide range of heating systems as stoves, small-scale boilers and furnaces that burned solid fuels such as biomass (wood, pellets or logs), liquid fuels or gaseous fuels for space heating and how water production.

2.1 Main technology types used in small-scale combustion sector

The small-scale combustion sector incorporates various technologies for heating and energy production. Some of the commonly used technology types in this sector include:

- **Gas-fired boilers**: Gas-fired boilers are widely used for heating purposes in small-scale applications. They burn natural gas or liquefied petroleum gas (LPG) to produce heat for space heating and domestic hot water. Over-fire and under-fire boilers can be distinguished.
- **Oil-fired boilers**: Oil-fired boilers utilize heating oil as a fuel source. They are commonly used in areas where natural gas infrastructure is limited or unavailable.
- **Biomass boilers**: Biomass boilers burn organic materials such as wood pellets, wood chips, or agricultural residues to generate heat.
- **Pellet stoves**: Pellet stoves are compact heating devices that burn biomass pellets made from compressed sawdust or agricultural waste. They are often used as a space heating solution in residential settings.
- **Wood-burning stoves**: Traditional wood-burning stoves use firewood as a fuel source. They have been used for centuries and are still prevalent in some rural areas. However, modern wood-burning stoves incorporate advanced combustion technology to improve efficiency and reduce emissions.
- **Combined Heat and Power (CHP) systems**: CHP systems, also known as cogeneration, simultaneously produce heat and electricity from a single energy source. In the small-scale combustion sector, small-scale CHP units, such as micro-CHP or mini-CHP systems, can be found utilizing gas, oil, or biomass as fuel.
- **Heat pumps**: Heat pumps extract heat from the environment (air, ground, or water) and amplify it to provide space heating and hot water. They are highly efficient and can significantly reduce energy consumption compared to traditional combustion-based systems.

In an assessment of the space heating and domestic hot water market in the EU27+UK, it was determined that boilers have the highest prevalence, with approximately 95 million devices installed. Following boilers, stoves accounted for nearly 60 million installations (Pezzutto S., et al., 2019). Boilers can be categorized into two types: condensing and non-condensing, which differ in terms of their efficiency and operational principles. The above-mentioned assessment reveals that non-condensing boilers have a dominant market share, exceeding 85%.

2.2 Fuel use in the EU27 small-scale combustion sector

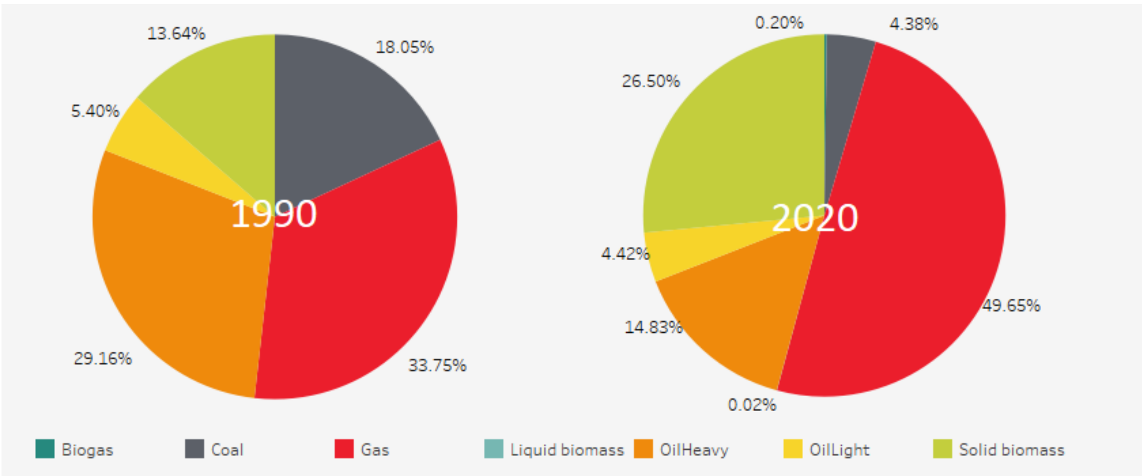
The EU27 small-scale combustion sector is characterized by a variety of fuels and technologies being applied for heating and cooking (stationary combustion). Wood use in the small-scale combustion sector is a common source of energy, particularly in rural areas.

Wood is used as a primary heating source or as a supplementary source of heat and can be burned in traditional fireplaces, or in stoves and boilers fuelled with wood or pellets. Wood combustion in the residential sector remains a significant source of air pollution, particularly during winter months when heating demand is highest (Wolf T., et al., 2021)

The share of fuel use in the small-scale combustion sector varies across countries depending on factors such as fuel availability, climate and policy measures aimed at promoting energy efficiency and emissions reduction. Residential subsector remains the main sector in EU27 small-scale combustion covering nearly two-thirds of fuel consumption over period 1990-2020 (EDGAR, 2023[2]). Nearly 90% of biomass in the small-scale combustion sector is consumed in this subsector, 7% in Commercial/Institutional subsector and the rest in Agriculture/Fishing/Other.

Analysing fuel consumption trends in the small-scale combustion sector over the years, a noticeable shift towards the use of biomass and gas has emerged. Biomass consumption has doubled between 1990 and 2020, while gas accounted for almost half of the fuel used in the sector in 2020. (see Figure 1).

Figure 1. Fuel consumption share in the EU27 residential subsector, 1990 and 2020



Source: EDGAR, 2023

Figure 2 illustrates the fuel shares in each MS residential, commercial/institutional and agriculture/fishing/other subsectors in the year 2020. As shown in this figure the shares of the fuel use in small-scale combustion sector varies widely across subsectors and countries.

Biomass and gas are the fuels that dominate the residential subsector whereas gas and oil dominates the commercial subsector. The subsector of agriculture/fishing/other is dominated mainly by oil fuel.

(2) Fuels use in each MS small-scale combustion sector are sourced from the IEA-EDGAR CO2, a component of the EDGAR (Emissions Database for Global Atmospheric Research) Community GHG database version 8.0 (2023) including or based on data from IEA (2022) Greenhouse Gas Emissions from Energy, www.iea.org/data-and-statistics , as modified by the Joint Research Centre. The analysis presented in this section does not include electrical energy and derived heat (refer to EUROSTAT for this information).

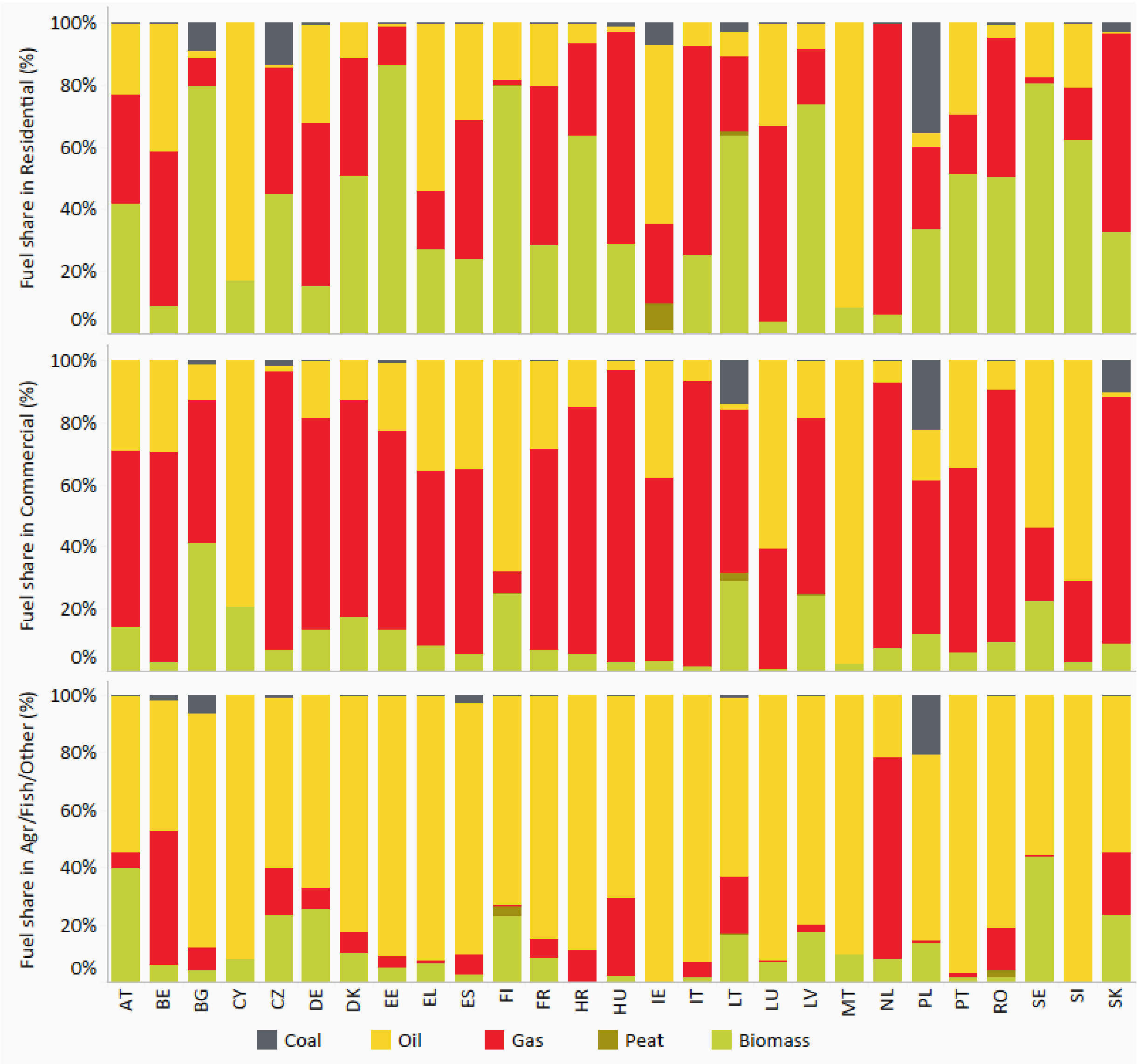
In some countries with abundant forest resources, such as Finland and Sweden, wood is the dominant fuel in residential subsector technologies, accounting for nearly 80% of the total fuel consumption in 2020 (EDGAR, 2023).

In contrast, in countries such as Netherlands where natural gas is widely available and heavily promoted, this is the dominant fuel in residential subsector, accounting for over 90% of the total fuel consumption in 2020. In other countries, such as Ireland, the use of biomass is at the lowest levels and this sector is more affected from the role of fossil fuels (EDGAR, 2023).

In 2020, nearly 75% of coal in the EU27 residential subsector is consumed in Poland. More than half of oil is consumed in Germany (42.7%) and France (14.1%).

More than two-thirds of gas is consumed in Germany (27.7%), Italy (20.3%), France (13.7%) and Netherlands (8.1%). Nearly 95% of biogas is consumed in Germany; more than 62% of bio liquids is consumed in Sweden; and more than half of solid biomass is consumed in Italy (14.3%), France (14.2%), Germany (13.9%) and Poland (11.6%).

Figure 2. Fuel shares in EU2 MS residential, commercial and agriculture/fishing/other subsectors. 2020[3]



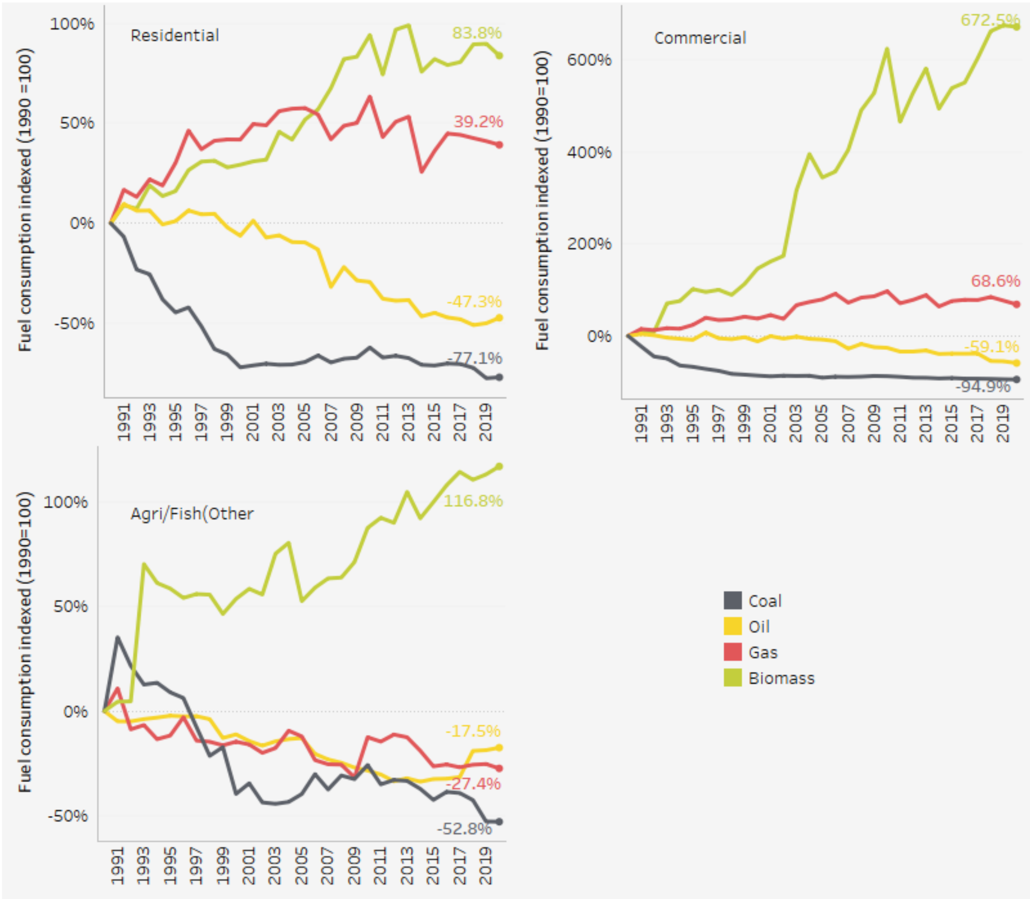
Source: EDGAR, 2023

(3) Fuel description according to the IEA World Energy Balance Database Documentation https://wds.iea.org/wds/pdf/worldbal_documentation.pdf

Within the EU27 small-scale combustion sector, the residential subsector accounted for approximately two-thirds of the fuel consumption in 2020, a proportion that has remained relatively consistent throughout the period from 1990 to 2020. Over the years since 1990, the consumption of biomass in the small-scale combustion sector of the EU27 has experienced varying growth rates (see Figure 3). However, there has been an overall upward trend, with the commercial/institutional sector witnessing the highest increase. This sector has seen an average annual growth rate of 22.4% of biomass consumption.

In 2022, the trends presented in Figure 3 are affected by the Ukraine war and energy crisis especially related to the drop in gas use, which by the end of 2022 was 21.4% below the consumption in 3rd Quarter of 2022. An analysis of this impact in the EU27 energy structure including residential subsector has been already published in the JRC yearly report of GHG emissions of all world countries (Crippa et al., 2023).

Figure 3. Growth rates of fuels consumed in the EU27 small-scale combustion sector (relative to1990), 1990-2020



Source: EDGAR, 2023

2.3 Emissions from the EU27 small-scale combustion sector

The NECD (2016/2284/EU) sets obligations for MS to reduce emissions of five significant air pollutants: nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), ammonia (NH_3), and fine particulate matter ($PM_{2.5}$). These pollutants contribute to the degradation of air quality, causing significant harm to human health and the environment.

In the case of CO emissions, even that this pollutant is not covered by the NECD it holds significant relevance within this sector. The contribution of CO emissions from this sector to national totals is notably significant, particularly with the growing use of biomass and similar energy sources. This pollutant is in the focus of the Eco-Design Directive 2009/125/EC[4] under which specific measures are adopted for combustion appliances like boilers and heaters, including limits for the CO emissions.

(4) Eco-design Directive 2009/125/EC focuses on NOx, Particulate Matter (PM), Organic Gaseous Compounds (OGCs) and CO.

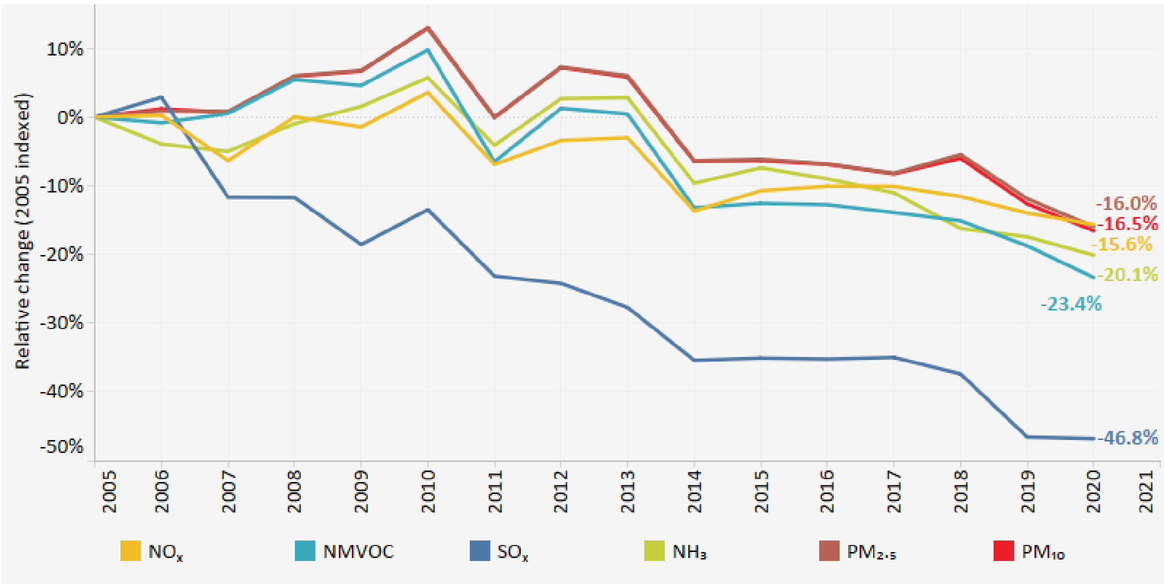
The NECD, in effect since December 31, 2016, replaced the previous Directive 2001/81/EC. It sets emission reduction commitments for the years 2020-2029 and more ambitious ones for 2030-onward for these five air pollutants.

Figure 4 shows the trend that each air pollutant emissions in EU27 have followed in the small-scale combustion sector compared with the level they had in year 2005[5]. Data sourced from EMEP/CEIP Data viewer[6] are the officially reported data submitted to the Air Convention up to 1st of June 2023. The Nomenclature for Reporting (NFR) categories included in the following analysis are 1A4ai, 1A4bi, 1A4ci and 1A5a.

Comparing the 2020 and 1990 levels, air pollutant emissions from small-scale combustion sources in the EU27 have witnessed a decline in overall. However, the extent of reduction varies among different pollutants and countries. Sulphur oxide emissions (SO_2) have been reduced by nearly 47%, whereas emissions of fine particulate matter ($PM_{2.5}$ and PM_{10}) have been reduced by approximately 16%.

The emissions of particulates ($PM_{2.5}$ and PM_{10}) and non-methane volatile organic compounds (NMVOCs) reached their highest levels in 2010 and have since gradually declined. On the other hand, emissions of other pollutants as NOx and NH_3 from this sector have been steadily decreasing since 2005 respectively by 23.4% and 20%.

Figure 4. Trend of main air pollutant emissions in small-scale combustion[7] over period 2005-2020 (2005 indexed)



Source: EMEP/CEIP 2023, JRC elaboration

The evolution of main air pollutants emission since 2005 in each subsector of small-scale combustion sector is shown in Figure 5 and more in detail for each MS and each main air pollutant is shown in Annex 1.

As shown in Figure 5, except for NOx and NH_3 emissions from agriculture/fishing and NMVOC from commercial subsectors, the air pollutants released from stationary agricultural activities within the small-scale combustion sector have seen significant reductions.

Since 2005, the NH_3 emissions from agriculture/fishing subsector have increased by 82% starting from a very low level of 0.55 kt to reach only 1.0 kt in 2020. The NOx emissions from this subsector increased by 26.5% between the same period reaching nearly 65 kt in 2020.

In contrast, NOx emissions from stationary residential and commercial subsectors have shown a similar downward trend, with levels approximately 19% and 20% lower than those recorded in 2005. The decrease of NOx emission in the other subsector by nearly 30%.

(5) The analysis on air pollutant emissions in EU27 covers period 2005-2020. At the time of writing this report, the Croatian 2023 Informative Inventory Report (covering 2021 emission data) was not yet available at the EIONET CDR webpage.

(6) Tableau software is used to elaborate data from EMEP/CEIP Data viewer https://www.ceip.at/data-viewer-2

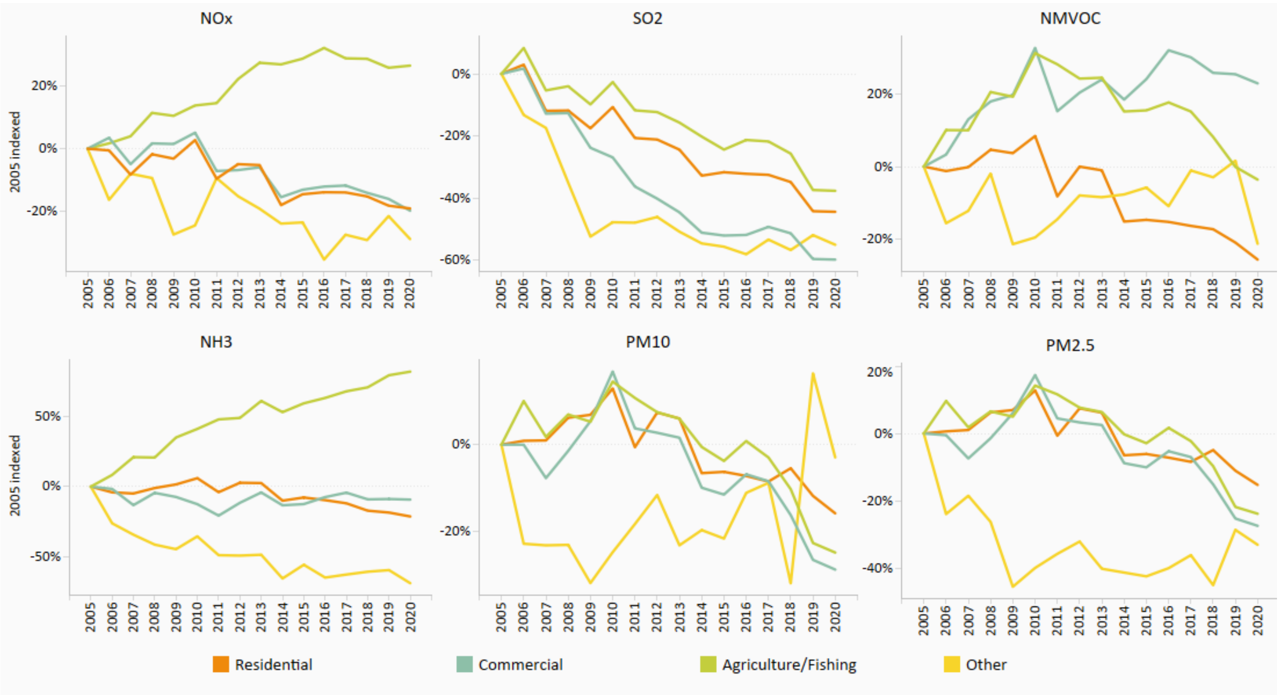
(7) Small-scale combustion emissions include only the stationary subsectors: 1A4ai (Commercial), 1A4bi (Residential), 1A4ci (Agriculture/Fishing) and 1A5a (Other).

The largest decline in emissions occurred in the small-scale combustion subsectors for SO_2: 44.5% in residential, 60% in commercial, 37.7% in agriculture, and 55% in other subsector.

Among NMVOC emissions, only the commercial subsector exhibited an increasing trend after 2010, reaching levels in 2020 that were 22.6% above the levels in 2005. Conversely, emissions from other subsectors decreased by 25.6% in residential, nearly 4.0% in agriculture, and 21.3% in others. The overall trend in NMVOC emissions from the commercial subsector is influenced by the increase in emissions in Slovakia, which reported a very low level of NMVOC emissions for this subsector only in 2005. Additionally, the trend in these emissions in Spain from 2005 to 2012 is notable, with emissions more than doubling from 1.25 kt to 2.58 kt. It is worth mentioning that the trend in these emissions has shown oscillations in several MS over the years.

The trends for PM_{10} and $PM_{2.5}$ emissions have followed a similar pattern since 2005 in almost all subsectors. The decrease in the residential and commercial subsectors were by 15.0% and 28.0%, respectively. In the other subsector, PM_{10} emissions decreased by only 2.9%, while $PM_{2.5}$ emissions witnessed a reduction of 33.0%. In 2017, the PM_{10} emissions from the other subsector were nearly 32% below the 2005 level. The rapid increase in PM_{10} emissions from this subsector between 2018 and 2019 is primarily due to the emissions reported in Finland[8].

Figure 5. Trend of main air pollutant emissions in the EU27 small-scale combustion subsectors, 2005-2020, (%)



Source: EMEP/CEIP 2023, JRC elaboration

As shown in Table 1, the primary sources of NOx and SO_2 emissions within the combustion subsector consist of residential and commercial/institutional activities. Residential activities play a significant role as the primary source of pollution for particulate matter, NMVOC and NH_3.

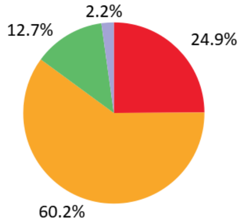
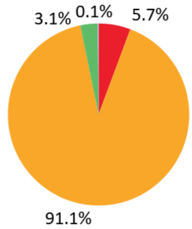
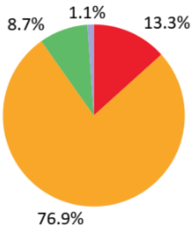
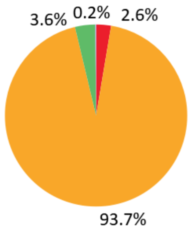
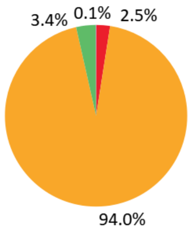
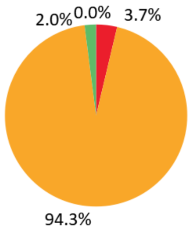
For NOx emissions, residential activities accounted for 60.0% of the total EU27 small-scale combustion NOx emissions in 2020, just above 90.0% for NMVOC emissions, and 77.0% for SO_2 emissions in the same year.

In the case of particulate matter emissions (PM_{10} and $PM_{2.5}$), the residential subsector played a dominant role in the small-scale combustion sector, contributing 94.0% to the corresponding EU27 small-scale combustion totals emissions. As for $PM_{2.5}$ emissions from small-scale combustion, their share in total EU27 $PM_{2.5}$ reached nearly 65% in 2020. This share varied among MS, with the highest proportions in Romania at 84.0%, followed by Slovakia (80.0%), Bulgaria and Hungary, each with 78.0%.

([8]) According to the FI IIR 2023, all emissions previously categorized under 1A5b have been reassigned to 1A5a for the entire time series.

Residential subsector was dominant in overall $PM_{2.5}$ emissions in 2020 with more than 50.0% of contribution in other 10 MS: Croatia (76.0%), Poland (75.0%), Slovenia (74.0%), France (63.0%), Latvia (62.0%), Czechia (62.0%), Italy (60.0%), Ireland (55.0%), Finland (52.0%) and Denmark (52.0%). Malta had the lowest penetration of residential sector in the overall level of $PM_{2.5}$ emissions in 2020, with only 3.6%.

Table 1. Breakdown of the EU27 small-scale combustion sector main air pollutants emissions by subsectors, 2020

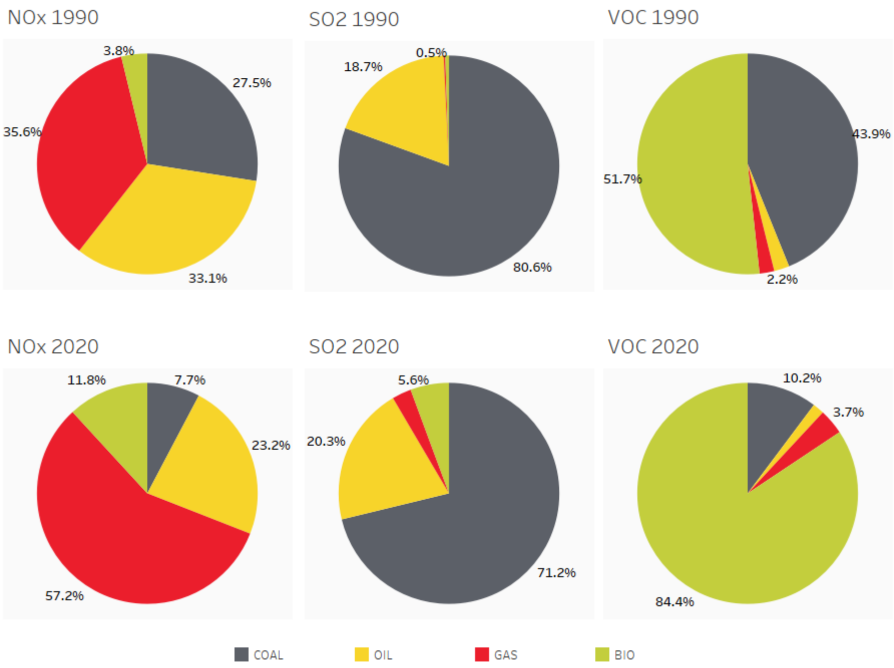
Pollutants	Key categories	Emissions breakdown by subsectors	Share in total EU27 air pollutant emissions
NO_2	1A4bi, 1A4ai		NOx emissions from small scale combustion activities in 2020 totaled 546 kt, accounting for approximately 9.8% of the overall NOx emissions in the EU27. Within the small-scale combustion sector, residential and commercial activities serve as the primary sources of NOx emissions, collectively contributing to 85.0% of this total.
NMVOC	1A4bi		In 2020, NMVOC emissions resulting from small-scale combustion activities amounted to 959 kt, which represents approximately 14.8% of the total NMVOC emissions in the EU27. The residential subsector predominantly accounts for this contribution, covering over 90.0% of the emissions.
SO_2	1A4bi		Emissions of SO_2 from small-scale combustion sector were nearly 280 kt in 2020. This contribution represents almost 20.0% of total SO_2 emissions in the EU27. The residential subsector accounts for just 77% of SO_2 emissions stemming from small-scale combustion activities, contributing to 15.3% of the total SO_2 emissions in the EU27.
PM_{10}	1A4bi		Small-scale combustion activities accounted for nearly 43.0% of PM_{10} emissions in the EU27, corresponding to a quantity of 857 kt in 2020. The residential subsector alone contributed to nearly 94.0% of these emissions, indicating its significant role in PM_{10} pollution.
$PM_{2.5}$	1A4bi		In 2020, $PM_{2.5}$ emissions from the small-scale combustion sector reached 814 kt, accounting for 62.3% of the total $PM_{2.5}$ emissions in the EU27. The residential subsector played a dominant role, contributing over 94.0% to this emission total.
NH_3			The NH_3 emissions from small-scale combustion sector accounted for nearly 50 kt in 2020, thus very small in absolute terms, representing only 1.5% of the overall EU27 NH_3 emissions. Residential subsector is the main source for these emissions with a contribution above 94.0%.

Source: EMEP/CEIP 2023, JRC elaboration

The reporting under the NECD does not include data on emissions based on fuel consumption. However, to provide some insights into the role of fuels in NOx, SO_2, and NMVOC emissions, data from the POLES JRC model[9] for the year 2020 have been utilized in this report. In the POLES JRC model, air pollution modelling is conducted on a sector and fuel basis. This process involves utilizing inputs from sources such as the GAINS IIASA model, which provides emission factors specific to pollutants by sector and fuels. In practice, the modelling process incorporates multiple flows/pollutants, each with specific emission factors. These emission factors are treated as direct inputs and adjusted based on historical data. For the residential and commercial subsectors, this includes accounting for coal consumption and other relevant factors (Banja. M., Schmitz. A., 2022).

As shown in Figure 6 in 2020 gas was the primary source of EU27 NOx emissions in the residential and commercial subsectors taken together. However, coal predominantly contributed to SO_2 emissions, while biomass[10] accounted for nearly 85.0% of NMVOC emissions. Over the years, there has been a shift trend mainly from coal towards gas for NOx emissions, which became their predominant source. However, when it comes to SO_2 emissions, coal remains the primary source, despite the increased contributions from gas and biomass. In the case of NMVOC emissions, there has been a noticeable shift from coal towards a greater utilization of biomass, indicating a change in the emission profile. All these shares should be seen in the context of the declining trends in these pollutants' emissions as shown in above figures.

Figure 6. NOx, SO_2 and NMVOC emissions in EU27 residential & commercial subsectors by fuel, 1990 & 2020 (%)



Source: POLES JRC model

2.4 Health impacts of air pollution from $PM_{2.5}$ in EU 27 countries

As part of the EU Green Deal's key policies, the Zero Pollution Action Plan seeks to achieve a reduction of over 55% in the health impacts, specifically premature deaths, caused by air pollution by the year 2030. According to data from (EEA 2022), there has been a notable reduction in the average concentration of $PM_{2.5}$ in Europe, declining from 14.8 ug/m^3 in 2005 to 8.4 ug/m^3 in 2020. This positive trend in air quality has significant implications for public health, as reflected in the decrease in premature deaths associated with air pollution over the years.

The analysis conducted by (EEA 2022) reveals a decreasing trend in premature deaths associated with $PM_{2.5}$ exposures, coinciding with the decline in air pollution. In 2005, the estimated number of premature deaths

(9) https://joint-research-centre.ec.europa.eu/geco/geco-2022_en
(10) The estimated contribution of biomass over the years in NOx, NMVOC and SO2 emissions shown in this figure includes the contribution of all forms of biomass: solid biomass, biogas and bioliquids.

associated with $PM_{2.5}$ was approximately 430,000. However, by 2020, within the MS, exposure to $PM_{2.5}$ concentrations exceeding the WHO guideline of 5 µg/m³ was responsible for roughly 238,000 premature deaths. This represents a nearly 50% reduction in premature deaths during this timeframe (EEA, 2022).

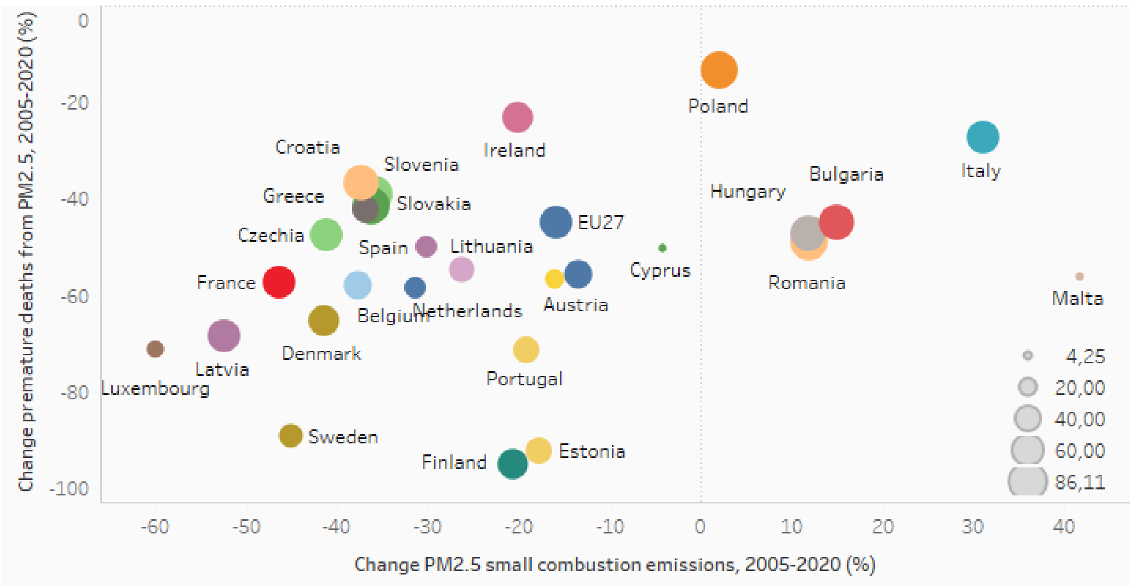
The EEA's 2023 report "Air Pollution and Children's Health" reveals a substantial impact on children's well-being. Projections indicate around 1200 annual fatalities among individuals under 18 in EEA member nations due to air pollution's adverse effects. Children and adolescents often spend more time outdoors and engage in higher levels of physical activity compared to adults, which may potentially elevate their exposure to ambient air pollution. (EEA 2023).

The residential subsector significantly contributes to $PM_{2.5}$ emissions in half of MS (see section 2.3) and changes in these emissions from small-scale combustion sources can potentially lead to alterations in ambient air quality. Figure 7 illustrates for each MS the comparison between changes in $PM_{2.5}$ emissions from small-scale combustion and changes in premature deaths related to $PM_{2.5}$.

Most MS reduced their $PM_{2.5}$ emissions from small-scale combustion between 2005 and 2020. In relation to the premature $PM_{2.5}$ deaths Poland showed the smallest decrease in 2020 (-13.0%), with $PM_{2.5}$ emissions from small-scale combustion only 2.0% below 2005 levels.

In contrast, Finland had the most significant reduction in $PM_{2.5}$ deaths (-95.0%), with a nearly 20.6% drop in $PM_{2.5}$ small-scale combustion emissions. Malta had the highest relative increase in $PM_{2.5}$ emissions from this sector in 2020, despite its low absolute contribution.

Figure 7. Changes in $PM_{2.5}$ premature deaths and emissions from small-scale combustion in EU27 MS, 2005-2020[11]



Source: EMEP/CEIP 2023, EEA 2022, JRC elaboration

Hungary, Bulgaria, and Romania increased $PM_{2.5}$ small-scale combustion emissions but reduced deaths, aligning with the EU average. In 2020, Estonia achieved the lowest $PM_{2.5}$-related deaths, advancing from its 4th -place position in 2005 and swapping positions with Luxembourg, which now held the 3rd place in the $PM_{2.5}$ related to lowest deaths ranking.

Despite our discussion in this section showing relationship between changes in $PM_{2.5}$ emissions from small-scale combustion sources and changes in premature deaths attributed to $PM_{2.5}$ exposures, it is imperative to acknowledge that understanding this intricate relationship is a complex endeavour. The variations seen in this relationship are likely due to a combination of various factors, including initial emission levels, policy effectiveness, sources of $PM_{2.5}$, technological advancements, socioeconomic influences, data quality, time lags in health effects, and regional/global contributions.

(11) The size of the bubbles represents the proportional contribution of $PM_{2.5}$ emissions from the small-scale combustion sector to the total $PM_{2.5}$ emissions in each of the MS.

Establishing a direct and quantifiable link between such changes and premature deaths is challenging for several reasons. People's exposure to $PM_{2.5}$ emissions from small-scale combustion sources can differ widely based on factors like proximity to emission sources, indoor versus outdoor exposure, and time spent in polluted environments. This variability makes it difficult to pinpoint the exact health impact at an individual level. Premature deaths associated with PM2.5 exposures are influenced by various other factors, including co-exposure to other pollutants, lifestyle choices, and pre-existing health conditions.

These confounding variables can obscure the cause-and-effect relationship between $PM_{2.5}$ emissions and premature mortality. Comprehensive and long-term studies in diverse settings are often lacking, making it challenging to draw concrete conclusions. More the small-scale combustion sector is continually evolving with technological advancements aimed at reducing emissions. As such, the impact of emissions on health may change over time, further complicating the establishment of consistent quantitative relationships.

Research in this field remains ongoing, and further advancements are expected to enhance our understanding of this intricate relationship between $PM_{2.5}$ emissions from small-scale combustion and premature deaths linked to $PM_{2.5}$ exposures.

2.5 Policy measures in some EU27 MS to address the air pollution from small-scale combustion sector

There are still significant obstacles to overcome in the transition to cleaner and more sustainable energy sources in the EU as for example the increasing subsidies for fossil fuels in the EU households. A study[12] commissioned by the European Commission found that in 2021, energy subsidies in the EU increased overall. Household fossil fuel subsidies grew by 15% (EUR 0.4 billion) from 2015-2020, mainly supporting heating oil and natural gas consumption (COM(2022) 642 final).

The growing concerns about the environmental and health impacts of fuel, especially wood, combustion in the EU residential sector are now addressed in several MS that have introduced regulations and incentives to encourage the use of cleaner more efficient wood burning technologies. Some countries have introduced emissions standards for wood boilers and stoves, while others offer subsidies for the installation of modern, efficient pellet stoves. Some MS have implemented bans or restrictions on the use of highly polluting fuels, such as coal and certain types of solid fuels, in residential heating systems. This encourages the transition to cleaner and more sustainable alternatives.

Germany promotes energy-efficient heating systems and renewable energy sources through subsidies and incentives, implementation of emission standards for residential heating appliances and flue gas cleaning requirements, bans on certain types of solid fuels with high pollutant content, such as coal, in certain regions.

To fight against climate change, reduce air pollution and improve the purchasing power of the **French** people, the Government has set the objective of eliminating all oil-fired boilers within the next 10 years. The State is assisting households in replacing old boilers and reducing the energy bill through the boiler conversion grant, which is now available to all French citizens.

On September 12, 2022, the **Austrian** Ministers of Energy and Economy presented the "Mission 11" plan, a list of tips for households to save up to 11% energy per household. This includes measures to reduce heating and lighting consumption (Devrere-austria.eu, 2022). Private households are currently receiving a subsidy of up to EUR 7 500 from the state when replacing a fossil heating system with a heat pump or a biomass heating system[13].

By the end of 2021, 4.5 million euros in non-refundable grants have been paid out to support energy renovation in **Portugal**. Owners of properties built before the end of 2006 can apply for reimbursement of up to 70% of their energy optimization costs. Eligible expenses are strictly regulated by the government and fall into six categories: windows, thermal insulation, air heating/cooling and domestic hot water systems, renewable energy production equipment, optimized water management and, finally, the integration of biomaterials, recycled materials, green roofs and facades and bioclimatic architectural solutions. Reimbursements are limited to €15,000 per owner and €7,500 per property (Edifícios mais sustentáveis Program, 2020)

It is estimated that of the approximately 5.5 million single-family homes in **Poland**, around 80% are heated using obsolete stoves and boilers, and that almost 150,000 of these appliances were sold each year before the new

(12) https://op.europa.eu/o/opportal-service/download-handler?identifier=34a55767-55a1-11ed-92ed-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=

(13) https://bioenergyinternational.com/biomass-the-enabler-of-austrias-energy-transition/

standards came into force in 2018. Polish new "Clean Air" program under the recovery and resilience plan, will invest 3.5 billion euros promoting a gradual phasing out of public assistance for coal-fired boilers and the enforcement of mandatory criteria for solid fuels to mitigate air pollution (EC Factsheet, 2022).

The **Luxembourg** Environment Administration grants subsidies for investment projects aimed at rational energy use and the development of renewable energy sources. It grants financial aid (subsidies for technical installations), known as "PRIMe House" for the investment and installation costs: a solar thermal system; solar photovoltaic systems a heat pump; a wood-fired boiler; installation of a heating network and/or connection to a heating network (Communiqué du Ministère de l'Environnement, du Climat et du Développement durable,2021).

In **Greece**, the government has been conducting an awareness campaign for energy savings. In September 2022, proposals were presented to citizens to reduce their energy bills, including insulating unused spaces in homes and adopting small daily habits like unplugging devices instead of keeping them on standby. Greece has also utilized European funds for a national recycling and replacement program for electrical appliances, with a budget of 150 million euros (Toute l'Europe).

2.6 Methodological overview of emission estimation in small-scale combustion sector

An overview of the methodology applied by the MS to estimate air pollutant emissions from the small-scale combustion sector for reporting under the NECD is conducted using data from the Informative Inventory Reports (IIRs) available at the EEA EIONET Central Data Repository (EEA, 2023). The collected information includes details on technologies, fuels and emission factors applied in this sector. The database created include information since year 1990 (when available) up to year 2020 (in some cases also year 2021).

Table 2. Methodology, technology split and emission factors typology in the small-scale combustion sector as reported by the MS Informative Inventory Reports

Countries	Emission Factor	Technology split by fuel	Method
Austria	CS, D	Yes	Tier 2
Belgium	D, CS	Yes (only gas & oil)	Tier 2, Tier 1
Bulgaria	D	Yes	Tier 2
Croatia	D	Yes	Tier 1, Tier 2
Cyprus	D	No	Tier 1
Czechia	CS	Yes	Tier 2
Denmark	CS, D	Yes (only wood)	Tier 1, Tier 2
Estonia	D, CS	No	Tier 1, Tier 2
Finland	CS	Yes	Tier 2, Tier 3
France	CS, D	No	Tier 1, Tier 2
Germany	CS	Yes	Tier 2, Tier 3
Greece	D, CS	No	Tier 2, Tier 1
Hungary	D	Yes	Tier 1 , Tier 2
Ireland	CS	Yes (only for residential)	Tier 2
Italy	CS, D	Yes (only wood)	Tier 2
Latvia	D	No	Tier 1, Tier 2
Lithuania	D	No	Tier 2
Luxembourg	D, CS	Yes	Tier 1, Tier 2, Tier 3
Malta	D	No	Tier 1
Netherlands	CS, D	No	Tier 2
Poland	CS, D	Yes	Tier 1, Tier 2
Portugal	D	Yes	Tier 1, Tier 2
Romania	D	Yes	Tier 1, Tier 2
Slovakia	CS, D	Yes	Tier 2
Slovenia	D	Yes	Tier 2, Tier 1
Spain	D	Yes (only by technology)	Tier 1, Tier 2
Sweden	D, CS	No	Tier 2, Tier 3 (mobile)

Source: EIONET CDR (EEA, 2023) – JRC elaboration

Table 2 provides a summary of the methods employed (Tier 1 (T1), Tier 2 (T2), Tier 3 (T3)), the type of emission factors (country specific (CS) or default (D)) and the technology split in each MS. The information is collected for main air pollutant covered by NECD but also for black carbon (BC), carbon monoxide (CO) and total suspended particles (TSP).

As depicted in Table 2, sixteen MS apply country specific emission factors or a combination of country specific and default (EMEP/EEA Guidebooks 2016 and 2019) emission factors to estimate air pollutant emissions from small-scale combustion sector. Information regarding the technology split is reported only in 18 MS' IIRs, providing insight into the distribution of technologies used in this sector.

Here below a short description of the methodology applied in the MS small-scale combustion sector is provided having in focus the technology split and the emission factors.

Austria reports to have applied a country specific Tier 2 method for space heating to estimate the air pollutant emissions from small-scale combustion sector. Technology fleet in the Austria's small-scale combustion sector is composed by 22 technologies and several fuels in the main sub categories (heating types). A detailed information on these technologies and fuel allocation is provided in the Austria's IIRs over years. For each technology, a fuel dependent emission factor is applied. Country specific emission factors for main air pollutants are applied for certain technologies/fuels. For other substances, the default emission factors are used. Table 3 shows the share of technologies for the fuelwood in Austria's residential subsector in 2021 and the country specific emission factors for nitrogen oxides (NOx) (AT, IIR 2023).

Table 3. Technology share for fuelwood use in Austrian residential sector and the CS NOx emission factor, 2021

Technology	Fuel	Technology share (%)	NOx EF (g/GJ)
Wood stoves and cooking stoves	Fuelwood	10.7	106.0
Tiled wood stoves and masonry heaters		9.8	80.0
Mixed-fuel wood boilers		37.7	121.8
Natural-draft wood boiler		7.6	107.0
Forced-draft wood boilers		34.2	80.0

Source: (AT, IIR 2023)

Belgium reports to use the default emission factors from the EMEP/EEA Guidebook 2019[14]. Country-specific values are employed only when supported by available data or within the context of agreements with the various regions of Belgium. A Tier 2 methodology is applied, except for NOx emissions from diesel and natural gas, where the ECONOTEC study 2010 is referenced. For a comprehensive overview of emission factors specific to sector 1A4 in the Flanders region of Belgium, Annex 3A of the Belgium IIRs 2023 provides detailed information. Table 4 presents the 2010 technology distribution for gaseous and liquid fuels within Belgium's residential subsector, sourced from a 2012 survey on energy consumption in Belgian households. It is important to note that data for the other years and other fuels is not available.

Table 4. Technology share for different fuel use in Belgium residential sector, 2010

Technology	Fuel	Technology share (%)
High efficiency boiler - central heating	Gas	35.0
Condensing boiler - central heating	Gas	26.0
Conventional boiler - central heating	Gas	39.0
High efficiency boiler - central heating	Oil	25.0
Condensing boiler - central heating	Oil	9.0
Conventional boiler - central heating	Oil	66.0

Source ((Jespers, 2012))

Bulgaria reports to apply the default emission factors from the GB 2019 to estimate air pollutant emissions from small-scale combustion sector using liquid, solid and gaseous fuels, as well as biomass. In the residential subsector, the Tier 1 and Tier 2 methodologies are applied. In the Tier 2 method the share of fuel used in the combustion technologies is used in the calculations. In commercial/institutional subsector the emission factors for So2 are calculated using the specific amount of sulphur in the fuels. The following Table 5 shows the share of technologies reported for the combustion of biomass and solid fuels in residential subsector.

([14]) Here after the EMEP/EEA Guidebook 2019 will be mentioned as GB 2019

Table 5. Technology share for different fuel in Bulgarian residential subsector, 1990-2020, (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2020
Conventional stoves	Biomass	96.0	96.0	96.0	96.0	95.0	95.0	93.0
Conventional boilers		4.0	4.0	4.0	4.0	4.0	4.0	4.0
Pellet stoves and boilers						1	1	3
Stoves	Solid fuels	53.0	52.0	51.0	49.0	30.0	30.0	30.0
Small boilers (<50MW)		47.0	48.0	49.0	51.0	70.0	70.0	70.0

Source: (BG IIR 2023)

Croatia reports to apply the default emission factors from the GB 2019 for most of air pollutants**.** According to the Croatian 2022 IIR report the Tier 1 methodology is applied for the agricultural subsector while the Tier 2 methodology is utilised for the commercial and residential subsectors The country specific emission factors are only applicable to SO_2 emissions. Table 6 presents the technology split in the residential subsector for solid biomass combustion in Croatia for the years 1990, 2005 and 2010.

Table 6. Technology split for solid biomass use in the Croatian residential subsector, 1990-2010 (%)

Technology	Fuel	1990	2005	2010
Open fireplaces	Solid biomass	4.4	5.0	6.0
Boilers (manual feed)		39.	29.0	18.0
Conventional stoves		56.2	64.0	44.0
Advanced /ECO-labelled stoves				31.0
Pellet stoves and boilers				0.1

Source : (HR, IIR 2022)

Cyprus reports to apply the default emission factors outlined in the GB 2019. For emissions in the agricultural subsector, a Tier 1 methodology is employed, while a Tier 2 methodology is applied for the residential subsector.

Czech Republic reports to apply a Tier 2 method for the estimation of air pollutant emissions from residential subsector. To estimate air pollutant emissions from solid fuels in residential subsector the country specific emission factors are used.

The country specific values are used for over-fire boilers, under-fire boilers, gasification boilers and automatic boilers (see Table 7). For stoves, grates and cookers there were used same values of emission factors as for over-fire boilers (similar mode of combustion). A new emission factors is calculated for NH_3 emissions for biomass use in boilers with an input of up to 5 MW with a value of 5.2 g/GJ (CZ IIR 2023).

Table 7. Technology share by fuel in Czechia residential subsector, 2015 and 2019-2021 (%)

Technology	Fuel	2015	2019	2020	2021
Over-fire boilers	Brown coal	23.0	23.0	23.0	6.0
Under-fire boilers		31.0	31.0	31.0	45.0
Automatic boilers		33.0	32.0	33.0	36.0
Gasification boilers		9.0	8.0	9.0	9.0
Stoves/fireplaces		5.0	5.0	5.0	4.0
Over-fire boilers	Wood dry	31.0	31.0	31.0	34.0
Under-fire boilers		17.0	18.0	17.0	14.0
Automatic boilers		4.0	4.0	4.0	4.0
Gasification boilers		19.0	18.0	19.0	22.0
Stoves/fireplaces		29.0	29.0	29.0	26.0

Source: (CZ IIR 2023)

Denmark reports to apply a combination of country-specific and default emission factors to estimate air pollutant emissions from the small-scale combustion sector. For the main air pollutants such as SO_2, NOx, NMVOC, PM, and CO, a combination of country-specific and Tier 2 methodology is employed. In the case of ammonia emissions, Tier 1 methodology is used, incorporating a mix of country-specific and default GB 2019 emission factors. Notably, Denmark's IIRs offer comprehensive insights into fuel-specific emission factors applied to various technologies, particularly for wood combustion. However, in Denmark's reports information on technology split is solely available for wood combustion in residential subsector.

Table 8 shows the technology shares in Denmark’s residential subsector when wood is used as fuel (DK IIR 2023).

Table 8. Technology shares for wood combustion in residential subsector in Denmark, 1990-2021, (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2020	2021
Stoves	wood	58.6	59.2	52.6	42.8	35.5	26.2	15.8	14.0
Eco-labelled stoves		-	-	-	4.1	10.8	15.5	16.3	16.1
Open fireplaces		2.4	2.3	2.0	1.7	1.6	1.4	1.1	1.0
Masonry heat stoves		0.6	0.6	0.5	0.4	0.4	0.3	0.3	0.2
Boilers		37.1	36.2	30.5	25.7	24.3	21.9	16.8	15.8
Pellet boilers		1.3	1.7	14.4	25.3	27.4	34.6	49.7	52.9

Source: (DK IIR 2023)

Estonia reports to apply a Tier 2 methodology to estimate the emissions of main air pollutants in the commercial, residential, and agricultural subsectors. A combination of country specific and GB 2019 emission factors are applied, and emissions are calculated based on the energy balance data. The Estonia's IIR 2023 report provides detailed information on emission factors from wood combustion in boilers (conventional and advanced) and stoves (conventional and advanced) for the residential subsector (see Table 9). However, no information of technology split by fuel is provided for residential and commercial subsectors (EE IIR 2023).

Table 9. NOx, PM_{10}, $PM_{2.5}$ and SO_2 wood emission factors in residential subsector in Estonia, 2021 (g/GJ)

Technology	Fuel	NOx	PM_{10}	$PM_{2.5}$	SO_2
Conventional stoves & fireplace	Wood	140.4	257.6	249.9	11.0
Advanced stoves		117.6	24.2	24.0	10.9
Conventional small boilers (<=35 kWth)		2382.8	310.6	295.1	26.6
Advanced small boilers (<=35 kWth)		74.5	9.7	9.2	11.0
Wood briquette stoves and boilers		176.2	720.2	684.2	10.9
Wood pellet stoves and boilers		45.9	24.0	22.9	12.3

Source: (EE IIR, 2023)

Finland reports that it employs emission factors specific for main air pollutants, except for HCB and PCB emission factors, which are sourced from the EMEP EEA Guidebook 2019. The Finland's IIR 2023 report reveals the utilization of a combination of Tier 1 and Tier 2 methodologies in the small-scale combustion sector. The Finland's IIRs emphasise that in Finland, the residential wood-burning appliances have a specific design to burn wood at a high rate in a short amount of time. Because of this design, these appliances have a higher combustion efficiency burning the wood more completely. Table 10 illustrates the distribution of technologies used for wood combustion, pellets, and wood chips within the residential subsector from 1990 to 2020.

Table 10. Technology shares for wood, pellets, and wood chips in Finland residential subsector, 1990-2020, (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2020
Iron stoves conventional	Wood	3	3	3	3	3	2.5	2
Automatic fed boilers	Wood chips	5	5	5	5	5	6	7
Automatic fed boilers	Pellets	0	0	1	2	1.5	1.5	1.5
Manually fed boilers with accumulator	Wood	24	24	24	23	20	16	17
Manually fed boilers w/o accumulator	Wood	7	7	6	6	6	4	3
Open fire place and other stoves	Wood	1	1	1	1	1	1	1
Stove kitchen range	Wood	10	10	10	10	10	7	7
Masonry heaters conventional	Wood	21	21	21	21	23	25	25
Masonry heaters modern	Wood	0	0	0.2	0.4	1.5	3	5
Masonry ovens	Wood	14	14	13.8	13.6	13	13	13
Sauna stoves	Wood	15	15	15	15	15	13	8.5
Sauna stoves modern	Wood	0	0	0	0	1	8	10

Source : FI IIR 2023

France reports to use country specific emission factors to estimate air pollutant emissions in the residential subsector. They apply a combination of Tier 1 and Tier 2 methodology. However, the France's IIR report do not include information on the technology shares for wood use in small-scale combustion sector. In Table 11 the technology shares for wood combustion in residential and commercial subsectors are sourced from a series of publications from French Agency for Ecological Transition (ADEME) and L'Observatoire des énergies renouvelables (Observ'ER). Evaluating emissions linked to the utilization of wood in various household appliances is accomplished using a country specific methodology that considers the diversity of domestic wood-burning devices. The estimation of NOx emissions from residential gas boilers incorporates the advancements in gasburner performance over the period of analysis assuming a steady renewal rate of 4% throughout the time (FR, IIR 2023).

Table 11. Technology shares for wood use in commercial and residential subsector in France, 2017-2021, (%)

Technology	Fuel	2017	2019	2020	2021
Closed fireplace	Pellet	42	43	43	39
Stove	Pellet	27	24	23	30
Boiler	Wood log	9	11	12	17
Closed fireplace	Wood log	12	11	11	7
Stove	Wood log	5	5.5	5	4
Open fireplace	Wood	1	1.5	2	2
Boiler	Pellet	1	1	1	1
Cookers	Wood	3	3	3	0

Source : ADEME, Obser'ER 2022

Germany reports only the implied emission factors for main pollutants in all the small-scale combustion subsectors. For black carbon the GB 2019 emission factors is used. In terms of technology distribution, Germany adopts the 2005 technology shares by fuel specifically for the residential and commercial sectors, which were sourced from a study conducted by the Federal Ministry for the Environment, Nature Protection, and Reactor Safety (Struschka M., et al, 2008) . The implied emission factors for hard coal in Germany's commercial subsector are presented in the following Table 12 (DE IIR, 2023).

Table 12. Implied emission factor for hard coal in Germany's commercial subsector for 2019-2021, (kg/TJ)

Substance	2019	2020	2021
NOx	89.8	89.8	89.8
SO_2	331.7	331.7	331.7
CO	2.162	2.162	2.162
NMVOC	30.3	30.3	30.3
PM_{10}	17.6	17.6	17.6
$PM_{2.5}$	15.7	15.7	15.7

Source : (DE IIR, 2023), (Struschka M., et al, 2008)

Greece reports the implementation of a Tier 2 methodology for SO_2 emissions originating from liquid fuels, as well as for all pollutants emitted from biomass combustion within the residential subsector. In the absence of these specific cases, a Tier 1 method is utilized. Country-specific emission factors for SO_2 are applied based on the measurements of the sulphur content of oil products. The biomass consumption in the residential sector is used into the following appliance types: pellet stoves and boilers, open fireplaces, high-efficiency fireplaces, conventional stoves, high-efficiency stoves, and conventional boilers (EL IIR 2023). However, no information on technology split can be found at the Greece IIR reports.

Hungary reports to use emission factors from the EMEP EEA 2019 Guidebook. The reported emissions encompass a range of pollutants including main pollutants, particulate matter, carbon monoxide, heavy metals, and persistent organic pollutants (POPs). The emissions estimation has been carried out using a combination of Tier 1 and Tier 2 methodologies. Default Tier 1 or Tier 2 emission factors have been employed for residential sources such as coal and biomass, while country-specific emission factors have been used for the estimation of SO_2 emissions. Table 13 shows the technology shares applied in the Hungarian residential subsector for the use of biomass.

Table 13. Technology shares for biomass use in the Hungarian residential subsector, 2021 (%)

Technology	Fuel	2021
Fireplace	Biomass	1
Stove		31
Effective stove		12
Modern advanced		5
Boiler		50
Pellet-Auto		1

Source : (HU IIR 2023)

Ireland reports to have applied for the first time in its 2023 submission a Tier 2 methodology for residential subsector using a based expert opinion for the shares of stoves and fireplaces. Since no fuels are assigned to sector 1A4aii (Mobile) or 1A4bii, (Household and Gardening (Mobile), all gasoline, it is instead considered and included in category 1A3b Road Transport. Table 14 provides technology shares for solid fuel fireplace and stove use in residential subsector.

Table 14. Technology shares for solid fuel fireplace and stoves in residential subsector in Ireland, 1990-2020 (%)

Technology	1990	1995	2000	2005	2010	2015	2020
Fireplace use	95.0	86.7	78.3	70.0	61.7	53.3	45.0
Stove use	5.0	13.3	21.7	30.0	38.3	46.7	55.0

Source: (IE IIR, 2023)

Italy reports to apply the Tier 2 methodology across the entire small-scale combustion sector to estimate emissions. This methodology is utilized to estimate NOx emissions from natural gas, incorporating emission factors specific to the country. For other fuels, default emission factors from the EMEP/CORINAIR 2007 Guidebook are utilized. Wood combustion is driving prevalently the air pollutant as NMVOC, PM, CO, NH_3 emissions in Italy while the trend of SO_2 emissions is determined by the changes in liquid fuels as gasoil and their sulphur content following the European Union and national legislation (IT, IIR, 2023). Table 15 shows the shares of wood used by technology in residential and commercial subsectors.

Table 15. Technology shares for wood use in commercial and residential subsector in Italy, 1990-2020, (%)

Technology	Fuel	1990	2006	2012	2015	2020
Fireplaces	Wood	51.3	44.7	51.2	49	39.7
Stoves		28.4	27.5	22.9	21	17.9
Advanced fireplaces		15.4	20.2	15.8	15	19.5
Pellet stoves			3.1	4	9	15.1
Advanced stoves		4.8	4.4	6	6	7.8

Source : (IT IIR, 2023)

Latvia reports to apply both Tier 1 and Tier 2 approaches to assess emissions originating from stationary fuel combustion within the Commercial/Institutional subsector (1A4a). To estimate emissions from natural gas, solid fuel, and biomass during the periods 1990-2020 and 2005-2020, Latvia employs the Tier 2 methodology. Furthermore, Latvia determines emissions from mobile combustion within subsectors 1A4aii and NFR 1A4cii.

Lithuania reports to apply the default emission factors from the GB 2019 with Tier 2 methodology. No information on technology shares is provided at the Lithuania IIRs.

The **Luxembourg** IIRs provide comprehensive descriptions of the methodology used, emission factors employed, and technology distribution across all subsectors of small-scale combustion. A combination of Tier 1, Tier 2 and Tier 3 methods, along with a blend of default and country-specific emission factors, is reported to have been applied to estimate the air pollutant emissions from the small-scale combustion sector (LU IIR 2023). Technology shares for natural gas in the Luxembourg residential subsector are shown in Table 16.

Table 16. Technology shares for natural gas use in the Luxembourg residential subsector, 1990-2021 (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2020	2021
Conventional boiler	Natural gas	100	100	97.44	92.44	65.68	58.43	48.43	46.43
New conventional boiler		-	-	0.75	0.75	2.2	1.58	1.58	1.58
Condensing boiler		-	-	1.81	6.81	32.11	39.99	49.99	51.99

Source : (LU IIR 2023)

Malta reports to apply the default emission factors from the GB 2019. According to the Maltese 2023 IIR report the Tier 2 methodology is applied for the estimation of air pollutant emissions from commercial/institutional subsector. For residential subsector, a combination of Tier 1 (for gaseous and liquid fuels) and Tier 2 (for primary solid fuels) has been applied and technology shares are taken from GAINS IIASA model. Tier 1 methodology is applied for the Agriculture/Forestry/Fishing subsector.

The Netherlands reports to apply a combination of country-specific emission factors and GB 2019 default values. No information about the technology split by fuel is provided in the Netherlands'' IIRs. Country reports that the use of wood fuels in the residential subsector as fireplaces and wood stoves is negligible compared to the use of natural gas. Country specific emission factors are applied to estimate NOx emissions from natural gas in small-scale combustion sector (NL IIR, 2023).

Poland reports to apply a combination of country-specific emission factors and default values from GB 2019 for small-scale combustion sector with a combination of Tier 1 and Tier 2 methodology. Wood combustion shares in Poland's residential sector are shown in Table 17. In the case of filterable particulate matter emission factors for wood in residential and solid fuel in commercial/institutional and agriculture/fishing a combination of default values from EMEP/EEA Guidebooks 2016 and 2019 and the value from national studies is applied. Condensable PM emission factors for commercial/institutional and agriculture/fishing subsectors were determined through laboratory measurements or estimated based on the fine total suspended particulate matter (FTSP) to particulate matter (PM) ratios calculated for the residential subsector. Since Poland reports the technology shares for all fuels used, a recalculation of shares for each fuel has been performed.

Table 17. Technology shares for wood and coal in the Polish residential subsector, 1990-2019 (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2019
Bolier gasifying- new construction	Wood	100	100	98.1	87.8	78.6	62.6	14.0
Boiler gasifying 5 class - eco-design								4.6
Boiler - automatic				1.89	12.2	21.4	37.4	10.6
Boiler - automatic 5 class eco-design								70.8
Boiler - manual	Coal	100	100	99.94	99.1	94.5	90.1	85.4
Boiler - manual 5 class eco-design								2.2
Boiler - automatic				0.06	0.9	5.5	9.9	9.0
Boiler – automatic 5 class eco-design								3.4

Source : (PL IIR, 2023)

Portugal reports to combine Tier 1 and Tier 2 methodologies for the Commercial/Institutional subsector. Portugal reports technology-specific fuel consumption in the small-scale combustion sector since 1990. The calculation of technology split for wood combustion in residential subsector is shown in Table 18.

Table 18. Technology shares for wood in the Portuguese residential subsector, 1990-2020 (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2020
Conventional stoves	Wood	59.5	57.70	56.70	55.70	54.70	53.70	52.70
Open fireplaces		20	19	18	17	16	15	14
Conventional stoves		18	16.75	15.5	14.25	13	11.75	10.5
Pellet stoves and		2	5.25	8.5	11.75	15	18.25	21.5
Automatic boilers		0	0	0	0	0.45	0.9	1.35

Source : (PT IIR, 2023)

Romania reports to apply the Tier 2 emission factors from the GB 2019 Guidebook for biomass, liquid fuels and gaseous fuels, whereas the Tier 1 emissions factors are used for solid fuels. Technology split is provided only for fuelwood used in Romanian residential subsector (see Table 19). This split has remained constant over the years. For liquid and gaseous fuels, the technology split suggested at the GB 2019 is applied (RO IIR, 2023).

Table 19. Technology shares for wood in Romanian residential sector, 2021, (%)

Technology	Fuel	2021
Conventional Stoves	Wood	91
Boilers (<50 KW)		7
Pellet stoves		2

Source: (RO IIR, 2023)

Slovakia reports to apply Tier 2 methodology to estimate the air pollutant emissions from small-scale combustion sector.

Table 20. Technology shares for brown coal in Slovakian residential sector, 1990-2021, (%)

Technology	Fuel	1990	2005	2019	2021
Over-fire boilers	Brown coal	59.1	58.3	55.5	54.5
Under-fire boilers		33	32.2	29.4	28.4
Gasification boilers		0	1	2.7	3.7
Automatic boilers		1.9	2.5	6.4	7.4
Fireplaces, stoves, masonry stoves		5.9	5.9	5.7	4.7
Modern masonry stoves and pellets stoves		0	0	0.2	1.2

Source : (SK IIR, 2023)

According to SK IIR 2023, a revision of household energy statistics has been performed focusing on solid fuels and biomass. A survey supported by Eurostat and carried out in collaboration with the Statistical Office of the Slovakia had as he main output the technology structure of fuels uses in the residential subsector. Table 20 shows the technology split for brown coal in Slovak residential subsector.

Slovenia reports to use emission factors from the EMEP EEA 2019 Guidebook. Table 21 shows the technology split for wood combustion, wood waste and pellets over the 2015-2020 period. The emission calculation for biomass burning in residential areas utilized the Tier 2 methodology, whereas the estimation of emissions resulting from burning alternative fuels (natural gas, LPG, residual fuel oil, and sub-bituminous coal) employed the Tier 1 methodology.

Table 21. Technology shares for wood in Slovenian residential and commercial subsector, 2015-2020, (%)

Technology	Fuel	2015	2016	2017	2018	2019	2020
Conventional boiler	Wood /wood	67	67	67	64	68	65
Advanced / eco-labelled stoves and boilers	Wood	12	13	13	14	8	9
Pellet stoves and boilers	Wood pellets	5	4	4	5	8	9
Open fireplaces	Wood	1	1	1	2	1	1
Conventional stoves	Wood /wood	15	15	15	15	15	16

Source : (SI IIR, 2023)

Spain reports to apply a combination of Tier1 and Tier 2 methods for estimation of main air pollutants from small-scale combustion sector using the default emission factors as in the EMEP EEA 2019 Guidebook and EMEP/CORINAIR 2007**.** Default emission factors are used depending on the type of installation and fuel consumed. Boilers with capacity less than 50 MW are the main technology used in Spain residential subsector. Spain do not report information on technology split by fuel. However, as shown in Table 22 information on fuel use for each type of technology part of each subsector is included in the additional information provided in the methodology factsheet of Spain IIRs (ES IIR 2023).

Table 22. Fuel use split for boilers in Spanish residential sector 1990-2018, (%)

Technology	Fuel	1990	1995	2000	2005	2010	2015	2018
Boiler	Fuel oil	0.14	0.38	0.74	0.33	0.80	0.12	0.04
	Gas oil	11.7	15.6	17.5	19.2	12.8	14.6	13.3
	Natural gas	3.12	7.66	14.64	20.74	25.74	20.45	19.22
	GLP	19.15	16.88	14.52	11.74	8.86	7.39	7.64
	Manufactured gas	4.98	0.97	0.88	0.44	0.04	0.0	0.0
	Biomass	55.9	54.6	49.4	45.0	49.8	56.4	58.9
	Petroleum coke	0.093	0.095	0.043	0.046	0.028	0.0	0.0
	Coal and	4.46	3.78	2.27	2.53	1.89	1.09	0.87
	Sub-bituminous	0.37	0.0	0.0	0.0	0.0	0.0	0.0
	Patented fuel	0.046	0.0	0.0	0.0	0.0	0.0	0.0

Source : (ES IIR, 2023)

Sweden reports that the emissions from stationary combustion are estimated at the national level based on activity data and emission factors categorized by fuel type, indicating compliance with Tier 2 standards. Emissions from all operational machinery utilized in Sweden are estimated using a national model, which conforms to Tier 3 standards for most emissions. However, for SO_2, Tier 2 estimation methodology is employed. Further details about the model can be found in Annex 2 of the 2023 report.

3 EDGAR methodology for small-scale combustion sector

3.1 Methodology - short description

The Emissions Database for Global Atmospheric Research (EDGAR) is a global database that provides estimates of country and sector-specific emissions of greenhouse gases (GHGs), including CO_2, and air pollutants, implementing a transparent state-of-the-art methodology. EDGAR provides emissions consistently estimated for 208 world countries based on international statistics and a detailed bottom-up methodology following the Intergovernmental Panel on Climate Change (IPCC) guidelines.

To achieve this estimation, EDGAR uses four different dimensions: (i) sector, (ii) fuel; (iii) a general-purpose technology, and (iv) a range of so-called end-of-pipe (EOP) measures. The EDGAR methodology used is transparent and in line with the most recent scientific literature and Intergovernmental Panel on Climate Change (IPCC) recommendations.

In EDGAR, air pollutant emissions estimation is based on activity variables at the level of sector, fuel, and general-purpose technology. Emissions are calculated by multiplying activity variables by emission factors (EF) of the EOP measures. The latter calculations are repeated over all kind of GHGs and pollutants.

Emissions from small-scale combustion are included in the EDGAR sector named as “RCO” and are part of the fuel combustion process. Activity data comes from the IEA Fuel balances (see section 2.2). The basis for technology is the EMEP-CORINAIR Emission Inventory Guidebook 2009 section on small-scale combustion Installations. Since the detailed technology, information is often not available with a global coverage it has been decided to define only main combustion technologies (see section 3.1.1).

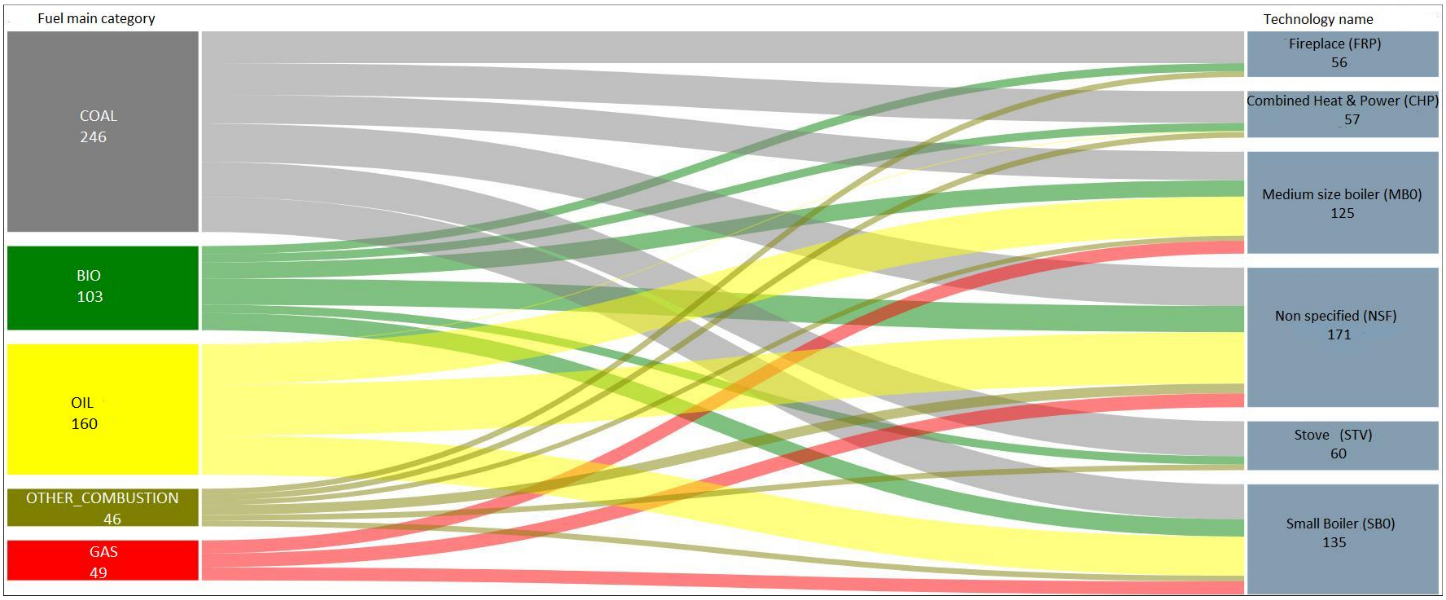
For biomass, especially the residential sector is using a large fraction of non-commercial biomass like fuelwood or crop residues left on the field. Based on data from the calculations in the agricultural sector the amount of fuelwood, vegetal waste and animal waste used for household consumption has been calculated.

Emission factors for main air pollutants as NOx, SO_2, CO, NH_3, BC NMVOC, OC, PM_{10}, and $PM_{2.5}$ are mainly from the GB 2009 and IPCC 2006.

3.1.1 Technologies, fuels and categories

The EDGAR database incorporates 47 fuel types within the small-scale combustion sector. These fuel types, which include coal, oil, gas, and biomass, are appropriately assigned to the relevant technologies used for estimating emissions within the sector (see Figure 8).

Figure 8. Fuel allocation in EDGAR database small-scale combustion sector technologies



Source: EDGAR database

The following activities are included in small-scale combustion sector in EDGAR database applying specific fuels for coal, oil, gas, and biomass:

- Fuel combustion in households for heating and cooking (RCO.RES),
- Fuel combustion in agriculture sector (RCO.AGR),
- Fuel combustion in commercial/institutional buildings for energy and heat production (RCO.COM),
- Fuel combustion in the fishery sector (includes both building fuel and theoretical fishing ship fuel use although quality of IEA does not allow to distinguish this) (RCO.FSH), and
- When the energy data provided does not allow distinguishing the specific end-use (e.g. residential combustion) the data has been assigned to non-specified (RCO.OTH).

In the EDGAR database the following combustion technologies are defined (as in Figure 3):

- Non-specified combustion technology (NSF),
- Fireplace (both heating and esthetical) (FRP),
- Stoves (either for cooking or heating) (STV),
- Small boilers (<50 kWth) (SB0) for single household heating, and
- Medium boilers (50 kWth-50MW) for multi residential or commercial buildings (MBO)

It can be seen by the distribution of technologies within EDGAR database subsectors in Table 23 that in residential and commercial/institutional subsectors all technologies are assigned. In agriculture/fishing subsector, only stoves are assigned as technology whereas in other subsector fireplaces are not included.

Table 23. Technologies in EDGAR database for small-scale combustion subsectors

Residential	Commercial/Institutional	Agriculture/Fishing	Other
FRP	FRP		
STV	STV	STV	STV
SB0	SB0		SB0
MB0	MB0		MB0
NSF	NSF	NSF	NSF

Source: EDGAR database

3.1.2 Issues in EDGAR estimation of air pollutants

Over the years, there has been an evolution in household appliances in the small-scale combustion sector, which brings the need for improvements within the EDGAR system. Some of the key developments of technologies in the EU27 small-scale combustion sector are:

- Improving the energy efficiency of household appliances – EU energy efficiency standards
- Shift towards more advanced household appliances as boilers and stoves has become more prevalent:
  - Condensing boilers
  - Biomass and pellet stoves
- Design of boilers and stoves has evolved to work in conjunction with renewable energy systems.
- Incorporating emission reduction technologies into stoves and boilers to comply with environmental regulations.

A comparison work (Thunis et.al. 2023[15]) was conducted between the air pollutant emissions of the MS in the EDGARv6.1 inventory and other sources such as EMEP and Copernicus Atmosphere Monitoring Service (CAMS)-Regional (REG) v5.1 inventories for the year 2018.

Differences in the air pollutant emissions are observed which can be attributed to several factors, including the use of different methodologies, data sources, and emission factors. These variations may result in divergent estimates for specific pollutants or regions.

The largest discrepancies between EDGARv6.1 and Member State emission inventories were found for particulate matter, mainly in the small-scale combustion sector. One of *the key issues* with EDGAR's air pollutant emissions estimation for the EU27 small-scale combustion sector is the lack of allocation of biomass in any known

(15) Preprint available at https://egusphere.copernicus.org/preprints/2023/egusphere-2023-1257/

technologies within this sector. Biomass combustion, such as wood burning, plays a significant role in residential heating and cooking, particularly in rural areas. However, EDGAR does not specifically account for the emissions from biomass combustion in its allocation to specific technologies.

Biomass is the main fuel used in the residential sector that affect the emission level of particulate matter. The lack of explicit allocation for biomass combustion in EDGAR's small-scale combustion sector leads to an incomplete representation of the emissions profile. It may underestimate/overestimate the contribution of biomass burning to air pollution levels.

Another issue within the EDGAR database related to biomass is that fuel as pellets are not included as a separate fuel[16] in the calculations, due to the missing allocation in the database. However, it is assumed that this contribution is included under the solid biomass. The effect of this issue in the air pollutant emissions estimation varies from country to country depending also on the penetration of technologies that use this type of fuel.

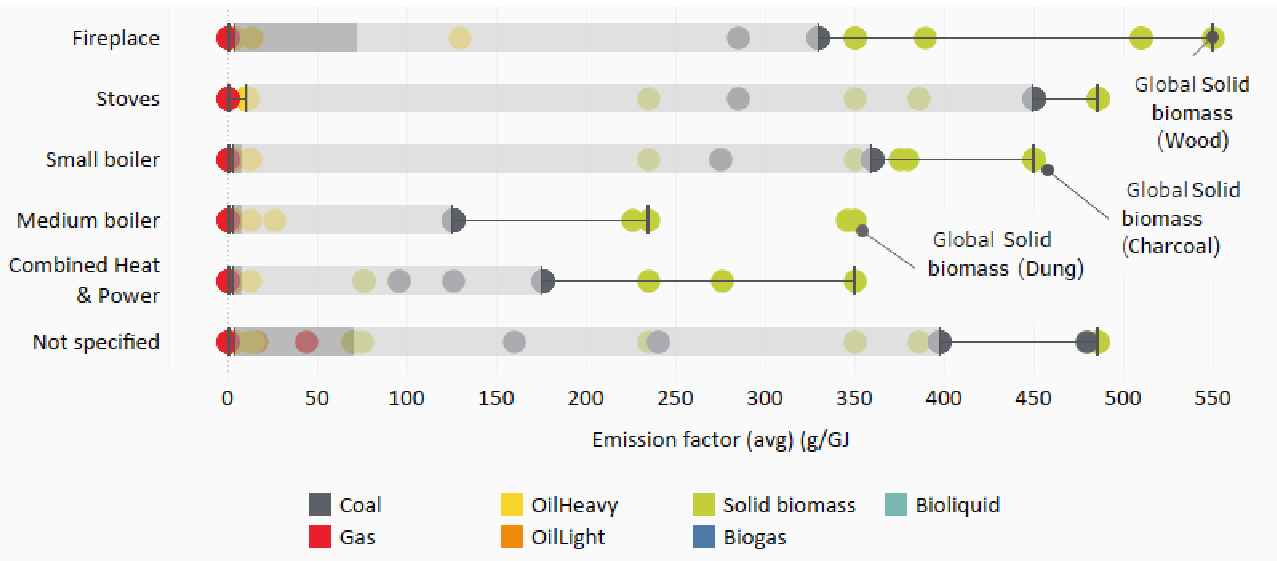
The pellet market in the EU27 is becoming more competitive and remains a global leader in wood pellet production and consumption. In 2021, the rise of pellet consumption in EU27 took place with nearly 19% compared with previous year covering just 52% of global pellet consumption. Germany, Latvia, Sweden, France, Poland, Austria, and Estonia are among the biggest pellets producers worldwide.

Residential and commercial market of pellets in Europe has overcome the industrial market covering in 2021 just above the half of the entire pellet market. The residential heating sector represents the most significant volume of consumption in Italy, Germany, and France (Bioenergy Europe Pellet Report 2022). From the data collected from 18 MS on technology split, the use of pellets technologies has been reported for residential and commercial subsectors in Austria, Bulgaria, Germany, Denmark, Czechia, Croatia, Hungary, Italy, Finland, France, Luxembourg, Portugal Romania, Slovakia, and Slovenia.

A third issue concerns the emission factors utilised in the EDGAR database for the small-scale combustion sector in the MS where significant revisions have been primarily focused on fossil fuels, mainly coal, and pollutants as SO_2 on a country-by-country basis. In contrast, global and regional values are predominantly applied for biomass and particulate matter across the majority of MS.

Figure 9 illustrates the average $PM_{2.5}$ emission factors from the EDGAR database for the residential subsector.

Figure 9. EDGAR database $PM_{2.5}$ average emission factors[17] for residential subsector by main fuels carries, g/GJ



Source: EDGAR database

(16) This is an ongoing collaboration with the IEA to establish pellet consumption within the energy sector as a distinct fuel source.

(17) Figure 9 presents the average PM2.5 emission factors for various fuel carriers, including those associated with global, regional (Western and Eastern Europe), and EU27 MS (Austria, Germany, Belgium, Netherlands, and Sweden).

3.2 Small-scale combustion in the EMEP/EEA Guidebook 2019

The GB 2019[18] provides guidelines and methodologies for the estimation of air emissions, including those from small-scale combustion sector including a detailed information for subsectors such as residential, commercial/institutional, and agriculture/fishing. Several MS relies on emission factors from GB 2019 (see section 2.6). Table 24 provides a summary of the technologies that are included in the GB 2019 for the small-scale combustion subsectors.

Table 24. Technologies in small-scale combustion subsectors as in GB 2019

Subsector	GB 2019	Technology name	Description
Residential	FRP	Fireplaces	Open/Closed/Partially open/Gas fuelled fireplaces, Barbeques,
	SBC	Conventional boilers	Over-fire/Under-fire boilers
	SBA	Small advanced boilers	Advanced Under Fire coal boilers Down-draught wood boilers Stocker coal burners Wood boilers Liquid/gas fuelled small boilers Vaporizing burners
	SVC	Conventional stoves	Conventional, radiating stoves High Efficiency Conventional Stoves
	SVA	Advanced stoves	Pellet / Liquid/gas- fuelled/ Wood Stove
	CHP	Reciprocating engines	small combined heat and power
Commercial Agriculture Fishing	SBA	Small advanced boilers	Advanced Under Fire coal boilers Down-draught wood boilers Stocker coal burners Wood boilers Liquid/gas fuelled small boilers Vaporizing burners
	MBC	Conventional medium boilers	Overfed boiler, over-fire burning Overfed boilers, under-fire boilers coal/biomass
	MBA	Advanced medium boilers	Underfeed coal/wood boilers; upper-fire burning, stoker boilers, underfeed rotating grate Pre-ovens combustion system: Cigar straw boiler In-direct combustor, gasifier of wood biomass In-direct combustor, gasifier of wood biomass Liquid/gaseous- based technologies
	MBM	Manual medium boilers	Coal / Biomass/Straw / Wood Boilers
	MBL	Labelled/Eco labelled medium boilers	Labelled Medium Boilers
	CHP	Reciprocating engines	Small combined heat and power

Source: GB 2019

The GB 2019 offers comprehensive information on emission factors applicable to the small-scale combustion sector. These emission factors are categorized based on two methodologies: Tier 1, which provides factors by fuel, and Tier 2, which provides factors by technology/fuel combination. However, regarding the issue of particulate matter emission factors, the GB 2019 do not provide always indications if the condensable fraction is included or not.

For the residential sector, Tier 2 emission factors are available for coal-burning advanced stoves (SVA). On the other hand, in the commercial, institutional, agriculture, fishing, and other sectors, Tier 2 emission factors are

(18) While this report was under preparation, the EMEP/EEA Guidebook 2019 has been revised and is now referred to as the EMEP/EEA Guidebook 2023. This review in the small-scale combustion sector, which has not influenced any of the conclusions presented here based on the GB 2019, examined the emission factors for NH_3 from wood use in both residential and non-residential sources providing an update on these values as well as the real life emission estimation (Annex of GB 2023) and wood combustion technologies.

provided specifically for medium-sized boilers, which represent the predominant technology used in these sectors. Emission factors for fuel oil are provided for medium sized boilers.

For solid fuels (excluding biomass), the emission factors are provided for fireplaces and conventional stoves and boilers.

The GB 2019 includes Tier 2 emission factors for natural gas in various subsectors. For the commercial/institutional and agriculture/fishing/other sectors, the guidebook provides Tier 2 emission factors for fireplaces, conventional and standard boilers, gas turbines, and stationary reciprocating engines.

Additionally, Tier 2 emission factors for natural gas in gas turbines and stationary reciprocating engines are also available for the residential subsector. Main air pollutant Tier 2 emission factors for residential sector as in the GB 2019 are shown in Table 25.

Table 25. The GB 2019 Tier 2 average emission factors for residential subsector by main fuel carriers (g/GJ)

Subsector	Fuel	Technology	NOx	SO_2	NMVOC	PM_{10}	$PM_{2.5}$
Residential	Biomass[19]	FRP	50	11	600	840	820
		SBA	95	11	250	95	93
		SBC	80	11	350	480	470
		SVA	80	11	350	380	370
		SVC	50	11	600	760	740
	Gas	FRP	60	0.3	2	2.2	2.2
		SBA	42	0.3	1.8	0.2	0.2
		SBC	42	0.3	1.8	0.2	0.2
		SVA	60	0.3	2	2.2	2.2
		SVA	60	0.3	2	2.2	2.2
	Liquid fuels	FRP	34	60	1.2	2.2	2.2
		SBA	69	79	0.17	1.5	1.5
		SBC	69	79	0.17	1.5	1.5
		SVA	34	60	1.2	2.2	2.2
		SVC	34	60	1.2	2.2	2.2
	Solid fuels	FRP	60	500	600	330	330
		SBA	158	900	174	225	201
		SBC	158	900	174	225	201
		SVA	150	450	300	240	220
		SVC	100	900	600	450	450

Source: GB 2019

3.3 GAINS IIASA model: a benchmark for the technology split and fuel allocation

The GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model developed by IIASA (International Institute for Applied Systems Analysis) provides a detailed assessment of various technologies used in the domestic sector. It considers the characteristics of different technologies, including biomass stoves, residential boilers, and other combustion devices.

The EPE/EEA Guidebook 2019 recommends referring to this distribution if solid fuels play a significant role in the respective countries' small-scale combustion sector. Main GAINS IIASA model technologies for domestic sector are shown in Table 26.

Table 26. Technologies in the domestic sector as in GAINS IIASA model

GAINS technologies	GAINS codes	Subsector
Fireplaces	FPLACE	Residential, Commercial, Agriculture
Stoves for cooking	STOVE_C	Residential, Agriculture
Stoves for heating	STOVE_H	Residential, Agriculture
Single house boilers (<50kW) - manual feeding	SHB_M	Residential, Agriculture
Single house boilers (<50kW) - automatic feeding	SHB_A	Residential, Agriculture
Medium boilers (<1 MW) - manual feeding	MB_M	Residential, Commercial, Agriculture
Medium boilers (<50 MW) - automatic feeding	MB_A	Residential, Commercial, Agriculture

Source: GAINS IIASA

([19]) Here only the emission factors for wood combustion are included

In the GB 2019, the GAINS IIASA model was utilized to provide a default estimation of the technology distribution used for solid fuels in European countries for the year 2010. This estimation encompasses both the residential and commercial/institutional subsectors within the small-scale combustion sector.

The allocation to stoves and boilers proposed by IIASA for years 2000, 2005 and 2010, taking into account the energy balances as a basis for distributing them among the residential, commercial/institutional, and other sectors has also been provided in the GB 2019.

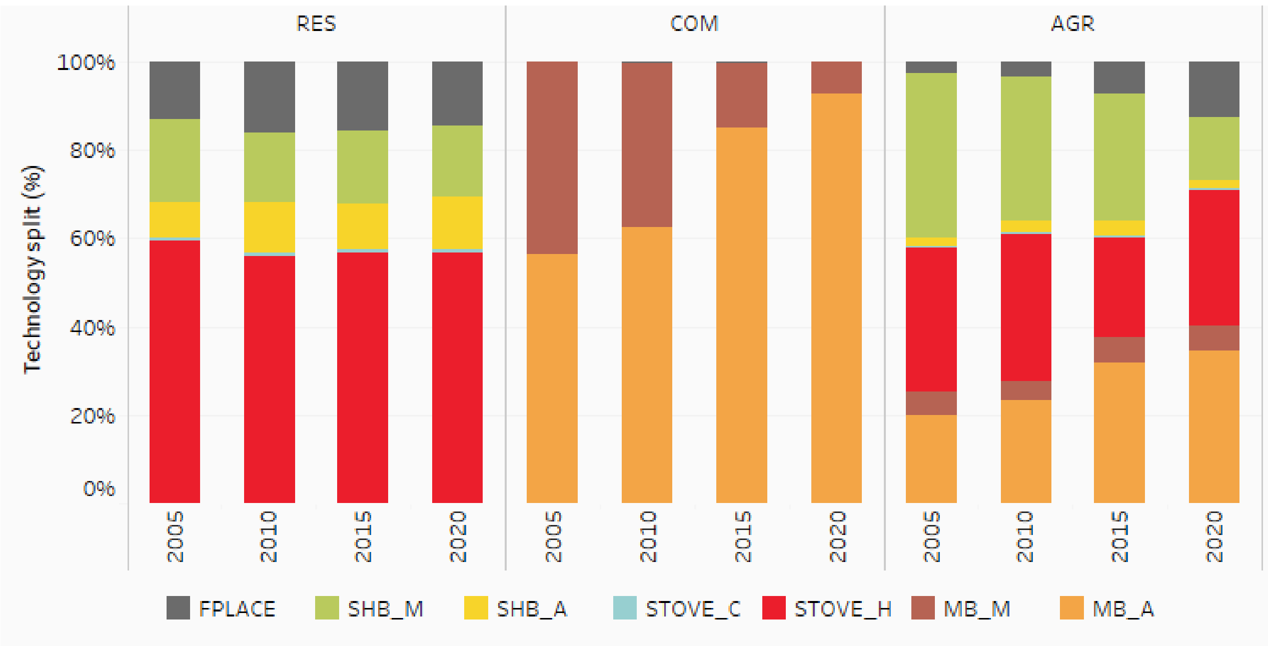
As stated in the GB 2019, this proposal underwent thorough discussions with countries during the country consultations, allowing for refinements and reaching a consensus on the allocation of stoves and boilers. It is important to note that the GB 2019 emphasizes that this information should only be used when data from the respective country regarding the distribution of different appliance types is unavailable.

The GAINS IIASA model is used as a benchmark for updating the technology allocation within the EDGAR system for the small-scale combustion sector. Data collection under this work was carried out for the EU27 MS, UK, and China, encompassing years 1990, 2005, 2010, 2015, and 2020.

The 2nd[20] Clean Air Outlook[21] study provided the data source for the EU27 and UK, specifically from the baseline scenario (COM(2021)3 final). For China, the Eclipse v6b CLE[22] baseline scenario was utilized for data gathering purposes.

The technology split for fuelwood in the EU27 small-scale combustion subsectors is shown in Figure 10 and Annex 3 provides the technology shares for fuelwood for residential subsector for each MS as they are used in the GIANS IIASA model.

Figure 10. GAINS estimated technology split for fuelwood in the EU27, 2005-2020, (%)



Source: GAINS IIASA model, JRC elaboration

The technology allocation from GAINS IIASA model is used also in cases where the technology split information for a certain fuel, usually solid biomass, is missing in countries reporting.

Some countries, such as Luxembourg provide the technology split for fuels such as coal, gas and liquid, while for wood combustion the split of technologies used for wood log, wood chips and wood pellets is not provided. For example, the wood log is reported to have been used in closed fireplaces, conventional traditional stoves and

(20) 3rd Clean Outlook has been released in December 2022, https://environment.ec.europa.eu/publications/third-clean-air-outlook_en
(21) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0003
(22) https://iiasa.ac.at/models-tools-data/global-emission-fields-of-air-pollutants-and-ghgs

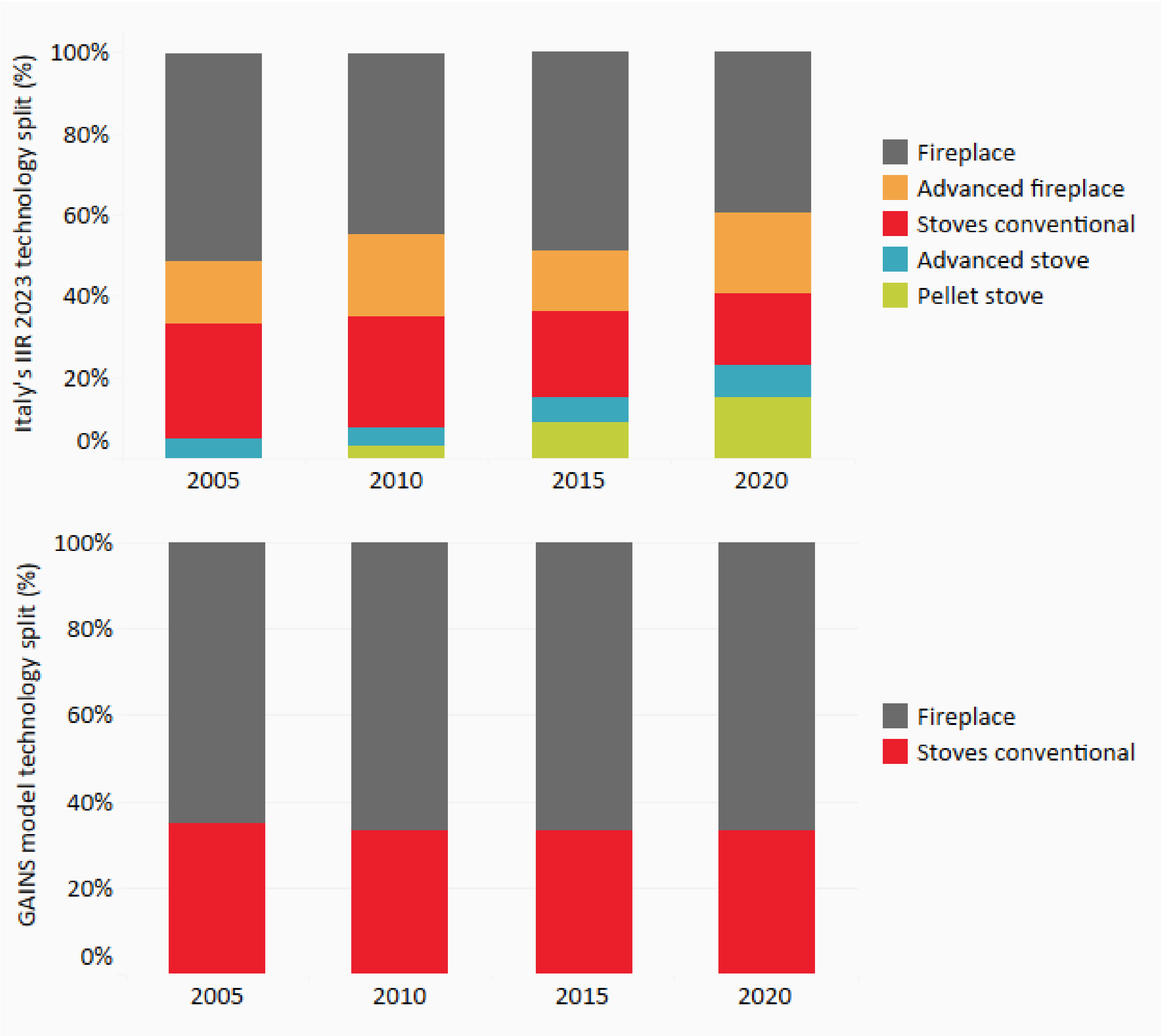
domestic cooking without providing the split between these technologies. In such case, the technology split provided by GAINS IIASA model can be used to fill the gaps.

The gap filling process is also applied in cases when the data from countries do not refer to a temporal coverage since 1990, but only from a certain year and afterwards. In such cases, the GAINS IIASA model technology shares are used to fill the gap for years before 2015.

However, it is worth to mention that the model has certain limitations. *Firstly*, it applies a uniform structure over the years for all fuels. *Secondly*, it provides inputs for every 5-year period and the current open version of the model does not include information before 2005 for the Europe under the 2nd Clean Air Outlook study. *Thirdly*, it does not provide inputs on the gaseous and liquid fuels allocation by technology. *Fourthly,* it may not fully represent the real situation in a specific country.

An example from Italy is provided below (see Figure 11), illustrating the technology distribution for fuelwood as per the Italian IIR 2023, and as per the GAINS IIASA model. As shown in this figure the GAINS IIASA model does not include the contribution of advanced stoves as well as the introduction of pellets stoves after 2005. Furthermore, the distribution of fireplaces and conventional stoves in GAINS IIASA model remains constant after the year 2010.

Figure 11. Technology split for fuelwood in Italy residential subsector: IT IIR 2023 (above)-GAINS (below) 2005-2020 (%)



Source: IT, IIR 2023, GAINS IIASA, JRC elaboration

Annex 2 provides the technology shares for fuelwood for each MS residential subsector as they are used in the GIANS IIASA model.

3.4 Approach for EDGAR database updates in small-scale combustion sector

The approach to update technology and emission factors in EDGAR database is based on the above-mentioned data collected by the EU MS reporting under the NECD, combined with the data gathered from GAINS model that are used as a benchmark in this process.

The approach concept considers the current structure of EDGAR v8.0 in relation to technology shares and fuel allocation. The update concept was based on one of the following approaches:

- **Approach 1**: Maintain the existing structure and establish compatibility between the current technology codes and the aggregations of the respective by typology of GB 2019 codes.
- **Approach 2**: Make changes for all fuels and all technology codes to ensure full compatibility with EMP/EEA Guidebook 2019,
- **Approach 3**: Adjust the existing technology codes by incorporating one or more codes from the GB 2019. The adjustment will be done for the key fuels based on their role in the selected countries and subsectors.

The pros and cons of the selection of one of the above-mentioned approaches are shown in table 27.

Table 27. Pros and Vons on the selection of approach for the update of EDGAR v8.0 database

Approaches	Pros	Cons
Approach 1	Easy implementation	High aggregation for technologies and EFs
Approach 2	Full alignment with GB 2019 technology structure allowing to apply more detailed emission factors	Difficult to implement – to consider the effect that the new technology distribution might have in the uniform structure of EDGAR applied to estimate the GHG emissions
Approach 3	- Alignment with GB 2019 technology structure for key fuels (mainly biomass) - Limited effect at the EDGAR structure applied to estimate the GHG emissions	Limited number of fuels for which the new structure is applied

In the case of Approach 1, the implementation is an easy process since the review of emissions factors is foreseen. However, the aggregation of technologies will be at the highest level especially for stoves and boilers (both small and medium).

Approach 2 has an important limitation related to its implementation, primarily stemming from the potential impact of the new technology distribution on the uniform EDGAR structure[23] applied for the estimation of greenhouse gas emissions from fossil fuels. The selected method for updating the EDGAR database entails the adoption of Approach 3. This approach involves aligning the technology structure of EDGAR with that of the GB 2019, focusing on key fuels within each MS and subsector.

One limitation of this approach concerns the range of fuels to which the modifications will be applied. Nonetheless, it is worth emphasizing that when focusing exclusively on the primary fuels, the adjustments to the EDGAR structure will remain minimal.

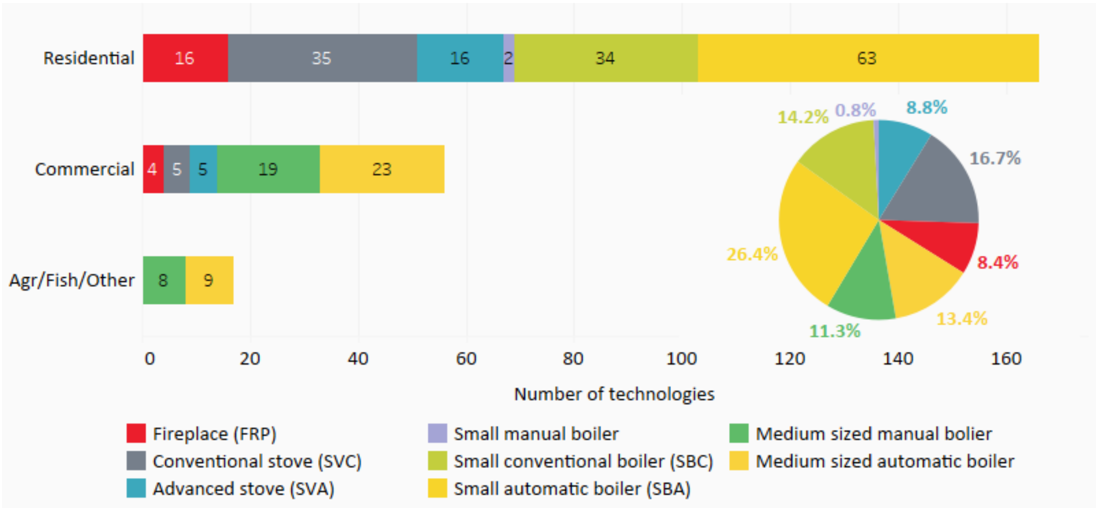
3.4.1 Technology data

The approach of the work related to the technology shares data has been focused on data gathering from MS' IIRs. Therefore, a technology shares database for each subsector has been build. More information on the data availability on emission factors in MS can be found at session 2.6.

([23]) EDGAR employs a uniform structure that incorporates sector, subsector, fuel, technology, emission factor, and abatement measures to calculate emissions of both greenhouse gases and air pollutants.

The largest number of data on technology split is provided for the residential subsector. Figure 12 illustrates the number and distribution of data on technologies as reported by eighteen MS for year 2020. The bar chart in this figure shows the number of records gathered for each technology and incorporated into the database, while the pie chart illustrates the distribution of these records by technology.

Figure 12. Number and distribution of technologies in eighteen EU27 MS in small-scale combustion sector, 2020.



Source : EU27 MS IIRs, JRC elaboration

To update the technology shares a comparison between EDGAR database, GB 2019 and GAINS model technology codes is performed and showed in Table 28.

Table 28. EDGAR, GAINS IIASA and GB 2019 small-scale combustion technology codes by subsector

Subsector	EDGAR database	GAINS IIASA model	GB 2019
Residential	FRP	FPLACE	FRP
	STV	STOVE_C	SVC
		STOVE_H	SVA
	SB0	SHB_M	SBM
		SHB_A	SBA
	MB0	-	-
	CHP	-	CHP
	NSF	-	NSF (Tier1)
Commercial/Institutional	FRP	-	-
	STV	-	-
	SB0	-	-
	MB0	MB_M	MBM
			MBC
		MB_A	MBA
			MBL
	-	-	CHP
	NSF	-	NSF (Tier1)
Agriculture/Fishing/Other		FPLACE	FRP
	STV	STOVE_C	SVC
		STOVE_H	SVA
		SHB_M	SBM
		SHB_A	SBA
		MB_M	MBM
		MB_A	MBA
	-	-	CHP
	NSF	-	NSF (Tier1)

Source: EDGAR database, GAINS IIASA model, GB 2019

As shown in the table the technology codes between the GAINS IIASA model and GB 2019 demonstrate a better match compared to the EDGAR database codes. EDGAR includes in its system the allocation of fuels, mainly biomass, at the non-specified technology code (NSF).

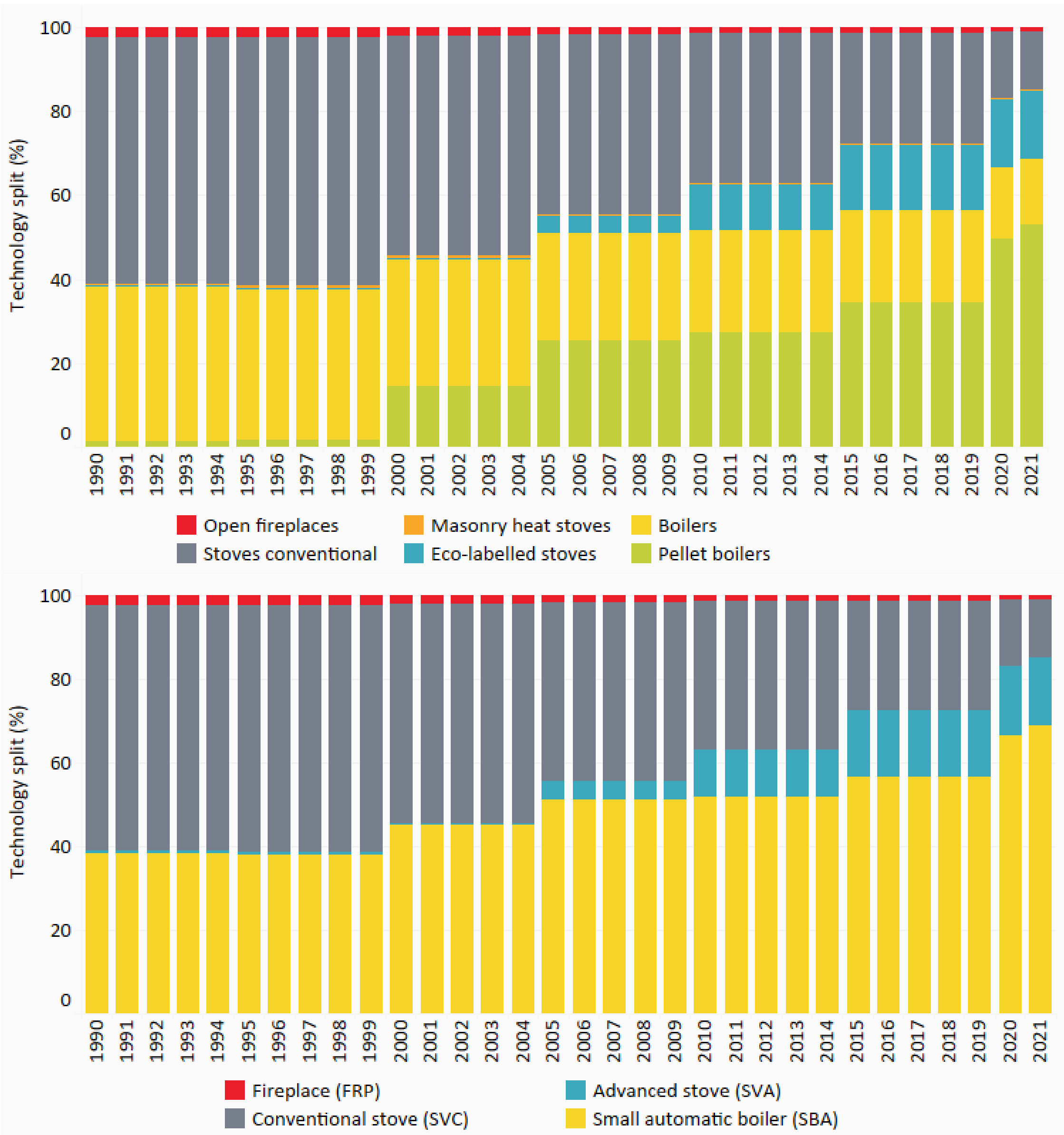
To achieve alignment through Approach 3, the current EDGAR codes for stoves and boilers are split into two distinct categories within the residential subsector: advanced and conventional stoves and boilers. Similarly, within the commercial subsector, the existing code for medium-sized boilers are substituted with codes for both manual medium-sized boilers and advanced boilers. Additionally, adopting the technology distribution from the GB 2019 in the agriculture/fishing/other subsector will lead to a major change of the existing structure.

In contrast to the current technology distribution across MS, adopting the technology composition specified in the GB 2019 might result in a simplification of the technological landscape present within each country's small-scale combustion sector as illustrated in Figure 13 for Denmark and Figure 14 for Finland in the case of residential subsector.

Figure 13. Fuelwood technology split in Denmark's residential subsector: a) country and b) GB 2019, (%)

a)

b)



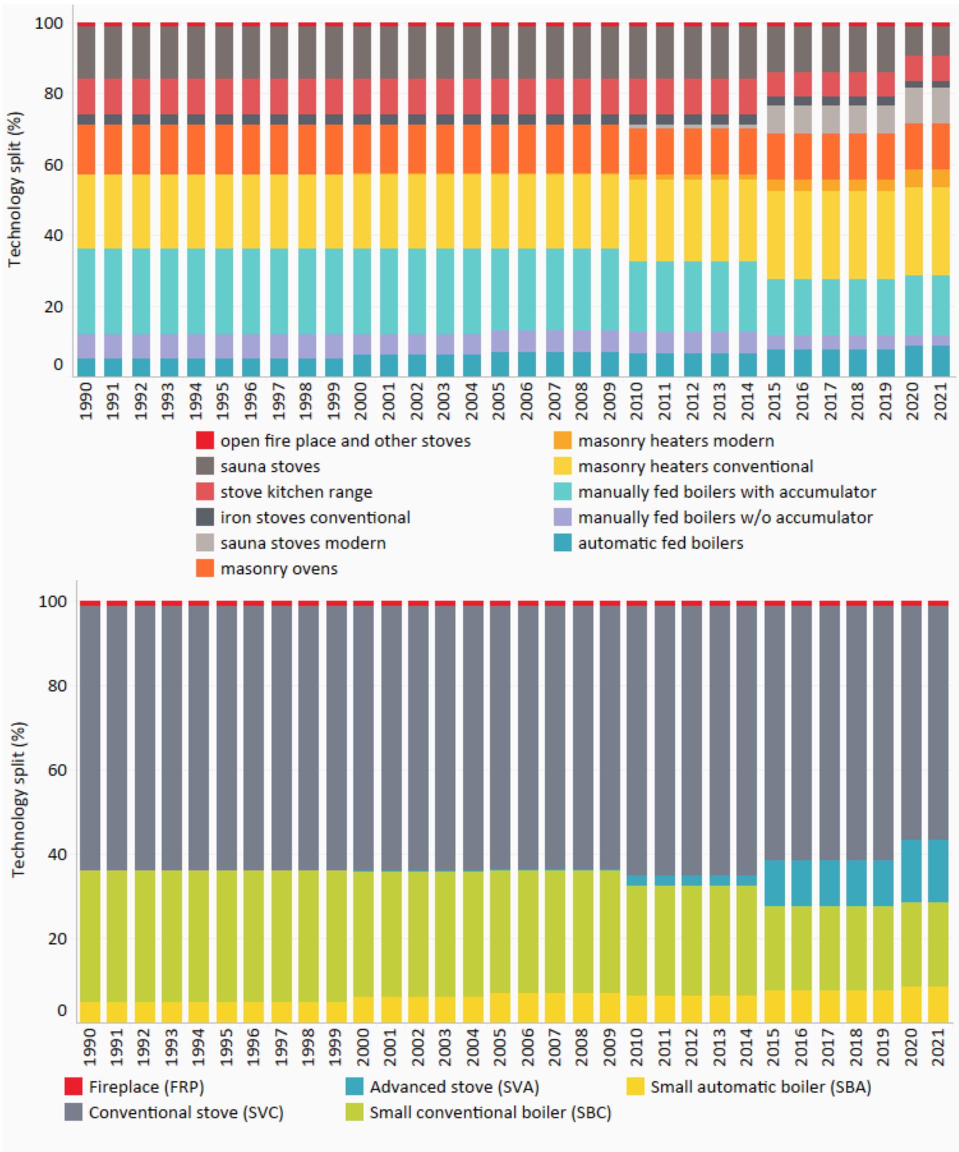
Source: DK IIRs, JRC elaboration

It is important to note that this aggregation applied in EDGAR approach3 might not accurately reflect the complexity of the current technological variations in place. However, in the previous EDGAR database, biomass allocation was categorized under the 'not specified' technology and in some cases also fuels as natural gas are not allocated to any specific technology. While certain MS may experience simplified fuel allocation compared with their specific technology split, the improvement compared to the current structure remains evident. Even with a simpler technology structure compared to the MS specific, there is an improvement in the estimation of air pollutant emissions for this sector.

Figure 14. Fuelwood technology split in Finland's residential subsector: a) country and b) GB 2019, (%)

a)

b)



Source: FI IIRs, JRC elaboration

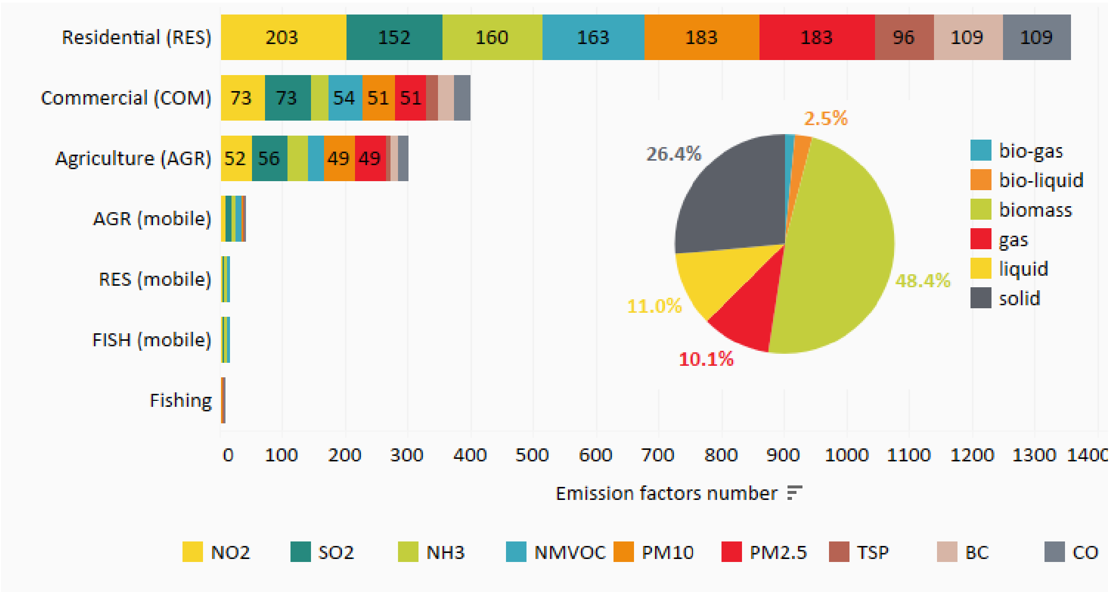
3.4.2 Emission factors data

The approach of the work related to the emission factors has been focused on data gathering from MS' IIRs and comparison with emission factors used in the EDGAR database. Therefore, an emission factors database for each of main air pollutant and each of combinations subsector/fuel/technology has been build. More information on the data availability on emission factors in MS can be found at session 2.6.

Sixteen MS apply a country specific or a combination with default emission factors for the estimation of air pollutant emissions from small-scale combustion sector. The reporting is mainly focused on residential sector and nearly two-third of the data are related to biomass (see Figure 15).

The bar chart shows the number of emission factors gathered for each air pollutant and incorporated into the created database, while the pie chart illustrates the distribution of these emission factors by fuel.

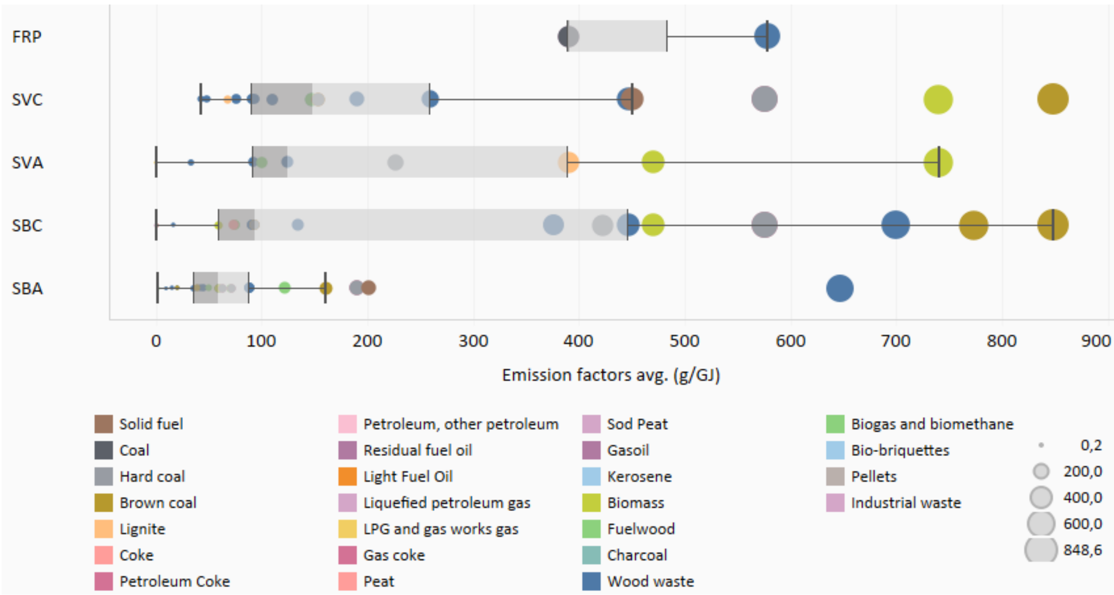
Figure 15. Number and distribution by small-scale combustion subsector of country specific emission factors as reported by sixteen EU27 MS, 2020



Source : EU27 MS IIRs, JRC elaboration

Figure 16 illustrates an example of emission factors within the EU27 residential subsector (as reported by sixteen MS) for estimating $PM_{2.5}$ emissions. It shows a wide range of $PM_{2.5}$ emission factors, with conventional technologies generally showing higher values compared to advanced technologies. This shows the broad range of the conventional technologies types used in the EU27 residential subsector. Among small conventional stoves and boilers, the highest observed values are associated with solid fuels, followed by biomass. In advanced technologies, biomass primarily exhibits the highest values.

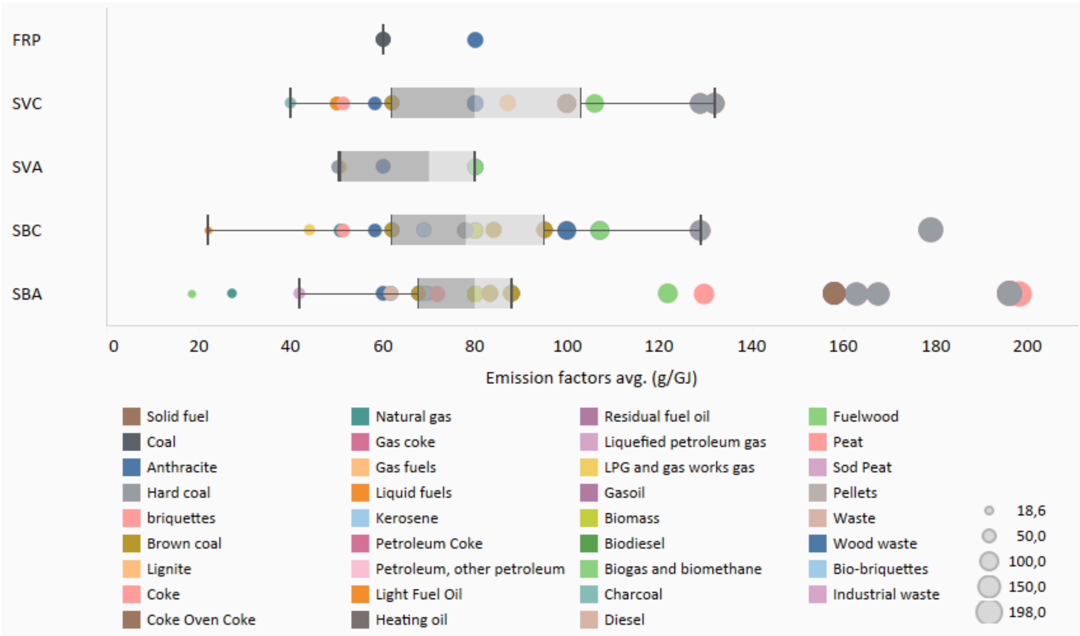
Figure 16. $PM_{2.5}$ emission factors for each type of fuel and technology in the EU27 residential subsector, 2020, as reported by sixteen MS (g/GJ)



Source : EU27 MS IIRs, JRC élaboration

Figure 17 presents a comparable illustration, focusing on NOx emission factors within the residential subsector. In general, the emission factors for advanced technologies exhibit a wider range, particularly for small boilers, where the highest values are associated with solid fuels, primarily hard coal. In contrast, for advanced stoves, a narrower range of emission factors is observed.

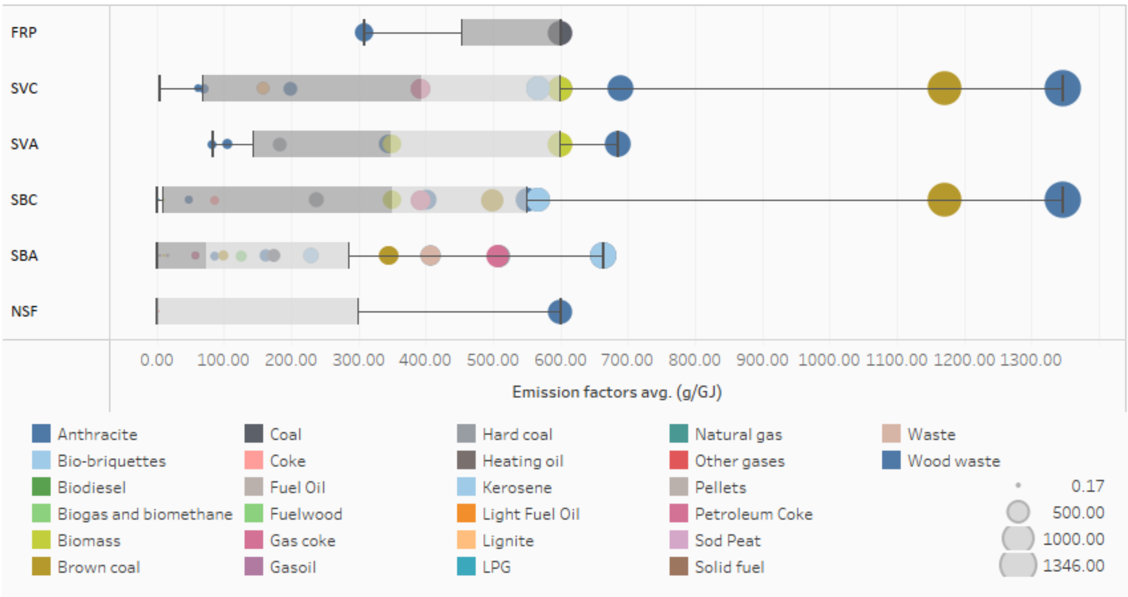
Figure 17. NOx emission factors for each type of fuel and technology in the EU27 residential subsector, 2020, as reported by sixteen MS (g/GJ)



Source : EU27 MS IIRs, JRC elaboration

A similar representation of emission factors for NMVOC in the residential subsector is presented in Figure 18. Notably, the highest emission factor values are associated with the use of wet wood[24] and brown coal in over-fire boilers as observed in Czechia and in advanced stoves as seen in Poland.

Figure 18. NMVOC emission factors for each type of fuel and technology in the EU27 residential subsector, 2020, as reported by sixteen MS (g/GJ)



Source : EU27 MS IIRs, JRC elaboration

(24) The wood emission factor of Finland applied for the iron stoves conventional as reported by the FI IIR 2023 has the highest value of 3030 mg/MJ (g/GJ). This value has been excluded from the analysis presented in Figure 17. Finland has revised its emission factors for NMVOC since in the reporting of year 2017 (moving from 200/600 mg/MJ to 3984.45 mg/MJ.

4 Improvement of the EDGAR air pollutant emissions estimation

The section below presents some comparisons between the air pollutant emissions as estimated previously by EDGAR with the emissions after the improvement and emissions as reported by the MS in their submissions under the NECD. Case studies are presented for the selected EU MS.

4.1 $PM_{2.5}$ emissions from residential sector - Italy

Italy reports to apply a Tier 2 methodology to estimate the $PM_{2.5}$ emissions from the residential subsector. Italy provides in its IIRs information on wood combustion distribution on technologies used in residential sector (refer to Table 15). As shown in this table the dominant technology in Italian residential subsector is the conventional fireplace. Over the years, the penetration of advanced fireplaces and pellet stoves is found. However still the conventional technology covers nearly 60% of technology use for wood combustion. Regarding the emission factors for wood combustion in the residential subsector, Italy reports only the implied emission factors for each air pollutant over years (see Table 29). Moreover, Italy includes in the estimation of particulate matter the condensable fraction based on several studies heating appliances, burning wood or other fuels (IT IIR, 2023).

Table 29. Wood combustion $PM_{2.5}$ implied EFs in residential subsector- Italy's IIR and EDGAR, 1990-2020

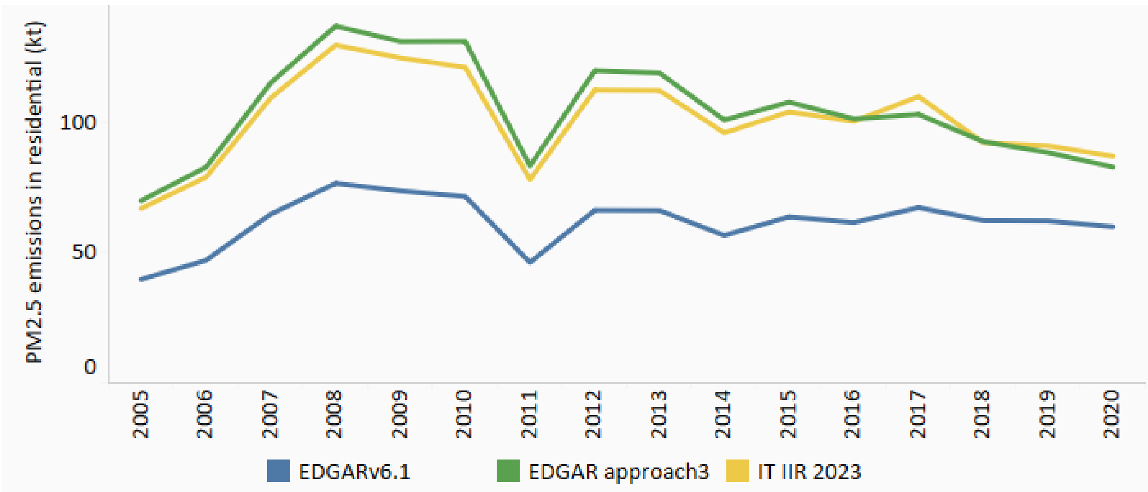
Substance	**1990**	**1995**	**2000**	**2006**	**2010**	**2015**	**2017**	**2019**	**2020**
$PM_{2.5}$ ITA IIRs (reported)	503	461	424	405	402	388	388	348	344
$PM_{2.5}$ EDGAR (calculated)	551	505	464.5	443.6	440.4	425	403.1	381.2	376.8

Source: IT, IIR 2023

From the comparison work described in section 3.1.2, the EDGARv6.1 $PM_{2.5}$ emissions for Italy's residential subsector are underestimated mainly due to the application of a lower emission factor for solid biomass which allocation was only at the "non-specified technology" option. EDGAR $PM_{2.5}$ emission factor for biomass applied was found to be lower with that reported by Italy but also lower when compared to the GB 2019 emission factors values for fireplaces and high efficiency stoves. The EDGAR $PM_{2.5}$ emission factor for natural gas was found to be similar with that of advanced medium boilers.

Improvement: Improving the estimation of $PM_{2.5}$ emissions for Italy within the EDGAR database involves the application of approach 3. This method incorporates the emission factors from the GB 2019 for fireplaces, where an implicit emission factor is computed by merging the emission factors from both advanced and conventional fireplaces. In addition, the emission factors from advanced and conventional stoves are also used. The temporal trend of the implied emission factors as reported by Italy has been integrated in the EDGAR database. The calculated EDGAR implied emission factors are shown at Table 29.

Figure 19. Italian residential subsector $PM_{2.5}$ emissions: EDGARv6.1, EDGAR_approach3, IT IIRs, 2005-2020 (kt)[25]



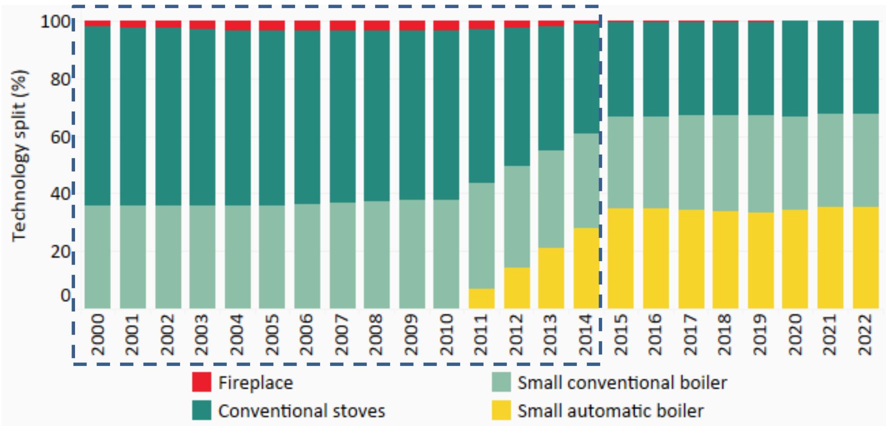
Source: EDGAR database, IT IIR 2023

([25]) The drop in $PM_{2.5}$ emissions in 2011 can be attributed to reduced biomass use for heating, primarily due to the mild winter in that year.

4.2 $PM_{2.5}$ emissions from residential sector - Czechia

Czechia applies a Tier 2 methodology for estimating $PM_{2.5}$ emissions from the residential subsector. While Czechia's IIRs offer comprehensive insights into fuel allocation for small-scale combustion technologies in this subsector, the available data cover only the period from 2015 to 2021 (see Table 7). To fill the gaps of the technology shares for 2000, 2005, and 2010, information from the GAINS IIASA model is utilized. Notably, conventional stoves and small conventional boilers, along with small advanced boilers, emerge as the primary technologies in Czechia's residential subsector when approaching the year 2021 (see Figure 20). Czechia provides detailed reports on country-specific emission factors applied to each type of fuel and pollutant. Since 2019, all data related to the emissions inventory have been accessible through an online e-Annex. However, the updates to this e-Annex do not facilitate the creation of a comprehensive time series for these emission factors.

Figure 20. Technology split for wood in Czechia residential subsector, 2000-2021, (%)

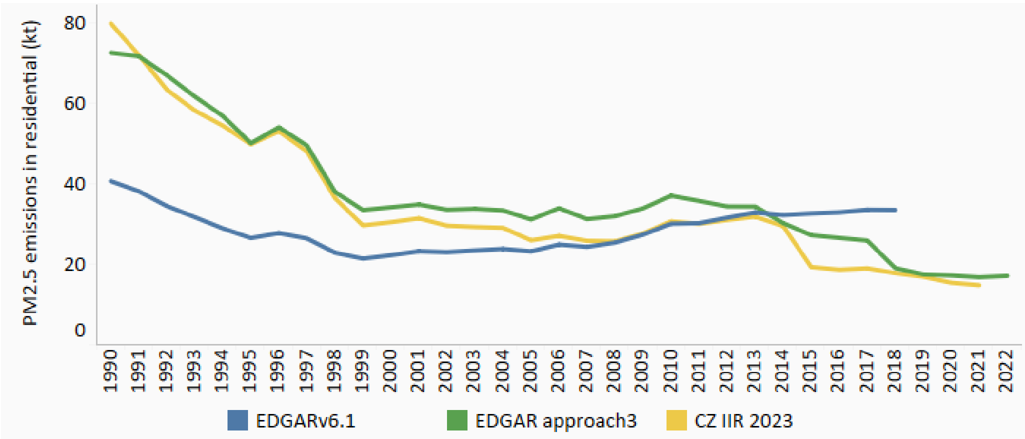


Source: CZ IIR 2023, GAINS IIASA

In the EDGARv6.1 system, $PM_{2.5}$ emissions estimates in the Czechia residential subsector rely on solid biomass, lignite/brown coal, and natural gas, aligning with country-specific estimations. However, our comparative analysis reveals discrepancies with officially reported trends mainly due to the absence of solid biomass allocation to technologies, predominant hard coal allocation to medium boilers and lower regional emission factors.

Improvement: Improving the estimation of PM_{10} emissions for Czechia within the EDGAR database involves the application of the approach 3. While no technology split is available for natural gas technology split is applied for solid biomass, lignite/brown coal and hard coal. A combination of country-specific and default GB 2019 emission factors is utilized. Default GB 2019 emission factors are applied to solid biomass use in fireplaces, small conventional and advanced boilers, and conventional stoves. Country-specific emission factors are primarily used for lignite/brown and hard coal fuels, while a default emission factor is applied for natural gas.

Figure 21. Czechia residential subsector $PM_{2.5}$ emissions: EDGARv6.1, EDGAR_approach3, CZ IIRs, 2000-2020 (kt)

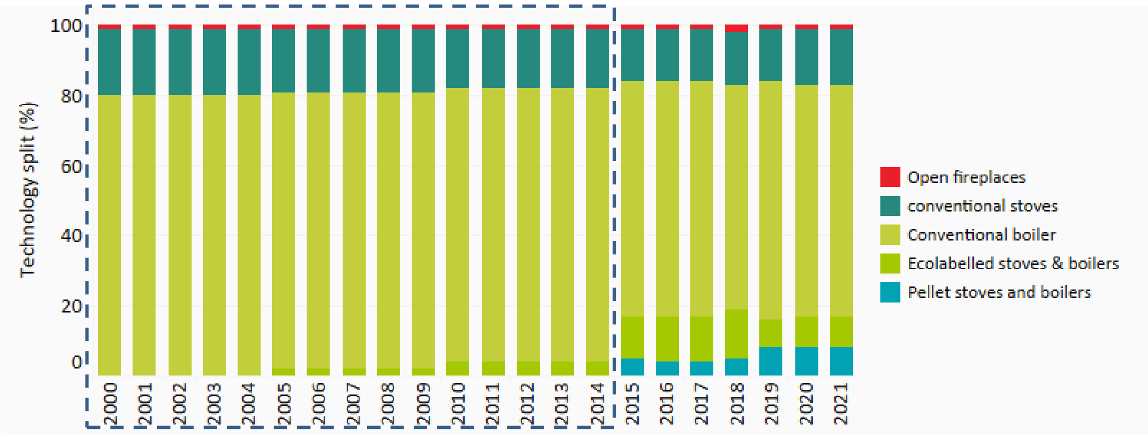


Source: EDGAR database, CZ IIR 2023

4.3 PM$_{10}$ emissions from residential sector - Slovenia

Slovenia reports on particulate matter emissions starting from year 2000. Slovenia reports to estimate the PM$_{10}$ emission in residential subsector applying a Tier 2 method, providing in its IIRs reports the information on wood combustion distribution by technology (refer to Table 21). Slovenia reports to include in the calculations the condensable fraction of particulate matter. Wood is the main fuel used in the Slovenian residential subsector. However, this information is available since 2015 and afterwards. In order to fill the technology shares for wood combustion for years 2000, 2005 and 2010 the information from GAINS IIASA model is used (see Figure 22). Conventional boilers and stoves are the dominant technologies for wood combustion in the residential and commercial subsectors.

Figure 22. Technology split for wood in Slovenian residential subsector, 2000-2021, (%)

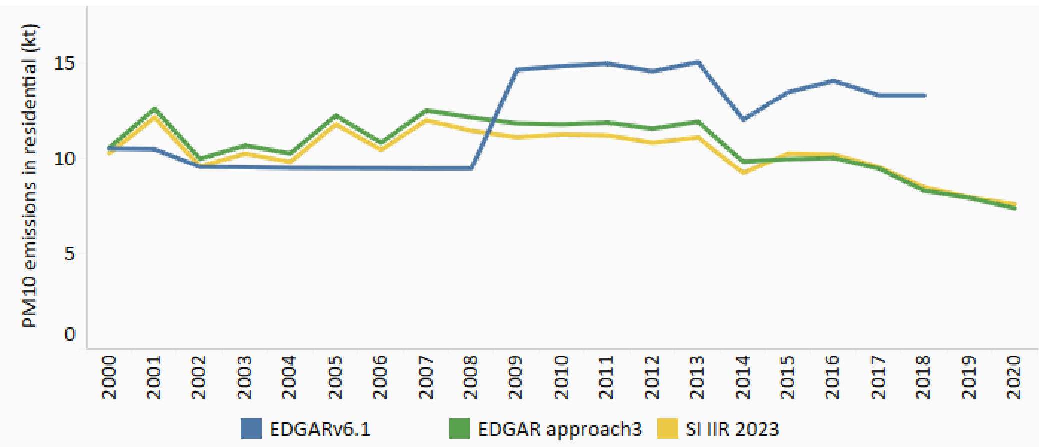


Source: SI IIR 2023, GAINS IIASA

From the comparison work described in section 3.1.2, the EDGARv6.1 PM$_{10}$ emissions for Slovenian residential subsector are found to be higher than the EMEP and CAMS-REG values in year 2018. The main issue is the allocation of solid biomass at the "non-specified technology" option and as result the application of only one emission factor, the regional one for Central Europe.

Improvement: Improving the estimation of PM$_{10}$ emissions for Slovenia within the EDGAR database involves the application of the approach 3. In the GAINS IIASA model, the wood combustion in Slovenian residential subsector takes place in conventional stoves, small conventional boilers and small advanced boilers, an information that is in line with data reported by the country. The contribution of fireplace has been kept constant all over period 2000-2020. The GB 2019 default emission factors for wood burning in each of these technologies are used.

Figure 23. Slovenian residential subsector PM$_{10}$ emissions: EDGARv6.1, EDGAR_approach3, SI IIRs, 2000-2020 (kt)[26]



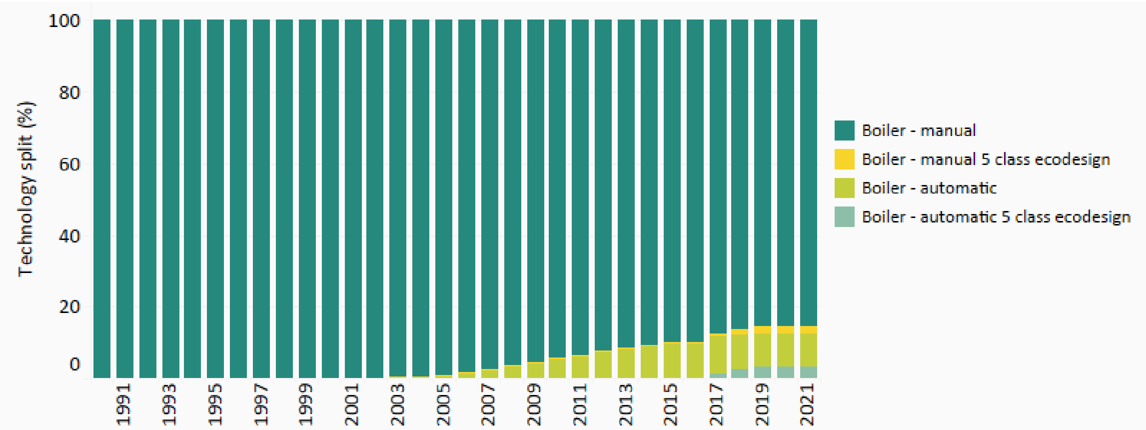
Source : EDGAR database, SI IIR 2023

(26) There is a change in the fuel consumption trend in Slovenian residential subsector used in EDGARv6.1 and EDGARv8.0 for 2000-2008.

4.4 SO_2 emissions from residential sector - Poland

Poland reports to apply a Tier 2 methodology for the estimation of SO_2 emissions from residential activities. The main fuel contributing to SO_2 emission in this subsector is coal (had coal and coke). Poland provides in its IIRs report information on the technology split for all the fuels, information that is presented in Table 17. Coal (hard and brown coal) is the main fuel that influence SO_2 emission levels in the Polish residential subsector. The role of biomass for this substance is minimal. Regarding the emission factors, the reporting in the Polish IIRs over the years has used different measurement unit not allowing building consistent time series. The introduction of advanced technologies in the Polish residential subsector has been seen only after year 2000 (see Figure 24).

Figure 24. Technology split for hard coal in Polish residential subsector, 1990-2021, (%)

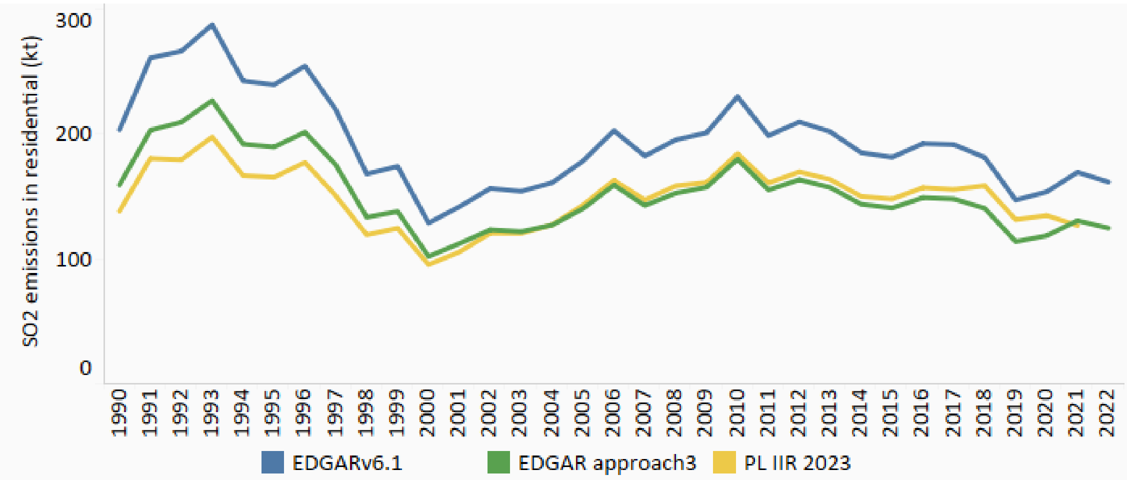


Source: PL IIR 2023

In the EDGARv6.1 system, the predominant source of SO_2 emissions estimation within the residential subsector is attributed to the use of other bituminous coal, consistent with country-specific estimations. However, our comparative analysis, as detailed in section 3.1.2, has revealed that SO_2 emissions for Poland in the EDGARv6.1 dataset tend to be overestimated. This discrepancy can be primarily attributed to the dominance of medium boilers within the technology split for coal in the EDGAR database.

Improvement: Improving the estimation of SO_2 emissions for Poland within the EDGAR database involves the application of approach 3 (see Figure 25). This method incorporates the technology split for coal mainly based on small boilers (manual and advanced) and the application of respective emission factors from the GB 2019. The default GB 2019 emission factor for solid biomass is applied.

Figure 25. Poland residential subsector SO_2 emissions: EDGARv6.1, EDGAR_approach3, PL IIRs, 1990-2022 (kt)

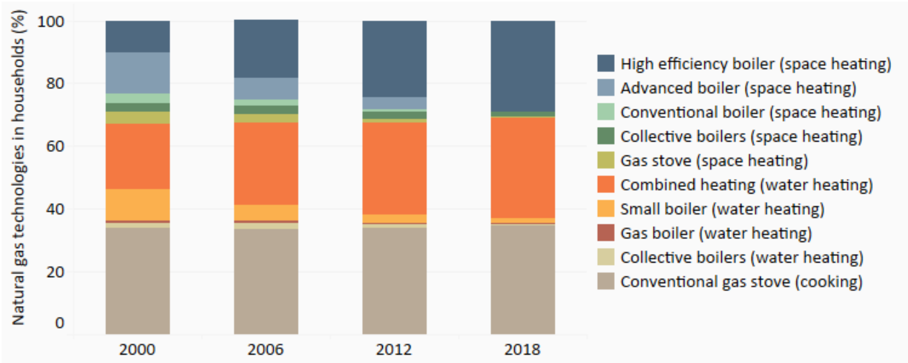


Source: EDGAR database, PL IIR 2023

4.5 NO_x emissions from residential sector - The Netherlands

The Netherlands applies a Tier 2 method for NOx emissions from the residential subsector, primarily relying on natural gas for space and water heating. However, these reports lack a breakdown of technology usage for small-scale combustion. When it comes to wood technologies, the IIRs mention various technology types, including fireplaces, conventional stoves, improved stoves, ecolabel stoves, eco-design stoves, and pellet stoves. However, the NL IIRs do not provide information on technology split for wood. Information on natural gas is limited to emission factors for heating and cooking without a technology split. The NOx emission factors used in the NL IIRs are derived from (TNO, 2014) study, which updated these factors for the household sector. This study offers insights on how natural gas is used in Dutch households and how it is allocated by technology for space heating, water heating, and cooking, including also projections covering the period from 2012 to 2018 (see Figure 26)

Figure 26. Technology split for natural gas in Dutch households, 2000-2018

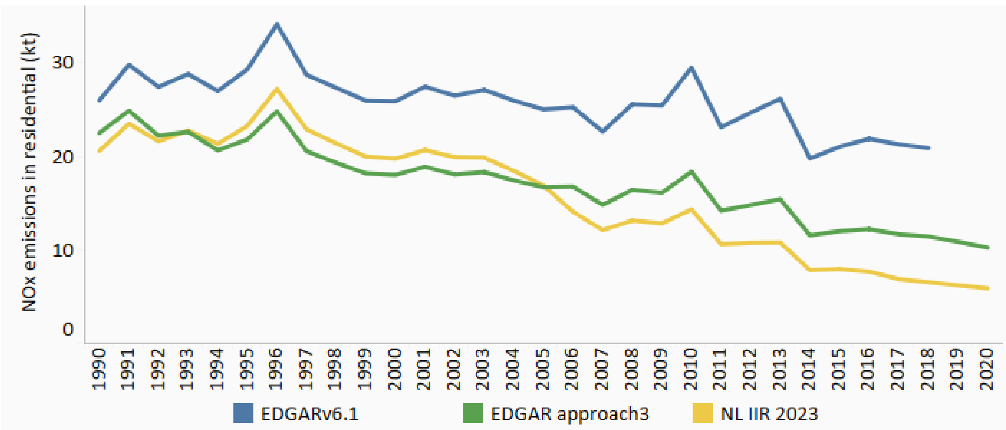


Source: TNO, 2014, JRC elaboration

Within the EDGARv6.1 estimation, natural gas consumption stands out as the dominant fuel source, aligning with the country's specific estimates. However, EDGAR system does not allocate natural gas to any technology in the residential subsector. As a result, the estimated EDGARv6.1 NOx emissions in the Netherlands' residential subsector are higher compared to the official country values (see Figure 27).

<u>Improvement:</u> Improving the estimation of NOx emissions for Netherlands within the EDGAR database involves the application of approach 3. Given the absence of data from the GAINS IIASA model, which exclusively covers fuelwood and coal fuels, the improvement in NOx emission estimation relies on technology split sourced from the above-mentioned study. This improvement involves the utilisation of default GB 2019 NOx emission factors for natural gas in various appliances, such as conventional stoves, small boilers (both conventional and advanced), and incorporates temporal trends of the implied values for heating and cooking as outlined in the TNO, 2014 study. Comparing natural gas usage in the Netherlands' residential subsector (UNFCCC, April 2023) with EDGAR_approach3 (IEA 2023), the country reported values were found lower after year 2005.

Figure 27. Dutch residential subsector NOx emissions: EDGARv6.1, EDGAR_approach3, PL IIRs, 1990-2022 (kt)



Source: EDGAR database, NL IIR 2023

5 Conclusions

Improving the estimation of air pollutant emissions from the small-scale combustion sector is an important issue for several reasons. Small-scale combustion sources such as residential wood-burning and heating systems can emit significant amounts of harmful pollutants like particulate matter, volatile organic compounds, and nitrogen oxides. These pollutants can have adverse effects on public health, causing respiratory and cardiovascular diseases and even premature death.

This report discusses **the issues related to the air pollutant emissions estimation for the EDGAR database** and **provides approaches for the improvement of this estimation**. Accurate estimation of air pollutant emissions is essential for understanding the contribution of the small-scale combustion sector to overall air pollution levels and for assessing their impact on local and global climate change.

Knowing the level of these emissions is important for formulating policies aimed at reducing pollution and transitioning to cleaner energy sources. Accurate data helps policymakers identify areas that require intervention and allocate resources effectively. Improving this estimation provides a more reliable foundation for scientific research and technological innovation helping to better understand emission trends, develop effective mitigation techniques, and assess the effectiveness of new technologies.

This report provides also an overview of the methodologies applied in each EU27 MS as they are reported in their yearly Informative Inventory Reports (IIRs). This overview includes the information on the data availability for the technology split in the small-scale combustion subsectors and the type of emission factors applied.

Almost all EU27 MS apply a Tier 2 method especially for the residential subsector and for the key fuels. The Tier 2 is the highly advisable method that can reflect changes in technology distribution and the role of moving towards more advanced and efficient technologies. Tier 2 method often requires more detailed information about technology characteristics, their share and performance. This encourages a thorough evaluation of existing and emerging technologies, enabling policymakers to identify the most effective and efficient solutions for emission reduction. In addition, the advanced Tier 3 method is applied by some MS for certain pollutants and subsector as Finland, Germany, Luxembourg and Sweden.

In the EU27 MS IIRs, the information related to the technology split in the small-scale combustion sector up to March 2023 is available for 18 countries whereas 16 countries report to apply a country specific or a combination of country specific emission factors. Detailed information is provided for biomass combustion especially when this fuel is a key category.

There is a broad range of technology types used in the EU27 small-scale combustion sector, which defines a wide range of emission factors applied. This shows that emission inventories in the EU27 can be highly variable and dependent on the mix of technologies in use. The broad range of technologies underlie the importance of comprehensive data collection and accurate emission factors implying the need for promoting the transition to advanced technologies in the residential sector. This includes replacing less advanced technologies by supporting the adoption of modern wood stoves, pellet stoves, and other cleaner-burning devices that have lower emissions.

Regarding the inclusions of condensable fraction of particulate matter in the estimations of emissions, **fifteen EU27 MS reports to apply the respective emission factors for the residential subsector and mainly for wood combustion.**

The use of models as GAINS IIASA provide the possibility to introduce technology split information when there is no data availability in the MS' IIRs. However, it's essential to acknowledge a limitation of this model, which is its utilization of a uniform structure for technologies and fuels, with data availability occurring every five years. Although the 3rd Clean Outlook was released at the end of 2023, the GAINS IIASA model continues to provide information and data that are utilized for the 2nd Clean Outlook study in Europe. Despite these limitations, the model serves as a useful tool for bridging data gaps in years with missing information and shedding light on the primary technologies employed during those periods. Offering global coverage, the model can be utilised in a subsequent phase to re-evaluate EDGAR's estimations for other countries worldwide, particularly focusing on the top emitters.

The EMEP/EEA Guidebooks (2013, 2016, 2019 and 2023) provide methodologies and default emission factors for the estimation of air pollutant emissions from small-scale combustion sector. These emission factors are provided for main fuels and main technologies used in this sector. There is also relevant information in these guidebooks on the technology split by fuel especially for biomass combustion.

However, these guidebooks in several cases do not include enough information especially on what is related to the inclusion of condensable fraction of particulate matter. The EMEP/EEA Guidebook 2016 provides emission factors for both cases of inclusion/exclusion of condensable fraction whereas the EMEP/EEA Guidebook 2019 do not provide any more this split. A planned update of the EMEP/EEA Guidebook related to the condensable fraction of particulate matter is already in place.

As part of the improvement on the estimation of air pollutant emissions from small-scale combustion, the importance of a comprehensive reporting, encompassing methodologies, emission factors, and technology distribution, lies in the creation of comparable and reliable data.

The NECD (2016/2284/EU) introduced several new reporting requirements for MS defined in the Annex I of the Directive. Comparing to the previous reporting approach there are the enhancements as the incorporation of detailed methodological descriptions, data sources, uncertainty considerations, discussions on quality assurance and quality control procedures, as well as evaluations of emission trends and patterns.

The present structure of IIRs lacks several components to offer comparable information regarding emission factors and technological distribution within the small-scale combustion sector that can be summarized as follows:

- No harmonization on how the emission factors / technology shares are reported;
- Information sourced from scientific specific references not always included in the IIRs;
- Temporal data coverage is different, not all countries report data since 1990;
- In-depth comprehension of the methodology necessitates the search for additional documents, which may not always be translated;
- Unsystematic access to underlying databases;
- Variability in the measurement units for emission factors (g/GJ or kg/TJ or mg/MJ or t/TJ or mg/mg).

Improvements can be applied to the air pollutant emissions reporting for the small-scale combustion sector including:

- Needs for a unified template on emission factors and technology shares for each MS in order to have a greater comparability between EU27 MS, to enable the replication of the information used by countries in their estimation and to provide a systematic database access for scientists.;
- Needs for a unified way of presenting the applied methodology in place, since some countries provide only a short description in their IIRs reports;
- Needs to increase the transparency related to country specific activity data and emission factors,
- Needs to improve data gathering on technologies used in the small-scale combustion sector with surveys or questionnaires through the increase of their number over time.

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List of abbreviations and definitions

CEIP	Centre on Emission Inventories and Projections
CORINAIR	CORe INventory AIR
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme
GAINS	Greenhouse Gas
IEA	International Energy Agency
IIASA	International Institute for Applied System Analysis
IIRs	Informative Inventory Reports
IPCC	Intergovernmental Panel Climate Change
NECD	National Emission reduction Commitments Directive
NFR	Nomenclature for Reporting
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
NH_3	Ammonia
PM_{10}	Particulate matter 10µm
$PM_{2.5}$	Particulate matter 2.5µm
SO_2	Sulphur dioxide

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Annexes

Annex 1. Particulate matter emission factors for condensable fraction in EU MS residential and commercial subsectors

As required, the MS report in their IIRs on the inclusion/non-inclusion/unknown state of condensable fraction in the emission factors for particulate matter in the estimation of PM_{10} and $PM_{2.5}$ emissions. Table 30 provides an overview on this topic for residential and commercial subsectors.

Table 30. Inclusion of condensable fraction in residential and commercial subsectors particulate emission factors as reported by MS

	included		Not included		Unknown	
	RES	COM	RES	COM	RES	COM
Austria	x (mixed fuel wood boilers)	x (mixed fuel wood boilers)				
Belgium	p (x for wood)	p (x for gas)				
Bulgaria					x	x
Croatia					x	x
Cyprus	x	x				
Czechia	x					x
Denmark	x (for wood)				x (other fuels)	
Estonia			x	x		
Finland					x	x
France			x	x		x (for wood)
Germany					x	x
Greece					x	x
Hungary	x					x
Ireland					x	x
Italy	x		x			
Latvia	x					x
Lithuania			x	x		
Luxembourg					x	x
Malta					x	x
Netherlands	x(for wood)			x		
Poland			x(for solid fuels	x(for solid fuels		
Portugal	x	x				
Romania	x					x
Slovakia	x			x		
Slovenia	x		x			
Spain	x (for biomass)	x (for biomass)			x (other fuels)	x (other fuels)
Sweden	x		x			

Source: EU27 MS IIRs 2023

Note: p - partial

Annex 2. Relative changes of main air pollutant emissions in EU27 MS 2005-2020

Table 31. Relative changes since 2005 of NOx emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	-0.2%	-7.9%	-5.1%	-11.9%	-10.2%	-13.5%	-16.7%	-17.7%	-22.4%	-23.8%	-21.8%	-24.7%	-30.2%	-29.6%	-30.8%
Belgium	-4.0%	-7.8%	-5.0%	-6.6%	-3.2%	-18.3%	-16.9%	-13.0%	-24.9%	-20.0%	-21.8%	-24.3%	-24.4%	-26.4%	-29.9%
Bulgaria	0.9%	-13.9%	-38.2%	-41.0%	-39.6%	-35.5%	-32.7%	-41.0%	-50.9%	-49.4%	-49.8%	-47.4%	-47.4%	-48.9%	-50.5%
Croatia	-5.6%	-12.1%	-11.6%	-15.0%	-16.3%	-20.8%	-27.8%	-31.8%	-38.3%	-35.7%	-37.6%	-39.6%	-42.6%	-45.8%	-46.0%
Cyprus	-0.4%	-4.9%	-7.0%	-7.9%	-13.6%	-14.3%	-16.3%	-26.5%	-33.3%	-25.7%	-25.1%	-24.2%	-28.6%	-22.7%	-26.7%
Czechia	-10.5%	-19.2%	-21.0%	-23.5%	-22.3%	-25.8%	-22.9%	-18.6%	-19.6%	-18.8%	-17.3%	-16.8%	-17.9%	-19.1%	-21.8%
Denmark	-0.3%	-2.8%	-7.1%	-10.6%	-9.7%	-16.4%	-25.0%	-24.4%	-30.7%	-28.2%	-29.4%	-33.4%	-37.0%	-40.0%	-42.8%
Estonia	-10.2%	3.9%	4.7%	4.3%	0.9%	-9.5%	-7.9%	-15.4%	-17.5%	-22.2%	-22.3%	-23.8%	-26.4%	-31.1%	-32.4%
Finland	-3.5%	-6.3%	-11.7%	-16.4%	-14.0%	-22.3%	-20.5%	-24.7%	-28.0%	-35.1%	-36.1%	-39.5%	-42.5%	-44.6%	-48.7%
France	-6.8%	-13.0%	-11.6%	-12.7%	-18.1%	-27.0%	-27.9%	-27.8%	-36.3%	-39.0%	-44.0%	-46.4%	-50.7%	-53.2%	-55.0%
Germany	5.5%	-7.5%	3.6%	-2.6%	2.4%	-7.3%	-5.6%	-1.1%	-11.3%	-8.2%	-8.6%	-8.6%	-13.7%	-11.9%	-11.5%
Greece	3.4%	-6.6%	-9.6%	-27.2%	-34.5%	-29.5%	-60.7%	-73.1%	-74.6%	-70.2%	-73.0%	-72.8%	-73.6%	-73.2%	-67.8%
Hungary	-3.6%	-16.1%	-16.6%	-16.3%	-8.5%	-10.2%	-20.3%	-12.8%	-20.9%	-17.0%	-16.3%	-18.5%	-22.9%	-26.9%	-26.4%
Ireland	-5.9%	-11.4%	-9.0%	-19.3%	-22.9%	-32.2%	-35.5%	-38.4%	-45.5%	-45.6%	-45.4%	-46.4%	-42.5%	-45.5%	-45.1%
Italy	-3.7%	-7.3%	-8.5%	-8.7%	-11.7%	-19.1%	-19.0%	-18.6%	-23.9%	-22.1%	-22.4%	-23.3%	-24.0%	-27.0%	-30.1%
Latvia	-0.7%	-5.7%	-19.1%	-15.2%	-15.2%	-17.9%	-20.1%	-24.1%	-25.7%	-31.2%	-33.4%	-30.9%	-33.0%	-36.9%	-39.6%
Lithuania	4.3%	2.8%	3.8%	1.1%	6.1%	8.5%	7.2%	0.1%	-5.6%	-14.2%	-11.4%	-11.5%	-11.4%	-17.4%	-22.6%
Luxembourg	-2.7%	-9.9%	-7.9%	-10.0%	-7.2%	-24.3%	-17.7%	-19.5%	-27.8%	-18.0%	-17.2%	-16.0%	-19.4%	-21.2%	-24.9%
Malta	0.0%	-42.3%	-40.6%	-21.1%	10.4%	-10.7%	44.1%	35.4%	33.9%	46.4%	47.0%	29.9%	23.0%	30.6%	31.0%
Netherlands	-5.2%	-9.1%	-5.2%	-9.2%	-9.7%	-23.0%	-26.9%	-26.0%	-33.7%	-32.4%	-36.5%	-44.3%	-44.1%	-47.1%	-50.5%
Poland	-10.3%	-18.7%	-18.2%	-18.6%	-13.0%	-19.8%	-20.0%	-23.9%	-30.5%	-32.5%	-29.7%	-28.3%	-26.8%	-34.1%	-34.8%
Portugal	-9.6%	-16.0%	-22.0%	-22.8%	-25.2%	-30.4%	-33.1%	-33.2%	-37.9%	-40.1%	-41.3%	-43.2%	-43.1%	-42.8%	-41.2%
Romania	8.8%	-7.0%	-8.3%	-0.5%	0.9%	-0.7%	5.0%	-4.8%	-9.2%	-9.5%	-9.7%	-4.6%	-1.7%	-3.3%	-4.4%
Slovakia	-6.0%	-9.7%	-8.0%	-11.4%	-3.2%	-5.4%	-2.8%	-5.4%	-6.8%	-3.2%	-2.5%	-1.9%	-9.4%	-8.8%	-7.7%
Slovenia	-7.9%	-16.3%	-7.0%	-16.4%	-18.0%	-24.4%	-30.4%	-31.6%	-39.8%	-37.9%	-36.9%	-42.1%	-46.4%	-49.1%	-51.2%
Spain	-2.4%	-6.0%	-14.2%	-13.5%	-13.7%	-18.1%	-22.0%	-27.8%	-29.4%	-34.8%	-40.2%	-41.7%	-39.9%	-45.4%	-47.1%
Sweden	-5.1%	-7.3%	-10.4%	-13.5%	-14.3%	-17.1%	-19.8%	-22.7%	-27.2%	-31.1%	-32.4%	-35.2%	-41.1%	-42.6%	-43.6%

Source: EMEP/CEIP 2023, JRC elaboration

Table 32. Relative changes since 2005 of NMVOC emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	1.7%	-1.1%	-1.1%	-4.3%	3.4%	-5.3%	-3.5%	-3.3%	-15.7%	-13.6%	-12.8%	-13.3%	-20.5%	-20.2%	-20.9%
Belgium	0.9%	-0.7%	10.0%	17.1%	22.9%	-1.8%	7.8%	15.8%	-8.7%	-0.3%	1.9%	-4.8%	-6.8%	-11.6%	-18.4%
Bulgaria	5.3%	-2.4%	-5.3%	-8.4%	-4.6%	1.3%	1.9%	-2.1%	-7.8%	-9.7%	-4.5%	-4.3%	-10.6%	-14.4%	-3.2%
Croatia	-9.2%	-13.9%	-14.8%	-13.2%	-8.7%	-12.7%	-14.7%	-16.8%	-27.6%	-18.9%	-22.5%	-26.1%	-30.3%	-33.1%	-33.2%
Cyprus	-3.9%	17.8%	11.7%	-3.4%	-12.1%	-14.9%	4.8%	-6.4%	-15.3%	5.3%	20.5%	16.7%	-5.5%	-6.5%	-11.6%
Czechia	3.2%	1.3%	3.1%	9.8%	14.8%	13.4%	16.6%	20.7%	16.0%	-8.8%	-9.4%	-8.3%	-9.6%	-7.5%	-12.0%
Denmark	3.2%	17.5%	11.1%	2.3%	2.1%	-9.2%	-15.1%	-17.5%	-25.2%	-20.1%	-21.0%	-27.8%	-35.6%	-43.1%	-47.3%
Estonia	-6.0%	10.6%	9.7%	12.0%	6.4%	-10.2%	-8.6%	-17.6%	-19.0%	-24.4%	-22.9%	-24.2%	-27.8%	-31.7%	-32.7%
Finland	-7.2%	-9.1%	-17.2%	-20.4%	-15.5%	-24.7%	-21.0%	-26.2%	-27.6%	-33.5%	-31.3%	-33.3%	-35.0%	-36.6%	-46.5%
France	-9.4%	-16.4%	-15.6%	-19.0%	-15.4%	-35.6%	-32.0%	-31.8%	-46.6%	-46.0%	-44.7%	-48.7%	-52.8%	-54.8%	-60.4%
Germany	8.1%	10.3%	15.7%	4.1%	16.8%	7.3%	1.1%	-0.7%	-17.2%	-9.7%	-14.7%	-14.3%	-14.1%	-15.0%	-17.6%
Greece	-1.5%	2.1%	-13.4%	-23.5%	-34.3%	-26.2%	25.5%	-21.8%	-31.3%	-28.5%	-38.6%	-33.2%	-42.1%	-42.1%	-43.4%
Hungary	3.4%	1.5%	-10.9%	21.0%	36.4%	57.1%	64.6%	67.4%	36.5%	44.0%	40.9%	34.5%	12.9%	5.6%	4.4%
Ireland	-3.5%	-8.0%	-3.0%	-0.3%	-6.2%	-15.0%	-15.1%	-10.2%	-19.6%	-17.6%	-16.4%	-28.4%	-23.1%	-30.8%	-28.4%
Italy	11.7%	48.3%	69.9%	63.2%	60.1%	8.9%	46.5%	47.6%	31.0%	38.4%	35.0%	44.9%	26.5%	24.8%	19.3%
Latvia	-3.4%	-6.0%	-10.0%	-1.0%	-25.3%	-22.9%	-22.4%	-31.5%	-36.4%	-49.0%	-49.0%	-42.4%	-40.7%	-43.0%	-49.4%
Lithuania	4.4%	0.2%	3.0%	3.2%	2.6%	0.6%	-0.3%	-4.0%	-11.1%	-17.1%	-17.8%	-19.2%	-18.2%	-23.1%	-27.2%
Luxembourg	-5.5%	-14.1%	-12.0%	-8.0%	-5.7%	-23.8%	-12.5%	-6.4%	-0.3%	-15.4%	-4.2%	-12.8%	-8.0%	-35.5%	-46.8%
Malta	0.0%	-49.8%	-11.1%	-23.1%	-5.3%	-14.8%	10.0%	13.6%	8.7%	13.5%	12.9%	9.9%	2.6%	8.5%	14.2%
Netherlands	3.5%	5.1%	14.8%	12.0%	22.3%	7.0%	4.4%	3.1%	-13.8%	-12.2%	-17.3%	-21.2%	-24.6%	-28.1%	-33.7%
Poland	5.7%	-1.9%	0.5%	0.7%	11.8%	3.7%	4.9%	1.7%	-8.0%	-9.1%	-5.5%	-9.3%	22.6%	5.4%	-1.0%
Portugal	-5.2%	-9.3%	-13.2%	-17.2%	-20.8%	-16.4%	-18.0%	-16.8%	-18.3%	-19.6%	-20.1%	-20.9%	-21.6%	-22.6%	-21.5%
Romania	-7.5%	-9.5%	9.0%	4.8%	8.6%	-2.0%	1.8%	-3.1%	-2.7%	-6.5%	-6.3%	-4.5%	-4.6%	-3.7%	-4.0%
Slovakia	-2.3%	1.3%	-9.6%	-16.4%	-3.4%	-9.0%	-0.4%	-6.4%	-42.5%	-22.0%	-15.3%	-16.8%	-34.5%	-30.9%	-31.1%
Slovenia	-9.2%	-1.1%	-3.5%	-8.0%	-6.4%	-8.3%	-11.1%	-9.7%	-21.5%	-14.8%	-15.6%	-20.4%	-27.6%	-31.1%	-34.2%
Spain	0.0%	-1.4%	-2.5%	11.8%	10.6%	9.0%	13.2%	9.2%	10.7%	8.1%	-17.8%	-17.0%	-16.2%	-16.1%	-18.9%
Sweden	-7.6%	-2.9%	-2.1%	-4.0%	-6.7%	-10.2%	-16.4%	-20.5%	-25.9%	-29.1%	-30.4%	-31.8%	-38.4%	-39.4%	-41.9%

Source: EMEP/CEIP 2023, JRC elaboration

Table 33. Relative changes since 2005 of SO_2 emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	-1.8%	-19.2%	-19.4%	-65.6%	-64.8%	-73.0%	-73.8%	-76.1%	-79.4%	-80.2%	-79.5%	-79.6%	-81.9%	-82.0%	-83.9%
Belgium	-7.6%	-21.1%	-48.9%	-51.0%	-54.8%	-64.3%	-65.4%	-63.4%	-68.6%	-68.0%	-91.0%	-91.5%	-92.4%	-93.2%	-94.0%
Bulgaria	18.4%	-15.6%	-15.0%	-40.3%	-24.3%	-6.2%	-9.7%	-28.1%	-47.4%	-42.6%	-39.1%	-36.5%	-50.1%	-58.5%	-60.3%
Croatia	-10.7%	-32.8%	-31.2%	-25.4%	-36.0%	-50.2%	-56.3%	-77.4%	-84.0%	-83.6%	-84.8%	-85.0%	-88.0%	-88.6%	-88.6%
Cyprus	0.0%	-11.6%	-52.6%	-53.9%	-60.5%	-57.2%	-58.2%	-64.8%	-70.4%	-64.7%	-62.5%	-62.5%	-64.8%	-61.1%	-63.4%
Czechia	2.8%	-9.6%	-12.5%	-5.7%	6.1%	7.9%	9.3%	17.4%	-7.7%	0.5%	0.7%	5.7%	-11.1%	-22.3%	-27.4%
Denmark	-0.4%	-3.5%	-18.9%	-41.6%	-32.9%	-37.6%	-43.4%	-40.3%	-49.8%	-53.3%	-54.4%	-57.6%	-59.7%	-63.5%	-66.0%
Estonia	-25.1%	-42.8%	-33.2%	-47.9%	-48.5%	-46.1%	-48.3%	-50.0%	-54.0%	-56.3%	-61.0%	-66.3%	-66.9%	-66.8%	-70.7%
Finland	-7.7%	-9.3%	-17.3%	-14.9%	-8.4%	-24.7%	-23.8%	-31.6%	-34.6%	-40.0%	-35.9%	-37.9%	-39.2%	-41.6%	-49.1%
France	-8.0%	-15.2%	-40.4%	-45.6%	-51.3%	-62.0%	-65.8%	-65.0%	-71.2%	-71.0%	-72.6%	-73.1%	-75.6%	-76.8%	-77.1%
Germany	7.8%	-21.9%	-1.1%	-30.3%	-28.5%	-42.8%	-63.3%	-70.1%	-72.9%	-69.5%	-74.9%	-75.4%	-76.4%	-80.4%	-81.1%
Greece	-15.2%	-35.8%	-47.9%	-65.1%	-76.5%	-73.6%	-73.9%	-86.4%	-86.5%	-83.7%	-84.9%	-84.9%	-87.0%	-85.9%	-85.1%
Hungary	6.9%	-34.2%	-15.5%	-31.3%	-24.1%	-15.7%	-15.2%	-19.6%	-34.7%	-36.1%	-34.3%	-31.1%	-54.0%	-64.3%	-71.6%
Ireland	-10.5%	-13.2%	-28.7%	-31.6%	-34.4%	-43.4%	-44.8%	-42.2%	-49.4%	-49.1%	-44.6%	-49.6%	-50.2%	-55.1%	-52.7%
Italy	-6.5%	-10.5%	-32.5%	-36.5%	-46.9%	-57.6%	-54.1%	-54.1%	-59.1%	-54.8%	-54.8%	-55.5%	-54.3%	-55.6%	-57.0%
Latvia	-6.8%	-16.7%	-33.3%	-29.9%	-38.0%	-39.2%	-40.9%	-45.2%	-46.2%	-51.1%	-53.7%	-51.0%	-50.6%	-54.6%	-59.8%
Lithuania	13.7%	4.5%	-5.6%	-0.8%	14.9%	44.7%	17.2%	26.8%	11.5%	-8.9%	2.5%	9.5%	14.6%	-6.3%	-26.5%
Luxembourg	-5.5%	-10.1%	-54.6%	-55.1%	-57.2%	-67.2%	-61.2%	-61.4%	-67.3%	-60.0%	-95.3%	-96.3%	-96.8%	-97.3%	-97.3%
Malta	0.0%	-0.9%	-0.7%	-26.0%	28.9%	-32.5%	21.1%	46.5%	62.8%	89.8%	79.1%	55.0%	19.7%	38.4%	44.8%
Netherlands	-2.5%	-17.0%	-40.9%	-47.3%	-56.0%	-75.4%	-78.6%	-76.3%	-73.9%	-81.3%	-83.1%	-83.5%	-84.1%	-83.1%	-84.8%
Poland	14.1%	2.8%	11.1%	13.2%	28.9%	13.1%	18.4%	13.6%	4.3%	1.8%	7.9%	6.8%	6.9%	-11.8%	-9.6%
Portugal	0.1%	-10.8%	-42.2%	-50.7%	-33.8%	-51.7%	-66.8%	-68.7%	-67.5%	-59.5%	-66.1%	-68.9%	-71.3%	-72.6%	-72.1%
Romania	7.1%	3.8%	66.4%	11.4%	3.9%	15.3%	17.5%	20.6%	93.5%	109.3%	75.8%	44.4%	50.0%	61.7%	68.3%
Slovakia	-4.2%	-21.3%	-31.4%	-34.9%	-31.2%	-36.9%	-35.1%	-39.7%	-51.0%	-43.1%	-44.9%	-40.2%	-51.5%	-53.2%	-53.1%
Slovenia	-8.4%	-31.2%	-52.2%	-54.6%	-54.9%	-61.5%	-67.1%	-69.2%	-76.2%	-75.0%	-74.6%	-77.6%	-79.1%	-79.9%	-79.0%
Spain	-8.5%	-13.0%	-27.7%	-26.5%	-28.2%	-33.5%	-48.3%	-49.8%	-52.9%	-54.9%	-56.3%	-48.6%	-46.2%	-55.5%	-56.7%
Sweden	-14.9%	-31.8%	-40.8%	-45.0%	-45.7%	-49.9%	-51.0%	-52.7%	-56.3%	-56.9%	-56.2%	-56.3%	-62.5%	-62.6%	-64.2%

Source: EMEP/CEIP 2023, JRC elaboration

Table 34. Relative changes since 2005 of $PM_{2.5}$ emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	0.5%	-2.8%	-1.9%	-4.9%	1.5%	-5.8%	-5.3%	-5.2%	-15.8%	-14.9%	-14.6%	-15.2%	-22.3%	-22.5%	-23.7%
Belgium	2.9%	-1.3%	7.5%	12.2%	20.2%	-12.6%	-2.1%	8.2%	-22.3%	-14.8%	-12.6%	-21.8%	-26.2%	-29.5%	-37.4%
Bulgaria	6.1%	-0.6%	2.4%	0.5%	6.8%	14.0%	15.1%	11.2%	5.5%	3.3%	9.5%	10.0%	3.0%	-1.2%	12.9%
Croatia	-9.9%	-15.0%	-16.4%	-14.7%	-10.4%	-14.5%	-16.6%	-19.1%	-30.3%	-22.1%	-26.2%	-30.3%	-34.7%	-37.6%	-37.6%
Cyprus	-5.7%	26.3%	18.6%	-5.1%	-18.1%	-19.6%	14.4%	0.4%	-11.6%	18.6%	45.5%	37.5%	4.6%	-0.8%	-8.0%
Czechia	2.6%	-2.1%	-2.6%	4.0%	14.5%	12.0%	15.4%	18.3%	9.9%	-26.4%	-28.7%	-27.7%	-32.0%	-35.1%	-40.5%
Denmark	3.2%	21.3%	14.0%	6.6%	8.1%	-4.1%	-9.8%	-11.5%	-19.3%	-11.4%	-11.4%	-19.7%	-29.5%	-38.2%	-42.9%
Estonia	-6.1%	7.8%	6.8%	5.5%	3.8%	-8.7%	-8.1%	-16.3%	-16.6%	-20.7%	-18.6%	-18.3%	-20.0%	-25.3%	-19.8%
Finland	-5.8%	-3.2%	-4.5%	-1.4%	6.0%	-8.7%	-1.7%	-7.5%	-7.2%	-15.6%	-9.4%	-11.6%	-13.4%	-15.4%	-28.8%
France	-9.3%	-15.6%	-13.1%	-15.0%	-9.3%	-29.2%	-22.7%	-19.7%	-36.5%	-34.8%	-32.1%	-36.5%	-40.8%	-42.1%	-48.5%
Germany	10.6%	8.9%	22.0%	9.5%	29.4%	13.5%	17.7%	18.6%	-5.9%	-3.7%	-11.0%	-12.1%	-15.2%	-17.6%	-23.1%
Greece	-1.3%	3.2%	-16.2%	-27.9%	-38.4%	-18.7%	-7.2%	-19.5%	-21.0%	-18.2%	-29.3%	-27.2%	-33.3%	-35.4%	-39.3%
Hungary	5.9%	8.0%	-7.6%	32.3%	50.2%	74.3%	86.2%	89.0%	52.3%	59.7%	55.3%	47.2%	21.4%	12.2%	10.7%
Ireland	-3.2%	-7.1%	-1.9%	1.1%	-4.6%	-13.2%	-12.7%	-7.0%	-16.2%	-13.7%	-11.8%	-24.5%	-18.6%	-26.7%	-23.6%
Italy	13.3%	49.2%	72.9%	66.1%	60.5%	5.8%	48.0%	47.2%	27.3%	36.9%	32.4%	43.9%	21.2%	19.2%	13.6%
Latvia	-4.2%	-7.3%	-10.2%	-1.4%	-27.0%	-24.9%	-24.4%	-34.3%	-39.0%	-51.7%	-52.0%	-45.4%	-43.3%	-46.1%	-52.4%
Lithuania	7.6%	2.9%	4.7%	5.6%	8.9%	8.9%	6.4%	4.3%	-4.8%	-14.1%	-12.7%	-12.1%	-11.4%	-20.0%	-28.0%
Luxembourg	-1.7%	-11.3%	-3.7%	6.2%	8.9%	-15.2%	4.1%	12.9%	22.9%	-2.7%	15.7%	-1.5%	6.9%	-39.3%	-54.4%
Malta	0.0%	-16.5%	-15.7%	3.4%	19.7%	16.3%	41.7%	43.2%	37.7%	36.2%	36.8%	29.0%	21.8%	26.5%	46.0%
Netherlands	-1.6%	-6.9%	-6.2%	-8.6%	-0.5%	-16.9%	-15.3%	-13.7%	-27.2%	-24.8%	-26.9%	-31.6%	-33.3%	-36.3%	-39.5%
Poland	8.2%	0.0%	3.6%	4.2%	16.6%	7.2%	9.1%	5.7%	-4.1%	-5.3%	-1.2%	-4.9%	23.8%	5.7%	0.4%
Portugal	-4.1%	-7.9%	-11.8%	-15.7%	-19.5%	-15.1%	-16.1%	-14.8%	-15.9%	-17.1%	-17.6%	-18.2%	-18.8%	-19.8%	-18.7%
Romania	-5.9%	-2.1%	24.9%	23.2%	27.8%	14.2%	19.2%	13.1%	14.0%	8.5%	9.0%	11.2%	10.2%	11.1%	11.7%
Slovakia	-1.4%	-0.3%	-10.7%	-18.1%	-6.5%	-12.5%	-4.9%	-11.5%	-45.4%	-26.7%	-23.5%	-21.4%	-38.3%	-35.3%	-36.1%
Slovenia	-11.0%	0.6%	-3.4%	-7.0%	-5.9%	-6.8%	-10.0%	-8.0%	-23.1%	-15.0%	-15.5%	-21.0%	-29.6%	-34.0%	-37.1%
Spain	-1.6%	-3.0%	-3.5%	11.8%	10.2%	8.4%	9.4%	7.7%	7.9%	4.8%	-24.6%	-24.9%	-27.0%	-30.7%	-33.4%
Sweden	-14.4%	-8.6%	-8.5%	-8.3%	-9.9%	-11.3%	-17.0%	-20.8%	-27.5%	-30.3%	-30.8%	-32.0%	-41.6%	-42.1%	-44.8%

Source: EMEP/CEIP 2023, JRC elaboration

Table 35. Relative changes since 2005 of PM_{10} emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	0.6%	-2.6%	-1.6%	-4.7%	1.9%	-5.5%	-4.9%	-4.6%	-15.3%	-14.3%	-14.0%	-14.4%	-21.5%	-21.7%	-22.8%
Belgium	2.9%	-1.6%	7.2%	11.7%	19.5%	-13.2%	-2.7%	7.5%	-22.8%	-15.3%	-13.1%	-22.1%	-26.6%	-29.9%	-37.8%
Bulgaria	6.1%	-0.6%	2.4%	0.5%	7.0%	14.2%	15.4%	11.4%	5.6%	3.4%	9.6%	10.1%	3.1%	-1.2%	12.9%
Croatia	-9.9%	-15.0%	-16.5%	-14.7%	-10.4%	-14.5%	-16.7%	-19.1%	-30.4%	-22.2%	-26.3%	-30.3%	-34.7%	-37.6%	-37.7%
Cyprus	-5.5%	25.4%	17.8%	-5.2%	-17.8%	-19.5%	13.5%	-0.3%	-12.1%	17.4%	43.5%	35.7%	3.6%	-1.5%	-8.5%
Czechia	2.4%	-2.4%	-2.8%	3.6%	14.1%	11.6%	14.9%	17.8%	9.6%	-26.5%	-28.9%	-27.9%	-32.2%	-35.3%	-40.6%
Denmark	3.2%	21.4%	14.0%	6.5%	8.1%	-4.1%	-9.9%	-11.6%	-19.4%	-11.4%	-11.4%	-19.8%	-29.6%	-38.4%	-43.1%
Estonia	-6.0%	7.8%	6.8%	5.4%	3.8%	-8.7%	-8.1%	-16.3%	-16.6%	-20.6%	-18.5%	-18.2%	-19.9%	-25.2%	-19.6%
Finland	-5.7%	-3.0%	-4.2%	-1.0%	6.8%	-8.3%	-1.2%	-7.2%	-7.0%	-15.4%	-9.1%	-11.2%	-12.9%	-14.8%	-28.6%
France	-9.3%	-15.6%	-13.0%	-14.9%	-9.3%	-29.2%	-22.7%	-19.7%	-36.5%	-34.8%	-32.2%	-36.6%	-40.8%	-42.1%	-48.5%
Germany	10.7%	8.9%	22.1%	9.6%	30.0%	14.0%	18.0%	19.1%	-5.6%	-3.3%	-10.6%	-11.8%	-14.8%	-17.3%	-22.8%
Greece	-1.3%	3.2%	-16.2%	-27.9%	-38.4%	-18.7%	-7.1%	-19.5%	-20.9%	-18.2%	-29.3%	-27.1%	-33.2%	-35.4%	-39.3%
Hungary	5.9%	7.8%	-7.7%	32.0%	50.0%	74.0%	85.9%	88.6%	52.0%	59.4%	55.0%	46.9%	21.2%	11.9%	10.4%
Ireland	-3.2%	-7.2%	-2.0%	0.7%	-4.9%	-13.5%	-13.0%	-7.3%	-16.4%	-13.9%	-12.0%	-24.6%	-18.7%	-26.8%	-23.8%
Italy	13.3%	49.3%	73.1%	66.3%	60.7%	5.9%	48.3%	47.5%	27.5%	37.2%	32.7%	44.1%	21.6%	19.6%	14.0%
Latvia	-4.2%	-7.3%	-10.3%	-1.5%	-27.0%	-25.0%	-24.4%	-34.4%	-39.1%	-51.8%	-52.1%	-45.5%	-43.4%	-46.2%	-52.5%
Lithuania	7.5%	2.8%	4.5%	5.4%	8.4%	8.3%	5.7%	3.5%	-5.4%	-14.6%	-13.3%	-12.7%	-12.1%	-20.6%	-28.4%
Luxembourg	-1.7%	-11.3%	-3.7%	6.2%	9.0%	-15.1%	4.2%	13.0%	23.1%	-2.7%	15.8%	-1.4%	6.9%	-39.3%	-54.5%
Malta	0.0%	-17.0%	-16.3%	2.5%	19.1%	15.2%	41.0%	41.8%	36.5%	34.7%	35.3%	27.7%	21.0%	25.6%	45.0%
Netherlands	-0.8%	-6.9%	-6.2%	-8.6%	-0.5%	-16.8%	-15.2%	-13.6%	-27.1%	-24.6%	-26.8%	-31.5%	-33.2%	-36.2%	-39.4%
Poland	8.7%	0.1%	4.0%	4.6%	17.1%	6.9%	9.1%	5.5%	-4.3%	-5.7%	-1.6%	-5.2%	19.8%	1.8%	-2.8%
Portugal	-4.1%	-7.9%	-11.8%	-15.7%	-19.5%	-15.1%	-16.1%	-14.8%	-15.9%	-17.1%	-17.6%	-18.2%	-18.9%	-19.9%	-18.7%
Romania	-5.9%	-2.1%	24.9%	23.2%	27.8%	14.2%	19.2%	13.1%	14.0%	8.5%	9.0%	11.2%	10.3%	11.1%	11.7%
Slovakia	-1.5%	-0.4%	-10.8%	-18.2%	-6.6%	-12.5%	-5.0%	-11.6%	-45.4%	-26.8%	-23.6%	-21.5%	-38.4%	-35.4%	-36.1%
Slovenia	-11.0%	0.5%	-3.4%	-7.0%	-5.9%	-6.8%	-10.1%	-8.0%	-23.1%	-15.1%	-15.5%	-21.1%	-29.7%	-34.0%	-37.1%
Spain	-1.9%	-3.3%	-3.9%	11.2%	9.6%	7.8%	8.7%	7.1%	7.1%	4.0%	-25.0%	-25.3%	-27.4%	-31.0%	-33.7%
Sweden	-14.4%	-8.6%	-8.5%	-8.3%	-9.9%	-11.3%	-17.0%	-20.8%	-27.5%	-30.2%	-30.8%	-31.9%	-41.6%	-42.1%	-44.8%

Source: EMEP/CEIP 2023, JRC elaboration

Table 36. Relative changes since 2005 of NH_3 emissions in each EU27 MS small-scale combustion sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	2.3%	-5.0%	-2.1%	-4.6%	2.3%	-5.7%	-4.7%	-1.4%	-13.0%	-7.8%	-6.0%	-3.9%	-11.8%	-10.3%	-9.9%
Belgium	6.2%	5.2%	19.7%	25.9%	46.5%	2.8%	21.4%	35.8%	-2.9%	13.0%	23.0%	13.2%	8.9%	6.8%	-3.9%
Bulgaria	6.2%	1.3%	6.7%	8.6%	14.1%	19.9%	24.7%	21.2%	16.4%	14.5%	20.3%	24.3%	22.0%	18.9%	34.2%
Croatia	-9.5%	-13.9%	-15.0%	-12.5%	-7.5%	-11.1%	-12.7%	-14.7%	-26.0%	-16.6%	-20.4%	-24.2%	-28.7%	-31.5%	-31.3%
Cyprus	-17.0%	85.7%	67.6%	6.7%	-24.7%	-30.4%	76.2%	47.3%	25.1%	99.8%	180.6%	152.1%	64.3%	37.6%	18.8%
Czechia	-2.0%	2.8%	21.1%	21.7%	26.6%	28.9%	34.9%	37.4%	37.5%	18.2%	21.9%	22.9%	26.2%	36.4%	33.2%
Denmark	5.5%	26.0%	20.6%	16.0%	20.5%	8.9%	4.5%	4.9%	-1.7%	10.8%	13.8%	5.4%	-4.6%	-14.8%	-20.3%
Estonia	10.3%	16.6%	18.8%	18.7%	20.9%	6.1%	-0.7%	-0.8%	-3.3%	-6.2%	-5.8%	-3.9%	-5.2%	-7.7%	-2.9%
Finland	-4.3%	0.1%	0.2%	5.7%	18.2%	1.4%	10.7%	4.5%	5.7%	0.1%	9.0%	6.9%	5.0%	3.3%	-8.9%
France	-9.6%	-15.3%	-12.3%	-13.2%	-5.9%	-26.7%	-18.3%	-13.9%	-31.7%	-29.0%	-25.6%	-30.4%	-34.7%	-35.3%	-41.8%
Germany	5.8%	-30.1%	-2.8%	-15.2%	-12.2%	-26.0%	-20.4%	-14.1%	-27.4%	-27.6%	-28.5%	-29.3%	-36.5%	-30.9%	-26.3%
Greece	-1.5%	4.7%	-16.3%	-27.0%	-36.3%	-14.1%	2.4%	-10.8%	-12.5%	-9.6%	-21.6%	-19.2%	-25.4%	-27.7%	-32.8%
Hungary	7.4%	15.1%	-4.3%	43.0%	63.2%	88.7%	105.4%	110.9%	71.2%	82.1%	77.2%	66.8%	38.6%	29.1%	28.3%
Ireland	-2.0%	2.5%	8.5%	17.4%	8.9%	4.0%	14.6%	26.6%	19.3%	8.3%	22.7%	4.6%	4.8%	-9.3%	-6.5%
Italy	16.9%	61.1%	90.6%	83.5%	78.5%	16.0%	73.5%	73.7%	50.4%	60.6%	55.5%	69.7%	33.6%	31.0%	24.2%
Latvia	-3.4%	-4.8%	-9.8%	-0.3%	-24.6%	-23.2%	-19.6%	-29.1%	-33.7%	-46.1%	-46.3%	-39.1%	-37.7%	-40.7%	-47.8%
Lithuania	5.7%	-0.2%	0.7%	3.8%	2.6%	2.6%	0.0%	-1.6%	-7.6%	-12.5%	-11.7%	-13.5%	-11.1%	-15.9%	-17.5%
Luxembourg	-0.8%	-10.7%	-1.7%	10.2%	13.2%	-12.8%	9.9%	21.0%	34.2%	8.4%	29.6%	8.6%	18.3%	-34.3%	-49.7%
Malta	0.0%	-0.4%	0.0%	1.2%	1.3%	2.2%	2.3%	2.6%	1.7%	-13.5%	-13.5%	-13.6%	-13.6%	-13.6%	24.7%
Netherlands	4.3%	4.3%	10.0%	10.2%	19.3%	4.5%	10.5%	14.0%	0.3%	5.8%	12.3%	19.1%	31.8%	40.3%	52.3%
Poland	4.0%	-1.2%	0.6%	1.8%	12.7%	10.7%	10.6%	9.2%	-1.0%	-0.1%	3.6%	0.0%	60.6%	42.2%	30.6%
Portugal	-3.8%	-7.6%	-11.3%	-15.1%	-18.8%	-11.0%	-13.2%	-12.0%	-12.5%	-14.4%	-15.1%	-15.5%	-16.3%	-17.2%	-16.6%
Romania	-5.9%	-1.9%	23.6%	22.2%	26.9%	12.5%	17.2%	11.5%	11.1%	6.3%	7.5%	9.8%	8.8%	9.5%	9.8%
Slovakia	-4.1%	6.3%	-6.4%	-12.8%	1.3%	-5.4%	3.8%	-3.8%	-46.6%	-21.1%	-11.2%	-14.7%	-33.2%	-27.2%	-26.3%
Slovenia	-12.5%	1.6%	-2.1%	-5.3%	-4.1%	-3.8%	-7.0%	-4.3%	-21.7%	-11.7%	-11.4%	-17.0%	-27.0%	-32.1%	-36.2%
Spain	0.2%	-0.5%	0.0%	19.2%	17.7%	16.7%	18.6%	17.5%	18.7%	17.1%	-16.0%	-16.6%	-17.6%	-18.3%	-18.6%
Sweden	-7.8%	-3.4%	-6.5%	-3.3%	-2.7%	-3.8%	-6.8%	-10.7%	-16.5%	-17.4%	-15.7%	-15.2%	-24.9%	-26.1%	-26.7%

Source: EMEP/CEIP 2023, JRC elaboration

Annex 3 GAINS model for fuel wood – technology split in residential subsector

Table 37. GAINS technology split for fuelwood in each EU27 MS residential subsector[27]

	2005					2010					2015					2020				
	FPLACE	SHB_A	SHB_M	STOVE_C	STOVE_H	FPLACE	SHB_A	SHB_M	STOVE_C	STOVE_H	FPLACE	SHB_A	SHB_M	STOVE_C	STOVE_H	FPLACE	SHB_A	SHB_M	STOVE_C	STOVE_H
Austria	1.2%	8.4%	61.5%		28.9%	1.2%	11.5%	60.1%		27.2%	1.2%	14.8%	59.0%		25.0%	1.3%	18.1%	57.9%		22.8%
Belgium	7.7%	3.8%	3.8%		84.7%	7.7%	3.9%	3.9%		84.6%	7.7%	3.9%	3.9%		84.6%	7.7%	3.9%	3.9%		84.6%
Bulgaria			2.2%		97.8%		1.1%	4.5%		94.3%	1.1%	1.1%	5.7%		92.1%	2.4%	2.4%	7.1%		88.2%
Croatia	5.9%		29.4%		64.7%	6.1%		27.3%		66.7%	6.1%	3.0%	24.3%		66.7%	6.2%	6.2%	21.9%		65.7%
Cyprus	8.7%	39.1%	17.4%		34.8%	8.3%	58.3%	8.3%		25.0%	8.3%	58.3%	8.3%		25.0%	8.7%	56.5%	8.7%		26.1%
Czechia	3.5%		36.0%		60.5%	3.5%		38.0%		58.5%	3.5%		40.0%		56.5%	3.5%	2.0%	40.0%		54.5%
Denmark	1.0%	22.0%	28.0%		49.0%	1.0%	27.0%	24.0%		48.0%	1.0%	27.0%	25.0%		47.0%	1.0%	28.0%	27.0%		44.0%
Estonia	6.0%		25.0%		69.0%	6.0%	0.5%	24.5%		69.0%	5.5%	1.0%	24.5%		69.0%	5.0%	2.0%	24.0%		69.0%
Finland	3.5%	5.0%	22.0%	26.0%	43.5%	3.2%	5.7%	22.2%	24.2%	44.7%	3.0%	6.0%	20.0%	21.0%	50.0%	2.8%	7.0%	20.0%	20.0%	50.2%
France	6.6%	0.0%	11.1%	0.0%	82.3%	6.6%	0.0%	11.1%	0.0%	82.3%	4.8%	0.0%	13.5%	0.0%	81.7%	3.1%	0.0%	18.4%	0.0%	78.5%
Germany	8.3%	41.7%	16.7%		33.3%	8.3%	58.3%	8.3%		25.0%	8.3%	58.3%	8.3%		25.0%	8.3%	58.3%	8.3%		25.0%
Greece	6.3%	6.3%	25.0%		62.5%	6.2%	12.5%	18.7%		62.5%	6.2%	18.8%	18.8%		56.2%	6.7%	20.0%	20.0%		53.3%
Hungary	2.5%	1.0%	46.5%		50.0%	3.0%	1.0%	46.0%		50.0%	3.5%	1.0%	45.5%		50.0%	3.5%	2.5%	40.0%		54.0%
Ireland	19.4%		4.5%		76.1%		1.1%	6.5%		92.5%		7.3%	3.6%		89.1%	7.0%	15.0%	1.9%		76.0%
Italy	65.0%				35.0%	67.0%				33.0%	67.0%				33.0%	67.0%				33.0%
Latvia	6.6%	2.0%	14.9%		76.5%	8.3%	3.3%	13.3%		75.0%	7.0%	7.0%	10.5%		75.4%	5.7%	11.5%	5.7%		77.0%
Lithuania	7.0%	2.0%	41.0%		50.0%	7.0%	3.0%	40.0%		50.0%	6.0%	4.0%	38.0%		52.0%	5.0%	6.0%	35.0%		54.0%
Luxembourg	6.2%	6.2%	24.6%		63.1%	5.9%	18.8%	18.8%		56.5%	5.9%	18.8%	18.8%		56.5%	6.7%	20.1%	20.1%		53.1%
Malta						0.0%	66.7%	0.0%		33.3%	0.0%	75.0%	0.0%		25.0%	11.1%	55.6%	11.1%		22.2%
Netherlands	80.0%				20.0%	80.0%				20.0%	80.0%				20.0%	80.0%				20.0%
Poland	5.0%	0.5%	9.5%		85.0%	5.0%	1.0%	8.0%		86.0%	4.4%	2.0%	9.4%		84.1%	4.2%	3.1%	9.1%		83.6%
Portugal	20.7%	13.8%	13.8%		51.7%	20.7%	13.8%	13.8%		51.7%	19.3%	19.7%	19.7%		41.3%	17.8%	25.6%	25.6%		31.1%
Romania			2.2%		97.8%		1.1%	4.5%		94.3%	1.1%	1.1%	5.7%		92.0%	2.4%	2.4%	7.1%		88.2%
Slovakia	4.0%	1.6%	69.1%		25.3%	4.0%	1.6%	69.1%		25.3%	4.0%	1.6%	69.1%		25.3%	4.0%	1.7%	68.8%		25.4%
Slovenia			80.0%		20.0%		1.0%	79.0%		20.0%		2.0%	78.0%		20.0%		3.0%	77.0%		20.0%
Spain	6.3%	6.3%	25.0%		62.5%	6.0%	6.5%	25.0%		62.5%	6.0%	7.0%	25.0%		62.0%	6.0%	7.5%	24.5%		62.0%
Sweden	7.0%	20.0%	59.0%		14.0%	6.0%	21.0%	59.0%		14.0%	6.0%	22.0%	58.0%		14.0%	5.0%	23.0%	58.0%		14.0%

([27]) The E27 MS GAINS IIASA model data elaborated by the JRC and presented in table 37 are those used for the 2nd Climate Outlook Study.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society