ISSN 1831-9424

European
Commission

Air pollution trends in the heating and cooling sector in the EU-27: A forward look to 2030

Perspectives based on the national energy and climate plans

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2024

Joint
Research
Centre

EUR 40034

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EU Science Hub

JRC138715

EUR 40034

Print	ISBN 978-92-68-20680-5	ISSN 1018-5593	doi:10.2760/0456379	KJ-01-24-030-EN-C
PDF	ISBN 978-92-68-20679-9	ISSN 1831-9424	doi:10.2760/2166850	KJ-01-24-030-EN-N

Luxembourg: Publications Office of the European Union, 2024

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How to cite this report: European Commission, Joint Research Centre, Banja, M., Carlsson, J., Roca Reina, J.C., Toleikyte, A., Monforti-Ferrario, F., Crippa, M. and Pisoni, E.*, Air pollution trends in the heating and cooling sector in the EU-27: A forward look to 2030*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/2166850, JRC138715.

Contents

Abstract

The heating and cooling sector is an important contributor to air pollution, with various factors influencing the trends observed in pollutant emissions. A comprehensive understanding of these factors is crucial for developing effective strategies to mitigate the environmental impact of the sector.

The transition from conventional to cleaner technologies in the heating and cooling sector in the EU-27 offers many compelling benefits, such as significantly reducing air pollution levels and energy demand. This transition can not only improve air quality and public health but also contribute to mitigating climate change and preserving ecosystems.

Decreasing heating and cooling demand is crucial in facilitating the transition to a low-carbon future. While reducing demand though energy efficiency initiatives is important, this alone is insufficient to achieve carbon neutrality. A comprehensive strategy for the decarbonisation of the heating and cooling sector is essential, involving the implementation of a low-carbon energy mix, heating and cooling technologies that are energy efficient and the use of clean energy carriers to reduce greenhouse gas emissions and air pollution.

In this context, we provide insights into trends in energy indicators and air pollutant emissions and technological shifts towards cleaner options. We also assess the availability of information for projecting the levels of air pollutant emissions in the heating and cooling sector by 2030. By examining the factors shaping these trends, we aim to underscore the importance of reducing air pollution emissions related to the sector.

Acknowledgements

This report was jointly produced by the Clean Air and Climate Unit (C5) and the Energy Transition Insights for Policy Unit (C7) of the Joint Research Centre (JRC) and developed as part of the JRC's agile self-allocation scheme.

The authors would like to thank their colleagues in the JRC's Emissions Database for Global Atmospheric Research group, Diego Guizzardi and Federico Pagani, for their contribution in providing the database's estimations of air pollutant emissions in the small-scale combustion sector.

The authors would also like to thank Antoine Ebeling (a JRC trainee), who contributed to the collection of the latest data on air pollutant emissions for the small-scale combustion sector of each EU Member State, which have been compiled into a comprehensive database including both technology shares and emission factors.

In addition, the authors wish to extend their thanks to their colleagues at the European Commission's Directorate-General for Environment, particularly Bettina Kretschmer and Jesús Alquézar Sabadie, for their valuable reviews, comments and suggestions.

The report has also benefited from the comments and suggestions of Victor Valverde Morales (from the JRC's Sustainable, Smart and Safe Mobility Unit (C4)).

The authors would like to thank the Language-editing service of the European Commission for their valuable detailed and complete proofreading of this report.

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Executive summary

Policy context

Air pollution is a significant environmental challenge in the EU. The EU's integrated approach to tackling air pollution includes regulatory measures, strategic initiatives and a strong focus on renewable energy and energy efficiency. It aligns with the European Green Deal and the zero pollution action plan, targeting emission reductions through increased energy efficiency and the adoption of renewable energy sources.

The 2016 EU heating and cooling strategy detailed energy use in buildings and industry, setting out actions to achieve climate neutrality by 2050 that were then included in the 2019 clean energy for all Europeans (1) package. To support the decarbonisation of the heating and cooling sector, the EU has implemented several directives, including the energy efficiency directive (Article 24, setting district heating and cooling targets), the energy performance of buildings directive, the emissions trading system directive, the eco-design directive and the revised renewable energy directive (Article 23, to strengthen heating and cooling targets). Furthermore, initiatives such as the renovation wave initiative and the repowerEU plan are designed to accelerate the transition towards renewable energy.

The national emission reduction commitments directive (NECD) sets legally binding national emission reduction commitments for key air pollutants in each EU Member State for 2020–2029, and more ambitious ones for 2030. These complement the broader goals of the Green Deal and the zero pollution action plan.

Key conclusions

The heating and cooling sector contributes significantly to air pollution, as a result of fuel-related, technological, regulatory and economic factors. Analysing this contribution requires a detailed understanding of the factors driving these pollution trends.

Analysis shows that since 2005 the reduction in air pollutant emissions related to heating activities has been moderate for nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$ and PM_{10}), non-methane volatile organic compounds (NMVOCs), ammonia (NH_3) and carbon monoxide (CO), whereas for sulphur dioxide (SO_2) the trend has been more pronounced. This indicates varying progress in emission reduction across pollutants.

The residential sector in the EU-27 remains predominantly reliant on conventional technologies, although there has been a gradual shift towards cleaner alternatives. Promoting the adoption of these cleaner alternatives can significantly reduce emissions in this sector, thereby improving public health and contributing to climate change mitigation efforts.

The Member States' 2023 national energy and climate plan (NECP) drafts show increased levels of ambition for renewable energy deployment in the heating and cooling sector compared with previously submitted plans, for example in the area of heat pump deployment. In addition, some Member States have projected lower use of biomass for heating, which is related to issues with air pollution.

To achieve the 2030 renewable energy goals outlined in the fit for 55 package, the heating and cooling sector in the EU-27 needs to significantly boost its adoption of renewable technologies. Accelerating

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(1) https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en.

the deployment of renewable energy technologies in this sector and continuing to implement stricter regulations on emissions from fossil-fuel-based systems are necessary.

Impact assessments of planned policies and measures, which form part of the Member States' NECPs, should include, where relevant, detailed projections of air pollutant emissions. However, the assessments often provide more detailed information on greenhouse gas emissions than air pollutants. More detailed historical and projected reports on air pollutant emissions by Member States can enhance the monitoring process and help identify specific sectors and fuels contributing to air pollution.

Main findings

The gross final energy consumption (GFEC) (2) in the EU-27 decreased by 9.5 % between 2005 and 2022, with a 16 % reduction in the heating and cooling sector. Targeted efforts reduced in 2022 the final energy consumption in the heating and industry sectors by 23.8 % and 27.1 %, respectively, compared with 1990.

Fossil fuels still make the greatest contribution to gross heat production, producing 60 % in 2022. This is despite renewable heat production more than doubling since 2005, increasing its share from 11.2 % to 35 %. Renewable heat production's contribution to GFEC has risen by nearly 68 % since 2005 and 37 % since 1990. Renewables' contribution to GFEC saw a notable increase, with the consumption of heat pumps increasing to over six times the 2005 level. The share of heat pumps' consumption in GFEC increased from 0.4 % in 2005 to 3.7 % in 2022, nearly a ninefold increase.

Sweden leads in terms of renewable energy shares, reaching 66 % overall and 69.4 % in the heating and cooling sector in 2022, while Ireland has the lowest shares, at 13.1 % overall and 6.3 % in the sector. The EU-27's renewable energy now accounts for 24.8 % of the GFEC, an increase of 8 pp since 2009.

The heating and cooling sectors (3) have a significant impact on air quality in the EU-27, contributing nearly 73 % of $PM_{2.5}$, 60 % of CO, 32.6 % of NO_x, 48.6 % of SO_2 and 18.2 % of NMVOC emissions in 2022. The residential subsector is a major source of particulate matter, NMVOCs, NH_3 and CO emissions.

A notable transition from coal-/oil-based fuels to solid biomass has occurred in the residential sector, while natural gas remains the primary fuel in heating plants. Biomass's role in district heating and the co-generation of heat increased in 2022, indicating a shift from oil- and coal-based fuels towards biomass.

NECPs (2019 and 2023 drafts) show increased renewable energy contributions but still fall short of revised renewable energy directive requirements in 12 Member States. Sweden projects a 73 % renewable energy share in the heating and cooling sector by 2030, with Denmark having the largest increase in ambition. However, many Member States' projected 2030 renewable energy shares remain below expected levels.

Heat pump energy consumption was projected to rise by nearly 22 % in the EU-27 between the 2019 NECPS and the 2023 NECP drafts. Biomass heating's projected contribution for 2030 has only slightly

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(2) GFEC and final energy consumption are two distinct energy indicators. GFEC is specifically used to measure progress towards renewable energy targets, while final energy consumption is used to measure progress towards energy efficiency targets.

(3) See note 23 in Section 4 on the activities that are included in the heating and cooling sectors.

increased, with decreases in Greece, Croatia, Hungary, Finland and Sweden due to air pollution concerns among other factors.

The baseline projections for the EU-27 published in the European Commission's second and third clean air outlook reports indicate reductions in NO_x emissions similar to the Commission's EU reference scenario 2020, while $PM_{2.5}$ emission reductions are more closely aligned with the MIX scenario. SO_2 reductions projected by Member States exceed the NECD target by 3.3 pp, yet still fall short of the ambitions set out in the second and third clean air outlook reports.

Projections from Member States for 2030 indicate reductions of 23 %, 4 % and 37 % below 2022 levels for NO_x, SO_2 and $PM_{2.5}$, respectively. The fit for 55 scenarios forecast greater reductions, highlighting the need for more ambitious and detailed sectoral emission projections from Member States.

The small combustion sector is expected to remain a major source of $PM_{2.5}$ emissions, while its relative contribution to NO_x emissions is projected to rise due to the decrease in the transport sector.

Related and future work by the Joint Research Centre

The analysis presented in this report complements the Joint Research Centre report on the small-scale combustion sector in the EU-27 (4) and the centre's efforts to improve the estimation of air pollutant emissions using the Emissions Database for Global Atmospheric Research. By integrating detailed information broken down by subsector, fuel and technology, this study highlights the impact of transitioning from conventional to advanced technologies and of the shift towards renewable technologies. The report serves as a valuable input into ongoing work to understand how the heating and cooling sector contributes to air pollution levels and the technological shift that is taking place.

Quick guide

This report aims to provide a comprehensive analysis of the current air pollutant levels in heating and cooling sector emissions in the EU-27, with a specific focus on the residential subsector. Starting with an exploration of both existing and emerging technologies in this area in *Chapter 2*, the report describes their operational principles and assesses their contributions to air pollution.

Furthermore, in this report we aim to identify and recommend cleaner technologies that can replace current practices, thereby promoting a more sustainable and environmentally conscious approach in the heating and cooling sector.

In *Chapter 3*, the report provides an overview of energy indicators in the heating and cooling sector. *Chapter 4* analyses trends in air pollutants, with a specific focus on 2005–2022. *Chapter 5* provides an overview of the technological landscape in the residential sector, detailing the distribution of technologies across Member State, categorised by fuel type.

An investigation of the key factors influencing the current trajectory of air pollutant trends in this sector is conducted in *Chapter 6*, offering valuable insights into the primary drivers of environmental impact from 1990 to 2022.

Furthermore, this report provides valuable insights into air pollutant emissions projections using data from Member States reported under the governance regulation of the clean energy for all Europeans package and the NECD. In addition, the analysis incorporates inputs from the European Commission's

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(4) Banja, M. and Ebeling, A., *Improving the estimation of air pollutant emissions from small-scale combustion sector*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/232693, JRC134941.

current modelling framework designed to deliver the Green Deal. By extending the scope of our analysis to 2030, *Chapter 7* aims to present the expected trajectory of air pollution trends in the heating and cooling sector.

1. Introduction

Air pollution remains a pressing environmental challenge in the EU. The heating and cooling sector, integral to the daily lives of citizens and industries and contributing to half of the gross final energy consumption (GFEC) in the EU-27, is a notable contributor to air pollutant emissions. As we confront the imperative of addressing climate change and improving air quality, understanding the current trends in air pollution from this sector becomes essential.

As part of the zero pollution action plan (5), the EU has pledged to decrease the prevalence of premature deaths resulting from air pollution by at least 55 % by 2030, compared with 2005 levels. Advancements in technology and the use of cleaner energy sources, as encouraged by environmental policies such as the European Green Deal, can significantly reduce the impact of heating and cooling systems on air quality.

The European Green Deal (6) presents the EU's framework for achieving sustainable and low-carbon solutions, and in particular targets the reduction of air pollutant emissions from buildings through various initiatives and strategies. The building sector is a significant contributor to air pollution, particularly in urban areas, where energy use in residential and commercial buildings is a major source of pollutants. The European Green Deal set a benchmark of 49 % for renewable energy use in buildings (7), and an increase in the renewable energy share by 1.1 percentage points (pp) and 2.2 pp, respectively, in the heating and cooling sector and the district heating subsector.

In the buildings sector, measures such as the thermal renovation of building envelopes (to reduce heating load), the replacement of fossil fuels (solid fossil fuels and oil) and measures to improve energy efficiency have a significant impact on nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOCs), 10 µm particulate matter (PM_{10}), 2.5 µm particulate matter ($PM_{2.5}$), carbon monoxide (CO), ammonia (NH_3) and other pollutant emissions. While replacing natural gas with cleaner alternatives is still important for reducing greenhouse gas (GHG) emissions, it has limited potential to reduce air pollutants; moreover, substituting natural gas with solid biomass could increase air pollution.

The decarbonisation of the heating and cooling sector in the EU-27 is supported by the energy efficiency directive, revised in 2023 (European Parliament and Council of the European Union, 2023a) (Article 3 on the overall energy efficiency target and Article 7 on energy savings obligations); the energy performance of buildings directive (European Parliament and Council of the European Union, 2010); the emissions trading system directive (European Parliament and Council of the European Union, 2023b) (8) (proposing a new emissions trading system in which buildings will be included together with transport sector); the eco-design directive (European Parliament and Council of the European Union, 2009) (on the efficiency of heating appliances and proposing the phaseout of fossil fuel heating); and the revised renewable energy directive (European Parliament and Council of the European Union, 2023c) (Article 23 on the renewables target in the heating and cooling sector) (Braungardt et al., 2023). The revised renewable energy directive elevates the EU's mandatory renewable target for 2030 to 42.5 %, with the ambition of achieving 45 %.

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(5) https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en.

(6) https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

(7) https://commission.europa.eu/publications/delivering-european-green-deal_en.

(8) https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en.

The renovation wave initiative aims to improve the energy efficiency of buildings across Europe. Decarbonising (9) heating and cooling is one of its areas of focus. By promoting building renovations and upgrades, in parallel with increasing the renewable energy share in the buildings sector, the initiative seeks to decrease reliance on fossil fuels for heating, thereby reducing the emission of pollutants such as NO_x and particulate matter.

The EU is actively promoting the adoption of 'clean' technologies, particularly renewables (e.g. heat pumps), as substitutes for 'dirty' technologies, in the buildings sector to enhance environmental sustainability. To achieve this goal and decarbonise the heating and cooling sector, the Commission started in 2023 its work on preparing the heat pump action plan (10). By promoting the use of heat pumps, solar thermal systems and district heating from renewable sources, the initiative seeks to replace traditional, pollutant-emitting heating systems.

The EU had introduced the repowerEU (11) plan by mid 2022, to rapidly reduce dependence on Russian fossil fuels by 2027. The plan also addresses the diversity of the energy supply, and for the heating and cooling sector the goal is to install 30 million hydronic heat pumps by 2030. This transition to non-combustible renewable energy sources contributes directly to improving air quality in and around buildings.

Both eco-design regulations and energy labelling requirements ensure that appliances meet specified efficiency and emission criteria. Concurrently, energy labels provide consumers with essential information regarding the energy efficiency and environmental performance of these appliances. Eco-design regulations, under Directive 2009/125/EC, establish emission limits for solid-fuel local space heaters (Regulation (EU) 2015/1185) and solid-fuel boilers (Regulation (EU) 2015/1189). These regulations are complemented by energy labelling provisions in the energy labelling regulation (Regulation (EU) 2017/1369) (repealing Directive (EU) 2010/30) (European Parliament and Council of the European Union, 2017), covering local space heaters (Regulation (EU) 2015/1186) and solid fuel boilers (Regulation (EU) 2015/1187). In addition, the new F-gas regulation (Regulation (EU) 2024/573) (European Parliament and Council of the European Union, 2024) aims to reduce the emission of fluorinated gases commonly used in refrigeration and air conditioning, indirectly contributing to the overall effort to mitigate the sector's impact on air quality.

Transitioning to cleaner, more efficient practices necessitates a forward-looking approach. The analysis presented in this report incorporates perspectives derived from the national energy and climate plans (NECPs) of individual EU Member States (12). Projections of the development of the energy system and GHG emission and removal, and, where relevant, the projected change in air pollutant emissions, in accordance with Directive (EU) 2016/2284, the national emission reduction commitments directive (NECD) (European Parliament and Council of the European Union, 2016), must be included in Section 5.1.1 of Member States' NECPs.

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(9) https://energy.ec.europa.eu/topics/energy-efficiency/heating-and-cooling_en.

(10) https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

(11) https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en.

(12) https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en.

2. Overview of current and emerging technologies in the heating and cooling sector

Heating and cooling technologies encompass a diverse range of systems, with some being cleaner and more environmentally friendly and others having a higher environmental impact. This chapter describes technologies/systems used in the heating and cooling sector, categorised based on the typology of the fuel/source used to produce heat and cold. All fuel types can be employed for both individual and centralised heating systems.

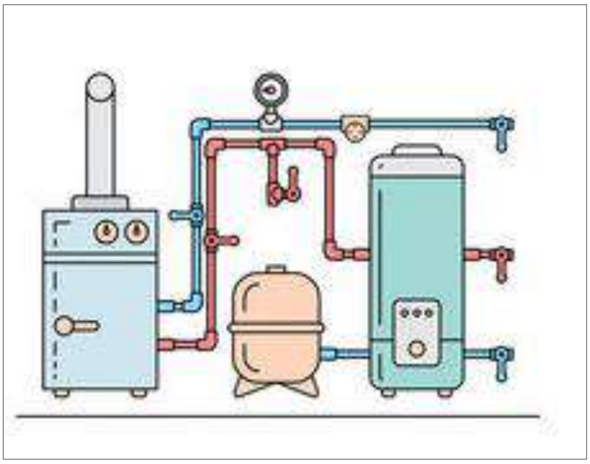
2.1. Fossil fuel combustion systems

Coal

Coal combustion emits both GHG and air pollutants. In terms of GHG, coal is a major contributor. Its combustion primarily releases carbon dioxide (CO_2), with minimal release of methane. In terms of air pollutants, coal combustion releases a variety of harmful substances, including SO_2, NO_x, particulate matter, mercury and other heavy metals. The number of substances released from coal burning and the level of emissions depends on various factors, such as the combustion efficiency of the coal, the coal type, the technology used in power plants and the presence of pollution control measures.

A coal-fired heating system (Figure 1) is a type of heating system that uses coal as its primary fuel source to generate heat for various applications, including space heating and water heating. Coal-fired heating systems typically have a boiler or furnace in which coal combustion occurs. Older technology is associated with higher levels of air pollutants and carbon emissions. Natural gas can serve as an effective substitute for coal in these systems, and various environmentally friendly technologies, such as heat pumps, solar thermal systems and district heating, offer a wide range of alternatives.

Figure 1. Schematic view of a coal-fired heating system showing the operational principle



Source: stock.adobe.com.

Heating oil

The use of heating oil releases mainly CO_2, SO_2, NO_x, particulate matter and, in lower quantities, volatile organic compounds, heavy metals and CO. The release of substances when using oil for heating purposes depends on factors such as the type and efficiency of the heating equipment, the composition of the heating oil, combustion conditions, pollution control technologies and operating conditions.

Oil-fired boilers are heating systems that burn oil as a fuel source to produce heat. These boilers are commonly used in residential, commercial and industrial settings for space heating and hot water production. The oil-fired combustion of heating oil mainly releases particulate matter, NO_x and SO_2. Oil-fired boilers can be categorised into two main types:

- **conventional oil-fired boilers** that burn heating oil in a combustion chamber, transferring the resulting heat to water or steam;
- **condensing oil-fired boilers** that are more energy efficient than conventional models because they recover heat from combustion gases that would otherwise be wasted.

Oil-fired furnaces are heating systems that burn oil in a combustion chamber to generate heat, which is then circulated through ductwork to distribute warm air throughout a building. Oil-fired furnaces are commonly used for forced-air heating in residential and commercial buildings.

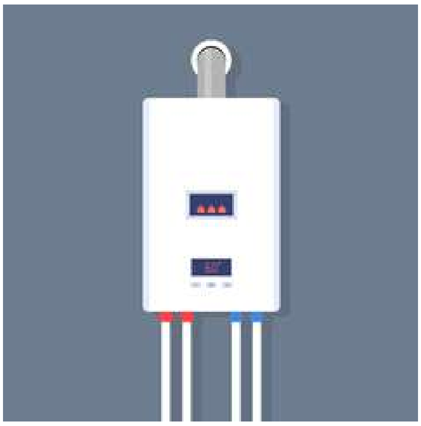
Oil-fired water heaters heat water using a burner system fuelled by heating oil. The heated water is stored in a tank for domestic use, such as bathing, washing dishes or laundry. Oil-fired water heaters are used in homes and buildings that do not have access to natural gas or electric water-heating options.

Natural gas

The combustion of natural gas or propane in a gas furnace produces CO_2, water (H_2O) vapour and small amounts of other pollutants, such as NO_x and CO. While natural gas is generally considered cleaner-burning than other fossil fuels, such as coal or oil, its combustion still contributes to air pollution and GHG emissions, albeit to a lesser extent.

Natural gas boilers (Figure 2) rely on the combustion of natural gas to generate heat for various applications, such as space heating, water heating and industrial processes.

Figure 2. Schematic view of a gas boiler installed in a residential building with no centralised system



Source: stock.adobe.com.

Natural gas boilers can be categorised into two main types.

- **Condensing gas boilers** are equipped with a secondary heat exchanger to recover heat from combustion gases, achieving higher efficiency by condensing water vapour in the flue gases.

Condensing boilers offer higher energy efficiency and results in less fuel consumption than non-condensing boilers, resulting in lower GHG emissions per unit of heat produced.

- **Non-condensing gas boilers** do not incorporate this secondary heat exchanger and operate at lower levels of efficiency.

Standard natural gas furnaces are designed to heat air directly, circulated through ductwork to deliver warm air to various rooms or areas within a building. These furnaces burn natural gas to produce heat and are commonly used for space heating in residential, commercial and industrial buildings.

High-efficiency gas furnaces are heating systems designed to maximise energy efficiency and minimise energy waste during combustion. These furnaces utilise advanced technologies and features to achieve higher levels of efficiency than standard gas furnaces, reducing energy consumption.

2.2. Renewable energy systems

Biomass

Biomass combustion releases CO_2 into the atmosphere, but this CO_2 is considered part of the biogenic carbon cycle, since the carbon it contains was recently absorbed from the atmosphere by plants during photosynthesis. However, biomass combustion is not always carbon neutral overall, due to factors such as land use changes and the time required for plants to reabsorb CO_2. Biomass combustion can also produce CH_4 and N_2O emissions, depending on combustion conditions and feedstock characteristics. In relation to air pollutants, biomass combustion releases mainly particulate matter, CO, NO_x, NMVOCs and SO_2. The levels of these pollutants can vary depending on the type of biomass and the combustion technology used.

Biomass heating systems are renewable energy systems that utilise biomass to generate heat for space heating, water heating or industrial processes. Biomass is derived from living or recently living organisms, including plant materials such as wood, agricultural crops and residues. These systems can replace coal or wood-burning stoves with cleaner combustion systems. The most common types of biomass heating systems include the following.

- **Biomass boilers** burn biomass directly to produce steam or hot water, which can be used for space heating or to generate electricity. Biomass boilers can be used with existing heating systems or as stand-alone units.

- **Biomass stoves** are designed for residential or small-scale applications, and burn biomass fuels to provide space heating. Pellet stoves, for example, use compressed wood pellets as a fuel source. There are two primary types of biomass stoves: conventional stoves and advanced stoves. These encompass a wide variety of designs, styles and features, and include iron heat stoves, masonry heat stoves and sauna stoves.

- **Biomass combined heat and power systems** are often used for district heating systems. This integrated approach can enhance overall energy efficiency since the combined production is more efficient than the stand-alone production of electricity and heat.

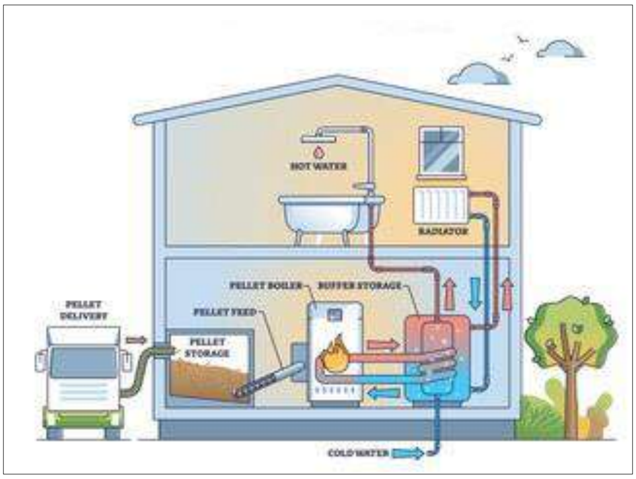
- **Biomass furnaces** are heating systems that use biomass materials as a fuel to generate heat. These furnaces are designed for space heating or water heating in residential, commercial and industrial settings.

Biogas systems for heating and cooling purposes utilise biogas, produced through the anaerobic digestion of organic materials such as animal manure, food waste, agricultural residues or sewage sludge. These systems capture the biogas generated from organic waste decomposition and utilise it as a fuel for heating and cooling applications. Biogas systems help divert organic waste from landfills, reducing methane emissions and mitigating environmental pollution.

Biogas boilers (Figure 3) operate similarly to natural gas or propane boilers, with adjustments made to accommodate the lower energy content and varying biogas composition.

Biogas combined heat and power systems generate both electricity and heat from biogas combustion. These systems use reciprocating engines, microturbines or fuel cells to convert biogas into electricity while capturing waste heat for space heating, water heating or absorption cooling.

Figure 3. Schematic view of a biomass boiler showing the operational principle within a building



Source: stock.adobe.com.

Heat pumps

Heat pumps have a lower environmental impact than traditional heating systems. Heat pumps typically operate more efficiently than combustion-based systems, resulting in lower overall CO_2 emissions. Heat pumps do not directly emit other GHGs such as CH_4 or N_2O, which can be associated with combustion processes. Since they do not involve combustion, heat pumps also do not directly emit air pollutants such as SO_2, NO_x, particulate matter, or volatile organic compounds. However, there can be indirect ([13]) emissions.

Heat pumps are energy-efficient heating and cooling systems that transfer heat between outdoor and indoor air to provide space heating, space cooling and hot water for residential and commercial buildings. The heat pump delivers heat to the outside air when it is in cooling mode, thereby cooling down the indoor space.

Geothermal heat pumps, also known as ground source heat pumps (Figure 4), are energy-efficient heating and cooling systems that utilise the relatively constant temperature of the Earth below the

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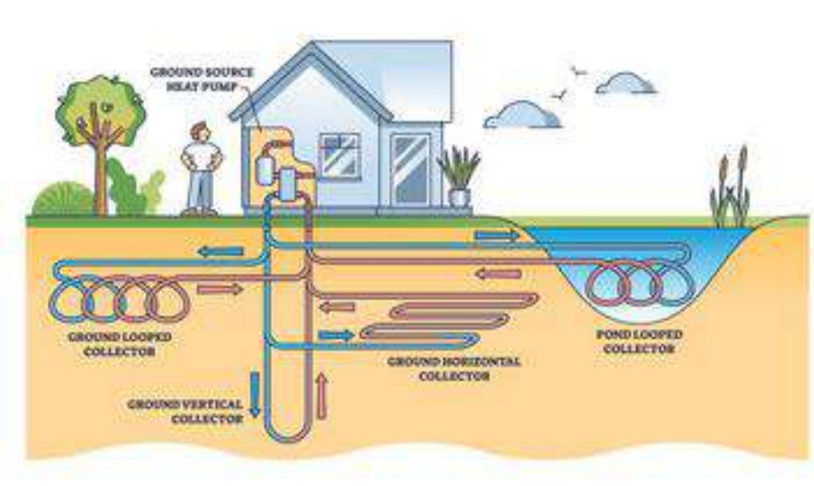
([13]) Heat pumps indirectly impact air pollution (and GHG emissions) through their energy source, since the electricity they use can come from fossil fuels. When powered by renewable energy sources such as solar or wind power, their impact is much lower than that of fossil-fuel-based systems.

surface. There are several types of geothermal heat pumps, each designed for specific applications and geological conditions. The main types include (i) closed-loop systems, (ii) open-loop systems, (iii) hybrid systems and (iv) direct exchange systems. Closed-loop systems are more common due to their flexibility and efficiency, while open-loop systems can be suitable in certain hydrogeological conditions. This technology has minimal impact on air quality through direct emissions. However, environmental impacts may arise during the manufacturing and installation phases. This technology could replace conventional gas or oil furnaces.

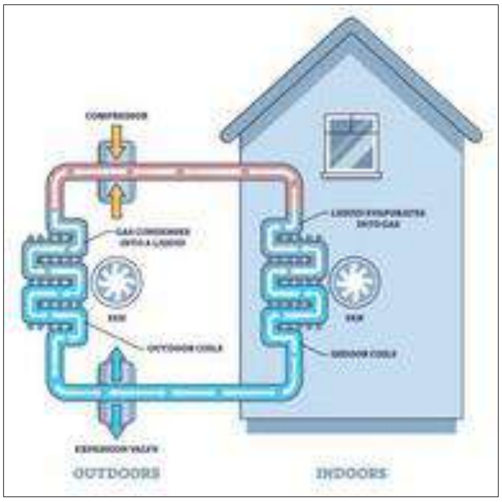
Figure 4. Schematic view of a ground source heat pump showing the operational principle within a building



Source: stock.adobe.com.

Air source heat pumps (Figure 5) are energy-efficient heating and cooling systems that work by extracting heat from the outside air (when they are in heating mode), even in cold weather, and delivering it to an indoor space. These systems could replace traditional heating systems using fossil fuels, assuring that the heating system can accommodate the lower temperatures produced by this type of heat pump. However, when using high-temperature heat pumps, this concern is minimised, as they can deliver heat at levels comparable, for example, to condensing boilers.

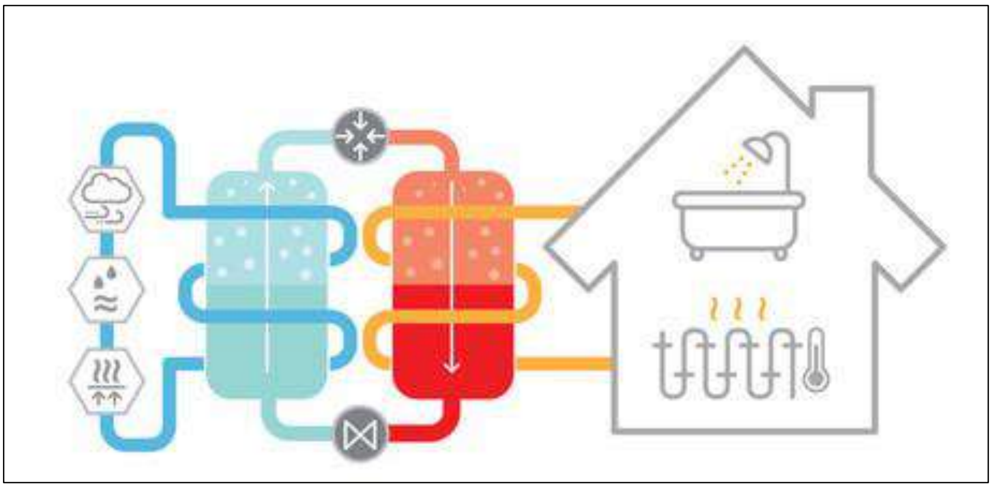
Figure 5. Schematic view of an air source heat pump showing the operational principle



Source: stock.adobe.com.

A **water source heat pump** (Figure 6) is a type of heat pump system that utilises water as a heat source or heat sink to provide heating and cooling systems and hot water for buildings. These pumps extract heat from a water source, such as a lake, river, pond or well, during the heating season and reject heat to the water source during the cooling season.

Figure 6. Schematic view of three types of heat pump, including a water source

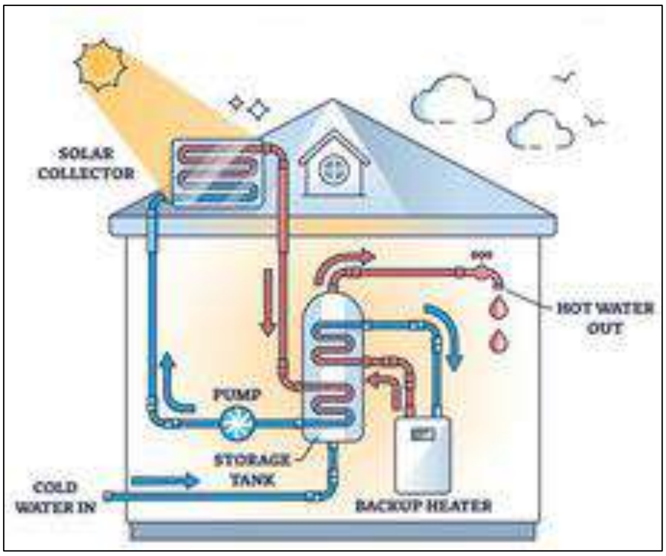


Source: stock.adobe.com.

Open-loop systems extract water directly from a natural water source, circulate it through the heat pump and then discharge it back into the source. Closed-loop systems circulate a water-based fluid (often a mixture of water and antifreeze) through a closed-loop piping system submerged in the water source.

Solar thermal heating systems (Figure 7) use the energy from the sun to generate heat for various applications, such as water heating and space heating. These systems use solar collectors to absorb sunlight and convert it into usable thermal energy.

Figure 7. Schematic view of a solar thermal heating system used to heat water showing the operational principle within a building



Source: stock.adobe.com.

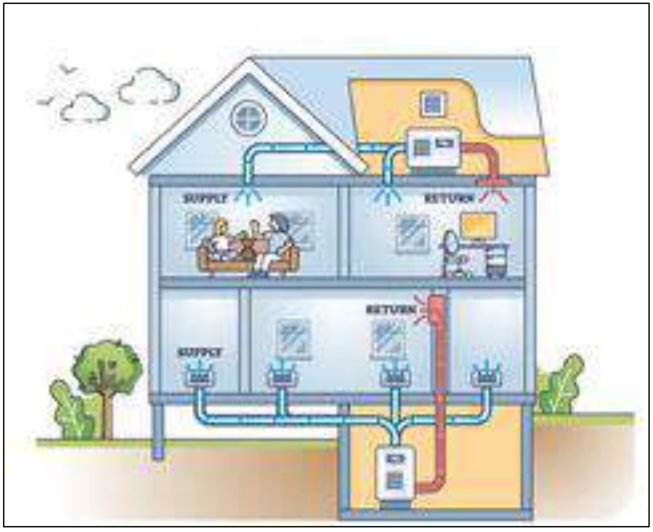
There are two main types of solar thermal heating systems: passive and active (or solar collector). Active solar thermal systems, particularly flat-plate collectors and evacuated tube collectors are commonly used for water and space heating in residential, commercial and industrial settings. These passive and active systems encompass low-temperature solar systems, utilising water below 60 °C. They are commonly employed for domestic hot water and space heating purposes.

2.3. Electricity-based systems

Electricity-based systems ([14]) in the heating and cooling sector utilise electricity as their primary energy source for heating, cooling and ventilation services. These systems leverage electrical energy to transfer heat, cool spaces or circulate air, offering efficient and versatile solutions for residential, commercial and industrial applications.

An **air conditioning system** (Figure 8) is a type of heat pump designed to control and maintain the temperature, humidity and air quality within a specific enclosed space, such as a building, vehicle or industrial facility. The primary goal of air conditioning is to create a comfortable indoor environment by removing heat from the air. Older models of air conditioning units may use refrigerants with high global warming potential and contribute to ozone depletion. They have an indirect impact on emissions through energy consumption and the potential for refrigerant leaks. Older models can be substituted with modern air conditioning systems, using high-efficiency and eco-friendly refrigerants.

Figure 8. Schematic view of a central air conditioning system showing the operational principle (with duct installation) within a building



Source: stock.adobe.com.

Heat recovery ventilation (HRV) systems (Figure 9) are energy efficient and designed to provide controlled air exchange in buildings while reducing heat loss. HRV systems are used in residential, commercial and industrial buildings to enhance indoor air quality and energy efficiency. The benefits of HRV systems include energy savings, reduced heating and cooling costs, improved indoor air quality

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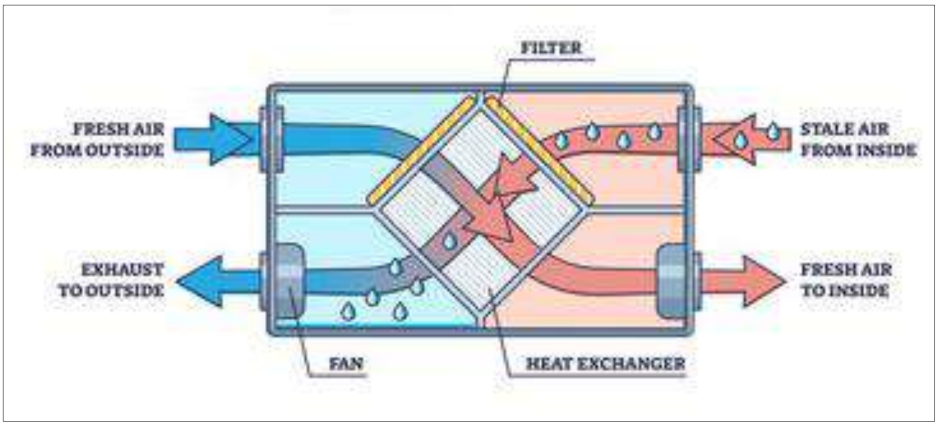
([14]) Heat pumps use the electricity as a carrier to transfer heat from one location to another. However, they are considered renewable energy systems (see Section 2.2) when the electricity powering them comes from renewable sources (air, ground or water). For information about the impact of these systems in terms of GHG emissions and air pollutants, see footnote 17.

and enhanced comfort. They are particularly beneficial in well-insulated and airtight buildings with limited natural ventilation. They can be integrated into various systems to reduce the demand for heating.

Figure 9. Schematic view of a heat recovery ventilation system showing the operational principle



Source: stock.adobe.com.

Electric boilers (Figure 10) generate hot water or steam for heating purposes using electricity. These boilers typically contain heating elements submerged in water, such as electric water heaters, that heat the water directly. Electric boilers are commonly used in residential, commercial and industrial settings where natural gas or other fuel sources are not available or practical. Electric boilers can be highly efficient at converting electrical energy into heat energy, especially when used with thermal energy storage systems or in demand–response strategies. However, their overall efficiency may be lower than other heating technologies (e.g. heat pumps) if the electricity used for heating is generated from fossil fuels, with associated losses in generation, transmission and distribution.

Figure 10. Schematic view of an electric boiler

Source: stock.adobe.com.

Electric furnaces heat air using electric resistance coils and then distribute it through ductwork for space heating. They are often used with central air conditioning systems for combined heating and cooling.

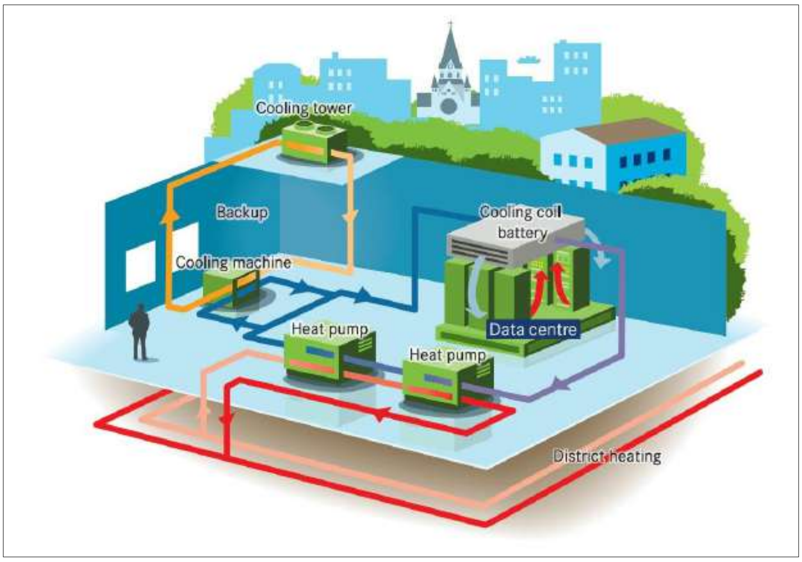
Electric radiant heating systems use electric cables or heating elements installed beneath floors, walls or ceilings to provide radiant heat directly to the occupants and objects in a room. They offer comfortable and efficient heating without the need for air circulation.

Electric thermal storage systems store off-peak electricity as heat in ceramic bricks or other materials during times of low demand. The stored heat can then be released when needed to provide space heating or hot water, offering flexibility and energy savings.

2.4. District heating and cooling systems

District heating and cooling systems (Figure 11) are centralised systems that distribute heat or cool air to multiple buildings, often utilising several heat sources per network. These systems offer efficient and cost-effective solutions for meeting the heating and cooling needs of residential, commercial and industrial buildings, particularly in urban or densely populated areas. District heating and cooling systems rely on a centralised energy generation facility to produce hot water, steam or chilled water. The energy generation facility may utilise various energy sources, including natural gas, biomass, waste heat recovery, geothermal energy or renewable sources such as solar or wind power.

Figure 11. Schematic view of a district heating system in an urban area



Source: IEA, 2020.

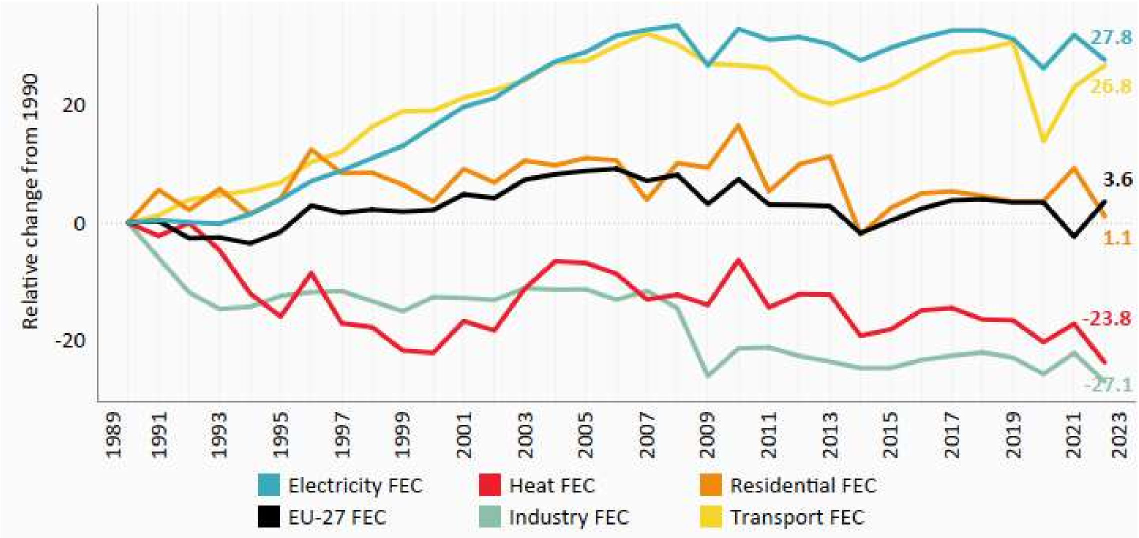
Once the thermal energy is generated, it is distributed through a network of insulated pipes or ducts to individual buildings or properties connected to the district heating system. The distribution network may consist of underground pipes for hot water or steam in district heating systems and above-ground or underground pipes for chilled water in district cooling systems. District heating and cooling systems typically include metering and billing systems to measure the thermal energy consumed by each building or property. Buildings connected to district heating and cooling systems can integrate the thermal energy supplied by the district system with their internal heating, cooling and hot water systems. This integration may involve using heat exchangers, heat pumps or other equipment to optimise energy efficiency and indoor comfort.

The impact of district heating on air pollution can vary depending on several factors, including the energy sources used for heat generation, the efficiency of the district heating system, and the emission control measures implemented. If the district heating system relies on fossil fuels such as coal, oil or natural gas, it can contribute to air pollution by emitting pollutants such as SO_2, NO_x and particulate matter. However, one of the benefits of centralised systems in reducing air pollutant emissions lies in the greater feasibility of implementing emission control measures than numerous smaller installations. Transitioning to renewable energy sources, such as biomass, solar thermal, geothermal sources, or facilitating waste heat recovery, can significantly reduce the environmental impact of district heating systems.

3. Outlook on energy indicators in the heating and cooling sector in the EU-27

In 2022, the **EU-27's final energy consumption** reached 939 million tonnes of oil equivalent (Mtoe), 3.6 % above the 1990 level (see Figure 12). The final energy consumption of the electricity, transport and residential sectors in the EU-27 was higher in 2022 than in 1990, by 27.8 %, 26.8 % and 1.1 %, respectively. Conversely, the final energy consumption in 2022 was found to be 23.8 % and 27.1 % below 1990 levels in the heating and industry sectors, respectively.

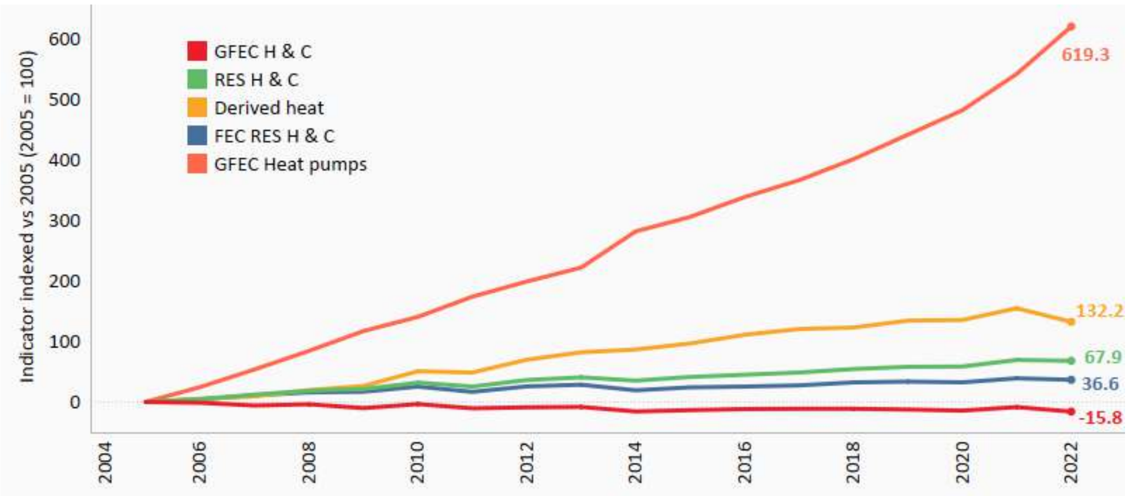
Figure 12. Relative change in final energy consumption in the EU-27, by sector, 1990–2022 (%)



Source: Directorate-General for Energy (DG Energy) country data sheets, 2024.

The **EU-27's GFEC** decreased by nearly 9.5 % between 2005 and 2022, to 972 Mtoe (according to Eurostat's 2024 short assessment of renewable energy sources). Over the same period, **the GFEC in the heating and cooling sector** dropped by nearly 16 %, from 530 Mtoe in 2005 (see Figure 13).

Figure 13. Trend in main indicators in the heating and cooling sector in the EU-27, 2005–2022 (2005 = 100) (%)



NB: H & C, heating and cooling; RES, renewable energy system.

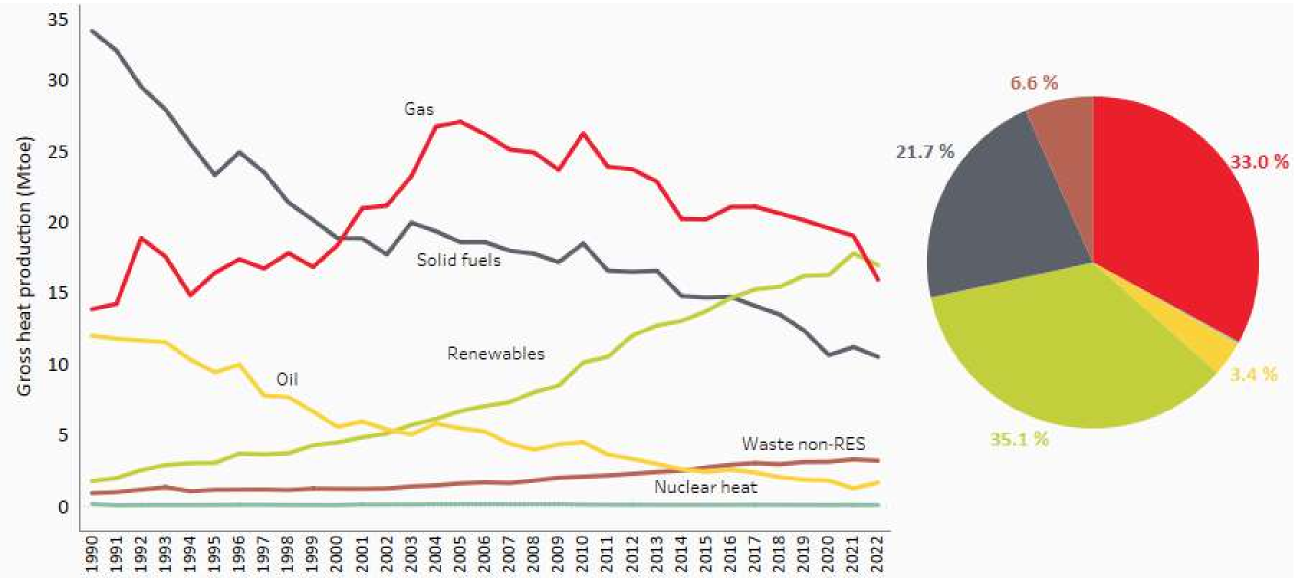
Source: Eurostat short assessment of renewable energy sources (Shares) tool, 2024.

In 2022, the GFEC attributed to heat pumps increased over sixfold from the 2005 level of only 2.2 Mtoe. In the same year, the share of heat pumps in the GFEC was around nine times higher than in 2005, increasing from 0.4 % to 3.7 %.

The absolute contribution of renewables to the GFEC increased significantly between 2005 and 2022, at a rate of nearly 68 %. Over 1990–2022, the increase was by 37 %.

Gross heat production in the EU-27 increased by 2.5 % between 2020 and 2021 but decreased by 8.3 % from 2021 to 2022, reaching 50 Mtoe. This was 17 % below the 2005 level and 18.8 % below the 1990 level. Gross heat production from renewables ([15]) increased by more than twofold from 2005 to 2022, and its share in production increased from 11.2 % to 35 % in the same period. Despite this increase in renewable energy use, fossil fuels still had the largest share in gross heat production in the EU-27, accounting for nearly 60 % of gross heat production in 2022: 21.7 % solid fuel, 33.0 % natural gas and 3.4 % oil (see Figure 14).

Figure 14. Gross heat production in the EU-27, by fuel, 1990–2022 (left) and 2022 (right)



Source: DG Energy country data sheets, 2024.

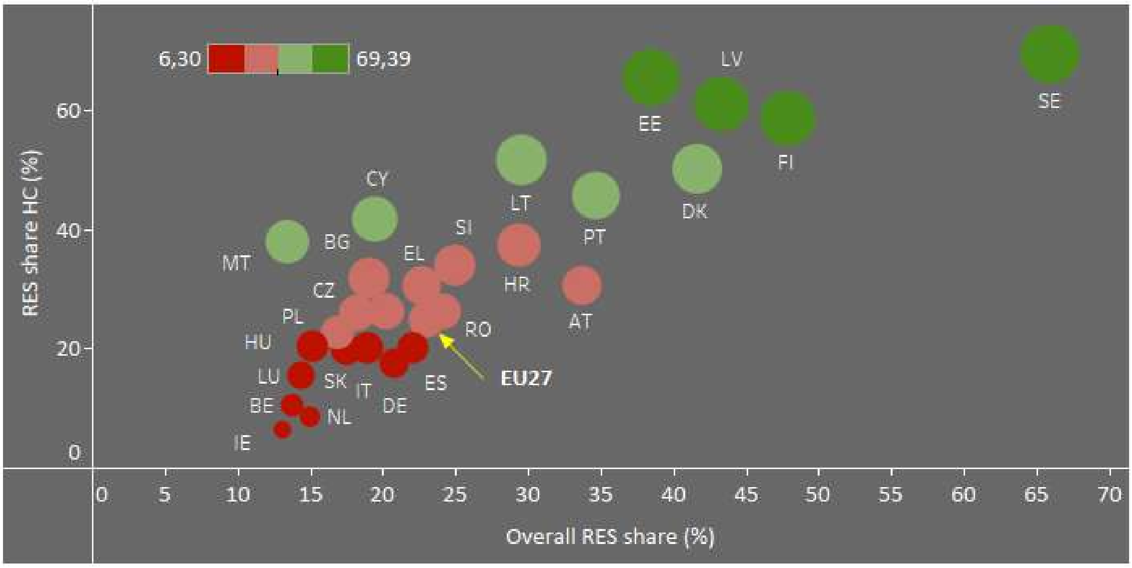
Figure 15 illustrates both the renewable energy shares of Member States in the heating and cooling sector (determining bubble size) and the overall renewable energy share in the EU-27. The Member States are categorised into four clusters based on their renewable shares: less than 20 %, between 20 % and 39 %, between 40 % and 60 %, and above 60 %.

Sweden, situated in the highest cluster, had the greatest overall renewable energy share in 2022 (66 %), with the share in the heating and cooling sector reaching 69.4 %. In contrast, Ireland had the lowest renewable energy share among Member States, at 13.1 % overall and 6.3 % in the heating and cooling sector in 2022.

The EU-27 is situated in another cluster of this analysis, with its renewable energy share in the heating and cooling sector reaching 24.8 % in 2022 (an increase of 8 pp from the 2009 level).

([15]) Renewables include both combustion sources (e.g. biomass) and non-combustion sources (e.g. solar, heat pumps).

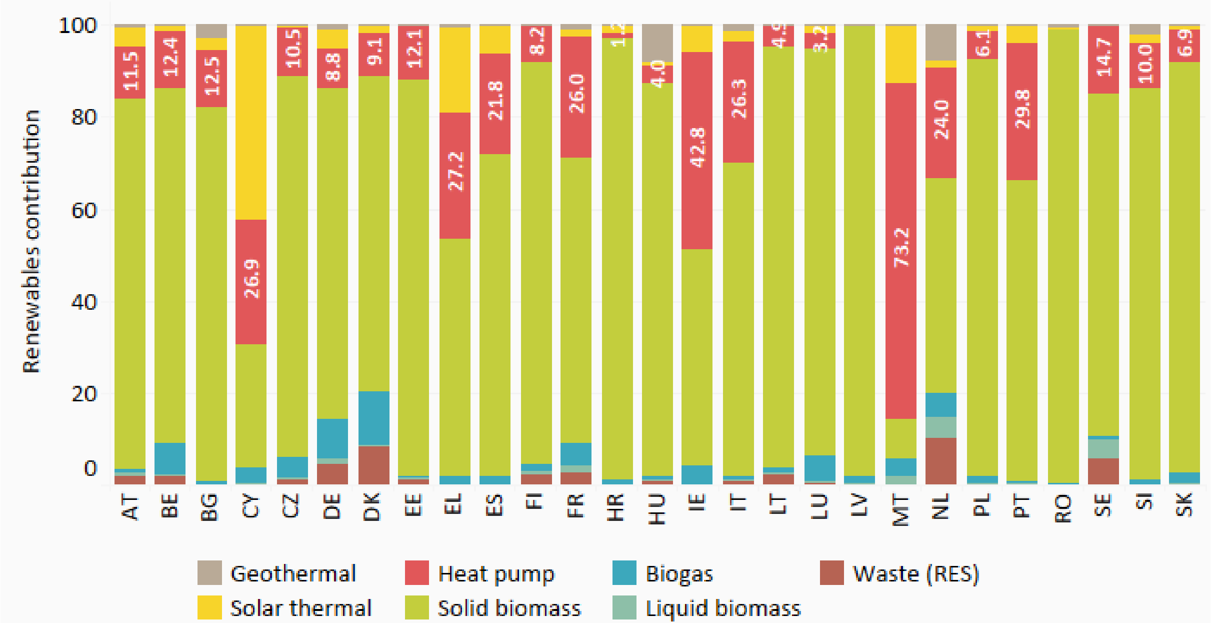
Figure 15. RES share in the EU-27 and each Member State in the heating and cooling sector compared with the overall RES share, 2022 (%)



Source: Eurostat Shares tool, 2024.

With regard to renewables' contribution in the heating and cooling sector in each Member State in 2022, solid biomass had the largest contribution in all Member States except Cyprus and Malta (see Figure 16). The second main contributor in that year was the heat pump, with the largest penetration rates in Malta, Ireland, Portugal, Greece and Cyprus.

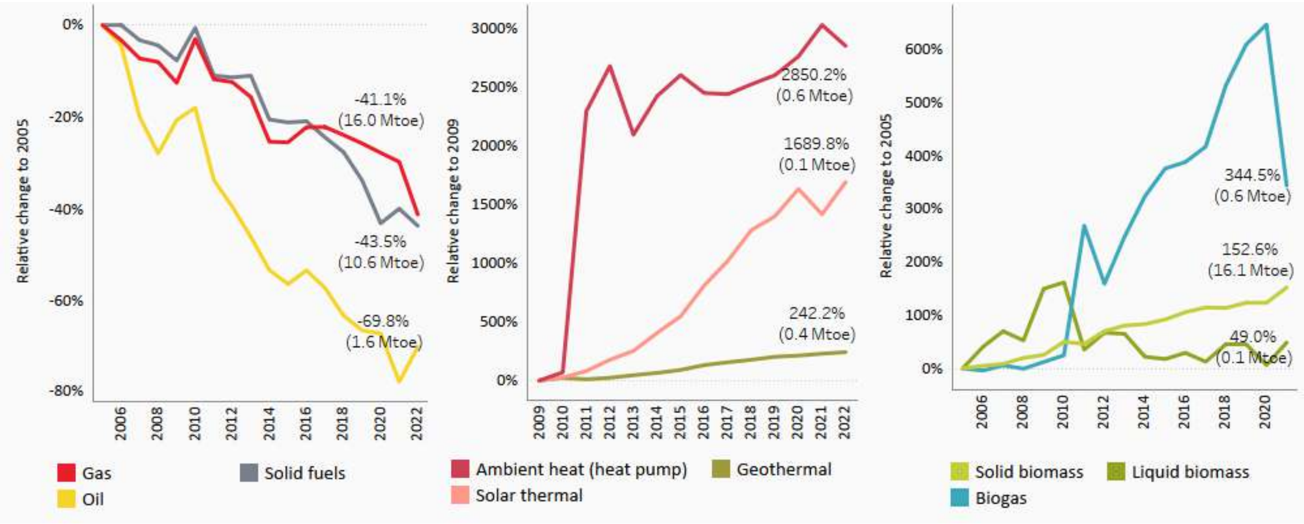
Figure 16. Relative contribution of renewables in each MS in the heating and cooling sector, 2022 (%)



Source: Eurostat Shares tool, 2024.

An investigation of heat generation from all fuels revealed that during 2005–2022 solid fossil fuels, oil and gas saw a decrease of 43.5 %, 69.8 % and 41.1 %, respectively (see Figure 17). The absolute levels for each fuel/technology in 2022 are provided in brackets in Figure 17.

Figure 17. Trends in fuels used for heat generation: fossil fuels and biomass (2005–2022) and other RESs (2009–2022) (%)

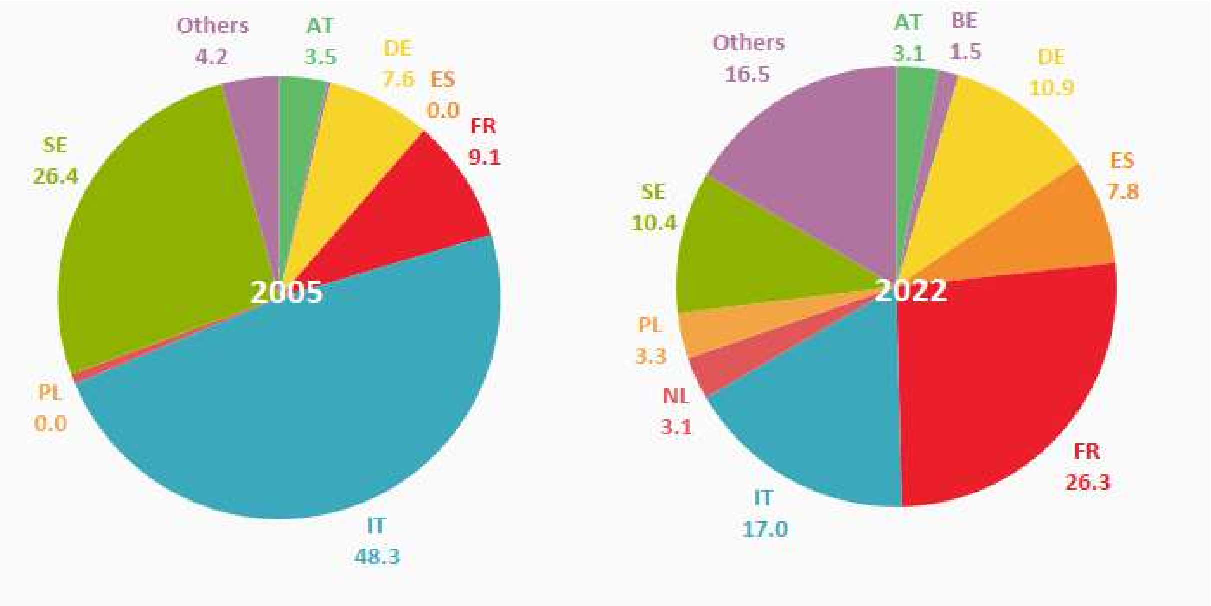


Source: DG Energy country data sheets, 2024.

Looking at biomass, there has been a consistent upward trajectory, with the highest relative increase observed for biogas. Despite a decrease after 2020, biogas consumption for heat generation increased more than fourfold between 2005 and 2022. Solid biomass consumption increased to more than 2.5 times the level in 2005, while liquid biomass consumption increased by less than double.

The role of other renewable energy systems, such as heat pumps, solar thermal and geothermal systems, saw significant growth after 2009. These technologies started from low levels, and their deployment increased due to the adoption of the renewable energy directive, which established mandatory renewable energy targets for each Member State in 2020. This resulted in heat generation from heat pumps increasing by nearly 30 times, while solar thermal and geothermal increased by more than 17 and 3 times, respectively.

Figure 18. Contribution of Member States to the heat pump GFEC, 2022 (%)



Source: Eurostat Shares tool, 2024.

The contribution of heat pumps to the GFEC in Member States has increased over time. Italy led this contribution in 2005, followed by Sweden, France, Germany and Austria (see Figure 18). By 2022, France had taken the lead, with a contribution of 26.3 %. Italy's contribution declined from 48.3 % in 2005 to 17 % in 2022. It is important to consider the climate conditions in which heat pumps are employed when evaluating countries' contributions to combating climate change, because heat pumps utilised for heating purposes are particularly impactful as they replace fossil-fuel-based technologies.

Most of the energy demand for heating and cooling is related to heating. Space and water heating needs in buildings represent over 60 % of the demand for heating in the EU-27, followed by industry, representing a further 32 %; the remainder is related to agricultural and building and industry cooling applications. In 2022, the contribution of renewables to cooling was 0.8 % of all renewable systems in the heating and cooling sector, and 0.2 % of GFEC in the heating and cooling sector (Gerard et al., 2021).

4. Air pollution trends in the heating and cooling sector in the EU-27

The Member States have implemented emission standards and regulations, such as the eco-design directive, that define thresholds for air pollutant emissions (e.g. NO_x, particulate matter, CO and organic gaseous compounds) from small-scale combustion appliances. The NECD is essential in the EU's efforts to tackle air pollution and protect human health and the environment, playing a crucial role in supporting the Green Deal's objectives by addressing one of its key pillars: ensuring a healthy and sustainable environment.

By setting out national emission reduction commitments for the air pollutants with the greatest negative impact on human health and the environment, the NECD contributes to the zero-pollution ambition set out in the Green Deal and the subsequent zero pollution action plan. While the NECD addresses air pollutant reduction, this effort complements the EU's overall strategy to reduce GHG emissions, in line with the Paris Agreement, and to transition to a low-carbon economy.

The directive sets ambitious targets for Member States to reduce the emission of certain pollutants by specific deadlines. As the NECD prioritises overall emission reduction goals, it mandates the reporting of emissions for each pollutant by sector or subsector, in accordance with the nomenclature for reporting structure and with European monitoring and evaluation programme (EMEP) guidelines ([16]). However, the EMEP guidelines do not specifically require the reporting of air pollutant emissions by fuel type. Therefore, in reporting air pollutant emissions, Member States provide only a single value for each pollutant per sector or subsector, encompassing aggregate emissions from fossil fuels and biomass contributions.

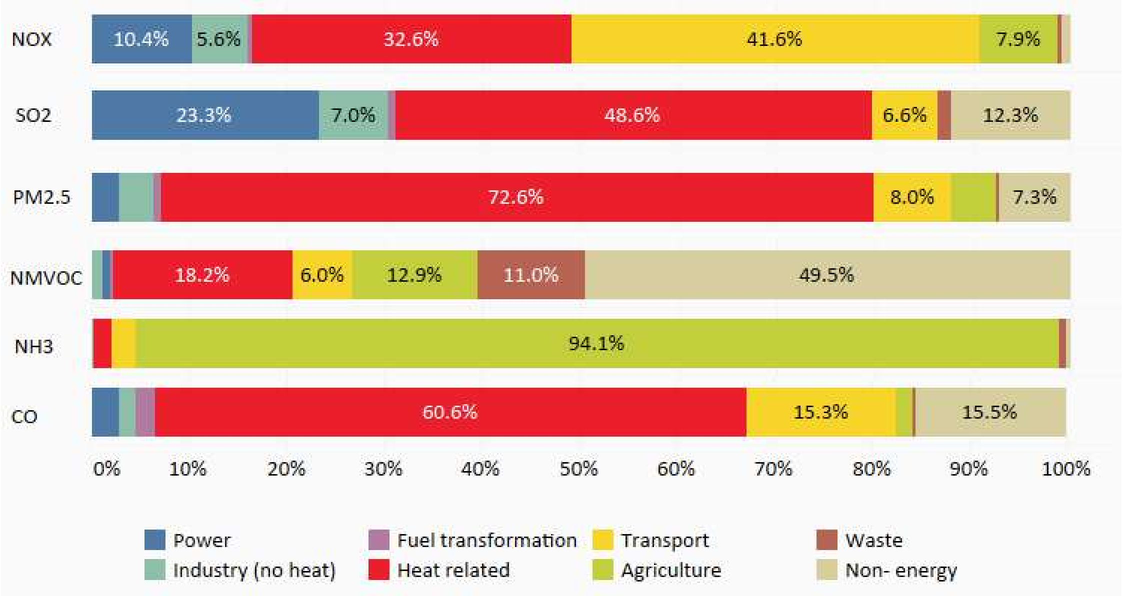
Efforts to improve the recording of emissions in the JRC's Emissions Database for Global Atmospheric Research (EDGAR) provide the opportunity to determine the contribution of each specific fuel to the emission of individual air pollutants from activities in the residential sector (Banja and Ebeling, 2023). The following analysis is mainly focused on the small-scale combustion sector, recognising buildings as a critical component of the heating and cooling sector. Given that buildings contribute significantly to both energy consumption and emissions, this focus enables a detailed examination of key factors in this integral segment of the sector. Figure 19 ([17]) illustrates the contribution of the heat-related sectors in the EU-27 ([18]) and other sectors, such as public power, industry and fuel transformation, transport agriculture and non-energy-related sectors, to the emission of each air pollutant in 2022.

([16]) https://www.ceip.at/reporting-instructions.

([17]) Since the EDGAR v8.1 release is based on the use of 2023 energy balances, the air pollutant emissions are comparable with EU27 MS emissions reported in the 2023 national inventories and the Informative Inventory Reports (IIRs). These submissions can be explored at https://www.eea.europa.eu/data-and-maps/dashboards/necd-directive-data-viewer-7). In the case of $PM_{2.5}$ emissions in the residential sector, the estimation considers the use of emission factors related to the condensable fraction, as reported by each Member State in their 2023 informative inventory reports. An analysis of the emission factors applied to particulate matter emissions, including or not including the condensable fraction, has been presented by Banja and Ebeling (2023).

([18]) Heat-related emissions are calculated as the sum of air pollutant emissions from heating plants (auto producer), district heating, co-generation of heat, buildings (residential, commercial/institutional and agriculture/fishing/other), and manufacturing industry (chemicals, iron and steel, food, paper, non-metallic minerals and non-ferrous metals) heating. To estimate the contribution of the co-generation of heat, the assumption that two thirds of emissions are sourced from heat-related co-generation is applied. This assumption is based on the split of heat generation data available from Member States' energy balances. The EDGAR sector and subsector structure is described by Banja and Schmitz (2022).

Figure 19. Contribution of sectors to air pollutant emissions in the EU-27, 2022 (%)

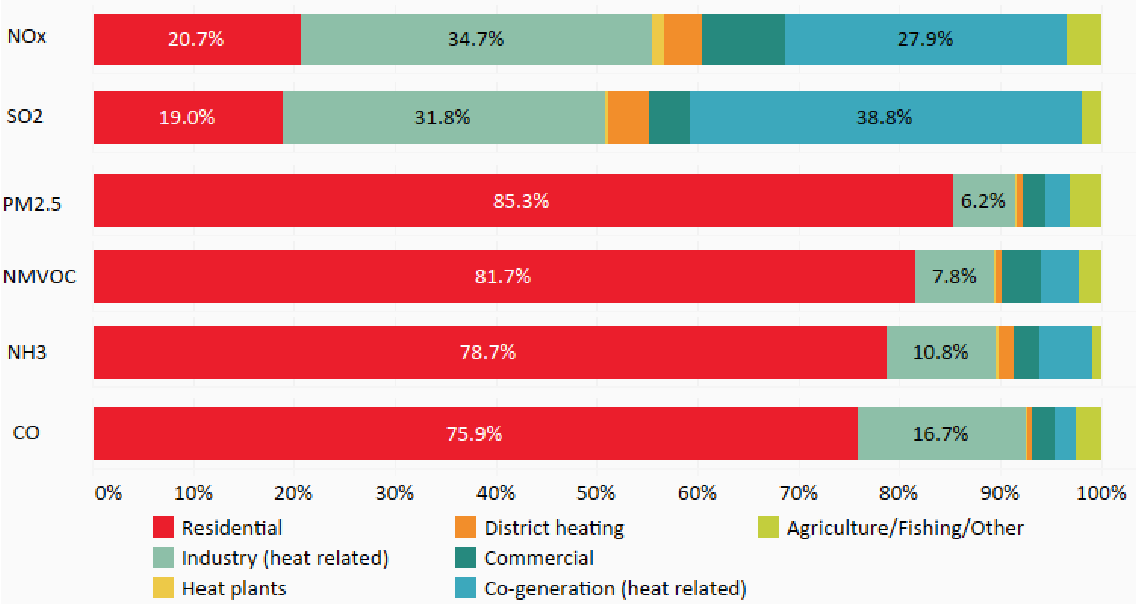


Source: EDGAR version 8.1, 2024.

Heat-related sectors play a significant role in air quality, particularly concerning particulate matter. In 2022, nearly 73 % of the EU-27's $PM_{2.5}$ emissions (with a similar contribution to PM_{10} emissions) originated from heat-related activities. In addition, over 60 % of CO emissions were attributed to heat-related activities. Regarding NO_x, SO_2 and NMVOC emissions, heat-related activities accounted for 32.6 %, 48.6 % and 18.2 %, respectively.

When examining heat-related emissions in the heat-related sectors in 2022, the importance of the residential subsector becomes apparent, particularly concerning particulate matter, NMVOCs, NH_3 and CO emissions (see Figure 20). In the case of NO_x and SO_2 emissions, the contribution of the residential subsector is complemented by those from heat co-generation and agricultural/fishing/other activities.

Figure 20. Contribution of heat-related sectors to air pollutant emissions in the EU-27, 2022 (%)



Sources: Eionet (n.d.) and EDGAR version 8.1, 2024.

Table 1 illustrates the changes in emissions from 2005 to 2022 for each air pollutant across all heat-related sectors and subsectors in the EU-27 (with red showing an increase and other colours showing degrees of decrease in emissions for each air pollutant). As shown in Table 1, in 2022 SO_2 emissions were found to be significantly below the 2005 levels in the EU-27 and all heat-related sectors. The decrease in NO_x, NMVOC, $PM_{2.5}$ and CO emissions over the same period was lower.

Table 1. Relative change in heat-related air pollutant emissions in the EU-27, 2005–2022 (%)

Sector/substance	NOx	SO2	PM2.5	NMVOC	NH3	CO
All sectors	🟡 -49.8	🟢 -82.1	🟡 -33.5	🟡 -36.9	🔴 -16.3	🟡 -42.1
Heat related	🟡 -36.0	🟢 -55.5	🔴 -10.0	🟡 -18.0	🔴 -11.1	🟡 -17.9
Residential	-16.4	-43.5	-4.9	-22.3	-15.7	-7.3
Commercial	-29.0	-67.4	-42.0	13.5	-31.4	-33.4
Agriculture/Fishing/Other	19.7	-51.9	-42.0	-21.0	100.0	-40.2
Manufacturing industry (heat related)	-49.3	-67.5	-53.7	-9.7	-17.8	-49.4
Heat plants	-41.9	-46.7	-3.3	-24.9	-15.8	-40.3
District heating	-31.5	-39.5	69.9	20.1	62.6	-15.8
Co-generation (heat related)	-28.6	-45.2	77.2	29.5	98.4	16.6

Source: Eionet (n.d.) and EDGAR version 8.1, 2024.

Compared with 2005, emissions of $PM_{2.5}$, NMVOC, and NH_3 have shown the most significant increases in the district heating and co-generation heat subsectors. This trend is largely attributed to the increased utilisation of biogas and liquid biomass, particularly evident in the heat co-generation subsector. The emission of NO_x and CO stemming from the utilisation of biogas in the co-generation subsector increased by nearly 10 times in 2022 compared with 2005. Meanwhile, the emission of NO_x decreased in nearly all subsectors, except for agriculture/fishing/other, primarily due to the prevalent use of oil. NMVOC emissions had decreased in 2022 compared with 2005 in the residential subsector and heating plant activities, mainly due to reductions in emissions from gas and oil.

Table 2 illustrates the changes in air pollutant emissions from biomass, coal, gas and oil fuels in the residential sector in 2022 compared with 2005. The relative changes in each fuel in each subsector and for each air pollutant over 2005–2022 are shown in Annex 1. NO_x and SO_2 emissions from biomass increased by nearly 33 % and over 22 %, respectively, from 2005 to 2022 whereas $PM_{2.5}$ emissions remained close to the same level as in 2005, with only a 1 % decrease. Meanwhile, all air pollutant emissions from coal, oil and gas used in the residential subsector in 2022 were below the 2005 levels.

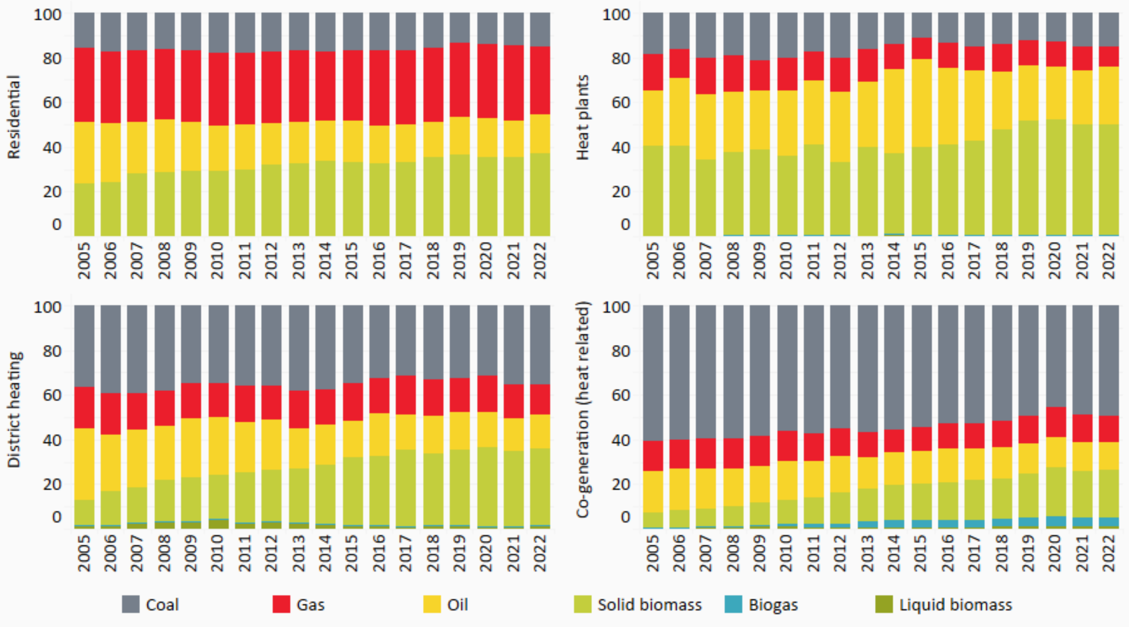
Table 2. Relative change in residential sector air pollutant emissions in the EU-27, by fuel, 2005–2022 (%)

	Biomass	Coal	Gas	Oil
NOx	32.74	-19.10	-23.40	-48.00
SO2	22.40	-26.10	-21.00	-80.10
PM2.5	-1.00	-19.60	-23.30	-41.40
NMVOC	-22.20	-22.80	-21.20	-37.90
NH3	-15.60	-30.90	-19.20	-36.20
CO	-3.20	-18.80	-20.80	-34.80

Source: EDGAR version 8.1, 2024.

Figure 21 shows the contribution of fossil fuels and biomass to NO_x emissions from the heat-related sectors in the EU-27 over 2005–2022. The contribution of solid biomass to NO_x emissions in the residential sector increased from 23.5 % in 2005 to nearly 37 % in 2022. The primary transition observed during this period in the sector was a shift from coal-/oil-based fuels to solid biomass NO_x emissions, while natural gas remained the primary fuel in heating plants.

Figure 21. Contribution of fuels to NO_x emissions from heat-related activities in the EU-27, 2005–2022 (%)



Source: EDGAR version 8.1, 2024.

Similarly, Figure 22 illustrates the contribution of fossil fuels and biomass to the $PM_{2.5}$ emissions in heat-related sectors in 2005–2022. Biomass remained a significant contributor to emissions from the residential and heating plant subsectors. The role of biomass in district heating and heat co-generation increased, producing, in 2022, 92 % and 85.5 %, respectively, of $PM_{2.5}$ emissions from heat-related activities. The shift took place mainly from oil and coal fuels towards biomass.

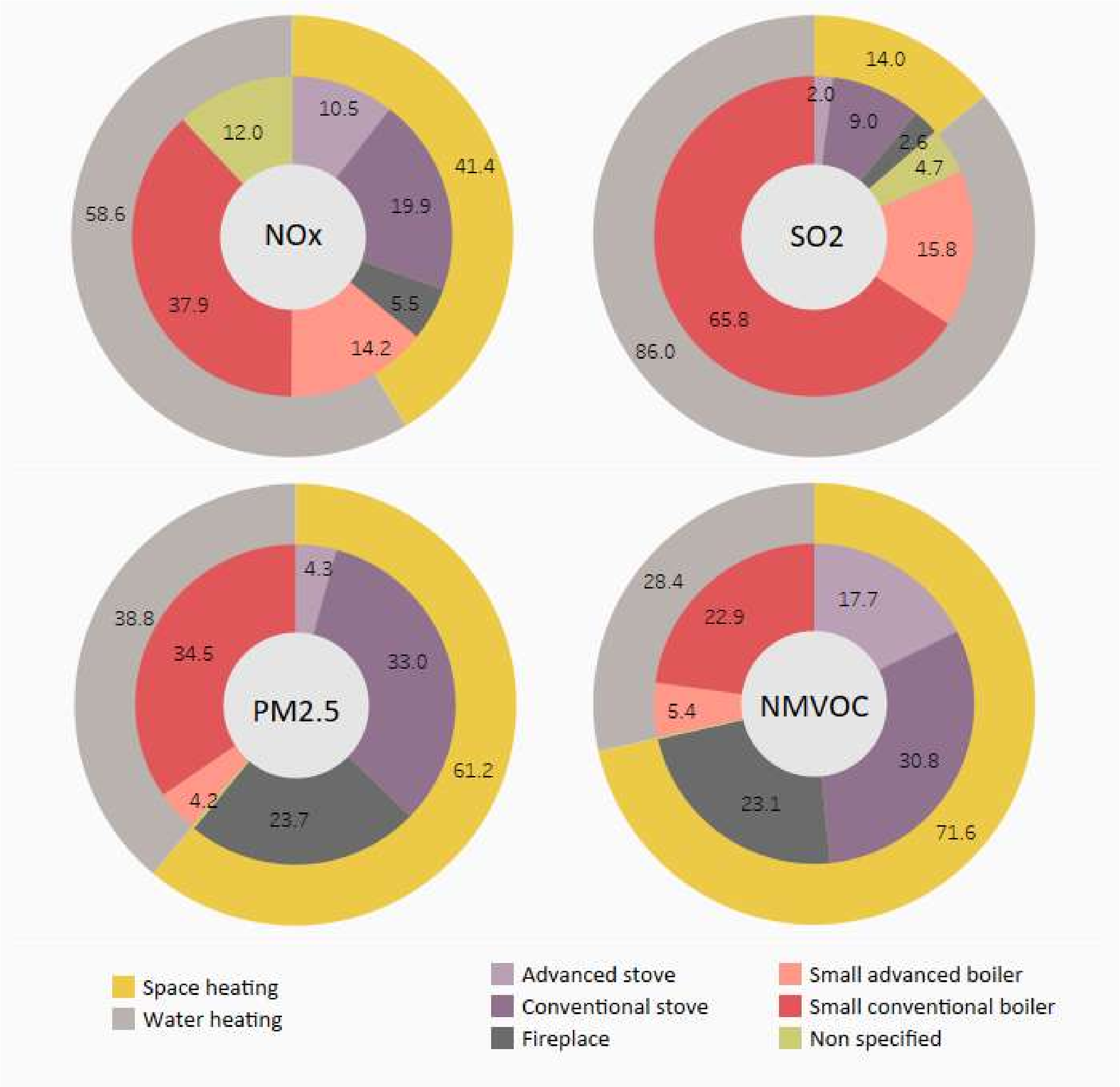
Figure 22. Contribution of fuels to $PM_{2.5}$ emissions from heat-related activities in the EU-27, 2005–2022 (%)

Source: EDGAR version 8.1, 2024.

The distribution of pollutant emissions from residential heating sources can be influenced by several factors related to the combustion process, fuel type and technologies used. Space heating and domestic water heating are responsible for around 80 % of energy consumption in buildings (Reiser et al., 2022) and are common activities that involve the combustion of fuels such as natural gas, oil and wood.

An analysis of the main air pollutants emitted by type of heating (19) is shown in Figure 23. Water heating is the main source of NO_x and SO_2 emissions, while space heating is the main source of $PM_{2.5}$ and NMVOC emissions. Conventional boilers are dominant in water heating for all air pollutants analysed, whereas in the case of space heating, conventional stoves have the highest shares in NOx, $PM_{2.5}$, NMVOC and SO_2 emissions.

Figure 23. EU-27 residential NO_x, SO_2, $PM_{2.5}$ and NMVOC emissions from space and water heating, 2022 (%)



Source: EDGAR version 8.1, 2024.

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(19) All fuels included. A technology approach was used to estimate the role of space and water heating in NO_x, SO_2, $PM_{2.5}$ and NMVOC emissions. Boilers are considered the main technology for water heating.

5. Technological landscape of the residential sector in the EU-27 and its evolution over time

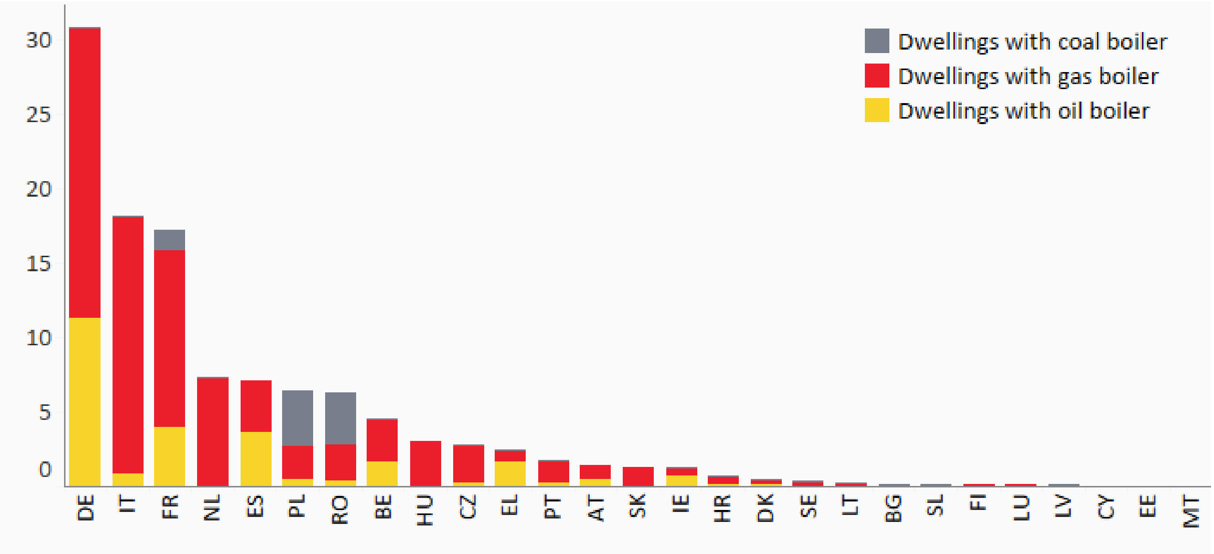
Conventional heating technologies, such as open fireplaces and outdated wood stoves, are significant sources of particulate matter and other pollutants that degrade air quality. The evolution of heating technologies in the residential sector in the EU-27 has led to diverse consumer choices, for example based on cost, energy efficiency, environmental impact and personal preferences. This variety of available options can lead to households making decisions based on statistically distributed parameters, meaning that different households may choose different heating technologies based on various factors distributed across the population (Knobloch et al., 2021).

The following analysis aims to provide an insight into the various technologies used in the residential sector, and how these technologies have changed or evolved over time.

A recent study by the Joint Research Centre (JRC) estimated that there are approximately 68 million gas and 18 million oil boilers in EU residential buildings (Toleikyte et al., 2023). The approximate current number of dwellings in the EU-27 that are furnished with gas, oil and coal boilers is shown in Figure 24.

Nearly 80 million dwellings in the EU-27 use gas boilers, nearly 26 million dwellings use oil boilers and nearly 9 million dwellings use coal. The Netherlands has the highest share of dwellings with gas boilers (more than 90 % of the total number of dwellings in the country), and Greece the highest share of dwellings with oil boilers (more than 70 %). Bulgaria and Poland have the highest share of coal boilers, 62% and 58.6% respectively (based on Member States' national statistics).

Figure 24. Number of dwellings with gas, oil and coal boilers in the EU-27 (millions)

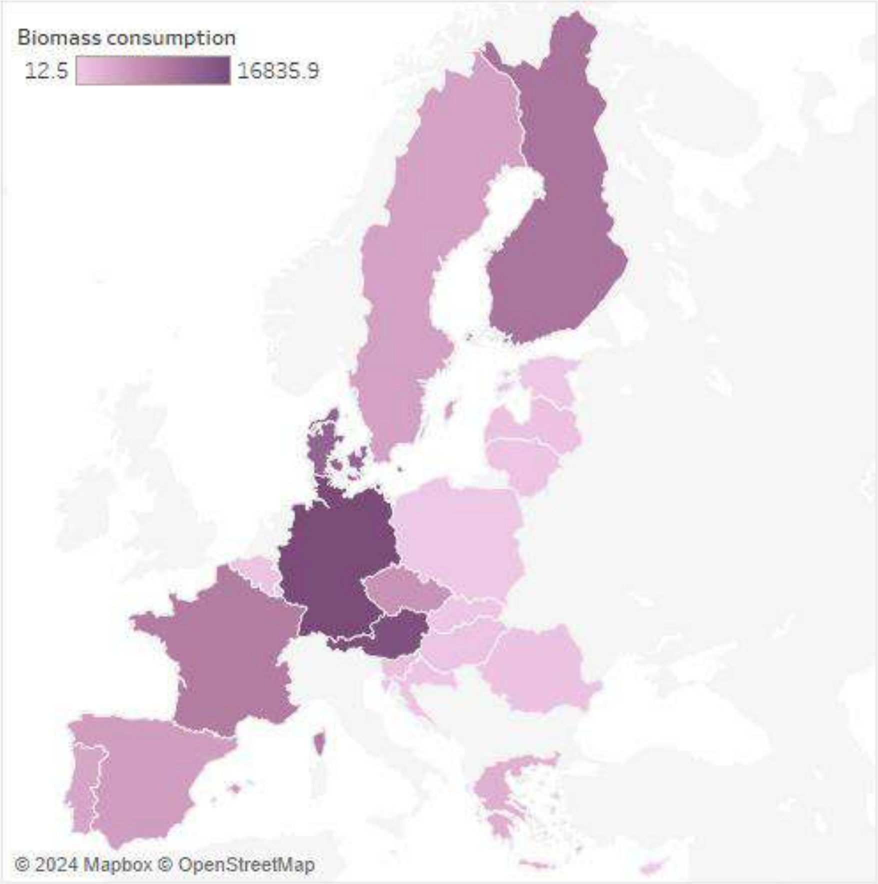


NB: The year of reference for this data collection differs among countries (e.g. 2018 for France; 2021 for Italy and Austria; 2022 for the Netherlands; 2023 for Belgium, Bulgaria and Germany).

Sources: Authors, based on Member States' national statistics (e.g. for Germany, data from Bundesverband der Energie- und Wasserwirtschaft; for France, data from the Ministry of Ecological Transition; for Italy, data from the National Institute of Statistics; for the Netherlands, CBS (2023); for Spain, IDAE (2016) and Eurostat (2022); for Austria, data from Bundesministerium für Klimaschultz, Umwelt, Energie, Mobilität, Innovation und Technologie; for Belgium, Vito (2012) and STATBEL (2023); for Bulgaria, data from the National Statistical Institute; for Cyprus from Economidou et al., 2018).

The work to improve the estimation of air pollutant emissions in EDGAR for the residential sector in the EU-27 provides insights into the evolution of energy consumed by each technology and by each fuel in this sector. Figure 25 illustrates the biomass consumption of small advanced boilers in each Member State in the residential sector in 2022.

Figure 25. Biomass consumption of small advanced boilers in the residential sector in the EU-27, 2022 (kilotonnes of oil equivalent)



Source: EDGAR version 8.1, 2024.

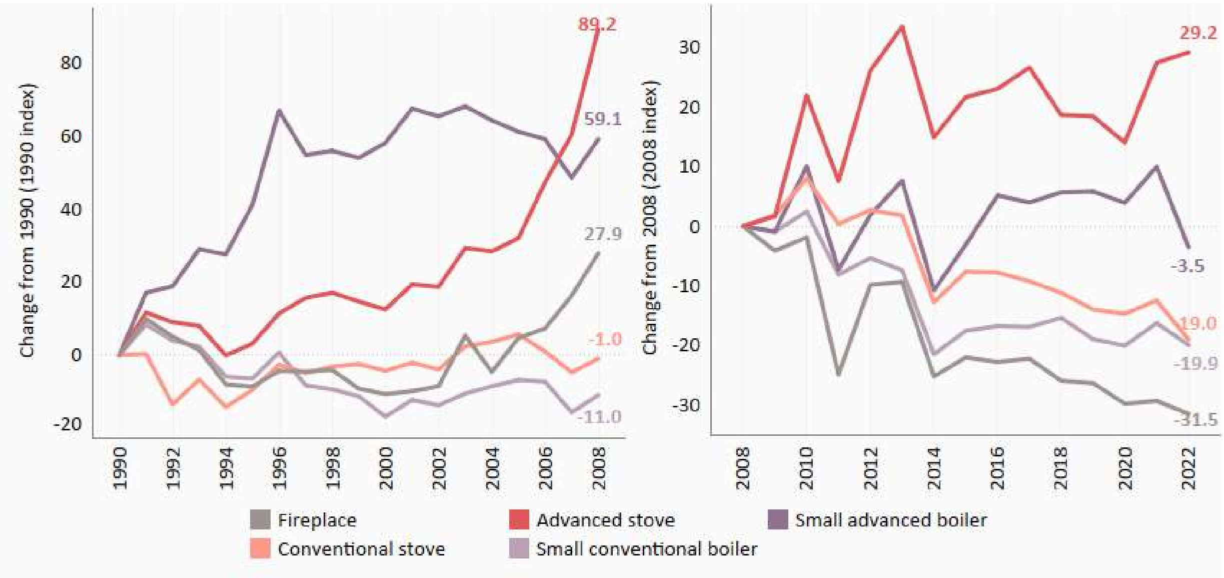
The evolution of energy consumption for 1990–2008 and 2008–2022 is shown in Figure 26. The evolution of energy consumption for advanced boilers and stoves has rapidly increased since 1990.

Between 1990 and 2022, the shares of small advanced boilers and advanced stoves shifted from 12.6 % and 2.6 % in 1990 to 18.5 % and 4.5 % in 2008, and to 20.9 % and 6.8 % in 2022, respectively. The significant increase in energy consumption by these two technologies is mainly attributed to the increased use of biomass.

From 1990 to 2022, the use of biomass in small advanced boilers saw a fivefold increase, while in advanced stoves, the use more than doubled, surpassing a 2.5-fold rise. Gas also played a role in the rising use of small advanced boilers, increasing its contribution by nearly 60 % from 1990 to 2022.

In 1990, nearly 77 % of biomass was used in fireplaces, conventional stoves and small conventional boilers (37 %, 25.2 % and 14.6 %, respectively). In 2008, the situation remained almost unchanged, with the shares of these three technologies dropping by only 2 pp. However, the transformation of the technology landscape of the residential sector in the EU-27 did not moved as fast from 2008 onwards, and in 2022 traditional and conventional technologies still covered more than 62 % of biomass used in this sector.

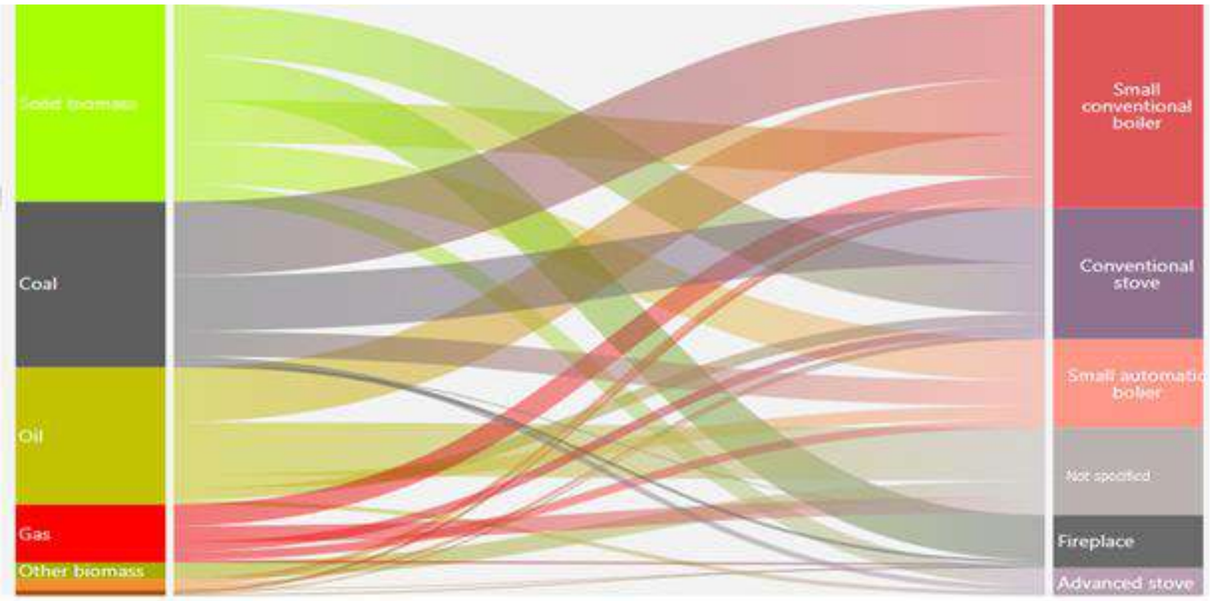
Figure 26. Evolution of technologies in the residential sector in the EU-27, 1990–2008 (left) and 2008–2022 (right) (%)



Source: EDGAR version 8.1, 2024.

Figure 27 illustrates the allocation of fuels to the main technologies in the residential sector: boilers (conventional and advanced), stoves (conventional and advanced) and fireplaces.

Figure 27. Number of fuels in EDGAR for the residential sector in the EU-27, 2022

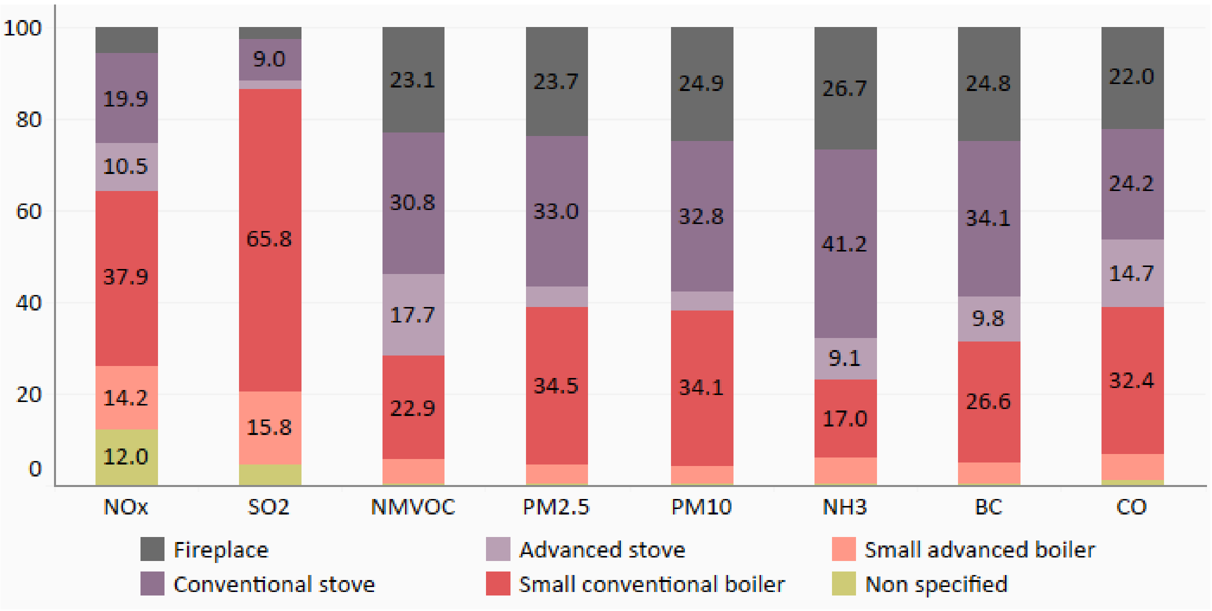


NB: The Sankey diagram shows the allocation of the main fuels (coal, oil, gas, solid biomass and other biomass) to each technology. The width of the lines corresponds to the number of fuels in each category, and not their relative contributions. In the coal category, for example, there is a greater number of fuels (including anthracite and sub-bituminous coal), than in the gas, oil and biomass categories.

Source: EDGAR version 8.1, 2024.

Coal fuels (anthracite, sub-bituminous coal, etc.) are mainly used in small conventional boilers, conventional stoves and fireplaces. Biomass is used in all those technologies with the largest numbers of conventional stoves and fireplaces. Figure 28 illustrates that small conventional boilers are the predominant technologies contributing to SO_2 emissions. In the case of particulate matter, fireplaces, conventional stoves and small conventional boilers are the primary technologies used.

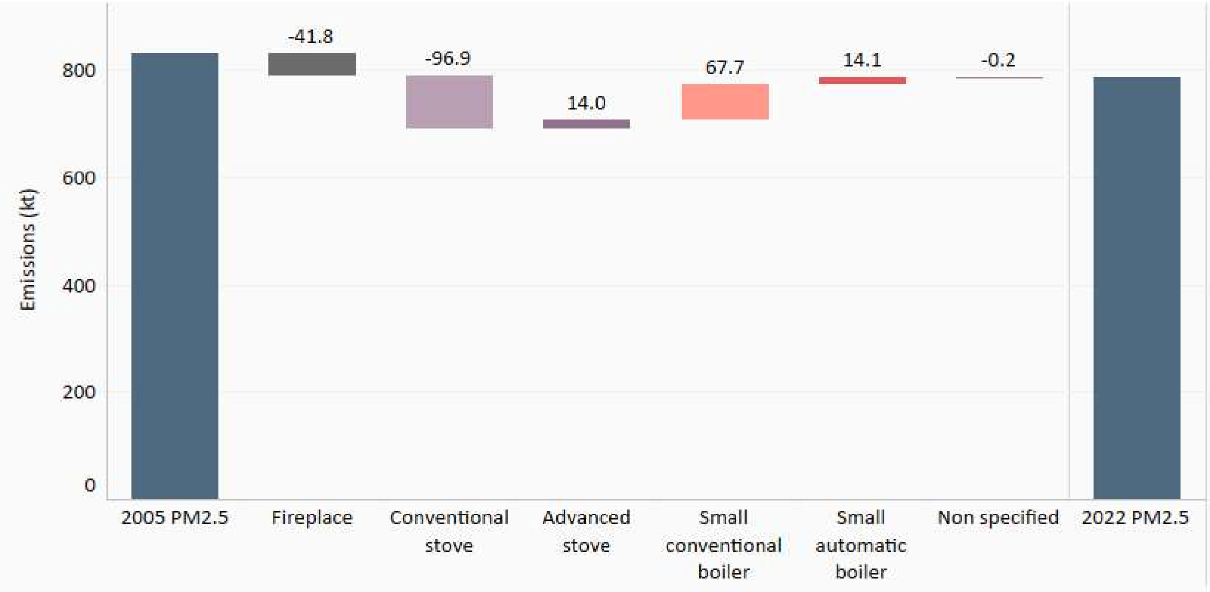
Figure 28. Contribution of technologies to air pollutant emissions in the EU-27 residential sector, 2022 (%)



Source: EDGAR version 8.1, 2024.

The most significant reductions in $PM_{2.5}$ emissions in the residential sector between 2005 and 2022 occurred among conventional stoves and fireplaces (see Figure 29). This reduction coincides with a transition towards using small conventional boilers.

Figure 29. Role of residential technologies in the trend in $PM_{2.5}$ emissions, 2005–2022



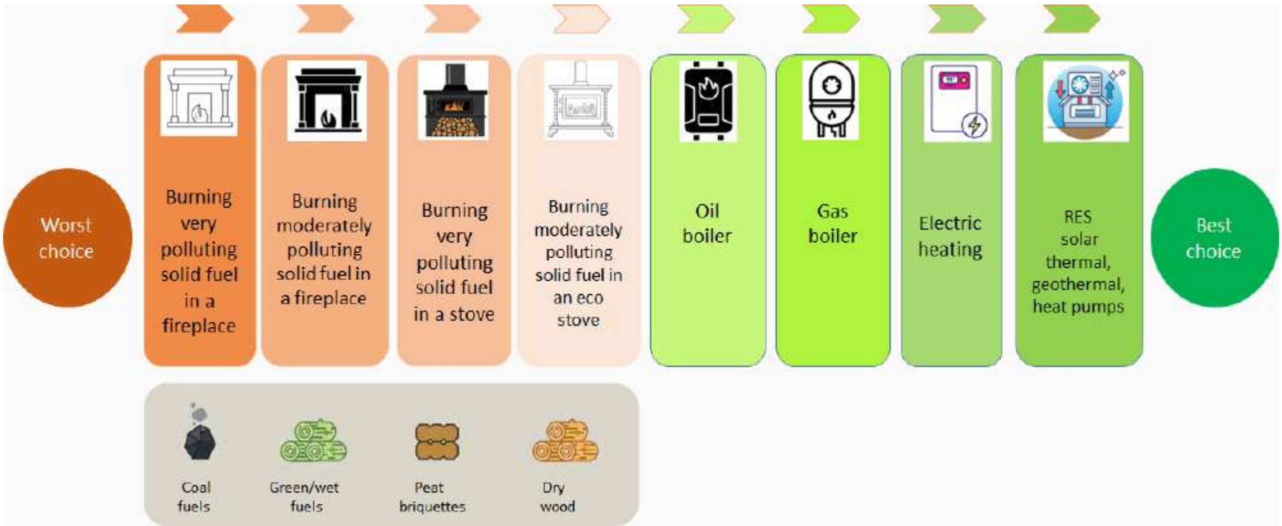
Source: EDGAR version 8.1, 2024.

6. Discussions on what influences trends in air pollutant emissions in the heating and cooling sector

The heating and cooling sector is a significant contributor to air pollution, with various factors influencing the trends observed in pollutant emissions. A comprehensive understanding of these factors is crucial for developing effective strategies to mitigate the environmental impact of the sector. In this context, we explore the technological, regulatory and economic influences shaping air pollution in the heating and cooling sector, focusing on identifying significant contributors to pollution trends.

Choice of fuel plays an important role in shaping the composition and magnitude of air pollutant emissions (Chaudhuri and Pfaff, 2003). Fuel quality also plays a crucial role ([20]) in determining emissions. Fuels with higher sulphur content, such as certain types of coal and oil, produce more SO_2 emissions when burned. In addition, fuels with a higher ash content result in higher particulate matter emissions. The moisture content of fuels also affects their combustion efficiency, resulting in incomplete combustion and higher emissions. Different types of fuels, such as coal, oil and natural gas, have varying impacts on emissions. For example, natural gas combustion generally produces lower pollutant emissions than coal and oil (IEA, 2019). Figure 30 illustrates the best and worst choices of technologies and fuels for heating homes, based on their expected environmental impact (specifically in terms of air pollution).

Figure 30. Choices of fuel and technology for heating homes



NB: The illustration provided is schematic and is intended to offer a general overview of the direct impacts of fuels and technology on air pollutant emissions. It does not present definitive or absolute conclusions.

Source: Authors, based on Passive House Plus (2021).

Figure 31(a) illustrates the correlation between the evolution of solid biomass consumption and the emission of NO_x, SO_2, $PM_{2.5}$, NMVOCs, NH_3 and CO from 1990 to 2022. The evolution of solid biomass consumption is shown for each technology. The role of solid biomass in reducing air pollutant emission is more evident after 2009, with the greatest impact on NMVOC and NH_3, a moderate impact on $PM_{2.5}$ and CO emissions and almost no impact on NO_x and SO_2 emissions. Overall, solid biomass consumption

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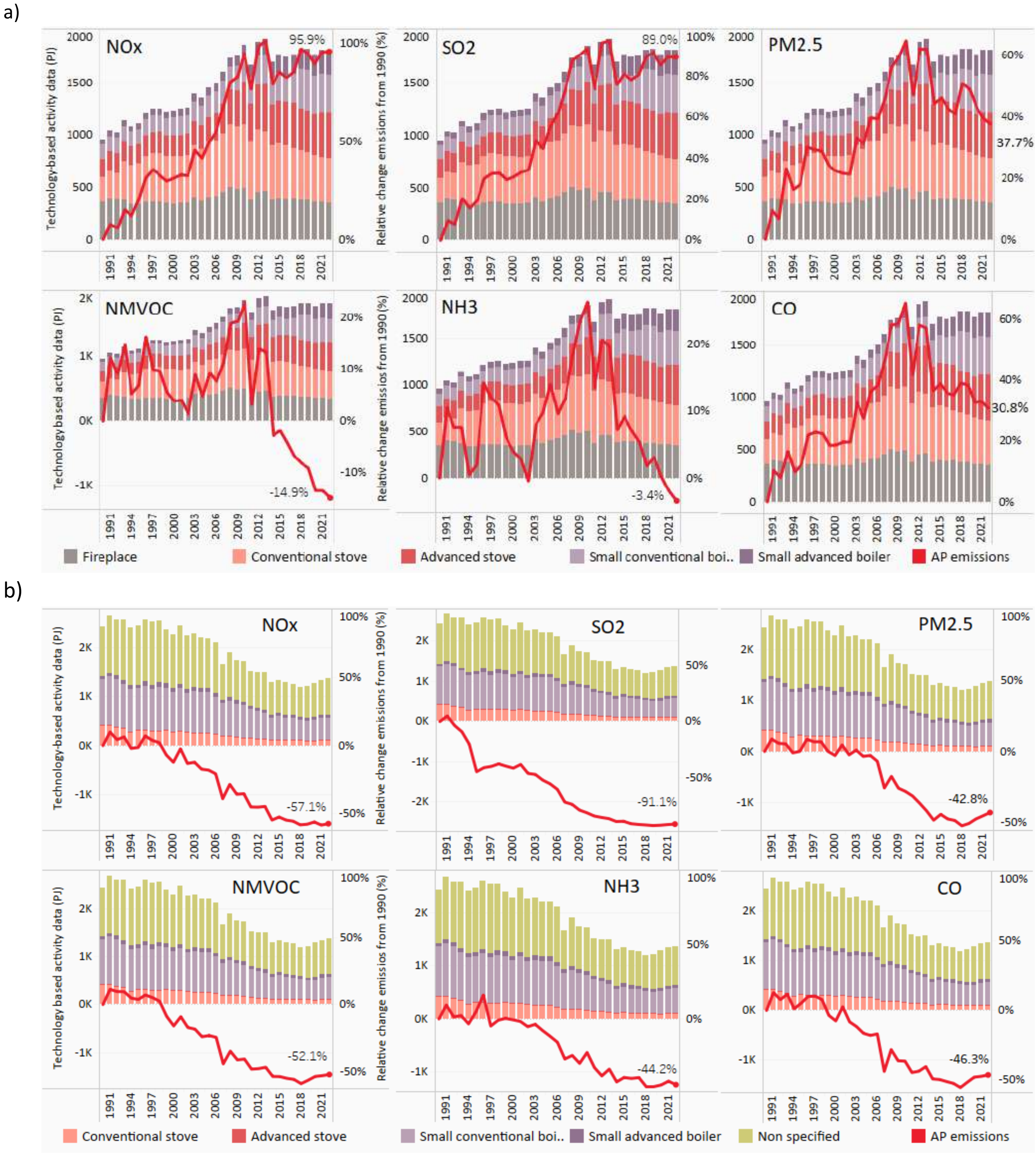
[20] https://climate.ec.europa.eu/eu-action/transport/fuel-quality_en.

increased, but after 2009 more solid biomass was consumed by advanced stoves and small conventional boilers.

Figure 31. Residential air pollutant emissions and fuel consumption for solid biomass (a) and oil (b), 1990–2022



NB: AP, air pollutant, PJ, Petajoule; The right axis shows the consumption of solid biomass and oil, while the left axis shows the relative change in emissions since 1990.

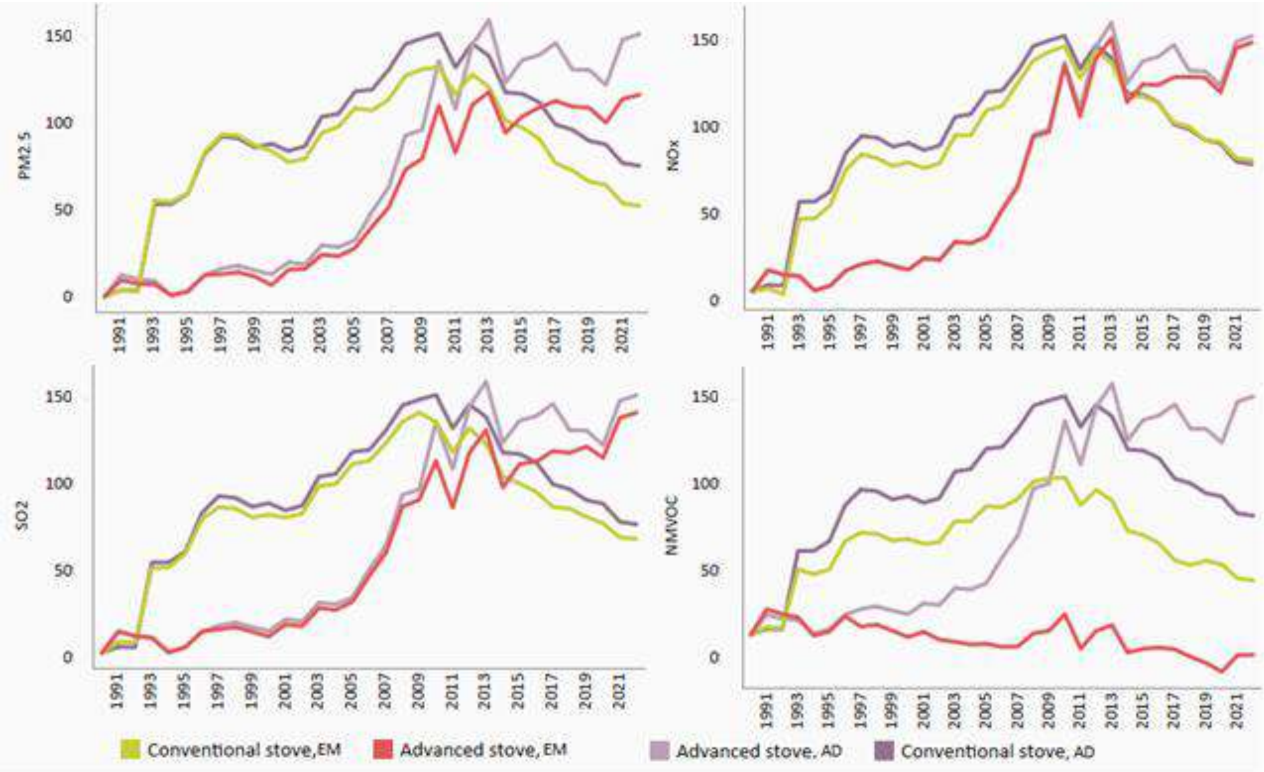
Source: EDGAR version 8.1, 2024.

Similarly, Figure 31(b) illustrates the correlation between oil consumption and air pollutant emission. The emission of all air pollutants shown in the figure decreased with oil consumption, with the highest impact (above 90 %) on SO_2 emissions.

The choice of technologies employed in the heating and cooling sector has a direct impact on air pollution. In addition, the type and age of the appliances used for combustion also influence emissions. Outdated and inefficient technologies, such as older heating systems and cooling equipment with poor energy efficiency, tend to produce higher emissions. Conversely, modern appliances equipped with emission control technologies can significantly reduce emissions. There is a broad technology typology in the heating and cooling sector, including both large- and small-scale combustion. Batch sizes in modern stoves are optimised for moderate to low heat generation, and the capacity of the air system is typically downsized (EMEP and EEA, 2023, annex 'A4bi residential combustion').

Large-scale combustion, such as in heating plants or the manufacturing sector, operates at a higher temperature than small-scale combustion, such as residential heating or cooking. These higher temperatures allow for better pollutant destruction through secondary combustion processes, potentially reducing emissions. Moreover, advanced emission control technologies, such as selective catalytic reduction and electrostatic precipitators, can be utilised more effectively in large-scale combustion processes.

Figure 32. Residential air pollutant emissions (EM) from and consumption (AD) of solid biomass in stoves, 1990–2022 (%)



Source: EDGAR version 8.1, 2024.

An investigation into the role of the fuel–technology relationship with regard to air pollutant emissions in the residential sector is shown in Figure 32. Examples of the role of the relationship between solid biomass and stoves (advanced and conventional) in $PM_{2.5}$, NO_x, SO_2 and NMVOCs are shown. The impact of advanced stove deployment is more pronounced for NMVOCs, in which there was a decrease from 1990 to 2022. The changes in emission factors for each air pollutant and for each technology are important indicators of the trends in emissions. These factors quantify the emissions of pollutants per unit of fuel consumed or energy produced.

The analysis of country-specific emission factors for each air pollutant and each technology revealed that, at the start of the period analysed, the NMVOC emission factors for both advanced and conventional stoves were very high. Over time, these emission factors decreased for both types of stoves, with a more pronounced decrease in advanced stoves.

In some Member States, such as France, the NMVOC emission factors for solid biomass in both technologies halved over the period analysed. In contrast, while $PM_{2.5}$ emission factors mainly decreased for conventional stoves, the emission factors for advanced stoves remained almost unchanged over the years, although they were still lower than those of conventional stoves. In the case of other pollutants, the deployment of advanced stoves had a moderate impact on the decrease in $PM_{2.5}$ emissions. In contrast, the effect on NO_x and SO_2 emissions is very minimal: both emissions and consumption follow a similar (increasing) trend.

The diversity of technology underscores the significance of emission factors related to fuels and technologies in shaping environmental outcomes and policy priorities across each Member State. Emissions factors play a crucial role in assessing the environmental impact of heating and cooling technologies.

To provide an overview of variations in the composition of boilers and stoves used in some of the Member States' residential sectors, both country-specific and default $PM_{2.5}$ and NO_x emission factors for solid biomass in small advanced boilers and small conventional boilers, as well as advanced and conventional stoves, are shown in Figure 33 (21).

In the case of solid biomass, significant variations in $PM_{2.5}$ emission factors are observed across the residential sector in the EU-27, unlike NO_x, for which mainly default emission factors are used. There is a considerable difference in the $PM_{2.5}$ emission factors of solid biomass between advanced and conventional boilers, and among Member States. The lowest solid-biomass country-specific $PM_{2.5}$ emission factors are typically associated with small advanced boilers. Finland and Germany exhibit the lowest values among country-specific values. These discrepancies are influenced by the requirements and limits in the emission control legislation of each Member State and the level of technological advancement in each technology category.

Some Member States apply similar country-specific $PM_{2.5}$ emission factors for solid biomass for both advanced boilers and advanced stoves. Among stoves, the advanced ones have lower solid biomass $PM_{2.5}$ emission factors. It can be seen, for example, that in the case of advanced boilers Denmark has

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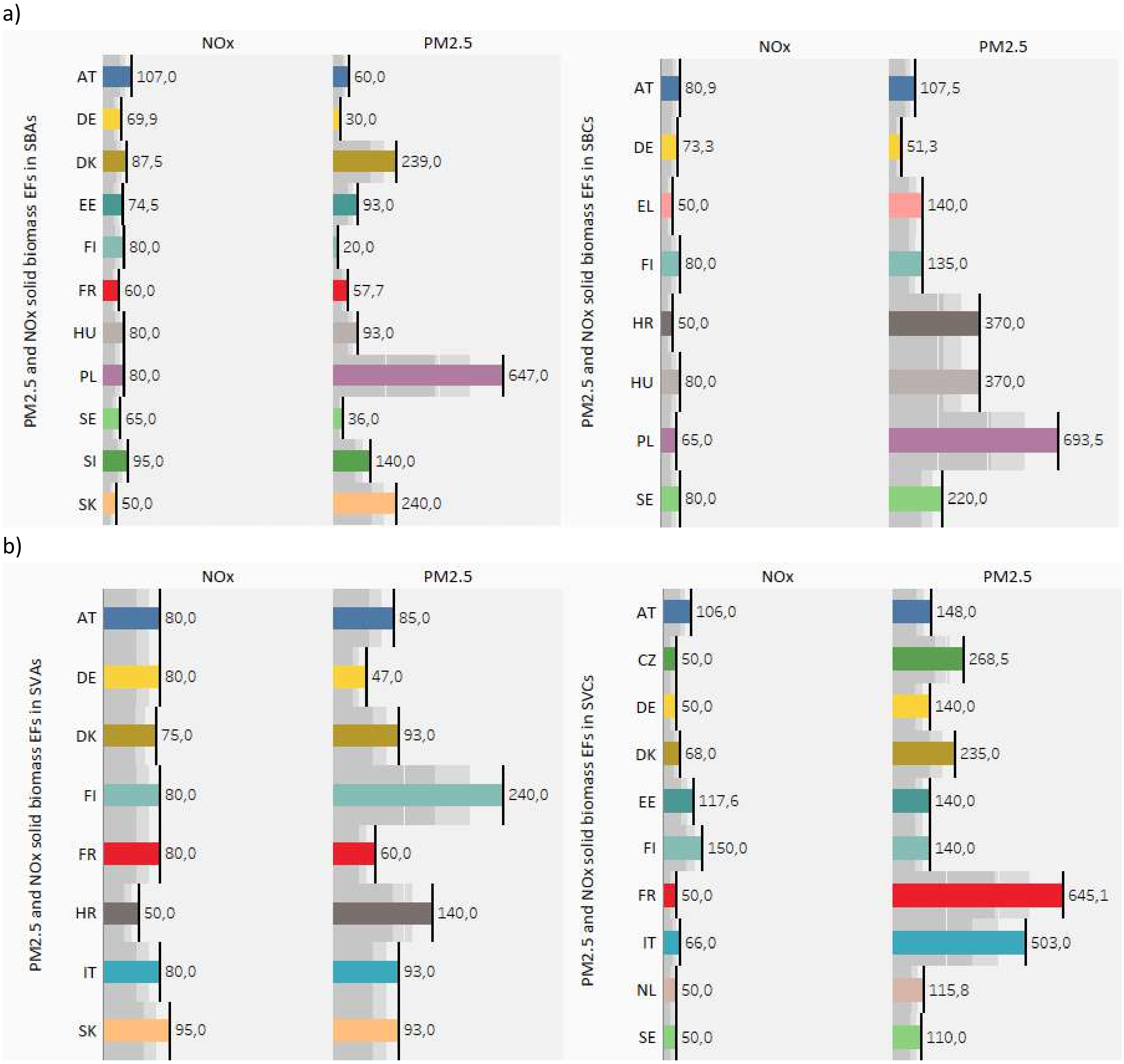
(21) The uncertainties of emission factors shown in this figure vary between countries and between air pollutants, and can be found in the countries' informative inventory reports. For example, the reported uncertainties of NO_x and $PM_{2.5}$ emission factors calculated for the residential sector (National Atmospheric Emissions Inventory code 1A4bi) in Austria are 40 % and 60 %, respectively. For Finland, the reported uncertainty for the biomass-related emission factors for $PM_{2.5}$ in the residential sector is 80% and for other fuels ranges from 100 % to 160 %. In the case of NO_x, this uncertainty is reported at 50 %. In Denmark, the estimated uncertainty for residential wood NO_x emission factors is reported at 50 %, whereas for other fuels it is reported at 30 %. For particulate matter, the estimated uncertainty for residential wood is reported at 200 %, whereas for other fuels it is reported at 50 %.

higher country-specific emission factors. The findings also highlight the differences in the methodologies ([22]) applied to estimate these country-specific values.

Figure 33. Residential $PM_{2.5}$ and NO_x average emission factors from solid biomass in boilers (a) and stoves (b), 2022 (kg/TJ)



NB: Grey shadows represent 80 % and 60 % (from light to dark) of the average emission factor. EF, emission factor; SBA, small advanced boiler; SBC, small conventional boiler; SVA, small advanced stove; SVC, small conventional stove.

Source: EDGAR version 8.1, 2024.

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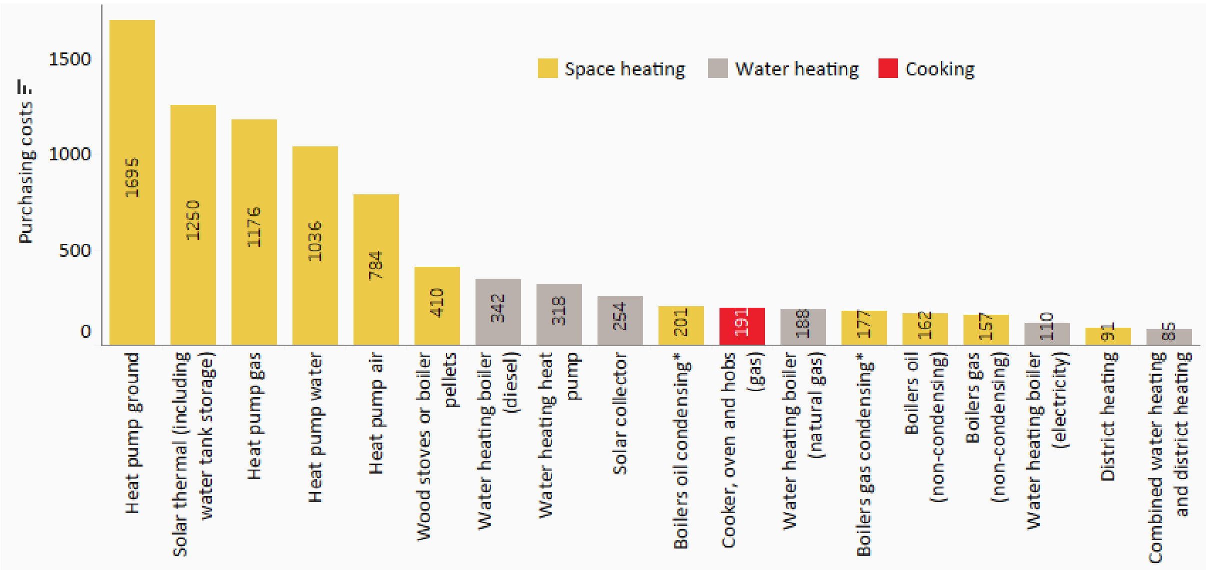
[22] More information on the methodology and typology applied in each Member State to determine emission factors in the residential sector can be found in Banja and Ebeling (2023).

Economic factors, including market dynamics and financial incentives, influence the choices made in the heating and cooling sector. Assessing the cost-effectiveness of different emission reduction measures or technology transitions is essential for the decision-making process. Often the scenarios developed incorporate factors such as purchasing costs, enabling a cost-effectiveness analysis, to evaluate the financial feasibility of implementing specific technologies or measures to reduce emissions. Higher purchasing costs may act as a barrier to the adoption of cleaner technologies.

Figure 34. Purchasing costs of technologies in the domestic sector based on reference scenario 2020 (EUR/kW)



NB: * The costs refer to the boilers only

Source: European Commission, reference scenario 2020

Figure 34 shows the current (as of end of 2019, and as such somewhat dated) purchasing costs based on the European Commission's EU reference scenario 2020. Technologies are split by end use: space heating, water heating and cooking. As shown, the purchasing costs for technologies used for space heating are among the highest.

Heat pumps seem to have the highest purchasing costs: for example, air heat pumps cost nearly double that of wood stoves and pellet boilers. The purchasing costs of wood stoves or boiler pellets are higher than those of oil boilers (condensing and non-condensing) and gas boilers (condensing and non-condensing).

The levelised cost of energy (LCOE) is another metric used to evaluate the lifetime costs of energy generation, providing a more comprehensive assessment that encompasses both upfront and ongoing expenses over the system's lifespan. The LCOE for domestic wood pellet boilers ranges from EUR 200/kW to EUR 600/kW; overall costs for domestic heat pumps range from EUR 750/kW to EUR 2 000/kW and those for domestic gas boilers range from EUR 100/kW to EUR 175/kW (Trinomics, 2020). However, the reliability of the LCOE depends on assumptions regarding future price developments.

7. Forward look to 2030 based on NECPs and European Commission scenarios for delivering the Green Deal

NECPs represent a cornerstone in the EU's strategy to combat climate change and foster a more sustainable energy landscape. Mandated by the governance regulation of the clean energy for all Europeans package (European Parliament and Council of the European Union, 2018), each Member State is required to submit an NECP outlining its strategic approach to achieving the EU's collective climate and energy targets.

NECPs provide a framework for aligning national efforts with the overarching objectives of the European Green Deal and the EU's commitment to becoming climate-neutral by 2050. Based on the governance regulation, NECPs discuss the GHG emission reduction targets, renewable energy deployment, energy efficiency measures, research and innovation, governance, and monitoring. In practice, the NECPs include, to varying extents and levels of detail, other policies interlinked with climate change and energy, for example on the circular economy, biodiversity and water. The NECPs typically outline the mechanisms for monitoring and reporting the progress of policies and measures implemented. This includes establishing indicators and metrics to track changes in air pollutant emissions and assess whether the planned interventions achieve the desired outcomes.

Section 5.1.1 of the NECPs, 'Impact assessment of planned policies and measures', involves a detailed analysis of the anticipated effects of the policies and measures proposed in the NECP on various aspects, including air quality and pollutants. It aims to evaluate the expected impact of the planned interventions in the energy and climate sectors on air pollutants, considering the reduction of harmful emissions and improvement in overall air quality.

The approach taken in this section of the report compares the estimated progress on air pollutant emissions in the energy system in the EU-27, as reported by Member States in accordance with the NECD, the European Commission scenarios under the Green Deal and JRC's in-house scenarios based on the *Global Energy and Climate Outlook* series of reports. This analysis does not prescribe a set of policy recommendations on reducing air pollutant emissions by 2030; it presents only an outlook for the emission of the main air pollutants until 2030. However, it should be noted that the scenarios developed to deliver the Green Deal provide only projections for total emissions for NO_x, $PM_{2.5}$ and SO_2. No information is available from these projections for individual sectors or fuels. The reductions used in the analysis are listed below:

- NEC directive reductions (by EU-27 and Member State);
- Member State projections (23) in their reporting under the NECD (by Member State):
  - the baseline established in the second and third clean air outlook reports (CAO2 and CAO3) and the maximum technically feasible reduction scenario (greenhouse gas and air pollution interactions and synergies (GAINS) model) (by Member State),
  - reference scenario 2020 (EU-27 and by Member State),
  - MIX scenario (EU-27 and by Member State),
  - MIX-CP scenario (EU-27 and by Member State),
  - REG scenario (EU-27 and by Member State)
  - the JRC's Prospective Outlook on Long-term Energy Systems 1.5-degree scenario (EU-27)

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(23) Projections reported under the NECD included in this report are those for existing measures, because not all Member States report projections for both existing and additional measures.

Box 1. Air pollutant emission projections under the NECD

The NECD sets legally binding limits on national emission reduction commitments for key air pollutants in Member States for 2020–2029, and more ambitious ones for 2030. Although the NECD does not establish EU-wide targets, the totals for the EU-28, given in Annex II of the directive, represent the combined national commitments, indicating an overall reduction if all Member States meet their targets. The reductions from 2005 levels for SO_2, NO_x, $PM_{2.5}$, NMVOC and NH_3 emissions are 79 %, 63 %, 49 %, 40 % and 19 %, respectively. Under the NECD, projections of air pollutant emissions must be reported every 2 years. In 2023, 15 Member States reported in accordance with the old version of the template in Annex IV to the EMEP guidelines on reporting to the United Nations Economic Commission for Europe's Air Convention, and the remaining Member States reported following the new Annex IV template (more disaggregated by sector) (see Table 3). The Annex IV template was revised as part of the 2023 reporting guidelines to be aligned with the sectoral disaggregation used to report (historic) emission inventories. This periodic reporting cycle enables the conduct of comprehensive assessments of air pollutant emissions trends and facilitates the development of long-term strategies to effectively address air quality challenges.

Table 3. Reporting formats for air pollutant emission projections in each Member State

Annex IV template (2014 version)	AT, BE, BG, CY, CZ, EE, ES, FI, HR, LV, NL, PT, RO, SI, SK
Annex IV template (2024 version)	DE, DK, EE, IE, IT, FR, HU, LT, LU, MT, PL, SE

Source: Authors, based on Eionet (n.d.) and Centre on Emission Inventories and Projections (n.d.)

Box 2. The European Commission's EU reference scenario 2020

The European Commission's EU reference scenario 2020 presents a projection of the evolution of the EU energy system, transport system and GHG emissions based on EU and Member State policies, as updated through the clean energy for all Europeans package. National policies accounted for in the reference scenario include the main policies set out in Member States' NECPs and in other national plans put forward as of the end of 2019. In the reference scenario, the implementation of EU and Member State policies intensifies until 2030 and continues afterwards, assuming that no additional measures are applied between 2030 and 2050.

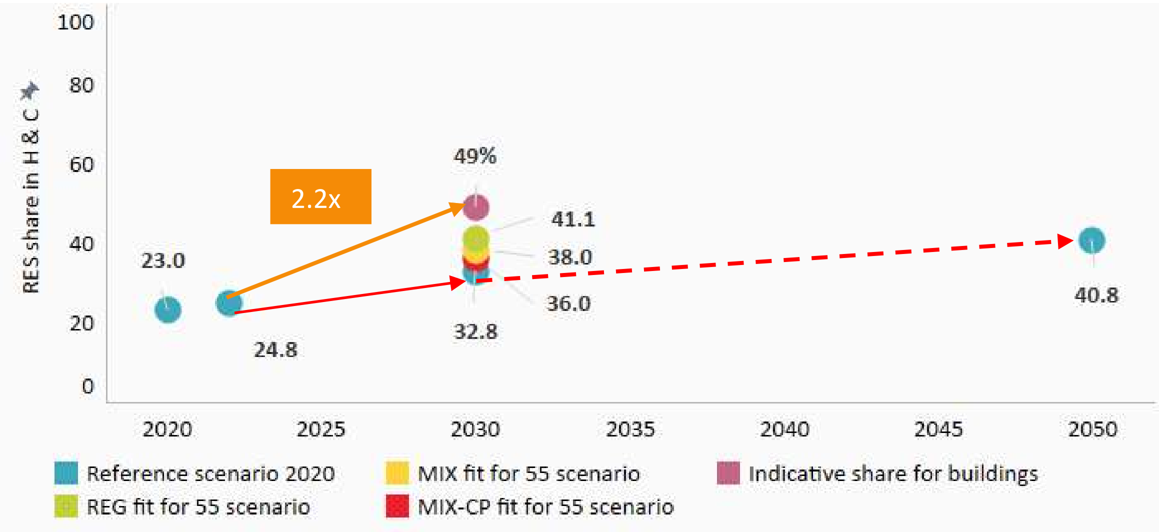
The scenario assumes the achievement of the national contributions to the EU's 2030 targets (based on the EU policy framework in place in May 2021) on energy efficiency and renewable energy: a 32.5 % improvement and a 32 % share, respectively. The reference scenario projects a share of the residential sector in the final energy consumption in 2030 of 24 % and a gross electricity demand that covers 28 % of all sectors in the same year.

The fuel mix in the residential building stock is projected to incorporate less solid fuels (coal) due to policies on air quality, and less liquid fuels (oil) due to growing electrification, connection to gas networks and some extension of district heating infrastructure. The share of electricity in the fuel mix is projected to rise (at a slow pace), driven by the increased use of appliances and the penetration of heat pumps. When projecting air pollutant emissions, the scenario developed by the International Institute for Applied System Analysis uses 2015 as a baseline.

Source: European Commission: DG Energy, n.d.a

The share of renewable energy in the EU-27 reached 24.8 % in 2022, an increase by 1.8 pp compared with 2020 (less than 1 pp annually). The reference scenario 2020 projects a renewable energy share in the heating and cooling sector in the EU-27 of 32.8 % for 2030, an increase of 1 pp annually compared with the 2022 level. The revised renewable energy directive provides an overall binding target of at least 42.5 % by 2030 at the EU level, with an ambition of reaching 45 %. Specifically for the heating and cooling sector, it provides an increase of 0.8 pp annually up to 2026 and an increase of 1.1 pp annually between 2026 and 2030 in the share of renewable energy. The REG scenario projects a 2030 renewable energy share of 41.1 %, whereas the projections for the MIX and MIX-CP scenarios are 38.0 % and 36.0 %, respectively (see Figure 35). As shown in Figure 35, an acceleration factor of 2.2 is needed to reach the 2030 target set in the modelling framework to reach the renewable target needed for climate neutrality by 2050.

Figure 35. Acceleration required to reach the 2030 RES share target in the EU-27 heating and cooling sector (%)



NB: The acceleration factor is calculated using the average of the annual change in historic RES share in the heating and cooling sector for 2020 and 2022, and the average of the annual change in projected RES share in this sector. The RES shares in the sector based on different scenarios are used to calculate the average annual change in projected RES share towards which the acceleration is calculated. H & C, heating and cooling.

Source: Authors, based on the European Commission's reference scenario 2020 and Green Deal scenarios.

Box 3. European Commission scenarios for delivering the Green Deal

'Fit for 55' policy scenarios present projections for an energy system and economy-wide GHG emissions balance compatible with at least a 55 % reduction in GHG emissions by 2030 in the presence of three representative policy mixes.

- The REG scenario relies on the very strong intensification of energy and transport policies in the absence of carbon pricing in the road transport and buildings sectors.
- The MIX scenario relies on both the extension of (uniform) carbon pricing to the road transport and buildings sectors and a substantial intensification of energy and transport policies.
- The MIX-CP scenario represents a more carbon-price-driven policy mix that illustrates a revision of the energy efficiency directive and the renewable energy directive but is limited to less intensification of current policies and the application of carbon pricing to new sectors.

These three fit for 55 core policy scenarios were produced based on the EU reference scenario 2020, and therefore use the same updated macroeconomic assumptions, including the impact of the COVID-19 pandemic and international fuel prices. All three scenarios have the same baseline as the reference scenario: the air pollutant emissions for 2015.

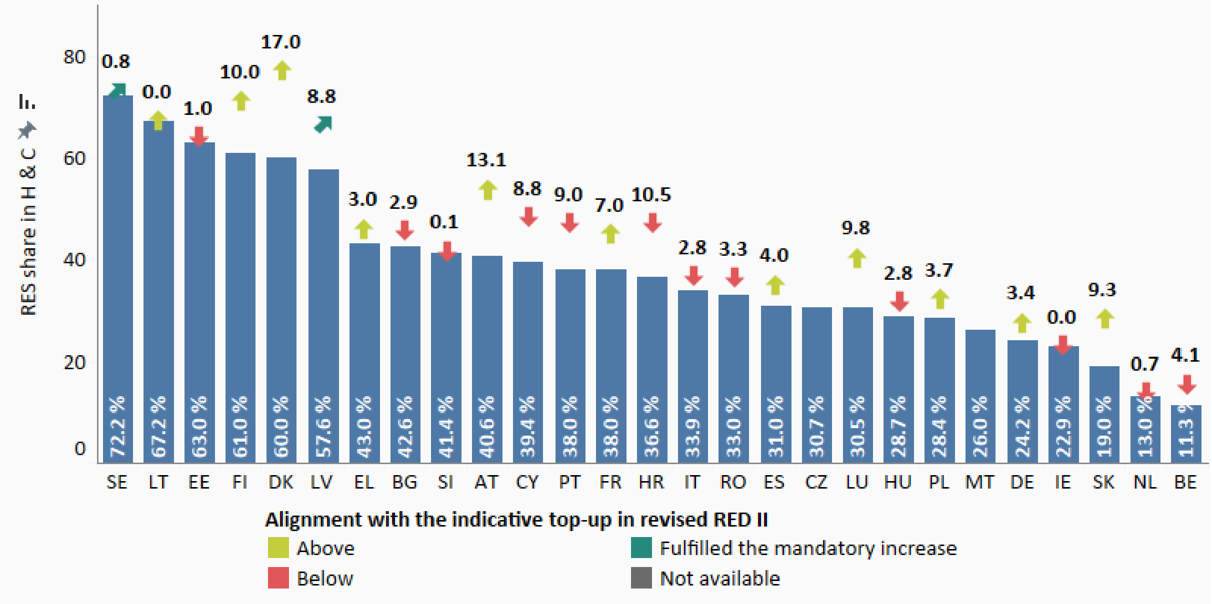
Source: European Commission: DG Energy, n.d.b

A recent JRC report (Toleikyte and Carlsson, 2021) revealed that, based on the 2019 NECPs, the renewable energy share in the heating and cooling sector in the EU-27 is expected to reach 33 % by 2030 (excluding Spain and Latvia from the evaluation). This level is comparable to the projected share in the EU reference scenario 2020.

Figure 36 shows the renewable energy share in the heating and cooling sector in each Member State, as projected in their 2019 NECPs (bars) and the change (in pp) between these 2019 projections and the 2023 draft NECPs ([24]).

As shown, some Member States increased their ambitions in the 2023 NECPs, reaching higher shares of renewable energy. Denmark has the largest increase (17 pp) from the share of renewables in the sector projected in its 2019 NECP. Sweden remains in 2030 the Member State with the highest penetration of renewable energy in its heating and cooling sector, with a projected 73 % share (2023 draft NECP), an increase by 7 pp from the 2022 level.

Figure 36. 2030 RES share in the heating and cooling sector in each Member State, 2019 and 2023 (%) and change between 2019 and 2023 (draft) (pp) NECPs



NB: Arrow colour and direction represent the alignment of the 2030 renewable energy share reported in the heating and cooling sector compared with the indicative top-up trajectory in the revised renewable energy directive. H & C, heating and cooling. Czechia and Malta have not reported their renewable energy share in the heating and cooling sector in their 2023 (draft) NECPs.

Source: Authors, based on 2019 and (draft) 2023 NECPs.

However, this increase in ambition does not always align with the requirements of the revised renewable energy directive (RED II). Comparing this increase with the expectations determined using the requirements outlined in the revised renewable energy directive (stating that the share of renewables in the heating and cooling sector should increase by 0.8 pp annually until 2025 and by 1.1

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[24] The analysis of the 2023 NECPs is based on the plans already submitted and on the Commission recommendations set out in staff working documents. The input for Austria comes from its NECP draft, submitted in August 2024.

pp from 2026 to 2030) reveals that the level of ambition has fallen below the trajectory required to achieve the 2030 targets in 12 Member States.

The overall renewable energy share projected for 2030 in the 2023 (draft (25)) NECPs remained below the shares calculated using the formula in Annex II of the governance regulation of the clean energy for all Europeans package in 19 Member States. Only three Member States reported a higher overall renewable energy share in their 2023 (draft) NECPs than their 2019 NECPs.

Looking at the contributions of technologies in the heating and cooling sector, an increase of nearly 22 % (26) between the 2019 NECPs and 2023 (draft) NECPs in heat pump energy consumption is found. Twelve EU-27 Member States projected higher heat pump energy consumptions in their 2023 (draft) NECPs. Italy's heat pump energy consumption contribution increased by 17 % between the releases of its NECPs, making it the Member State with the highest contribution (6.7 Mtoe in its 2023 NECP draft).

According to the 2023 NECP drafts, the projected contribution of biomass heating (27) is only 1.5 Mtoe higher than the projections from the 2019 NECPs, reaching nearly 90 Mtoe by 2030. Among Member States for which a comparative analysis between the 2019 and 2023 NECPs was available, the projected biomass for heating and cooling purposes decreased in Greece (by 34 %), Croatia (by 22 %), Sweden (by 10 %), Hungary (by 9 %), and Finland (by 4 %). As stated in Greece's 2023 NECP draft, the decrease in projected biomass consumption is mainly related to air pollution.

An increase of nearly 2.5 Mtoe in biomass used for heating and cooling purposes is projected in Italy's 2023 NECP draft compared with the 2019 submission. This increase is expected to mainly rely on the use of biomethane. Similarly, France's 2023 NECP draft projects a higher consumption of biomass for heating and cooling purposes, with an increase of nearly 0.7 Mtoe, primarily based on increased biogas consumption. Ireland projected an increase of 35 % between its two NECPs to 552 ktoe in 2030, more than double the biomass consumption in this sector in 2022.

The impact assessment of planned policies and measures that is required in Section 5.1.1 of the EU Member States' NECPs should include, where relevant, projections of air pollutant emissions in accordance with the NECD (Directive (EU) 2016/2284). From analysing the first release of the NECPs and the draft second release of the NECPs, a detailed report on air pollutant emission projections is rarely included in the section.

Evaluating the 2019 NECPs and the 2023 draft NECPs, few Member States include detailed data in their NECPs about their air pollutant emission projections. This may be linked to the fact that the air pollutant projections are reported under the NECD, and Member States – except Denmark, whose reporting was similar to that specified the NECD – include only projections for the total emission of the main air pollutants with no breakdown by sector contributing to the air pollution. Annex 2 summarises the reporting of the NECPs regarding air pollutant projections and impact assessments.

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(25) These were still drafts at the time this report was prepared.

(26) Five Member States did not provide information on the projected heat pump energy consumption in 2030 in their 2023 (draft) NECPs. For four Member States (Germany, Latvia, Lithuania and Austria), the Reference 2020 scenario data are used, whereas for Slovenia the value reported in the 2019 NECP is the same as in the 2023 NECP (draft).

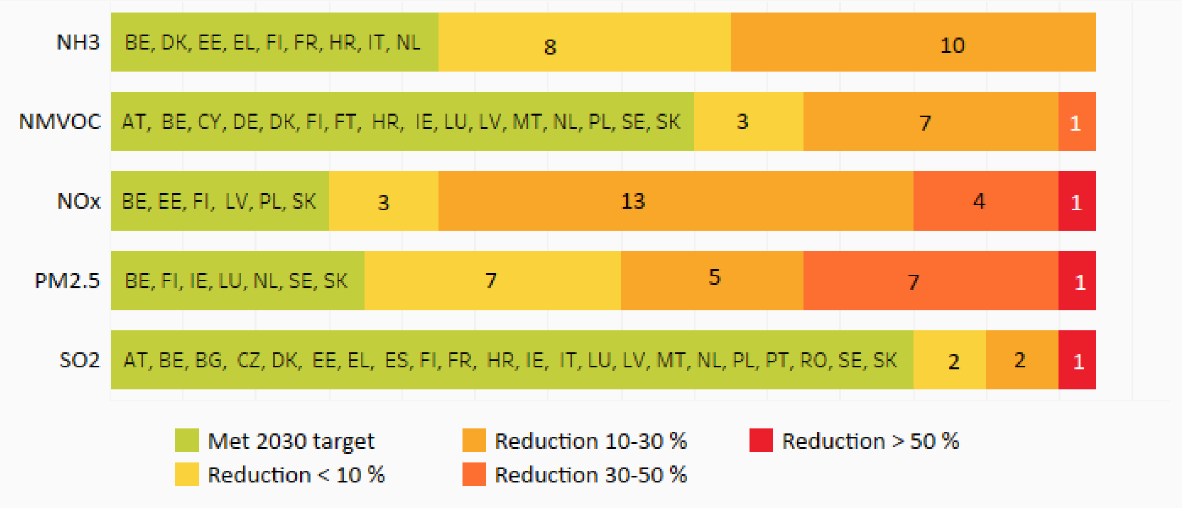
(27) Estimation based on the 2019 NECPs and the 2023 NECP drafts, excluding the projected biomass consumption in Spain, as this information is not provided in any of the NECPs it submitted.

Box 4. Current progress towards meeting the 2030 emission reduction commitments

In their reporting under the NECD, the Member States submit air pollutant emission inventories on a yearly basis. In accordance with the NECD, evaluations are conducted to assess compliance with national emission reduction commitments for 2020–2029 concerning the five key air pollutants ([28]). Apart from the formal compliance checks by the Commission, the European Environment Agency provides each year an early indication of where Member States stand in comparison to both the currently applicable reduction commitments and the more ambitious ones that will apply as of 2030.

The evaluation for 2022, which was based on Member States' reports in 2024, indicated that 16 Member States met the emission reduction commitments set for 2020–2029 for all five main pollutants. Figure 37 illustrates the status of progress towards emission reduction commitments for 2030 for each air pollutant in 2022.

Figure 37. Overview of the status of progress towards emission reduction commitments for 2030, 2022



Source: EEA, 2024.

The approach taken in this section is comparing the projections available for the air pollutant emissions for the EU-27 and each Member State. This analysis does not prescribe a set of policy recommendations on reducing air pollutant emissions by 2030; it presents only an outlook, based on various scenarios, on the levels of the main air pollutants in 2030.

Figure 38 ([29]) provides the reduction from the 2005 level for NO_x, $PM_{2.5}$ and SO_2 emissions, as projected in the abovementioned scenarios. The NO_x, $PM_{2.5}$ and SO_2 emissions for 2015 and 2022 are also shown.

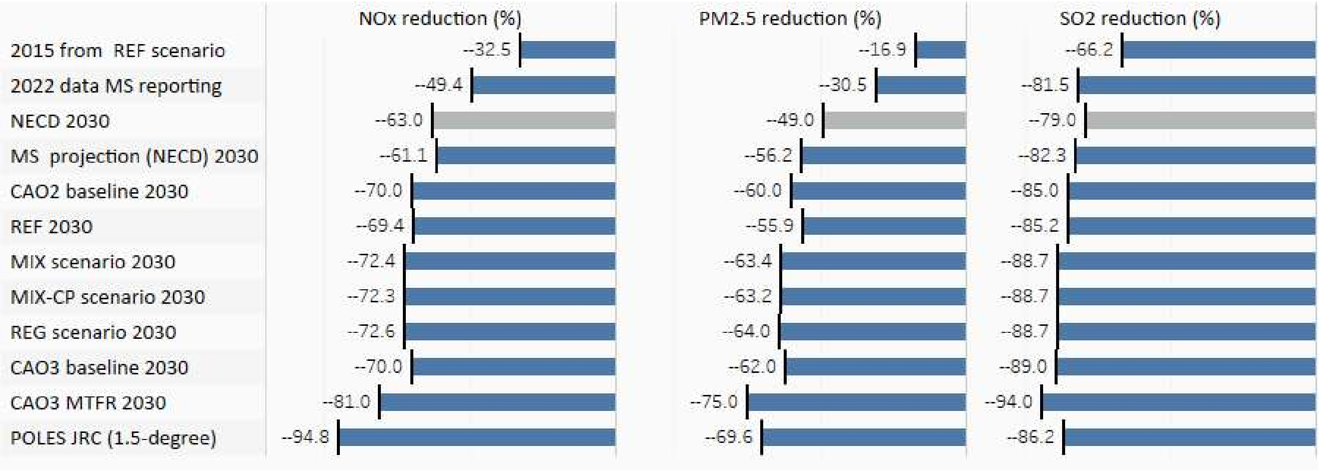
The CAO2 and CAO3 baseline projections for the EU-27 indicate the same reductions in NO_x emissions as in 2005. These reductions align with the projections in the EU reference scenario 2020, and are around 3 pp lower than the reductions in the fit for 55 scenarios. Conversely, the reductions projected for $PM_{2.5}$ emissions in both the CAO2 and thee CAO3 scenarios are more closely aligned with the MIX

([28]) The results of the inventory reviews are available at https://environment.ec.europa.eu/topics/air/reducing-emissions-air-pollutants/emissions-inventories_en#review-of-national-emission-inventories.

([29]) Relative reductions compared with 2005, for all scenarios except the NECD and CAO3 scenarios, are calculated based on the pollutant levels reported by Member States in 2023 under the NECD.

scenario, as the reference scenario forecasts a less significant reduction. Notably, all scenarios project higher reductions for $PM_{2.5}$ emissions than the NECD's 2030 projections.

Figure 38. Reduction by 2030 compared with 2005 projected under different scenarios in the EU-27 for NO_x, $PM_{2.5}$ and SO_2 (%)

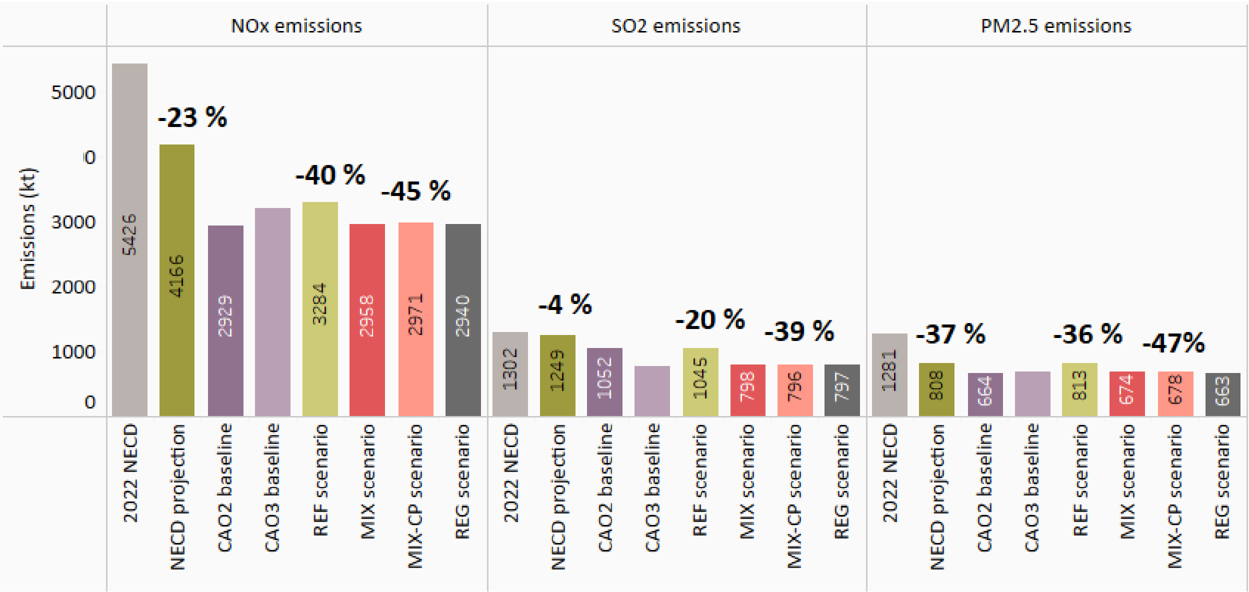


NB: MTFR, maximum technically feasible reduction; REF, reference scenario 2020.

Source: Authors, based on the European Commission's Green Deal scenarios, NECD-based reporting, the NECD, IIASA (n.d.), CAO3 and the JRC's Prospective Outlook on Long-term Energy Systems model.

Regarding SO_2 reductions, the 2023 projections for Member States under the NECD have resulted in larger reductions than the NECD target by 3.3 pp. However, the reduction projected by Member States is around 3 pp less ambitious than the reduction in the CAO2 scenario and nearly 7 pp less ambitious than in the CAO3 scenario. The reference scenario and the three fit for 55 scenarios show higher levels of ambition than the NECD target for SO_2, with reductions that are 6.2 pp and 9.7 pp larger, respectively.

Figure 39. Comparison of 2030 projections with 2022 data for NO_x, $PM_{2.5}$ and SO_2 emissions in the EU-27



Source: Authors, based on the European Commission's Green Deal scenarios, NECD-based reporting, the NECD, IIASA (n.d.) and the JRC's Prospective Outlook on Long-term Energy Systems model.

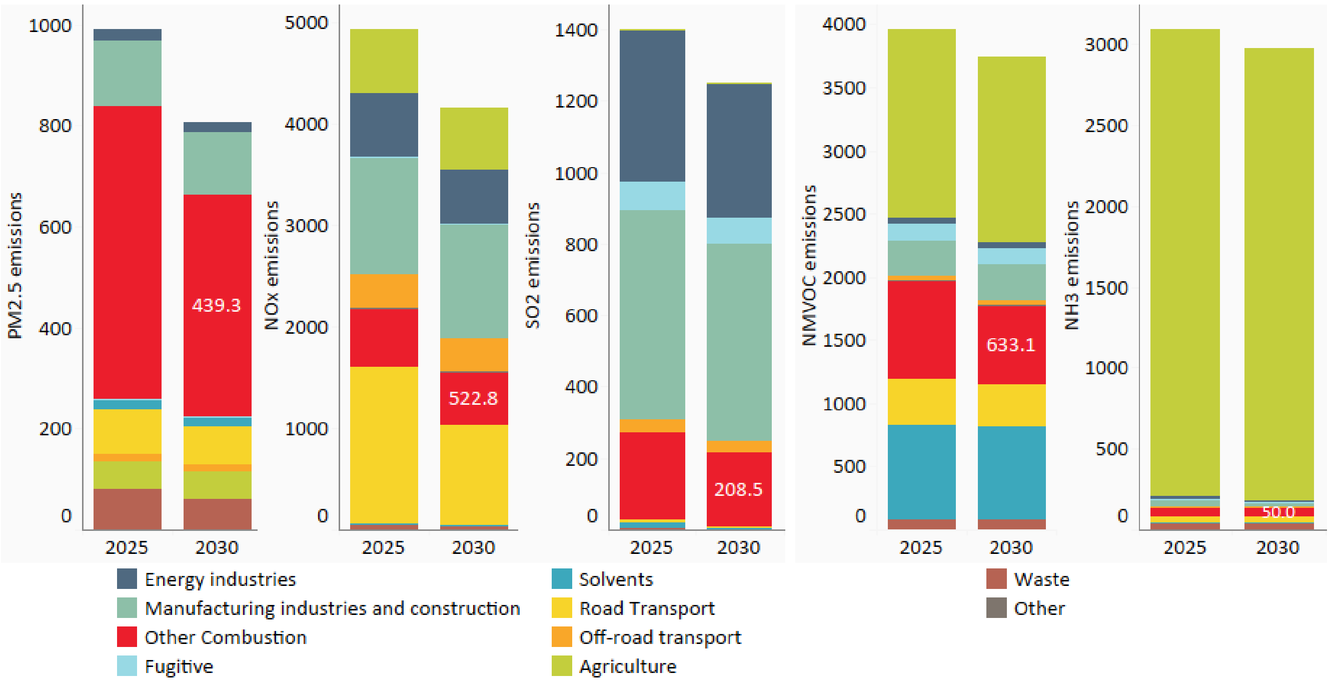
Figure 39 illustrates the absolute levels of projected NO_x, SO_2 and $PM_{2.5}$ emissions, alongside the necessary reductions compared with the 2022 level. Projections from Member States indicate reductions of 23 %, 4 % and 37 % below the 2022 level for NO_x, SO_2 and $PM_{2.5}$, respectively.

The reference scenario projects a 40 % reduction in NOx emissions from the 2022 level, while the fit for 55 scenarios anticipate a 45 % reduction.

For SO_2 emissions, the reference scenario projects a 20 % reduction from the 2022 level, while the fit for 55 scenarios forecast a 39 % reduction. Projected reductions in $PM_{2.5}$ emissions under the reference scenario and fit for 55 scenarios are 36 % and 47 %, respectively.

Given the lack of detailed sectoral projections for air pollutant emissions in most scenarios other than those provided by the International Institute for Applied System Analysis's GAINS model and those reported by Member States under the NECD, the following overview presents emission levels based on these two data sources.

Figure 40. Projected $PM_{2.5}$, NO_x, SO_2, NMVOC and NH_3 emissions in the EU-27, by sector, 2025 and 2030 (kt)



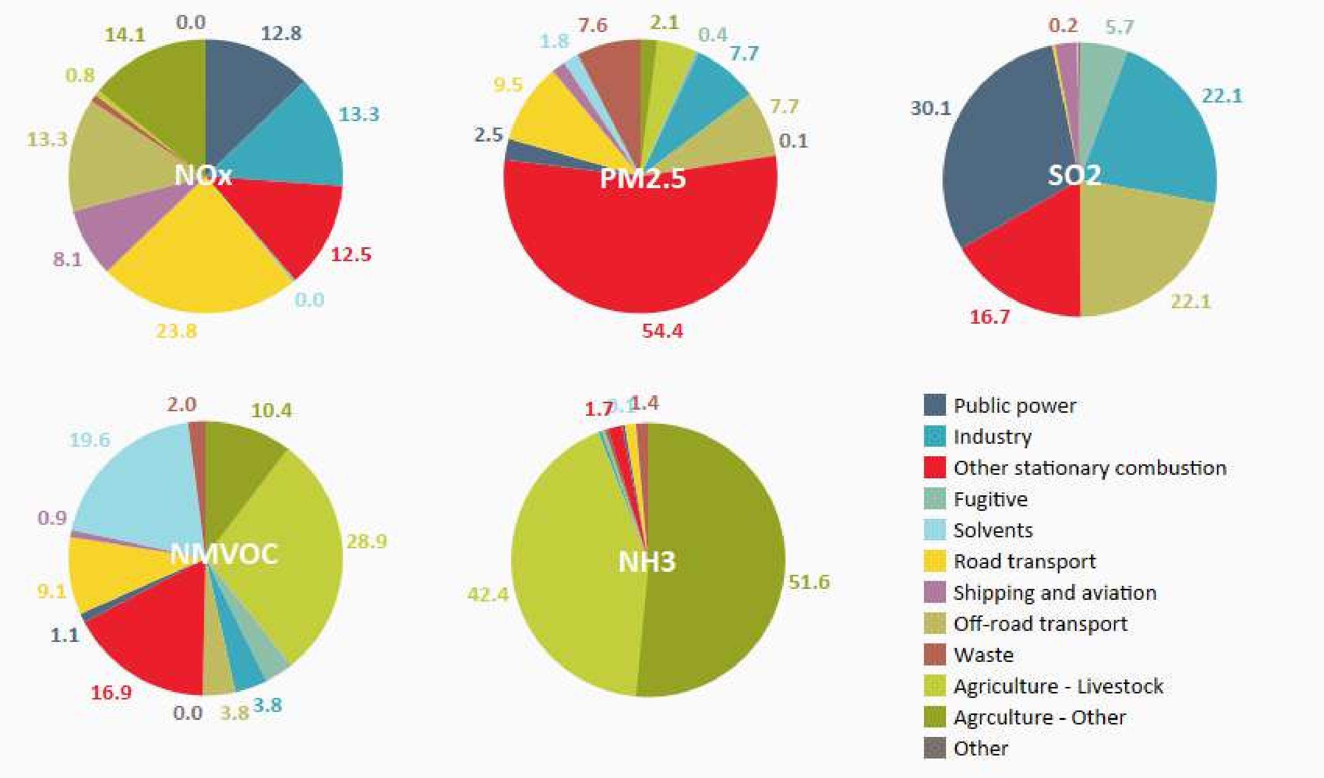
Source: Authors, based on Member State reporting under the NECD, 2023.

Figure 40 shows the projected emissions for NO_x, SO_2, $PM_{2.5}$, NMVOC and NH_3 in the EU-27 in 2025 and 2030, as reported by Member States in 2023.

Similarly, Figure 41 illustrates these projections in relative terms, indicating that small-scale combustion is expected to remain the primary source of $PM_{2.5}$ emissions in the EU-27 in 2030, with a slightly lower share than in 2022 (halved in absolute terms).

The relative contribution of small-scale combustion to NO_x emissions is projected to increase slightly, primarily due to the significant projected decline in the transport sector.

Figure 41. Projected 2030 NO_x, $PM_{2.5}$, SO_2, NMVOC, and NH_3 emissions in the EU-27, by sector (%)



Source: Authors, based on Member State reporting under the NECD, 2023.

8. Conclusions

The heating and cooling sector is a significant contributor to air pollution, with various factors influencing the trends observed in pollutant emissions. A comprehensive understanding of these factors is crucial for developing effective strategies to mitigate environmental impact. In this context, it is important to explore the technological, regulatory, and economic influences shaping air pollution in the heating and cooling sector, while also identifying significant contributors to pollution trends.

The EU has established a robust regulatory framework to address air quality concerns, with specific directives targeting emissions from the heating and cooling sector by enhancing energy efficiency and promoting the use of renewable energy sources. This sector is integral to reducing GHG emissions and improving air quality, in line with the broader goals of the Green Deal and the zero pollution action plan.

In their 2023 draft NECPs, the Member States increased their ambitions to deploy renewable energy systems in the heating and cooling sector compared with previous versions of the plans.

However, the heating and cooling sector needs to accelerate the deployment of renewable systems to achieve the renewable share targets for 2030 in the fit for 55 scenarios. Reaching a 32.8 % share of renewable heat, as in the EU reference scenario 2020, means achieving an 8 pp increase from 2022 to 2030 (1 pp annually). Previously, an 8 pp increase was achieved over 14 years (from 2009 to 2023). That transition in the heating and cooling sector is considered important at the policy level in the EU is expressed in the target established in the renewable directive for this sector, requiring an increase of 1.1 pp annually between 2026 and 2030.

An analysis of air pollutant emission trends since 2005 reveals that heat-related activities constitute a significant source not only of particulate matter but also of pollutants such as NO_x and SO_2, largely due to the substantial contribution of stationary combustion in the industrial sector. For instance, heat-related activities are estimated to be the second largest contributor to NO_x emissions, with the transport sector traditionally recognised as the primary source.

The reporting requirements outlined in the governance regulation of the clean energy for all Europeans package mandate Member States to incorporate in their NECP analyses data on the impact of policies concerning, where relevant, air pollution trends and projections. However, in most cases NECPs (2019 and 2023 drafts) provide more detailed information and data about GHG emissions than air pollution.

The European Commission's modelling of air pollutants in various scenarios offers projections only for total levels of NO_x, SO_2 and $PM_{2.5}$, using 2015 as the baseline year. There is a lack of data for intermediate years (e.g. 2025), and no sectoral, subsectoral or fuel-specific data are available for these scenarios. Furthermore, there are limitations on scenario choices, with only a few providing detailed data, which are used to assess progress on air pollutant emissions from heating and cooling as we move towards 2030. Details by sector/subsector on trends in air pollutants can be found in the Member States' projections. These are produced every 2 years, as required by the NECD.

Over 2018–2022, the European Commission published three clean air outlook reports (CAO1, CAO2 and CAO3), offering aggregated information on emission projections and deviations from the NECD reduction targets. Detailed information utilised in the CAO2 assessment is accessible through the IIASA's GAINS model (open data), while detailed data for each Member State and each sector used for the CAO3 assessment are not yet publicly available.

The analysis showed that the reductions in the Member States' projections under the NECD are less pronounced than those in the fit for 55 scenarios. Overall, the change in SO_2 emissions as we move towards 2030 aligns more with the targets in place.

According to the Member States' projections reported in 2023, the small combustion sector remains the main source of $PM_{2.5}$ emissions, with a slightly lower share than in 2022 (halved in absolute terms). The contribution of the heating and cooling sector to NO_x is projected to increase slightly. This is primarily due to the significant projected decline in the transport sector, with a minor decrease in absolute terms.

The analysis performed showed that there was a moderate decrease in air pollutant emissions related to heating. The residential sector in the EU-27 is still dominated by conventional technologies, and is transitioning slowly towards more cleaner technologies. The choice of technologies has a direct impact on air pollution, since outdated and inefficient technologies tend to produce higher emissions.

The way forward

- Better data on air pollutant emissions, including more detailed reporting of historic and projected values, will help in the monitoring process and the identification of specific sectors contributing to air pollution.
- Faster deployment of renewable energy technologies and stricter regulations on emissions from fossil-fuel-based systems are needed.
- Subsidies, tax incentives and grants can make renewable energy systems more affordable for residential and industrial users, facilitating the transition from fossil fuels.
- Encouraging a transition towards cleaner heating and cooling technologies, such as advanced heat pumps, solar thermal systems and next-generation bioenergy solutions, can contribute significantly to reducing emissions in the heating and cooling sector, helping to improve public health and assisting in climate change mitigation efforts.

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List of abbreviations and definitions

CAO	clean air outlook
CO	carbon monoxide
CO_2	carbon dioxide
EDGAR	Emissions Database for Global Atmospheric Research
EMEP	European monitoring and evaluation programme
GAINS	greenhouse gas and air pollution interactions and synergies
GHG	greenhouse gas
HRV	heat recovery ventilation
IIASA	International Institute for Applied System Analysis
LCOE	levelised cost of energy
NECD	national emission reduction commitments directive
NECP	national energy and climate plan
NMVOC	non-methane volatile organic compound
NH_3	ammonia
NO_x	nitrogen oxides
$PM_{2.5}$	2.5 µm particulate matter
PM_{10}	10 µm particulate matter
pp	percentage points
SO_2	sulphur dioxide

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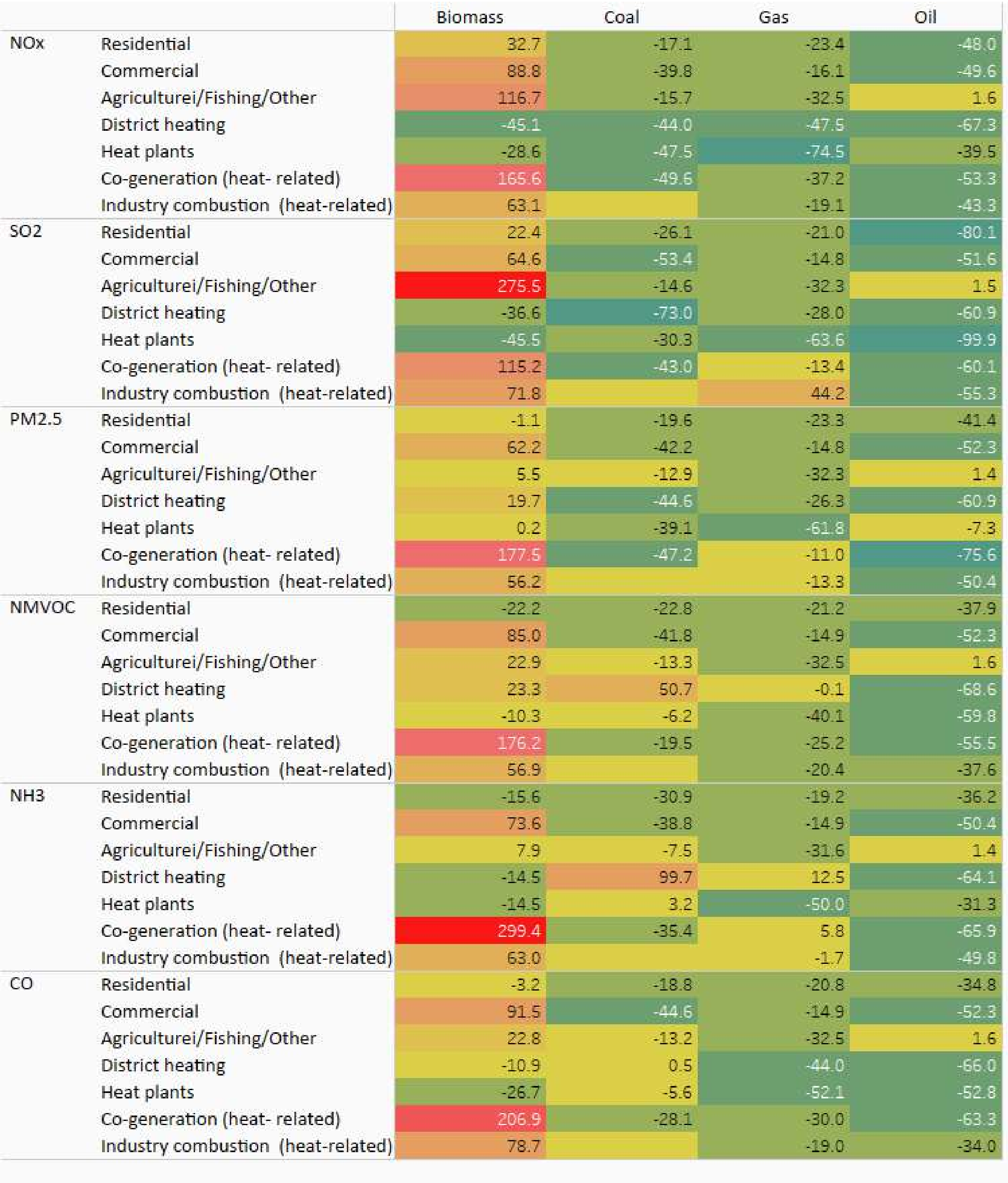
Annexes

Annex 1. Contribution of fuels to air pollutant emissions in the EU-27 heat-related sectors

Table 4. Relative changes in main fuel carriers in the EU-27 heat-related sectors, 2005–2022 (%)



		Biomass	Coal	Gas	Oil
NOx	Residential	32.7	-17.1	-23.4	-48.0
	Commercial	88.8	-39.8	-16.1	-49.6
	Agriculturei/Fishing/Other	116.7	-15.7	-32.5	1.6
	District heating	-45.1	-44.0	-47.5	-67.3
	Heat plants	-28.6	-47.5	-74.5	-39.5
	Co-generation (heat- related)	165.6	-49.6	-37.2	-53.3
	Industry combustion (heat-related)	63.1		-19.1	-43.3
SO2	Residential	22.4	-26.1	-21.0	-80.1
	Commercial	64.6	-53.4	-14.8	-51.6
	Agriculturei/Fishing/Other	275.5	-14.6	-32.3	1.5
	District heating	-36.6	-73.0	-28.0	-60.9
	Heat plants	-45.5	-30.3	-63.6	-99.9
	Co-generation (heat- related)	115.2	-43.0	-13.4	-60.1
	Industry combustion (heat-related)	71.8		44.2	-55.3
PM2.5	Residential	-1.1	-19.6	-23.3	-41.4
	Commercial	62.2	-42.2	-14.8	-52.3
	Agriculturei/Fishing/Other	5.5	-12.9	-32.3	1.4
	District heating	19.7	-44.6	-26.3	-60.9
	Heat plants	0.2	-39.1	-61.8	-7.3
	Co-generation (heat- related)	177.5	-47.2	-11.0	-75.6
	Industry combustion (heat-related)	56.2		-13.3	-50.4
NMVOC	Residential	-22.2	-22.8	-21.2	-37.9
	Commercial	85.0	-41.8	-14.9	-52.3
	Agriculturei/Fishing/Other	22.9	-13.3	-32.5	1.6
	District heating	23.3	50.7	-0.1	-68.6
	Heat plants	-10.3	-6.2	-40.1	-59.8
	Co-generation (heat- related)	176.2	-19.5	-25.2	-55.5
	Industry combustion (heat-related)	56.9		-20.4	-37.6
NH3	Residential	-15.6	-30.9	-19.2	-36.2
	Commercial	73.6	-38.8	-14.9	-50.4
	Agriculturei/Fishing/Other	7.9	-7.5	-31.6	1.4
	District heating	-14.5	99.7	12.5	-64.1
	Heat plants	-14.5	3.2	-50.0	-31.3
	Co-generation (heat- related)	299.4	-35.4	5.8	-65.9
	Industry combustion (heat-related)	63.0		-1.7	-49.8
CO	Residential	-3.2	-18.8	-20.8	-34.8
	Commercial	91.5	-44.6	-14.9	-52.3
	Agriculturei/Fishing/Other	22.8	-13.2	-32.5	1.6
	District heating	-10.9	0.5	-44.0	-66.0
	Heat plants	-26.7	-5.6	-52.1	-52.8
	Co-generation (heat- related)	206.9	-28.1	-30.0	-63.3
	Industry combustion (heat-related)	78.7		-19.0	-34.0

Source: EDGAR version 8.1, 2024.

Annex 2. Reporting on air pollutant projections and their impact on policy in NECPs

Table 5. Status of reporting on air pollutant projections and their impact on policy in Member States' NECPs

Country	Reporting in Section 5.1.1 of NECPs
AT	No
BE	Partially – only for Wallonia
BG	Yes
CY	Only totals in the 2019 NECP and the 2023 NECP (draft)
CZ	Only totals in the 2019 NECP
DK	Reports detailed air pollutant emissions
DE	Yes in final 2019 NECP; no in 2023 NECP (draft)
EE	Yes in final 2019 NECP; short analysis in the 2023 NECP (draft)
EL	No – needs to refer to the European Environment Information and Observation Network Central Data Repository
ES	Not in detail
IE	In graphical format in the 2019 NECP; no in the 2023 NECP (draft)
IT	Only totals in the 2019 NECP and the 2023 NECP (draft)
FR	Only totals in the 2019 NECP and the 2023 NECP (draft)
FI	No
LV	No
LT	Only totals in the 2019 NECP and the 2023 NECP (draft)
LU	No
HR	No
HU	No
MT	Analysis in the 2019 NECP – totals and by sector
NL	Short analysis of totals in the 2023 NECP (draft)
PL	Analysis and projection data by sector in the 2019 NECP and the 2023 NECP (draft)
PT	Only reductions (%) for main air pollutants in the 2019 NECP
RO	No
SI	No
SK	No
SE	Targets (absolute and relative) for totals in the 2019 NECP and the 2023 NECP (draft)

Source: Authors, based on 2019 and (draft) 2023 NECPs

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