Increasing policy coherence between bioenergy and clean air policies and measures

Final Project Report

Written by Logika Group, TNO and Ineris
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Directorate-General for Environment
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Contents

Tables

Figures

1 Executive Summary

This project was commissioned by DG Environment under the Air Quality Support Framework, to assess the evidence on the impacts of bioenergy use (solid biomass for heat and electricity generation) on air quality, the responses by Member States to such impacts, and to support increased policy coherence at the EU level in relation to this issue. The specific objectives were to:

1) Collate, analyse and summarise evidence on the air pollution effects of biomass combustion and related health impacts, to assess the size of the challenge and policy trade-offs arising from this. The project included an assessment of the impact of bioenergy emissions on Member States' ability to meet EU air quality standards and air pollutants emission reduction commitments

2) Draw together good practice and mitigation measures implemented or under consideration by Member States, regions and local authorities across the EU (and other European countries such as Norway, Switzerland and the UK) for dealing with the identified trade-offs

3) Provide support to the European Commission to help address trade-offs between bioenergy and clean air objectives through ecodesign and energy labelling, and in the context of the Energy Performance of Buildings Directive

The project included an extensive literature review to help provide the evidence underpinning the first and second objectives. This was supplemented by a stakeholder outreach programme which included both a survey and targeted interviews. Key stakeholders included NGOs, trade bodies and representatives from Member States, cities and regions (see section 3).

The research showed that solid biomass used for heat and energy generation is the single largest source of fine particulate matter ($PM_{2.5}$) emissions across the EU. This is largely as a result of domestic combustion, which makes up around half of total emissions, and which in turn is dominated by wood fuel combustion (see section 4). $PM_{2.5}$ is the main driver of the health effects of air pollution and is thus of primary concern for air quality policy. In the EU, the use of bioenergy increased rapidly between 2005 and 2020, although in recent years the growth has levelled out, potentially due to uncertainty in policies and debates about sustainability of bioenergy[1].

A review of EU legislation and policy showed that while there are drivers to facilitate the increased use of bioenergy, particularly within the energy and climate space, there is also a well-developed body of legislation and policy to control air quality. The two policy areas are, largely, separate and distinct, and stakeholder feedback suggested a perception of mixed messaging. Other than the requirements of the Ecodesign Directive, measures to specifically address the air quality impacts of small-scale bioenergy use largely rest at the Member State level (see section 5). During the lifetime of this project, two potential areas for better harmonisation of air quality and climate/energy interests with regard to bioenergy were available and have been studied. These were the revision of the Ecodesign Directive (2009/125/EC), and the revision of the Energy Performance of Buildings Directive (EPBD, 2010/31/EU). Consequently, this project has formulated recommendations on how to put in practice an indicator for $PM_{2.5}$ emissions from buildings under the Energy Performance of Buildings Directive (Annex 1)a)i)(1)(a)(i)A7). While this is an optional indicator, it does provide a small step towards greater integration of energy, climate and air quality considerations, in relation to domestic use of bioenergy in particular, at a practical level.

The project identified around 130 measures implemented in EU and other European countries to address the adverse impacts of small-scale bioenergy use (e.g. log burners, wood stoves, fireplaces and boilers) on air quality (see section 6). These have been classified according to four broad categories and analysed further for their key features. The categories are:

1 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130730/2022.5470_kjna31283enn.pdf

- Operational measures, aimed at improving the emissions from existing appliances (including improved fuel quality)
- Stack replacement measures, aimed at improving the emission performance of installed appliances through replacement with lower or zero emission alternatives
- Use restrictions, which prevent the use of all or certain categories of bioenergy appliances under given conditions
- Information and training

The analysis of these measures, assisted by targeted interviews with some stakeholders, has allowed the development of a set of principles for the development of measures at Member State, regional or city level. These are set out more fully in section 6.7 but in summary are:

- The measures need to fit the issues, i.e. the nature of bioenergy use, the location where the measures are to be targeted and the availability of alternative sources of heating
- A variety of measures is likely to be required, at different administrative levels, to provide an overall framework within which measures can be adapted to local circumstances
- Measures need to be bound together in a coherent, publicly accessible strategy, in order to make clear the overall intention of the policy and how the measures contribute towards it
- Measures need to include both suppliers and consumers, especially as a large proportion of fuel wood is sourced through grey or non-market routes
- Information is a key component, as is the way in which information is presented, including the routes through which it is disseminated. For example, chimney sweeps have been shown to be an effective route to informing appliance users about improved operational practice
- Measures need to take into account both fuel poverty and the access to alternatives, to avoid exchanging one set of issues for another
- Cultural drivers around the collection and use of wood as a heating fuel need to be taken into account

The emerging messages and recommendations from the work are set out in section 8. In summary, the key massages are:

- Bioenergy is also a significant part of the energy supply landscape in almost all EU Member States, small-scale bioenergy use presents a significant barrier to meeting clean air ambitions in some areas in the EU, and controlling air pollutant emissions from domestic-scale bioenergy use is a key challenge for air quality policy
- There are drivers to both increase bioenergy use and control its impacts within EU policy, and greater coherence is needed especially around domestic heating
- There are measures to address the air quality impacts of bioenergy use in most, if not all, Member States, following a similar pattern. However, variations in the way in which bioenergy is used at the domestic scale e.g. as primary or secondary heating, the age and type of appliances, etc, means that precise nature of the issues vary between Member States, as does the level of ambition shown in controlling air pollution emissions
- There are good examples of measures already introduced from a variety of Member States, at local, regional and national scale, although more work is needed to fully evaluate their effectiveness
- National strategies to address domestic bioenergy (and other solid fuel) use are likely to be needed in order to meet EU air quality and climate ambitions, as well as to address social issues such as fuel poverty

2 Introduction

This project was commissioned by DG ENV under the Air Quality Policy Support framework contract FRA/C.3/ ENV/2021/OP/0017. It has been undertaken by Air Quality Consultants (part of the Logika Group) supported by TNO, Ineris, IIASA and E3Modelling.

2.1 Project drivers and needs

Greenhouse gases and air pollutants share many of the same sources and source categories. Action to address either can be beneficial to the other, for example the electrification of the car fleet will also remove air pollutant emissions (NO_X, etc.) associated with internal combustion engines. However, they can also be antagonistic: measures to promote the shift from petrol cars to diesel had a beneficial impact on CO_2 emissions but increased NO_X and PM emissions (prior to the mandatory fitting of diesel particulate filters).

The need to reduce European reliance on fossil fuels, especially natural gas, for space heating and power has been strongly highlighted by recent events. Russia's unjustified and unprovoked invasion of Ukraine has shown the risks of relying on energy supplies from unstable political regimes, while the record high temperatures experienced in many European countries in Summer 2022 and the impact of water scarcity and temperatures on energy supply has underlined the vulnerabilities of the whole economic system, and the need to address climate change. Bioenergy, in the form of woody biomass, remains a significant part of the energy mix for many EU Member States and the increased use of wood and other biomass fuels is seen as a renewable and relatively low direct cost alternative combustion fuel. However, it carries with it the risk of greatly increased pollutant emissions – the cleanest wood-fired domestic boilers emit around 300 times more $PM_{2.5}$ than an equivalent gas fired boiler[2] – and also the potential to reintroduce pollutant emissions in cities, as large, centralised power stations are replaced with local biomass combined heat and power (CHP).

However, not all bioenergy is the same and this problem is not a new one. Potential solutions exist to help mitigate the negative effects of bioenergy on air quality, and to increase policy coherence between bioenergy and clean air policies in the EU.

2.2 Aims of the project

The principal aims of the project are twofold: to review the impact, measured and potential, of bioenergy use in the EU on air quality; and to investigate the ways in which Member States have, or could, help mitigate those impacts while supporting their obligations to increase renewable energy use.

In terms of outputs the project has:

- Collated, analysed and summarised evidence on the air pollution effects of biomass combustion and related health impacts, so as to assess the size of the challenge and policy trade-offs arising from this. The project included an assessment of the impacts on Member States' ability to meet EU air quality standards and air pollutants emission reduction commitments
- Drawn together good practice and mitigation measures implemented or under consideration by Member States, regions and local authorities across the EU (and neighbouring countries such as Norway, Switzerland and the UK) for dealing with the identified trade-offs
- Provided support to the European Commission to help address trade-offs between bioenergy and clean air objectives through eco-design and eco-labelling, and in the context of the Energy Performance of Buildings Directive

2 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

The project itself was structured around three main tasks:

- Task 1: Background analysis of air pollution associated with biomass combustion and its impacts: scientific evidence, regions more at risk, existing regulation, trade-offs between policies
- Task 2: Analysis of measures and available solutions to reduce trade-offs (based on best practices developed at Member State national, regional or local levels) and how to incentivise their uptake
- Task 3: Analysis of how best to use the existing and planned policy frameworks to reduce trade-offs in relation to biomass combustion whilst supporting EU clean air policy objectives

Tasks 1 and 2 both included a literature review element and so these were carried out in parallel. There was also a stakeholder outreach programme (see section 3) which mainly informed Task 2 but which also provided useful information on the drivers and impacts of bioenergy which helped inform Task 1. A key output of Task 2 was the development of a toolbox for Member States to help the design and implementation of measures and approaches to mitigate the impacts of bioenergy (see below).

The third task was more limited in scope. An initial discussion was held with the team helping to develop the impact assessment for the revision of the Ecodesign Directive, and while there was an exchange of information, the main focus and timing of the two projects precluded further interaction. The main focus under this task has been to develop a potential metric for an optional indicator on $PM_{2.5}$ emissions, for use in Energy Performance Certificates (EPCs), mandated under the Energy Performance of Buildings Directive (2010/31/EU), which was also subject to revision during the course of the study[3] (see section 7).

2.3 Introducing the toolbox

As mentioned in the previous section, one of the outputs from the review of bioenergy impact mitigation measures being undertaken or planned by Member States (and their regions and cities), is a toolbox aimed at supporting the development of further actions. This is, in effect, a summary of the findings of this project, and has been developed as a stand-alone document, alongside this report. The aim of the toolbox is both to act as a guide itself but also to provide links to other available resources to assist in policy or measure development.

Almost all Member States have some measures in place to help mitigate air pollutant emissions from the use of bioenergy, especially from domestic solid fuel use (the main focus of this project), and these break down into a few distinct types. However, there are also some novel features and approaches which could be used to supplement, enhance or extend measures already in place. Moreover, the project team has struggled to identify evidence showing the effectiveness of actions, largely because formal impact or process evaluation is still something of a rarity for these kinds of measure. Therefore, the toolbox introduces a potentially more systematic way of designing and implementing measures which will help support impact evaluation and ensure measures are targeted in a more cost-effective way.

The toolbox is published here.

2.4 Layout of the report and annexes

The remainder of this report addresses:

- Stakeholder outreach: what has been undertaken, why, how it was done and the key outcomes
- The impacts of bioenergy use on air quality, based on a review of the available literature
- The drivers, positive and negative, for bioenergy use in the EU

3 https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698901

- How EU Member States have responded to these drivers, including case studies of particularly notable measures
- Enabling action through policy development at the EU level
- Conclusions and key messages

The annexes to this report are as follows:

- A1: Measurement standards
- A2: Literature review
- A3: Stakeholder Interview Guides
- A4: Stakeholder survey
- A5: Summary of the EU policies, legislation and other regulatory instruments which currently impact on bioenergy
- A6: Policies and Measures at Member State, regional or local level
- A7: Energy Performance of Buildings Directive (EPBD): potential metrics for $PM_{2.5}$
- A8: Policy Evaluation

3 Stakeholder outreach

Summary and outcomes:

- A stakeholder outreach programme was developed to supplement and validate the findings of the project's literature review, and in particular to provide further detail on Member State measures to control the impact of bioenergy use on air quality
- Targeted interviews were undertaken with stakeholders, with a small online survey added to extend the range of views accessed
- The interviews and survey showed a generally high awareness of the potential impacts of bioenergy use on air quality, with domestic combustion a key source of emissions. Some concerns were raised in relation to the coherence between climate/energy and air quality policy at the EU and Member State level. Specifically, this was between facilitating the uptake of bioenergy to support renewable energy and heat goals, and the need to protect air quality and public health

3.1 Purpose of stakeholder outreach

A key aspect of this project has received input by stakeholders, from "umbrella" organisations (i.e. operating across Member States) and by representatives of Member States and/or their cities and regions. The purpose of this outreach work was to supplement the literature review elements of Tasks 1 and 2, and to gather information from stakeholders on:

- Measures to mitigate the impact of bioenergy use on air quality being developed or implemented at the Member State national, regional or local level
- Supplementary information on the drivers for bioenergy use at the Member State national level
- Evidence for the effectiveness of measures to mitigate the air quality impact of bioenergy use
- Barriers to and issues around the successful design and/or implementation of measures to mitigate the impact of bioenergy use

The information gained from stakeholders was used to inform the outcomes of Tasks 1 and 2 and, particularly, to support the development of the Toolbox for Member States described in section 2.3 above.

3.2 Approach and structure

Stakeholder input was mainly gathered through a series of structured interviews, carried out between May and December 2023. A two-tiered approach was used, to ensure that the project resources were used effectively. The first tier of stakeholders were "umbrella" type organisations, operating at a European (i.e. supra-national) level and, usually, representing collectives of Member State level organisations. The purpose of the first-tier interviews was to gather knowledge on measures implemented at Member State level (or below) and which have been brought to the attention of the organisation (through its membership or other routes). Such measures are more likely to have had an impact on bioenergy uptake or use and thus be of greater interest for this project. The interviews were carefully structured to avoid, as far as possible, assessments as to the desirability of measures (which may be regarded positively or negatively, depending on the organisation concerned) and a key aim was to identify both available evidence on the impact of the measure and contacts at Member State, regional or city level who may be able to provide additional detail.

The first tier of interviews followed the same process, using an interview guide (see Annex A2) which was shared with the interviewee prior to the interview. Consent forms were also provided and the interviews undertaken on a non-attribution basis, i.e. information provided was reported but it was not associated with particular individuals or organisations. The interviews were recorded, and the recordings deleted once the written outcomes were agreed post-interview. Tier 1 interviews were undertaken with:

- European Environment Bureau
- Bioenergy Europe
- IEA Bioenergy (Task 32)

Due to the large number of contacts supplied by Bioenergy Europe, a short survey was conducted with those contacts, to gather initial information about measures being implemented at Member State level, and to help direct the next stage of interviews. The survey was conducted using a short online form, shown in Annex 1)a)i)(1)(a)(i)A4. Of the 29 invitations to complete the survey issued, 10 were completed.

The second tier of interviews was with Member State level contacts. The purpose of these interviews was to gather more detailed information on the measures identified, including:

- the aims, scope, timing and mode of implementation for the measure
- the availability of evidence on impact
- costs (and any monetised benefits)
- barriers to implementation and potential solutions
- any accompanying measures (e.g. publicity campaigns)
- any formal evaluation that has been undertaken
- views on the success (or otherwise) of the measure and what contributed to this

Any available documentary support for the measure or the evidence of impact was also requested. The interviews were less formally structured than the Tier 1 interviews, reflecting differences in the information already held by the project team and the nature of both the measures concerned and the organisations involved, although they were still undertaken on a non-attribution basis. Tier 2 interviews were undertaken with:

- Environmental Protection Agency, Sweden
- Festbrennstoffe Technologie- und Förderzentrum (TFZ), Germany
- Ministry of Environment and Ineris, France
- Za Zemiata, Bulgaria

Correspondence was also exchanged with UBA, Germany; the Environmental Protection Agency, Denmark; and the cities of Malmo (Sweden), Grenoble (France) and Sofia (Bulgaria).

3.3 Key messages from stakeholder outreach

As mentioned above, the main purpose of the first round of interviews was to identify contacts and activities at Member State level (or below) which could merit a more detailed discussion/investigation. This aim was largely achieved, with around 30 additional contacts identified and some potential measures and information sources highlighted. The follow up survey and interviews were intended to supplement information gained through literature reviews and searches, adding detail which could be expanded into the case studies presented in section 6.5.

From all three stages of outreach, several common outcomes were apparent:

General awareness

All parties contacted were aware of the potential impact of bioenergy use on air quality, especially at the domestic scale. Views differed as to whether this was an issue simply of older appliances being used or an inevitable consequence of bioenergy use. However, there was a broad consensus that further action to reduce the air quality impact of bioenergy was necessary to bring an equivalent level of pollution control as that developed in other emitting sectors, such as transport or industry, where available abatement technologies are more fully exploited.

EU level

Another area of commonality was in the expression of frustration that policies and signals at the EU level appeared not to be well coordinated. There were perceptions of mixed messaging around the environmental benefits and disbenefits of bioenergy, and views were expressed in interviews that carbon neutrality was still being used to promote bioenergy (not necessarily by the Commission), despite evidence to the contrary.

Another area of concern was that emissions control legislation at the EU level focussed on the performance of new equipment (e.g. eco-design requirements for new stoves), but did little about the stock of existing bioenergy equipment, including the use of open fires. It was suggested that the conversion of all, or the majority of, solid fuel appliances to modern, pellet fed versions could alleviate the air quality impacts of bioenergy. However, the practicality of doing so, in addition to the financial and political support required, was questioned.

Member State level

As reflected in the literature review, it is clear that all or almost all Member States have some measures in place aimed at mitigating the air quality impacts of solid fuel (including bioenergy) use. This includes the domestic scale although the stringency and ambition of those measures differs considerably. Some Member States and regions were incentivising an upgrade to newer, less polluting equipment, although the picture is very mixed and schemes differed in detail.

Drivers for the uptake of bioenergy, or the failure to reduce bioenergy air pollution emissions, other than the perceived climate benefits or achievement of renewable energy targets, were raised. These included energy security, the cost of electricity and gas for heating[4], and the aesthetics of solid fuel use. Aesthetics and cultural drivers for bioenergy use, were identified as strong drivers in wealthier Member States, with the view expressed that coordinated messaging would be required to change attitudes around wood combustion in particular.

Evaluation

A consistent finding was the lack of effectiveness evaluation for national or local scale interventions on bioenergy. While there were some references made to air quality measures (and trends therein), other than a few examples there were no direct assessments found of the effectiveness of measures. Linking individual measures to changes in air pollutant concentrations is notoriously difficult, especially for a pollutant such as $PM_{2.5}$ which has multiple sources and is complex to measure. It is therefore not surprising that the impacts of measures on concentrations have generally not been assessed. However, effectiveness evaluation can also look at intermediate steps, such as changes in the appliance stock, quantity or quality of fuel, or rates of combustion. Unfortunately, there appears to be little information available on the impact on intermediates either.

The outcomes of the stakeholder engagement work have been combined with the literature review to form the principles for successful measure and key messages in sections 6.7 and 8.1.

4 Note that the relative cost of electricity, gas and wood pellet fuel is dynamic and the views expressed the pricing at the time of the interview.

4 Bioenergy Impacts on Air Quality

Summary and outcomes:

- $PM_{2.5}$ is the main driver of the health effects of air pollution and is thus of primary concern for air quality policy. Solid biomass used for heat and energy generation is the single largest source of fine particulate matter ($PM_{2.5}$) emissions across the EU
- This is largely as a result of domestic combustion, which makes up around half of total emissions, and which in turn is dominated by wood fuel combustion
- In the EU, the use of bioenergy increased rapidly between 2005 and 2020, although in recent years the growth has levelled out, potentially due to uncertainty in policies and debates about sustainability of bioenergy[5]
- Estimating emissions from bioenergy, especially small-scale bioenergy (i.e. domestic scale), is complex and challenging. Emissions vary significantly based on the quality of fuel, the type of appliance and the actions of the user. In addition, accurate information on fuel and appliance use is generally difficult to obtain. Finally, different Member States calculate emissions differently, particularly in the inclusion or exclusion of the condensable fraction of particulate matter

4.1 Introduction

This chapter reviews the evidence with regard to bioenergy use and air quality. For the purposes of this study, biogas production and biofuels used in transport are excluded. Moreover, while the analysis in this section touches on different types of non-transport bioenergy, the main focus is on the use of wood and woody biomass as a domestic space and water heating fuel. This is due to both the predominance of this use type within the sector, and the association of small-scale bioenergy (mainly wood fuel) combustion with the majority of air quality impacts. Larger combustion plants, such as that used in power generation, are subject to the same legislative emission controls as plants running on other fuels. However, small-scale combustion, especially "traditional" stoves and fireplaces burning wood logs, emit far higher levels of $PM_{2.5}$ (the principal driver of health effects from air pollution) than gas (including biogas) or non-combustion equivalents. In this section, little distinction is made between different types of solid biofuels used for domestic-scale heating – wood, wood ships and pellets, reconstituted wood or biological waste (e.g. coffee logs), etc. Each will have their own emission profile but the essential issue of controlling emissions from small-scale combustion applies to them all, accepting that such controls are more feasible for some (e.g. wood pellets) than others (e.g. log wood).

4.2 Approach and data sources

Bioenergy is defined in this study as the use of biomass in a wide range of energy related applications (typically for producing electricity and heat). This includes solid biofuels (wood) but also liquid and gaseous biofuels, while peat is classified as a fossil fuel and therefore excluded from biofuels. Also the production of biogas as well as the use of liquid biofuels in transport are excluded from the definition of bioenergy for the purposes of this study. To assess the impacts of bioenergy on air quality in Europe, a literature survey has been conducted, the full document list for which is shown in Annex 1)a)i)(1)(a)(i)A2. A long list of data sources has been identified, collected and examined. These include policy documents and legislation, project reports and websites, as well as scientific and other sources of grey literature. This chapter summarizes the bioenergy impacts on air pollution, now and (potentially) in the future, based on this assessment of literature.

5 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130730/2022.5470_kjna31283enn.pdf

4.3 Evidence for environmental impacts of bioenergy

The use of bioenergy has been increasing in recent years. The combustion of biomass emits CO_2, but it is considered “zero-rated” under the EU Emissions Trading System (ETS), because it is already counted under the Land Use, Land Use Change and Forestry (LULUCF) Regulation. Here it is accounted for in the form of reduction of carbon sinks, which implies that the CO2 emissions from combusting biomass correspond to the CO2 absorbed by the biomass during the growth of the feedstock. The increased use of biomass for energy purposes can worsen local and regional air pollution levels, since pollutant emissions from the use of biomass are typically greater than those from other fuels, especially when solid biomass is replacing natural gas as the combustion fuel.

This section explains the impacts of bioenergy on air pollutant emissions, air quality and human health. First a general overview of the bioenergy use and trends is given, then the focus is on air pollution impacts related to bioenergy.

4.3.1 Trends in the consumption of bioenergy in the EU

Bioenergy is the main source of renewables in the EU in terms of gross final energy consumption, representing almost 60% of renewable energy sources[6]. Its main use is for heating and cooling (around 75%). In the EU, the use of solid bioenergy increased by 33.5% between 2008 and 2021, however in recent years the growth seems to be levelling out because of uncertainties in policies and debates about sustainability of bioenergy[7]. Germany, France, Italy and Sweden are the EU27 Member States with the highest bioenergy consumption in absolute terms. Figure 4-1 shows the bioenergy use in EU27 in 2021, illustrating that the largest part of bioenergy is used in transformation input (mostly for electricity and heat generation) as well as in other sectors (mostly for small-scale heat generation). The contribution of liquid bioenergy in the energy sector in the figure excludes biodiesel and biogasoline inputs into the energy sector since these are largely used in transport. However, small quantities of liquid biofuels are used in industry and other sectors as illustrated by the Figure. Around 65% of this solid and gaseous bioenergy is used in combined heat and power (CHP) plants, whereas electricity and heat-only plants use 18% and 17% of the bioenergy in EU27 in 2021, respectively. Industry is a smaller but not negligible user of bioenergy, and within the industrial sector the main users are the pulp and paper industry and the wood and wood products industry (20%). In terms of the type of bioenergy used, industry and other sectors primarily use it in solid form (wood or similar), while the electricity and heat generation sector also utilises significant amounts of bioenergy in liquid and gaseous form. However, since the largest air pollution impacts are related to bioenergy in solid form, this study focuses on these. Figure 4-2 shows the per capita use of solid biomass in each MS and for the EU27 as a whole, illustrating that there are large variations between different Member States regarding the uptake of bioenergy. This mostly relates to the energy and industrial sectors, and is related to the presence of specific industries (e.g. pulp and paper production) in each Member State.

6 https://energy.ec.europa.eu/document/download/68e51bbf-aa4f-4570-9497-0af7c19c153c_en?filename=COM_2023_650_1_EN_annexe_autre_acte_part1_v7.pdf
7 Ibid.

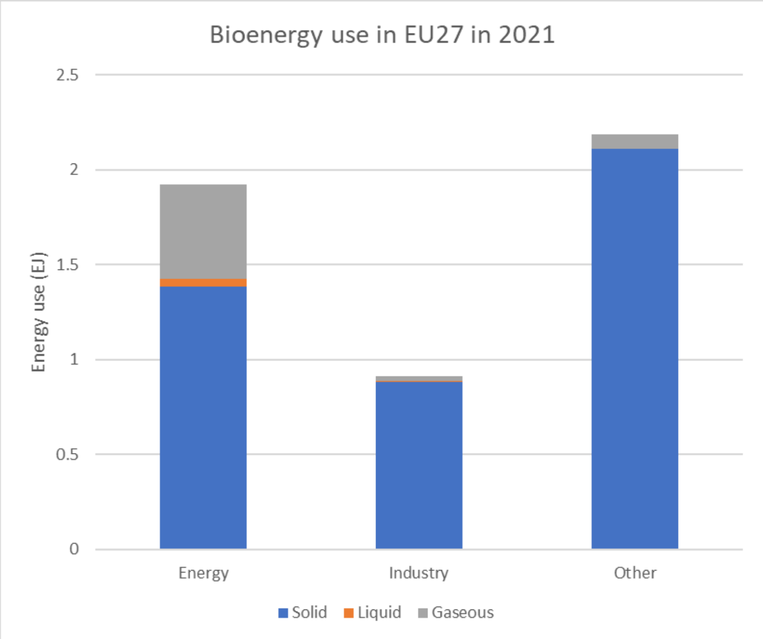


Figure 4-1: Bioenergy use in EU27 in 2021, main sectors and main fuel type. The figure includes the use of liquid biofuels in each sector, but excludes the use of biofuels in the transport sector (source: Eurostat energy balances[8])

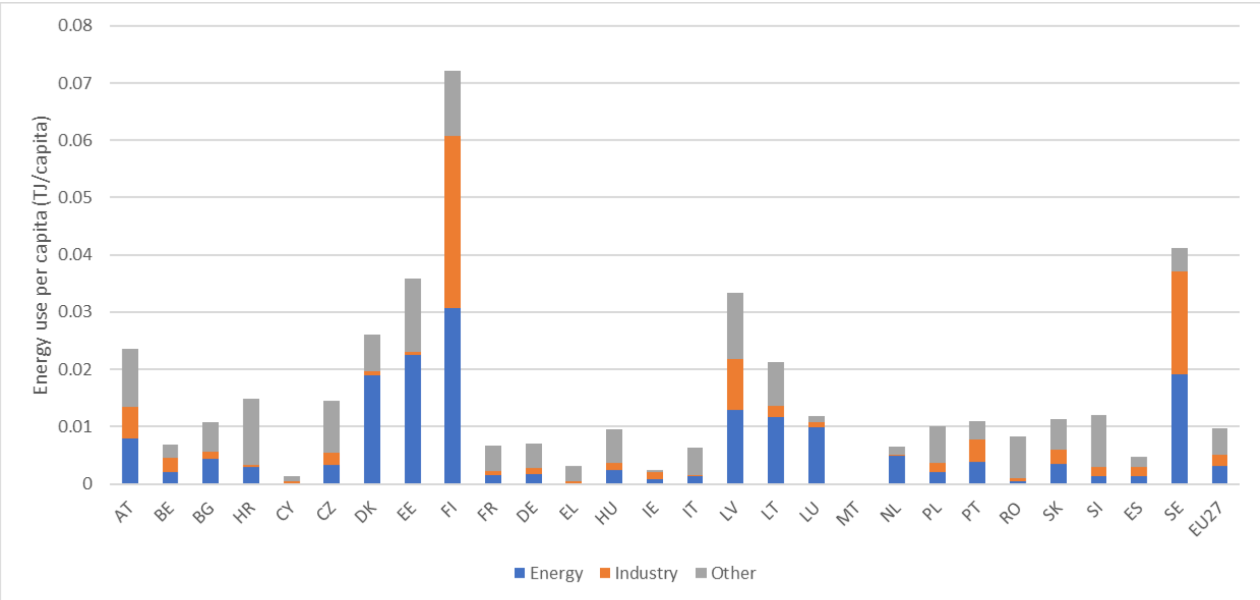


Figure 4-2: Per capita use of primary solid biofuels (the definition used by Eurostat for bioenergy in solid form) in each MS and the EU27 average (source: Eurostat[8])

4.3.2 Current air pollutant emissions from bioenergy use

Unfortunately for air pollutants, official reported emission inventories (reported under the National Emission reduction Commitments (NEC) Directive 2284/2016/EU) do not distinguish between fuels, which makes it impossible to analyse these data regarding the use of bioenergy. For instance, for residential combustion only the total emissions per pollutant are provided which represent the sum of emissions from the combustion of fossil

8 Eurostat complete energy balances, last updated 28/04/2023

and biomass sources. Therefore, air pollutant emissions data from the IIASA GAINS model, which is used to underpin much of the EU and international policies on clean air, have been used. Emissions were extracted per key fuel/activity and sector for the year 2020 in the "baseline" scenario which is used to underpin the analyses in the 3rd Clean Air Outlook (CAO3)[9]. It should be noted that these numbers are derived from emissions modelling rather than the official inventories, although they are aligned as much as possible with Member States as part of the CAO3 consultation processes[10].

Figure 4-3 shows the main sectors contributing to bioenergy emissions in the EU27 in the year 2020, for the main air pollutants which have reduction commitments specified in the NEC Directive. It shows that, for all 5 pollutants, small combustion installations are the main contributor to emissions from bioenergy, with significant contributions from energy and manufacturing industry for NO_X and SO_2. With the stricter emission limits included in the updated LCP BAT conclusions which are in place from 2021, the pollutant emissions from the use of bioenergy in these sectors probably decrease in the near future. However, for NH_3, NO_X and SO_2 the shares of bioenergy within the total emissions of the respective pollutants are between 2-8%. For NMVOC this share is 13%, while for $PM_{2.5}$ the emissions from bioenergy represent more than 50% of the total emissions in EU27 in 2020. $PM_{2.5}$ is also the pollutant that is typically associated with the most relevant health impacts.

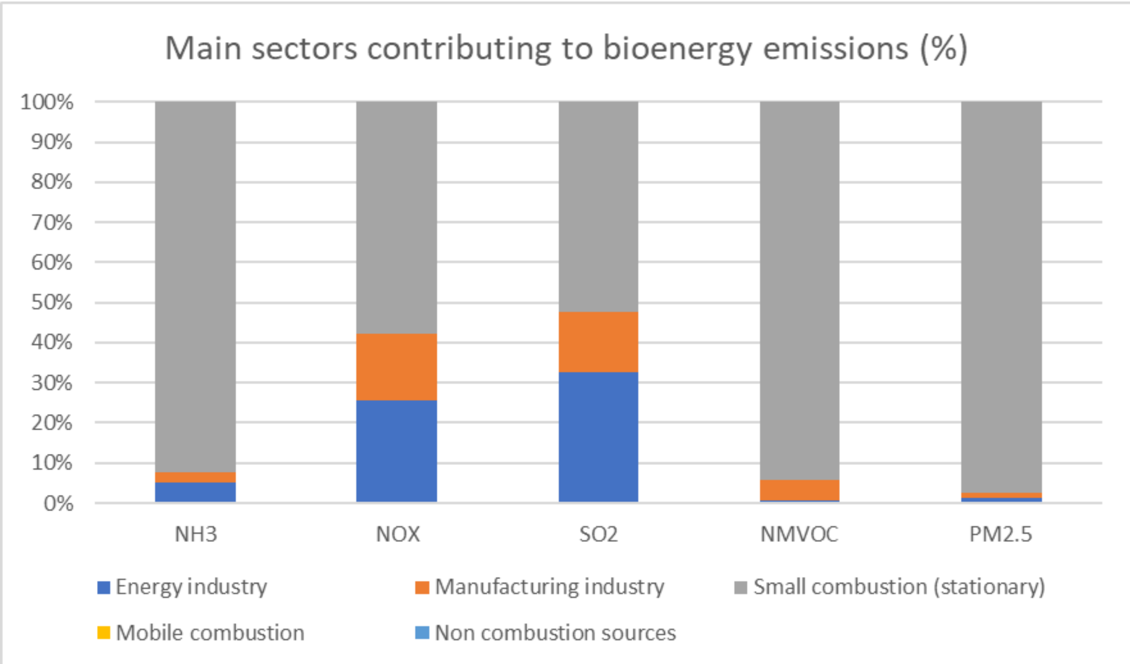


Figure 4-3: Main sectors contributing to bioenergy emissions in the EU27 in 2020 (source: CAO3 emission data)

Figure 4-4 shows total $PM_{2.5}$ emissions in EU27 distributed between the different sources, including both bioenergy and non-bioenergy. The figure shows that bioenergy use in small combustion is responsible for half the total $PM_{2.5}$ emissions in the EU27, and the use of bioenergy in other sectors only makes a small contribution. Hence, it can be concluded that when it comes to air pollution related to the use of bioenergy and its impacts, the main issue is the use of bioenergy in the small combustion sector, which mostly consists of wood used for heating purposes. Looking back at the last two to three decades, $PM_{2.5}$ emissions have decreased in the EU27 by 37% between 2000 and 2020[11]. However, this decrease is mostly attributed to sectors other than small combustion, in particular transport and industry, because of the abatement measures that were implemented in these sectors. Hence,

9 https://environment.ec.europa.eu/publications/third-clean-air-outlook_en
10 When preparing the CAO3, IIASA ran individual meetings with Member States to consult them on the baseline assumptions and underlying data in the model relating to the respective Member State.
11 https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer-4

the relative importance of small combustion in total $PM_{2.5}$ emissions in EU27, which are primarily related to bioenergy use, has increased in the last decades.

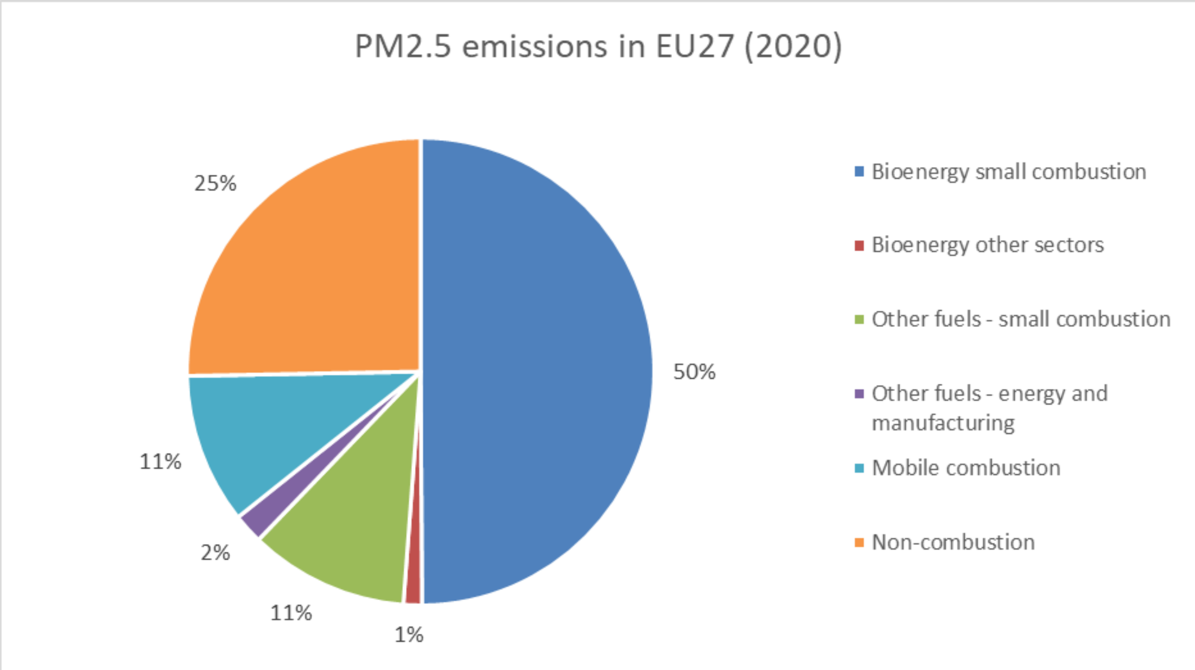


Figure 4-4: Main contributing sectors, differentiating between bioenergy and other fuels, for total $PM_{2.5}$ emissions in EU27 in 2020 (source: CAO3 emission data)

It should be noted that emissions from bioenergy use are particularly important in winter time, when European citizens use biomass for domestic heating. The actual emissions however depend strongly on the specific stove or boiler used – old stoves and especially open fireplaces have high emissions, the devices with latest technology that meet the latest European standards are significantly cleaner – but also on the quality of the feedstock as well as on the way the combustion device is operated by the user (Bioenergy Europe, 2021).

4.3.3 PM emissions and condensables

In recent years, it has become clear that, within Europe, there are different ways in which PM emissions are measured and reported (Simpson et al., 2020). The lack of a uniform standard and agreed upon way to quantify PM emissions in inventories causes significant differences in the comparability of reported PM emissions in emission inventories from different EU Member States, especially in the residential sector.

One common way to measure PM emissions is using a heated filter approach, where fine particulate matter is collected on a filter which is typically placed in the chimney. This way, only the particles which are already present in the hot flue gases are measured. However, upon leaving the chimney, the hot flue gases cool down and additional particles may be formed through condensation. Depending on the circumstances, this process takes place within seconds to minutes after the flue gases leave the stack, and may generate up to five times more particles than originally present in the exhaust gases. These additionally formed particles are typically referred to as “condensables”. Alternative methods to the heated filter, such as the use of a dilution tunnel based measurement approach, allow for condensation before the particle mass is collected and therefore include the condensable particles in the total PM mass, thus giving a more complete picture of particulate matter related pollution.

For practical reasons, different methods have been adopted in different sectors:

- In large stationary combustion installations (power plants, industry), the heated filter approach is used throughout Europe and therefore the condensables are excluded from the emissions in (practically) all cases

- In quantifying transport exhaust PM emissions, condensables are largely included when following the established measurement protocols in this sector. These include a cooling of the exhaust gases to 51°C which allows most of the condensables to be formed. However, further cooling could generate additional particles, although their contribution is likely to be limited

- For small stationary combustion processes, methods which include and exclude condensables are used in the absence of a common European measurement standard

More details regarding the different measurement and sampling methodologies are provided in general terms in Section 4.4.3 and in detail in Annex 1)a)i)(1)(a)(i)A1

When it became clear that this reporting inconsistency led to underestimated PM concentration levels by excluding condensable particles, most European countries updated their official inventories to include condensables for small combustion. However, as of the 2023 inventory submissions some Member States such as Austria and Germany still do not, or only partially, include condensables in their PM emission inventories for stationary small combustion, as was concluded by the 2022 CLRTAP Stage 3 emission inventory review[12].

It is important to note that a simple statement stating that condensables are included or excluded oversimplifies the real-world situation. The 2022 CLRTAP Stage 3 review, which focussed on the inclusion of condensables in small combustion and road transport, concluded that for road transport the situation is clear, as all emission factors used include condensables in a similar way. For small combustion however, in many countries a mix of emission factors is used. For one specific appliance an emission factor may be used that (partly) includes condensables (e.g. determined using a dilution tunnel approach), while for another appliance, this may not be the case. Also, it was found that in numerous cases the inclusion of condensables in the emission factor could not be determined.

To overcome this uncertainty in country reporting and examine the possible impacts on European emissions and air quality, an alternative and independent emission inventory ("Ref2") has been developed for PM emissions from the small combustion sector for all of Europe, in support of the review of the UNECE Gothenburg Protocol (Simpson et al., 2022). The Ref2 inventory includes specifically the filterable part of PM as well as the condensable part. This inventory includes all PM emissions from small combustion, not only from bioenergy. In the majority of countries however, bioenergy is responsible for more than 90% of $PM_{2.5}$ emissions from small combustion units. This is indicated by the black dots in Figure 4-5. The countries with a lower bioenergy share in their PM2.5 emissions from small combustion have significant contributions from coal (e.g. Czech Republic, Poland) or from peat (Ireland). Apart from the bioenergy share, Figure 4-5 also shows CAO3 emissions as well as the Ref2 inventory emissions with and without condensables. The Ref2 inventory with condensables included results with 19% higher $PM_{2.5}$ emissions for the EU27 in 2019 compared to the CAO3 emissions. However, when a similar comparison is made between the Ref2 inventory and the official inventories reported by each MS under the NEC Directive in 2023 the two are found to be very similar. This can be attributed largely to recalculations in 2023, submitted by France and Poland, both adding around 80 kt (thousand tonnes) additional emissions compared to their earlier submissions. For both of them, it implies their official submitted emission is now higher than the Ref2 inventory. Therefore, the fact that for EU27 as a whole the two inventories match does not mean that all MS now account for condensables in their PM emissions from small combustion. The fact that in some cases the official inventories are substantially higher than the Ref2 inventory compensates for missing condensables in other inventories. The methodological differences between Member States in the way they estimate PM emissions contributes to the high uncertainty in reported PM emissions from the domestic sector, in particular for the use of bioenergy.

12 https://www.ceip.at/status-of-reporting-and-review-results/2022-submission

The results also show that condensables make up around two thirds of the total $PM_{2.5}$ emissions from small-scale combustion in the EU27 in 2019, which underlines the importance of including them to assess the real impact of (bioenergy) emissions on air quality, human health and the environment.

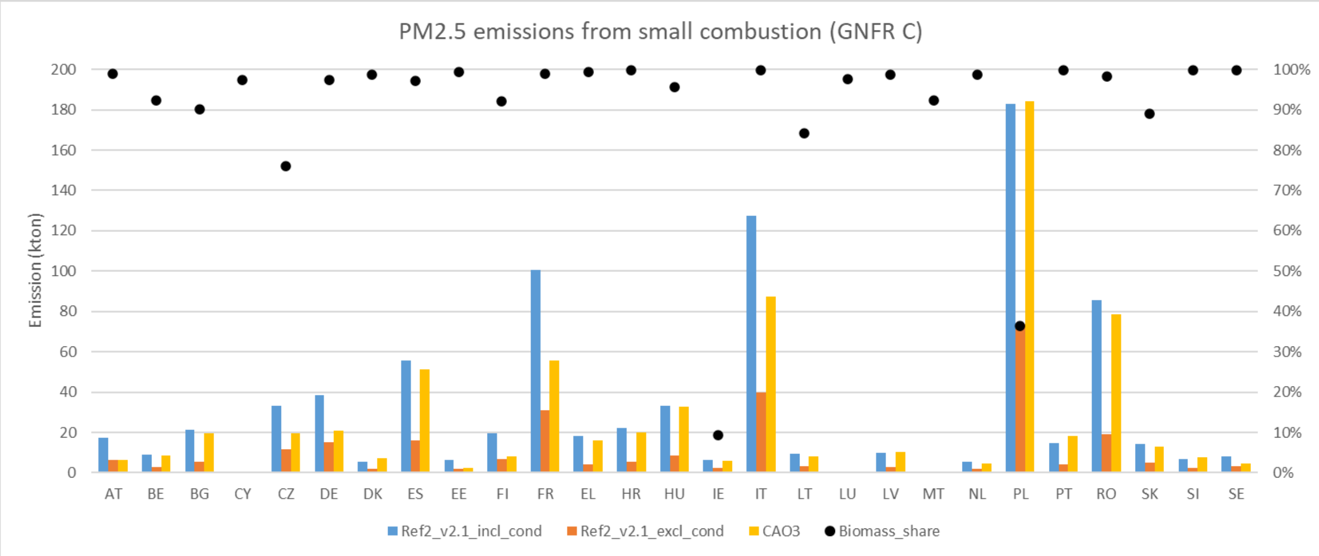


Figure 4-5: Alternative emission inventory of $PM_{2.5}$ emissions ("Ref2") from small-scale combustion (GNFR C) for 2019, with and without condensables, compared to the emissions used in CAO3. Black dots represent the share of solid biomass in the energy mix for this sector (based on Eurostat).

Finally, it should be noted that condensables may also be emitted from larger scale stationary combustion (in energy and manufacturing industries). While the $PM_{2.5}$ emissions from these sectors are significantly smaller, these should not be overlooked. There are indications that, especially for modern plants with low (filterable) PM emissions, the contribution of condensables may exceed the filterable PM emissions (Liu et al., 2022). More research is needed, however, to see how this applies to the European situation and how the importance of condensables fluctuates with technology and abatement levels. To better understand this, measurements aiming at quantifying the condensable contribution are needed, distinguishing between fuel types as well as between older and modern state-of-the-art plants that are being used throughout Europe.

4.3.4 Ambient air pollution impacts

The impact of emissions from bioenergy alone on outdoor air pollution is difficult to quantify, given the range of other sources of the same pollutants. Once released, the particles originating from bioenergy combustion mix with other particles and gases and undergo transformations and/or chemical reactions. During these processes, additional so-called "secondary particles" are formed through chemical reactions of its precursors: mainly NO_x, NH_3 and SO_2. This secondary PM is, in most cases, responsible for a significant share of the overall $PM_{2.5}$ concentrations. This – in combination with other local circumstances – makes the impacts of air pollution from bioenergy strongly location dependent. In addition, there is still not a full understanding of the role of ultrafine particles (UFPs), which are defined as those particles with a diameter below 100 nm[13]. UFP is in the spotlight because of some evidence that smaller particles may be more harmful to human health than larger particles, since the smaller the particle the more deeply it could penetrate into the lungs (Schraufnagel, 2020; Ohlwein et al., 2019). There is little information about emissions of UFPs. To address UFP, the Commission proposal for a revised Ambient Air Quality Directive (AAQD)[14] introduces monitoring of UFP at sites which are likely to have high concentrations. First indications at European scale suggest that transport (exhaust) emissions dominate UFP

13 Since at this size the mass of the particles becomes very small, UFPs are typically expressed as the number of particles.
14 https://environment.ec.europa.eu/publications/revision-eu-ambient-air-quality-legislation_en

emissions, but bioenergy use in residential combustion cannot be neglected[15]. However, the uncertainty around these initial estimates is high (and hence their contribution to ambient concentrations) and further research is needed to better understand the emissions and transformations, and especially how the smallest particles behave in their initial seconds to minutes after emission.

The above implies that for quantifying the impacts of PM2.5 emissions from bioenergy in terms of ambient air quality concentrations and impacts thereof, specific information is needed on many other pollutants, not only from bioenergy use but from all relevant sources of emissions. Using modelling tools, the relation between emission and concentrations, and the contribution of different sources to concentrations can be estimated for different regions or cities. The variation of the contribution from bioenergy use (and residential wood combustion in particular) is further elaborated upon for specific cities/regions in Section 4.4.4.

4.3.5 Indoor air pollution

The use of heating devices inside homes also affects the indoor air quality. A UK study looking specifically at wood-fired stoves has measured PM levels during use of these stoves in 20 different situations and concluded that PM emission levels were 2-3 times higher when the stove was in use (Chakraborty et al., 2020). On top of that, higher peak concentrations were clearly identified, showing that part of the PM emissions “leak” to the indoor environment. The peaks were mostly found to be associated with number of wood logs used and the length of the burn period. This points to the opening of the stove door as a primary mechanism for introducing PM into the home. A study in Norway (Wyss et al. 2016) found that residential homes with a wood stove showed typically higher $PM_{2.5}$ concentrations than those without, and in addition lower $PM_{2.5}$ levels were measured when newer wood stoves were installed.

4.3.6 Health effects

Wood or bioenergy combustion is known to emit particulate matter ($PM_{2.5}$, PM_{10}, ultrafine particles), NMVOCs, but also NO_x, SO_x and NH_3, as well as polycyclic aromatic hydrocarbons (PAHs) and dioxins. PM emissions from combustion sources contain a large fraction of carbonaceous aerosol, predominantly present in the sub-micron size fraction (<1µm). Amongst these pollutants, $PM_{2.5}$ (primary and secondary), as well as PAHs and dioxins are of specific health concern (Denier van der Gon et al., 2015; UK Air Quality Expert Group, 2017).

$PM_{2.5}$ has long been linked to mortality, to inflammation and oxidative stress, which compromises pulmonary immunity and increases the susceptibility to infection. The illnesses associated with the presence of $PM_{2.5}$ range from lung cancer, bronchitis and other respiratory infections to cardiovascular diseases, strokes, dementia, Parkinson’s disease and low birth weight. Effects are particularly pronounced for children, pregnant women, and the elderly (Chakraborty et al., 2020; Sigsgaard et al., 2015; WHO, 2015). PAHs can reduce the immune function and are known for their carcinogenic and mutagenic effects (Tsiodra et al., 2021), and dioxins are also carcinogenic (Coolproducts & ECOS, 2022). Both families of substances are known to be persistent and to accumulate. PAHs emitted to the atmosphere can be deposited onto soil, water and vegetation. In water they can accumulate in aquatic organisms, in soil they can enter the groundwater and be transported within an aquifer (EFSA, 2008). When accumulated in soil and water, they can enter the food chain also through their uptake by vegetation and plant materials, and through the use of contaminated vegetation to feed livestock (Sampaio et al., 2021). Dioxins bind to sediment and organic matter in the environment, they are absorbed in animal and human fatty tissue and bio-accumulate in the food chain (MEMO/01/270, 2001).

Epidemiological studies document that short- and long-term exposure to smoke from biomass combustion are responsible for chronic obstructive pulmonary disease (COPD) (Salvi & Barnes, 2009), acute respiratory and cardiovascular disease (Sigsgaard et al., 2015), pneumonia, tuberculosis, asthma and cancer (Patel et al., 2013). A strong relationship between PM from biomass combustion and health impacts such as hospitalisations,

15 https://riurbans.eu/wp-content/uploads/2022/11/RI-URBANS_M13_.pdf

cardiovascular and respiratory problems and premature mortality has been found (Pope & Dockery, 2006, Kukkonen et al., 2020).

The World Health Organisation (WHO) notes that short-term exposure to particles from wood combustion appears to be as harmful to health as exposure to particles from the combustion of fossil fuels (WHO, 2015). Other studies indicate that emissions from wood burning might be specifically dangerous for health: Danish Ecological Council (2016) suggests that soot particles, emitted amongst others from wood burning, might be more harmful than inorganic particles formed from the precursors NO_x, NH_3 and sulphates. And a study in Athens found that the fraction of PAHs associated with biomass burning was linked to increased health risk compared to other sources, accounting for 43% of the annual PAH carcinogenic potential (Tsiodra et al., 2021).

Wood combustion is an important source of air pollution in Europe. In some countries it is even the dominating source. In Finland, for example, residential wood combustion is the largest domestic source of $PM_{2.5}$ (Savolathi et al., 2019). This said, levels of ambient $PM_{2.5}$ concentrations are generally very low in Finland[16]..

A few studies have estimated the burden of disease due to exposure to $PM_{2.5}$ from wood or biomass combustion. Sigsgaard et al. (2015) estimated a contribution of biomass smoke to premature mortality in Europe at approximately 40,000 deaths per year. The authors derived this number from the estimation that premature deaths due to PM exposure in the EU amounted to around 400,000 annually in 2010 and 2012, and that the contribution of biomass smoke to population exposure is about 10%. Disease burden related to residential wood combustion in Finland, in 2015, was estimated to correspond to 204 deaths (Savolathi et al., 2019). In a study from 2016, fine particles from wood burning emitted in Denmark were estimated to account for 550 premature deaths in Denmark, and for 1000 premature deaths in Europe (Danish Ecological Council, 2016).The year this estimate corresponds to is not specified. In the 2022 update of the study the numbers are 300 premature deaths for Denmark and 600 for Europe (Green Transition Denmark, 2022).

Frequently, estimates are made for residential heating with wood and coal together. WHO (2015), for example, estimate the following numbers for premature deaths that can be attributed to residential heating with wood and coal in different European regions in 2010: 20,000 for Western Europe, 20,000 for Central Europe and 21,000 for Eastern Europe.

Looking at trends, the increase in residential wood burning between 2005 and 2016, was estimated to have been responsible for an increase of around 10,700 premature deaths in the EU27 & UK in 2016 relative to 2005. This is due particularly to the high emissions of fine particulate matter from domestic stoves (Couvidat et al., 2021).

In terms of socio-economic costs, it was estimated that in the EU27 & UK, in 2018, 31% of the health costs from ambient air pollution due to residential heating and cooking come from the use of wood burners (Kortekand et al., 2022; EPHA, 2022). The authors also calculated that health costs associated to using a wood stove, on average across the region, amount to 756 €/year/household, and those associated with using a non-condensing boiler for wood amount to 159 €/year/household. These costs are higher than those estimated for all other energy sources for heating, with the sole exception of non-condensing coal boilers (1233 €/year/household). Similar results are found for Denmark, where domestic wood burning in small stoves and boilers is the most expensive heat source in terms of estimated average health costs, amounting to 15.6 €/GJ house heating in Denmark. The health costs occurring outside Denmark are estimated at 18.9 €/GJ house heating (EEB, 2021). For Denmark, it was estimated in 2016 that fine particles emitted from wood burning contributed with about 50% to overall health damage from Danish pollution sources[17], and that pollution from wood burning was the most expensive environmental problem (Danish Ecological Council, 2016). The latter statement remains valid in the 2022 update of the study (Green Transition Denmark, 2022), while the share of costs associated with pollution from wood burning in total costs from air pollution from polluting sources in

16 https://www.eea.europa.eu/themes/air/urban-air-quality/european-city-air-quality-viewer
17 Note that the impact of secondary particles and the fact that different sources have a different particle composition and particle size range were not considered in this estimate.

Denmark is down to 40 %. These socio-economic costs of wood burning in Denmark amount to €750 million in Denmark and to €1.225 million in Europe due to the transboundary nature of air pollution (costs in Europe include costs in Denmark) according to the two sources.

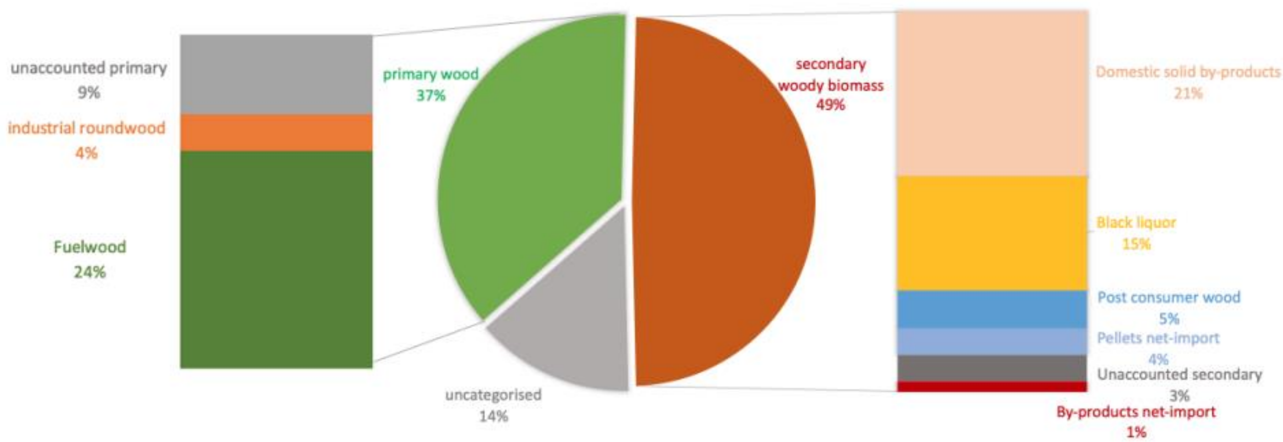
From the range of results reported above, it is clear that estimates of health impacts from air pollution bear some uncertainty. The physicochemical properties of particulate matter from biomass combustion vary with specific combustion conditions, and hence make the evaluation of the respiratory and cardiovascular toxicity of biomass emission complex (Sigsgaard et al., 2015). Uncertainty also remains about the relative toxicity of different particle types (Green Transition Denmark, 2022). These authors assume that air pollution from wood burning might be more damaging than estimated in current studies, also because some adverse health effects for which the epidemiological literature has been growing more recently (e.g., low birth weight, IQ loss), are not yet included in the studies for which results are summarised here.

4.4 Variability in bioenergy emissions and impacts

4.4.1 Fuel types and biomass amounts used

Bioenergy emissions per unit of energy generated vary significantly between the different regions in Europe, both in terms of bioenergy amounts and bioenergy types. The demand for bioenergy is largely related to the structure of the energy system in each Member State, especially when considering the residential sector. Member States with a low share of bioenergy in the final energy consumption in the residential sector in the EU27 in 2021 are Ireland (0.9%), Malta (1.3%), Luxembourg (3.3%) and Netherlands (3.8%)[18]. On the other hand, high bioenergy shares are reported for Croatia (46%), Estonia (40%), Slovenia (39%) and Latvia (38%) (European Commission, 2021).

Bioenergy is not a single type of fuel but a group of energy carriers derived from the conversion of natural or biological sources. In the EU overall, the use of bioenergy shows an increasing trend. However, the growth rate has slowed down in recent years. In the year 2015, primary wood contributed to 37% of the total wood used for energy, from which about 47% is stemwood while the remaining 53% are other wood components (treetops, branches, etc.). Secondary woody biomass (sawdust, chips, etc.) accounted for 49%, while the remaining part accounts for the woody biomass use for which the origin is unknown (14%) (European Commission, 2021). The Figure also shows that 75% of the biomass is used for heating purposes, other uses being electricity and fuel for transport. Woody biomass however may still consist of different tree species, wood types and can be used in different forms (large or small wood logs, wood chips, etc.), which may have an impact on emissions when the biomass is combusted.



18 Based on Eurostat energy balances for the year 2021 (accessed 10 October 2023)

Figure 4-6: Origin of bioenergy in the EU (2015), figure taken from JRC report (European Commission, 2021)

One of the reasons for variability and associated uncertainty in bioenergy emissions and impacts is the uncertainty around the amounts that are used. Official statistics of biomass use often only contain the amount of biomass that is recorded in the sales statistics. In fact, a gap exists between reported use and sources of woody biomass at EU level, which can be largely attributed to bioenergy use (European Commission, 2021) Especially in rural areas which are not (well) connected to power or gas networks, local inhabitants may harvest wood directly from the forest e.g. for heating and cooking purposes. Estimating the additional wood consumption (and associated emissions) resulting from this is a challenging task as typically no data are available.

4.4.2 Variation in appliances

There is a wide range in bioenergy appliances. In the larger combustion sectors (energy and manufacturing industries) biomass is often used in combination with other solid fuels (co-firing), although larger new biomass-only electricity plants have been built in recent years as well as CHP (combined heat and power) plants. However, these larger and new plants typically have lower emissions of hazardous air pollutants per unit of energy produced compared to smaller installations because their operating temperature is higher, which means most air pollutants are largely burned before they can be released, and larger installations typically have more advanced abatement equipment installed so that remaining air pollutants can be largely removed from the exhaust gases. The latter is also related to the regulation of these large installations under the Industrial Emissions Directive.

Hence, the largest share of emissions from the use of bioenergy comes from residential combustion (see also Section 4.3.2). Also, within this sector, a wide range of different equipment types are used. Distinctions can be made between boilers and stoves, between larger and smaller appliances and between different technology types (traditional appliances versus new appliances). More details on these different appliances used in residential combustion of bioenergy and their typical emission levels is provided in Section 4.4.3.

4.4.3 Emission factors

An emission factor specifies the amount of a certain air pollutant that will be released per unit of a certain activity, for instance the amount of a given fuel used. As such it is an important indicative number of how environmentally damaging the combustion of a specific fuel or a type of appliance can be considered. This should also be put into perspective with the output (heat or electricity produced) of this given input. According to the latest EEA Emission Inventory Guidebook[19] for instance, $PM_{2.5}$ emission factors for residential combustion vary between 0.12 and 2.2 g/GJ for natural gas, 0.75 and 6 g/GJ for distillate heating fuel and 72 and 480 g/GJ for bituminous coal, with the range primarily determined by the type of combustor.

For fuel wood the Guidebook $PM_{2.5}$ emission factors for residential combustion range from 37 to 1680 g/GJ (including the lower and upper ranges), so with a factor of 50 between the lowest and highest number. This particularly high range is the result of the wide range of combustor types in use in Europe, but also of the operator's significant influence on combustion efficiency and fuel quality (particularly its moisture content). To be able to estimate pollutant emissions from residential combustion of biomass with a sufficient degree of accuracy, it is evident that an inventory of combustion technologies used is a prerequisite. Furthermore, the actual range in operator behaviour should be characterised, as well the actual range in fuel quality.

During the last decade in particular, many emission measurements have been taken on wood-fired residential heating appliances throughout the world. Two publications are of particular interest to Europe and further discussed here.

19 EMEP/EEA Air Pollutant Emission Inventory Guidebook, 2019 edition, https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

Kindbom & Mawdsley (2018) presented and discussed new pollutant emission measurements on 20 different stoves and single house boilers, typical for Scandinavia. Measurements were taken under various appliance load factors, varying fuel quality (standard, moist and dry), and various other user-determined parameters, which will be further discussed in the remainder of this section. The report compares the measured emission factors for PM in particular to literature data and discusses the differences. Furthermore, it includes instructions on how to go from emission factors measured under standard conditions, to (much higher) real-world emission factors that include a certain amount of 'bad combustion' due to for instance part load instead of nominal load and moist fuel. The report confirmed what has been observed before, that emissions vary widely with appliance technology and user operation. In comparison to the emission factors from the EMEP/EEA Guidebook, Kindbom & Mawdsley (2018) generally measured somewhat lower emissions under standard conditions. Accounting for a certain amount of bad combustion brought the emission factors more in line however.

Klimont et al. (2017) collected and compared literature emission factors for wood-fired stoves and boilers to support a global emission inventory undertaking. On average, the data they collected show somewhat higher emission factors than Kindbom et al., being more in line with the EEA Guidebook recommended emission factors.

Impact of fuel quality

Both Kindbom & Mawdsley (2018) and Wohler et al. (2016) looked at the influence of fuel quality on emissions. Measurements taken by Kindbom & Mawdsley (2018) indicated that using wood with a higher (25-30%) or lower (5-15%) moisture content than standard fuel (16-20%) generally increased the emission factors by a factor of 1.5 – 2. Modern stoves appeared more sensitive to moist fuel, where emissions of $PM_{2.5}$ increased in the order of 5 – 8 times compared to when fired with standard fuel. Older technologies appeared less affected by moist fuel, and the emission levels were comparable to the standard fuel. Using extra dry fuel wood also increased emission factors, but not to the same extent as moist fuel. Wohler et al. (2016) surveyed behaviour of individual residential stove operators in Europe and found that 25% of the used fuel wood was not properly dried. A study for the Netherlands[20] suggested 20%.

Most emission measurements like those discussed here are taken with firewood or wood pellets as a fuel. Besides firewood and wood pellets, alternative types of solid biofuels may also be used for residential heating. These bioenergy carriers can be forest-derived (e.g. forest slash, bark or wood chips) or industrial waste from the wood industry (e.g. sawdust, splinter), or agricultural by-products (e.g. straw, olive bone and other herbaceous waste). The use of these or other lower quality bioenergy carriers or waste-like fuels is often associated with energy poverty. Also wood products other than pellets (e.g. densified pressed wood briquettes, or charcoal) may be used.

Often these alternative biofuels have a somewhat lower energy-content than dry firewood. Moreover, they may also have a large volume to weight ratio, which makes them impractical to handle by households. They may also require modified combustion equipment to burn efficiently. When these fuels are used for residential heating this tends to be in higher capacity equipment (>50 kW), for heating multiple homes, rather than in single house equipment (e.g. Musule et al. (2021)). This type of higher capacity boiler typically has much lower particulate matter emission factors than smaller single house equipment (as explained in the next section). Charcoal is used by households directly but mostly used outdoors for grilling foods. Wood briquettes are used by households for space heating but there are currently no indications that these would cause higher emissions compared to firewood logs (rather the contrary, see e.g. Mitchell et al. (2020)).

Impact of installation size/type and age

During the last decades much progress has been made in optimising combustion technology for domestic combustion of fuel wood. There are basically four types of appliances distinguished in international literature with each a different typical capacity range: log wood-fired stoves (5 – 10 kW), log wood fired single house

20 Van Middelkoop M., R. Segers, Wood use by households – WoON 2018 (in Dutch), CBS report The Hague (2019).

boilers (10 – 50 kW), medium sized log-fired boilers for heating multiple houses (50 -1000 kW) and wood pellet-fired stoves and boilers (5 – 1000 kW). For single house appliances, various forms of technology are used for each basic type, ranging from traditional cast iron and masonry stoves to advanced Ecodesign stoves and single house boilers, i.e. those stoves and boilers which are meeting the Ecodesign emission limit values.

Over the whole range of equipment used to generate heat from wood-firing, there are three main factors affecting the emissions from a small-scale combustion appliance. These are explained in Table 4-1.

Table 4-1: Main factors influencing the emissions of a small-scale combustion appliance

Size of the combustor	In general, particulate matter emission factors decrease with increasing capacity, mainly because of the increasing operating temperature that leads to more efficient and more complete combustion. There is also less disturbance of the fire when fresh fuel is added. For medium size boilers (50 – 1000 kW), Kindbom and Mawdsley (2018) measured emission factors roughly comparable to only the best in class among the smaller appliances. This is confirmed by literature emission factors collected and reported by Klimont et al. (2017).
Type of fuel feed	Fuel feeding in single house equipment is traditionally done manually, by periodically adding fresh chunks of wood to the fire. Directly after adding fuel, a period of high particulate matter emission may occur when the added fuel starts pyrolyzing under heat, but not yet fully burns. Volatile decomposition products are then released as particulate matter. When fuel is added continuously in small measured amounts this does not happen. Automatic pellet-firing has therefore far lower emission factors than (manual) log wood firing, because the precise metering of the fuel leads to a more complete combustion. In a higher capacity appliance (>50 kW) this is less of a factor because the added amount of fuel is much smaller compared to the amount already present, so complete combustion of the added fuel is achieved much quicker.
Type and technical sophistication of the combustor	In emission literature, combustion appliances of similar type are usually roughly ranked by their level of technical sophistication (which typically follows their environmental performance). Three categories are often distinguished: traditional/conventional, improved (having a basic form of emission optimisation) and modern/advanced, with the latter including the Ecodesign labelled installations.

For stoves and single house boilers using wood in the small combustion sector, the EEA Guidebook emission factors for $PM_{2.5}$ range from under 100 g/GJ for modern appliances to 5 – 10 times higher for traditional ones, with the improved appliances in between, around 200 – 300 g/GJ (for stoves as well as single house boilers)). Kindbom and Mawdsley (2018) measured up to 2 times higher emission factors in traditional stoves compared to modern stoves. The pellet-fired automated variants performed by far the best across all appliance types, with emission factors being at least a factor 2 below those of the most advanced log wood-fired stoves and boilers. For medium sized boilers (50 kW – 1000 kW) emission factors comparable to pellet stoves are reported.

Impact of behaviour

It has been shown many times that user behaviour has a big influence on the emissions of small wood combustors. User behaviour affects fuel quality, as well as load factor. A smouldering fire for instance (a very low load factor) emits relatively large amounts of PM whereas the actual amount of wood combusted is at the same time low. This condition then results in particularly high emissions compared to emission factors for nominal load operation (i.e. operating the appliance at the designed load).

Kindbom and Mawdsley (2018) found that part load combustion conditions (30% of the nominal load) in the measured boilers increased the emission factors between 2 – 6 times compared to nominal load. For the measured stoves, part load conditions generally increased the emission factors 1.5 – 3.5 times.

Both Kindbom and Mawdsley (2018) and Wohler et al. (2016) recommend that for emission inventories where "real life" emissions are estimated, the large sensitivity to operational conditions (moist fuel and part load) needs to be taken into consideration, and a certain percentage of incomplete combustion needs to be assumed. Relying on emission factors derived strictly for nominal load and standard fuel quality may give a significant underestimation of real-world emissions. Wohler et al. surveyed actual user operation of wood-fired appliances in Europe, and give guidelines to what degree operator-induced sub-optimal combustion conditions may be taken into account.

One way to reduce emissions is to provide the user with guidance on how to operate the device. A presentation[21] by the UNECE Task Force on Techno-Economic Issues (TFTEI) provides information on a code of good practice for solid fuel burning and small combustion installations based on Best Available Techniques (BAT) with the aim of reducing combustion pollutant emissions and the related impact on the environment and human health[22].

Influence of prescribed measurement standard

When emission inventories are compared between countries, emission factors used for residential biomass combustion often have a very different basis from country to country. They may vary widely as a result, even for comparable appliances. As has been discussed above emission factors are highly dependent on what exactly was measured in the underlying experimental evidence, and under what circumstances.

The two prime reasons for emission factor inconsistency is whether or not an emission factor includes condensables (see 4.2.3), and secondly, what user behaviour/fuel quality/combustion cycle is assumed, as is explained above. Ideally, condensables are fully accounted for in emission inventories and the assumed user behaviour/fuel quality/combustion cycle represents real-world conditions.

There are several reasons why this is sometimes not the case. Some countries require for legal reasons that emission factors used in inventories have to be based on emission factors measured in type testing, for instance to check whether a certain appliance meets an applicable emission limit value. Typically measurements which are intended intended to check whether a certain appliance meets legal emission limit values, such as those adopted under the Ecodesign Directive, use a dedicated measurement standard in which usually only solid particles are measured for consistency reasons. Such a dedicated standard may be very specific regarding equipment to use, procedures to be followed, fuel specification, load factors etc., which is necessary to get reproducible results. However, when these standards do not represent the real-world practice, they are unsuitable to assess real-world emissions. These specific type testing standards are therefore not discussed here in relation to emission factors.

Another reason to use domestic emission factor measurements exclusively are country-specific appliance types and available biomass types, for which there is little information available in literature.

In countries that do not have such obligations, inventory compilers can select any scientific source for emission factors that they deem appropriate. Usually, condensables are included in such cases and often a partly sub-optimal combustion cycle is assumed, which may include a certain amount of part load and moist fuel.

As discussed earlier, whether or not a used measurement standard includes condensables or not, will lead to very different results. Indicatively a relative increase of a factor 2 is often observed for modern appliance types, whereas for older appliance types this could be a factor of 3 to 4, and in some cases even higher (see e.g. EMEP/EEA Guidebook). A measurement standard may also prescribe a certain combustion cycle (prescribing the manner of ignition, fuel batch sizes, load factors, duration of the cycle, fuel quality etc.). Similar to the choice whether to include condensables, different combustion cycles can lead to very different results. An extreme case was described by Kindbom & Mawdsley (2018). They compared emission factors determined according

21 https://unece.org/fileadmin/DAM/env/documents/2019/AIR/WGSR/item_3_Tiziano_Pignatelli.pdf
22 Other examples of measures to reduce emissions or environmental impacts thereof are available from the case studies (see chapter 6).

to the European EN 16510 standard to the Norwegian NS3058 standard on the same two improved/modern stoves. The difference between the two standards is mainly the prescribed combustion cycle, as the firing scheme of the NS3058 standard included much more part load operation than EN 16510, and in fact adopted the majority of the operation at part load. The results showed that the Norwegian standard resulted in a factor of 5 higher $PM_{2.5}$ emission factor compared to nominal load and standard fuel quality as prescribed by EN 16510.

Annex A1 provides more technical background on the different measurement methods, and also describes how the appliance type test operating procedures fit in there. Annex A1 elaborates on the following two specific elements:

- The pollutant sampling method (with or without condensables for particulate emissions) used to determine the emissions
- Procedures for appliance tests (i.e. concerning combustion phases tested, types of nominal or reduced combustion speed, fuel quality) and how these relate to real-life emissions

Conclusion on emission factors

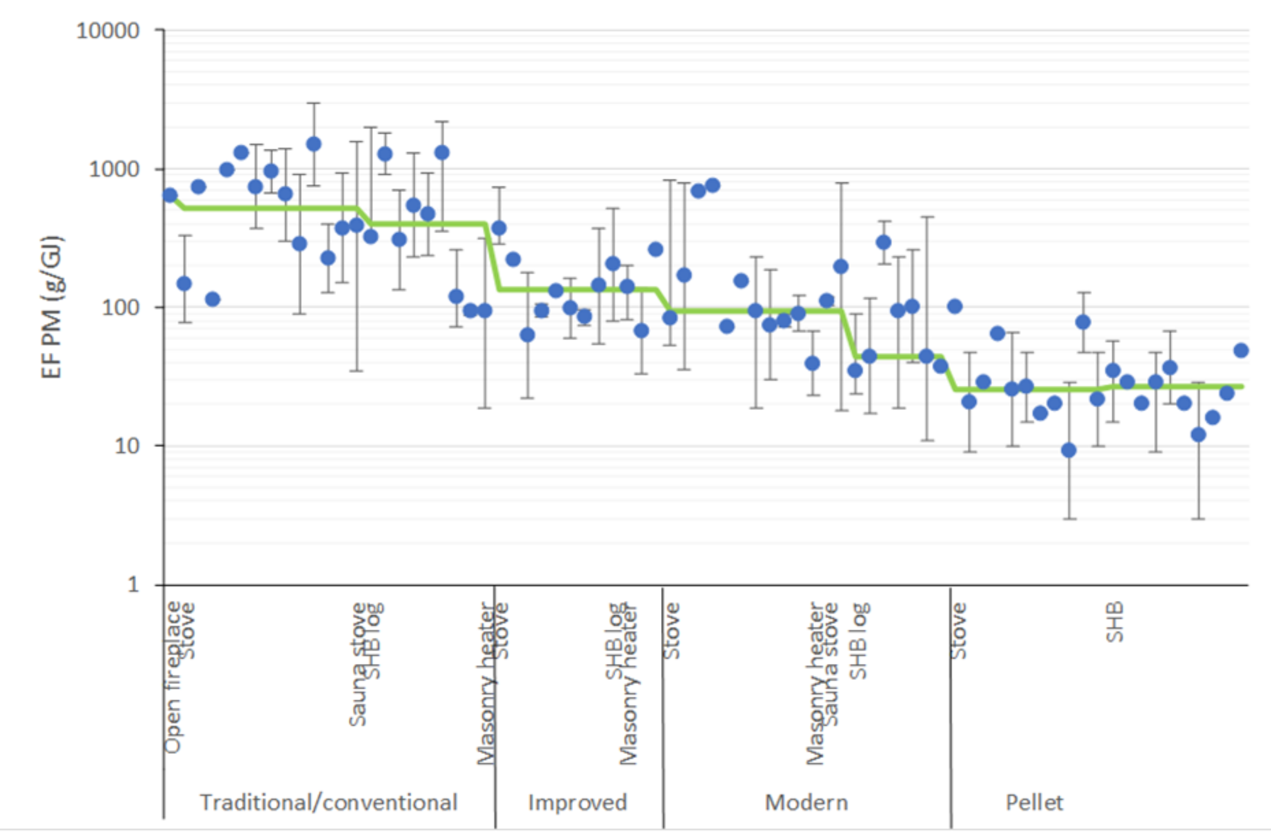
The $PM_{2.5}$ emission factors for **nominal load and standard fuel quality**, including ignition, **as measured by Kindbom & Mawdsley (2018)** and aggregated to rough environmental standard ('modern', 'old', 'pellet' boiler/stove) are provided in Table 4-2. All emission factors are based on measurements using a dilution tunnel approach at ambient temperature, thus fully including condensables.

Table 4-2: Emission factor (range) for most used appliances in residential wood combustion as measured by Kindbom & Mawdsley (2018)

Type	Stove (g/GJ)	Single house boiler (SHB) (g/GJ)
Modern	50-100	50-100
Old	100-200	~ 300
Pellet	~ 50	~ 30

Emission factors for boilers were found to be highly sensitive to part load operation, whereas modern stoves were very sensitive to fuel moisture content. A particular state-of-the-art stove measured by Kindbom & Mawdsley (2018) appeared only moderately sensitive to fuel moisture and almost insensitive to part load operation. As a result of these sensitivities, assuming a certain amount of part load operation, or moist fuel could easily double the emission factors in Table 4-2.

In Kindbom & Mawdsley (2018) an extensive comparison between their measured emission factors and literature data was made. All measured appliances in this study, including their range as a result of partial incomplete combustion, plus all literature values quoted in there (such as by Klimont et al. 2017, including range) have been plotted in Figure 4-7. Appliances are aggregated and sorted according to main type and environmental standard (X-axis categories). Blue dots represent the reported central values while the error bars represent their range. The green line shows the median values for stoves, boilers and pellet-fired appliances, by environmental standard. It is obvious from the figure that literature data vary widely. Even within comparable appliance classes the variation is typically around one order of magnitude. Note in this respect the logarithmic Y-axis. In spite of the large scatter, the median values do show a decreasing trend with technological sophistication, as expected.



Note: SHB = single-house boiler.

Figure 4-7: Range of emission factors for residential wood combustion reported in literature per main type and environmental class. Blue dots represent individual measurements, green line represent median value per appliance type. Adapted from Kindbom and Mawdsley (2018)

4.4.4 Regional impacts of bioenergy use

The impacts of bioenergy on air quality and associated impact on human health and the environment varies between different regions in Europe. This does not only depend on the actual emissions of bioenergy use, but also on emissions of other substances in the region, emissions from the neighbouring regions, local topography, climatological conditions, etc. The health impacts or possible exceedances of limit values are always due to the combination of all these factors. Hence, the areas with relatively high emissions from bioenergy are not necessarily the regions with the highest impacts.

In recent years, some tools have been built to assess the impact of specific sources on air quality in cities, mostly to provide policy makers at local level with information on the origin of the sources responsible for the pollution in their cities. This knowledge helps to define policy measures that are most effective given the local circumstances. One example is the **Urban $PM_{2.5}$ Atlas** from JRC[23]. It provides the annual average concentrations of $PM_{2.5}$ and PM_{10} for 150 cities in Europe, as well as a high-level breakdown of the main sources contributing to the concentrations, based on the SHERPA model approach. In addition to the sources, there is also a split between contributions from the local area, the rest of the country and of transboundary origin. While the sources do not specifically include emissions from the use of bioenergy, as pointed out previously, the $PM_{2.5}$ emissions from the residential sector largely originate from the use of bioenergy, while the $PM_{2.5}$ emissions from bioenergy use in large combustion plants (energy and manufacturing industry) are relatively small. The contribution of residential combustion is therefore a suitable approximation for the contribution of bioenergy use in most

23 https://publications.jrc.ec.europa.eu/repository/handle/JRC134950

Member States, only in those that have a significant share of coal use in the residential sector this approximation is not valid (cf. Figure 1-5).

The JRC Urban Atlas builds on emissions as reported and taken up by the CAMS-REG-v6.1 inventory (Kuenen et al. 2022). In contrast to the earlier Urban Atlas (2021) a CAMS-REG version is used where reported small combustion PM emissions are replaced with a dataset that consistently includes condensables (the "Ref2" dataset described in Section 4.3.3), to avoid the inconsistency between different countries and to be able to consistently assess the contribution of different sources across cities in Europe.

Apart from the estimation of bioenergy emissions at country level, also the spatial variability of the bioenergy emissions (from country to grid level) is a key source of uncertainty. A generic method was used over Europe for this purpose, where based on population density and degree of urbanisation, a hypothetical wood demand function was derived. Given that urban areas are typically connected to gas networks or other means of heating possibility, the use of bioenergy is less common compared to rural areas which are not connected to a network. However, some use of bioenergy, also in relation to recreational use in outdoor environments, is allowed to take place. In addition to this, a fuel supply function is derived estimating how much fuel wood is being produced based on land cover. These two functions are overlaid spatially assuming that locally produced fuelwood is mainly supplied to neighbouring area. This method implies most wood is used in rural areas and in urban areas a limited amount of wood burning is assumed to take place. In practice, however, some cities have put restrictions or even bans on wood burning, while in others it may be more widespread, which means that in some countries bioenergy use emissions in urban areas are likely to be overestimated while in others it may be underestimated. While the knowledge on where wood is used is clearly an uncertainty, the currently used methodology for spatially distributing wood combustion emissions is the state-of-the-art for Europe as a whole. Further improvements should focus on representing local regulatory and cultural aspects in the representation of wood burning emissions.

The JRC Urban Atlas finds that the **residential sector is responsible for more than 35% of the $PM_{2.5}$ urban background concentrations in a number of cities**, for instance in northern and central Italy but also in Poland, Czechia, Slovenia, Croatia, Hungary, Romania and Bulgaria. There is a wide range of cities across Europe which are largely affected by emissions from the residential sector which, given the large contribution of bioenergy to residential $PM_{2.5}$ emissions, in most cases also implies that they are largely affected by bioenergy combustion. In comparison to the earlier 2021 JRC Urban Atlas, the contribution of residential emissions to urban background $PM_{2.5}$ concentrations increased, which is partly related to higher emissions which include the condensable part of $PM_{2.5}$ across Europe.

The EEA annually publishes maps of the measured air pollutant concentrations in relation to the limit values currently in the EU legislation[24]. For $PM_{2.5}$ in 2021, in northern Italy, southern Poland and northern Czechia as well as in Croatia the reported annual mean concentrations exceed the annual mean concentration limit value. These regions are also regions where a high share of the residential sector is reported in the aforementioned Urban $PM_{2.5}$ Atlas, which implies that bioenergy use is likely an important contributor to the exceedances.

- For Croatia, the Urban Atlas only considers the city of Zagreb. The contribution of residential emissions in the PM2.5 mass is modelled to be above 45%
- In Italy, it is typically the Po Valley which shows exceedances. Looking specifically at the cities in this area, typically 35-45% contribution from the residential emissions is modelled, with for Turin and Florence higher contributions around 50%
- For the cities in southern Poland, typical contributions of the residential sector are modelled to be above 50% (for instance in Krakow and Warsaw). Important especially for Poland is that in contrast to most other

24 https://www.eea.europa.eu/publications/europes-air-quality-status-2023

Member States the residential PM2.5 emissions contain an important share of coal combustion, which implies that the bioenergy contribution is significantly lower than this share

- For Czechia, six different cities are considered, with a residential contribution to the modelled PM2.5 mass typically above 35% in all of them. Although less than in Poland, also in Czechia the use of coal for residential heating plays a role, which reduces the contribution from bioenergy alone

All in all, from the available information it can be concluded that especially in Croatia and northern Italy (Po Valley), the contribution of bioenergy use to the $PM_{2.5}$ exceedances is significant. For Poland on the other hand, the impact of the residential sector is a combination of the combustion of wood and coal, so the contribution of bioenergy use alone to the exceedances is not possible to quantify.

In addition to the JRC study, the CAMS policy service[25] provides similar information, but more focused on the short term (predicted $PM_{2.5}$ concentrations and responsible sectors in a set of cities in the next 4 days) to support short-term actions. However, given the temperature dependency of bioenergy use in the residential sector, such a short-term forecast cannot be used to assess the impact of bioenergy on average annual $PM_{2.5}$ concentration levels.

Furthermore, Kukkonen et al. (2020) aimed to quantify the importance of residential wood combustion on $PM_{2.5}$ concentration levels in four Nordic cities, and concluded that in three out of four cities, the predicted levels reached up to ~20%. For Oslo however, contributions up to 60% in specific areas of the cities were found.

4.5 Prospects for future bioenergy uptake and impacts

This section discusses the possible development of bioenergy uptake in the future and its impacts on air quality in the EU, building on the scenario modelling that has been performed at EU level underpinning the 3rd Clean Air Outlook (CAO3).

4.5.1 Future bioenergy uptake under various scenarios

The CAO3 baseline scenario has been derived from the PRIMES energy system model. The PRIMES energy system modelling suite includes different bioenergy products in all sectors of the economy. An overview of the bioenergy products included in the PRIMES model is available in Figure 4-8. The liquid bioenergy products are mainly used in the transport sector as biofuels, while gaseous products are used either for direct heat and power generation locally or are blended in the natural gas grid. Solid bioenergy is used for power generation and heat either in large-scale installations for power generation as well as CHPs for industry or district heating, or at a smaller scale for heating in the domestic sector (e.g. pellet burners). The PRIMES model also includes the use of waste (both renewable and non-renewable waste).

25 https://policy.atmosphere.copernicus.eu

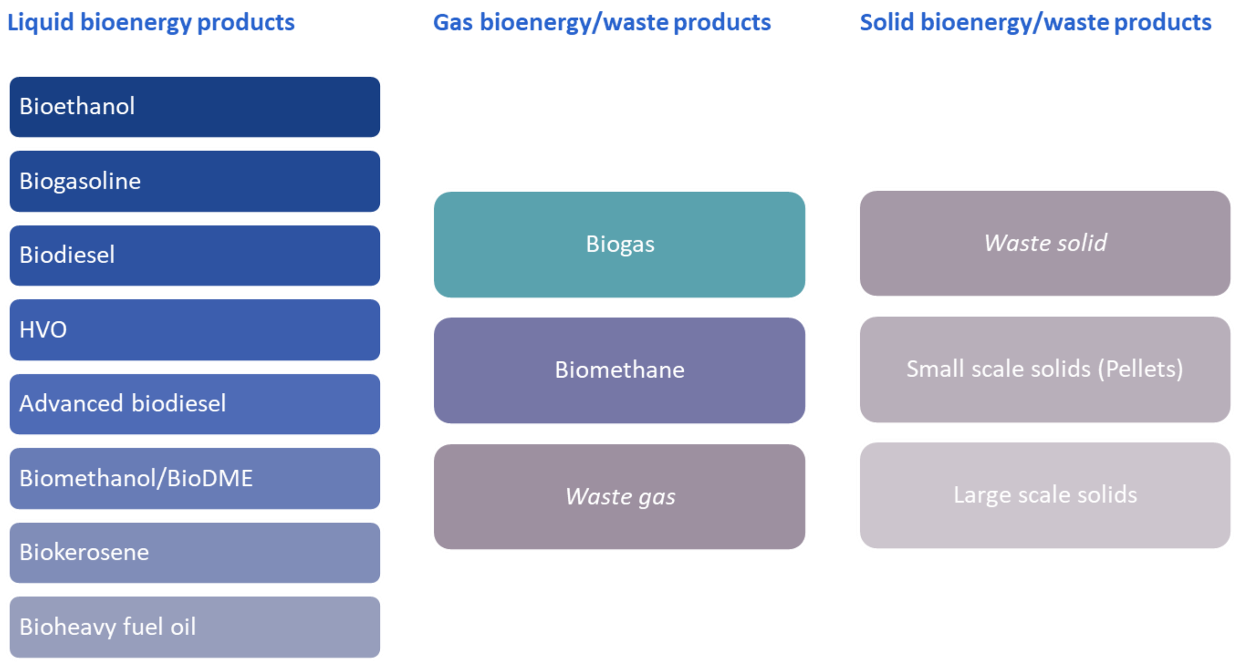


Figure 4-8: Bioenergy products included in the PRIMES Energy System model[26]

All bioenergy products used in PRIMES are considered sustainable, i.e. compliant with the sustainability criteria of the Renewable Energy Directive. The production of the quantities of bioenergy products is calculated through the PRIMES biomass model which computes the feedstock requirements for bioenergy and the potentials for bioenergy products are in turn derived from agricultural models such as CAPRI and Land Use Models such as GLOBIOM.

For the purpose of this study, we show the evolution of the consumption of solid bioenergy in the stationary demand. Currently solid bioenergy is used primarily (45%) in the small combustion sector which comprises the residential, commercial/institutional and agricultural stationary combustion. Combustion of biomass in the energy transformation sector[27] and in industry comprises 22% and 20%, respectively. The consumption in industry includes both consumption in onsite boilers or combined heat and power (CHP) units, as well as in furnaces. In future projections derived using the PRIMES model, when considering a net-zero scenario (e.g. the CAO3 scenario), the amount of bioenergy use increases and the split between sectors changes:

- Solid bioenergy use in the small combustion sector is projected to reduce and then almost stabilise. This is the result of renovation in European buildings incl. change of equipment to higher efficiency, as well as a shift towards electrification through heat pumps
- Similarly in the industrial sector: the solid bioenergy consumption reduces and then almost stabilises. This is also due to efficiency in equipment and processes (incl. heat recovery), electrification and the shift to new process types using e.g. hydrogen
- The energy transformation sector is the sector where the use of solid bioenergy consumption is increasing, which is due to a shift towards biomass in power and steam/heat generation, which represents a form of dispatchable power generation in a system otherwise dominated by variable renewable energy sources

Figure 4-9 shows these changes for the CAO3 baseline projection of bioenergy consumption in EU27 until 2050.

26 PRIMES model description 2022, available at https://e3modelling.com/modelling-tools/primes/
27 The energy transformation sector includes power, steam/heat generation as well as other elements of the transformation sector such as Blast Furnaces (based on the EUROSTAT energy balance split).

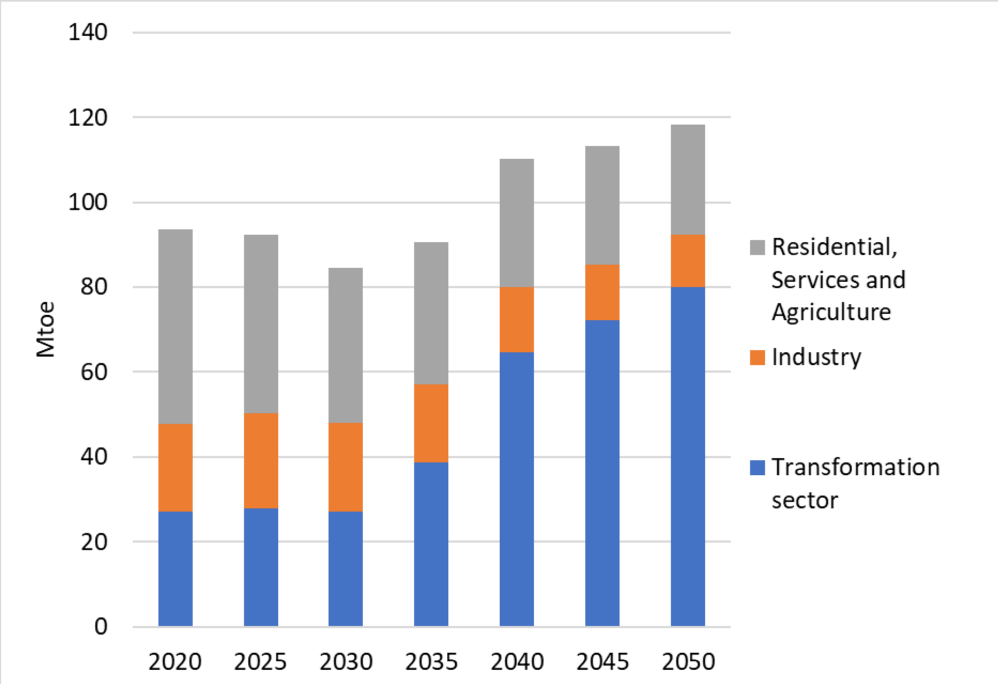


Figure 4-9: Consumption of solid bioenergy by sector in the stationary demand (source: PRIMES scenario that meets the Fit for 55 targets for 2030 and climate neutrality in 2050)

Finally, it should be mentioned that bioenergy consumption in EU27 in future years is dependent on the choices made for the scenario, for instance regarding assumptions about the potential of available biomass (and related products), biomass prices (and subsidies) and also regarding the (level of) deployment of the specific CO2 reduction options like Carbon Capture and Storage (CCS). The actual development of these factors in future years will also impact the bioenergy use and hence its environmental impact.

4.5.2 How bioenergy related emissions and their impacts are expected to evolve in the future

Current (2020) EU27 emissions of $PM_{2.5}$ from solid biomass use were estimated at 580 to 650 kt (Figure 4-12), where upper value includes harmonized set of emission factors including condensable PM from residential heating sector (Klimont et al., 2022a; Simpson et al., 2022), and over 97% of these emissions originated from residential heating sector (as shown also in Figure 4-4). Overall, bioenergy related emissions represented over 50% of total anthropogenic $PM_{2.5}$ emissions in the EU27 (Figure 4-10). While the increment in total $PM_{2.5}$ emissions due to inclusion of condensable PM seems rather small (about 10-20% at the EU27 level) this is variable across regions and the *Baseline* calculation in GAINS partially already includes the condensable fraction (comparable to the mixed reporting by countries as described in Section 4.3.3, see more detailed discussions in the reports supporting the 3rd Clean Air Outlook[28]; Klimont et al., 2022b). The *Baseline* scenario that includes assumptions consistent with the Green Deal objectives, which result in declining use of bioenergy in residential sector (see previous section) and assume implementation of Ecodesign, results in steady decline of emissions from bioenergy as well as declining share in total emissions. However, despite the overall reduction in emissions by over 50% by 2030 and nearly 80% by 2050, compared to 2020, bioenergy continues to represent over a third of total $PM_{2.5}$ emissions even by 2050 with residential sector contributing well over 90% out of all bioenergy emissions. The scenario which reflects the proposal for the revision of the Ambient Air Quality Directive, i.e., aiming at reducing the annual mean $PM_{2.5}$ concentrations to levels below 10 µg/m^3 – '*Baseline-OPT10*', brings additional 40% reduction of $PM_{2.5}$ emissions in 2030 resulting in over 70% reduction of bioenergy related emissions compared to 2020.

28 https://environment.ec.europa.eu/topics/air/clean-air-outlook_en

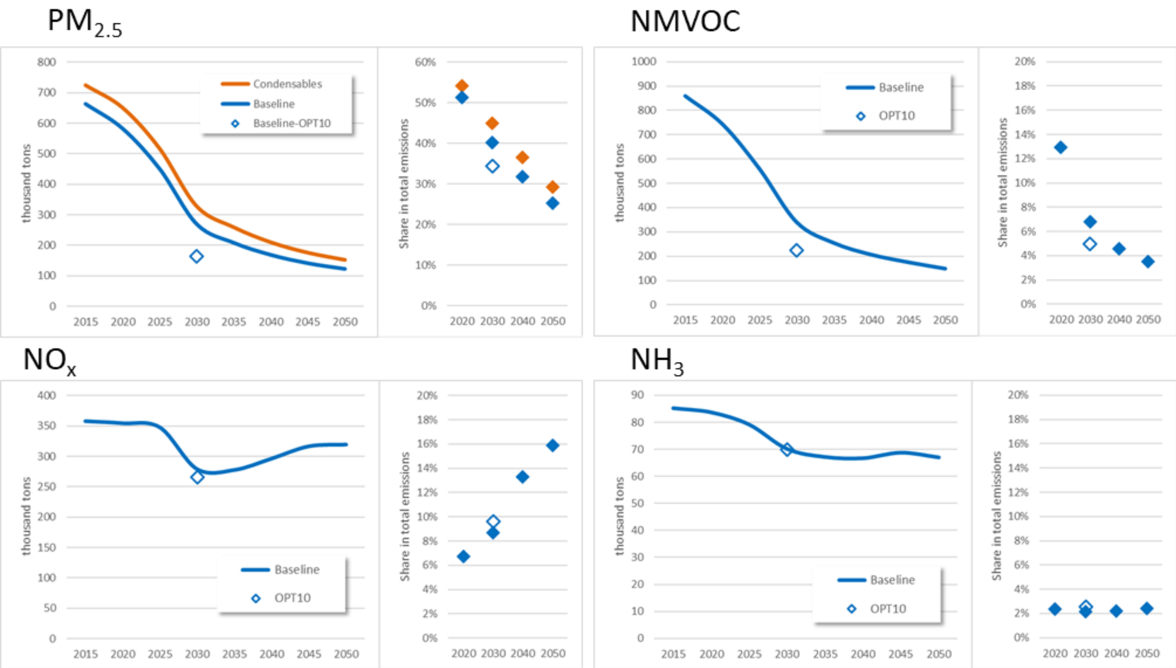


Figure 4-10: Emissions of $PM_{2.5}$ and selected air pollutants from bioenergy use in residential and in other sectors combined in the EU27 as well as share of bioenergy related emissions in total anthropogenic emissions. Source: GAINS model results from the third Clean Air Outlook (Klimont et al., 2022a, 2022b)

Figure 4-10 also shows emissions of selected air pollutants from bioenergy use. NMVOC emissions decline similarly to $PM_{2.5}$, largely because residential sector dominates these emissions (80-95%) and declining fuel use as well as improvement in efficiency of residential installations bring strong reductions. The share of bioenergy related emissions in total NMVOC drops from over 10% to below 5% in the long term. The picture looks different for Nox and NH_3, where for the latter the decline is driven by fuel use reduction and the overall share of bioenergy is very small, about 2-3%. For Nox, the emission trajectory is not alike for other species because overall contribution of the residential sector to all bioenergy related emissions is only about half while power generation and industrial uses represent the other half. Their fuel use trends are different, including in the longer term a slight decrease of bioenergy use in industry and an increase in the power and transformation sector. In the *Baseline*, the share of emissions from bioenergy in total NO_x emissions increases over time from about 6-7% in 2020 to about 15% in 2050, which is mostly driven by more significant reductions of Nox emissions in other sectors, including transportation and use of fossil fuels in stationary combustion. The share of bioenergy emissions in the *OPT10* case increases slightly for both NH_3 and NO_x because reductions in other sectors are much stronger.

As indicated earlier, consistent consideration of condensable fraction of PM (Simpson et al., 2022) in used emission factors (Efs) results in increased emissions from biomass combustion (Figure 4-11). This has implications on concentrations of ambient $PM_{2.5}$ which were analysed in the study supporting the 3rd Clean Air Outlook (Klimont et al., 2022a). Here we show a summary figure illustrating the $PM_{2.5}$ increment across the EU from including condensables in a consistent way, shown as increase/decrease in absolute terms (µg/m^3) and relative (%) change when compared to the *Baseline* case concentrations (Figure 4-11). Most significant increases are seen in central Europe including Austria, Czechia, and parts of Germany and Italy while small decreases (the original GAINS emission factors appear to be higher than the harmonized set of emission factors proposed in Simpson et al. (2022)) are shown for Poland and Norway. The relative changes (Figure 4-11, right) highlight importance of inclusion of condensable in Austria, Germany, France which is consistent with the reporting practice in these countries, i.e., reported $PM_{2.5}$ from residential sectors do not include condensable fraction of PM (based on the 2021 reporting cycle, in some countries this may have been updated since then). Overall, across the EU27, harmonization of condensable emission factors results in estimated higher number of premature deaths by about 2-3%, i.e., 7-8 thousand per year, compared to the *Baseline* case and similarly 2-3% in YOLLs[29], i.e., by about 6-7 million (more detailed results presented in Klimont et al. (2022b).

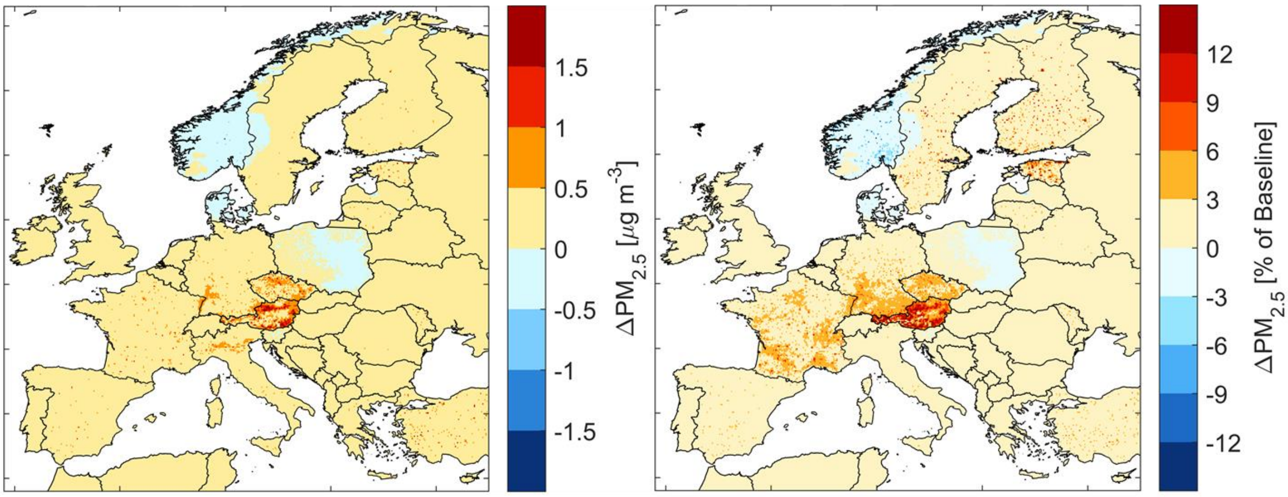


Figure 4-11: Comparison of annual mean concentrations of $PM_{2.5}$ in 2015 estimated in the GAINS model in the standard setup and using the harmonized set of $PM_{2.5}$ emission factors including condensable fraction of PM from Simpson et al. (2022). Difference maps (GAINS standard Efs vs GAINS with harmonized/condensable Efs) showing absolute (left) and relative (right) difference for 2015.

While primary $PM_{2.5}$ emissions from bioenergy play a very important role in contributing to total concentrations of $PM_{2.5}$, there are also significant sources (not bioenergy related) of other ambient PM precursors including SO_2, Nox and NH_3. Consequently, the contribution of bioenergy to the concentrations of $PM_{2.5}$ is smaller than its share in emissions of primary $PM_{2.5}$. This is illustrated in Figure 4-12. In general, residential combustion dominates contribution from bioenergy with power sector and industrial uses contributing only 1-2% to concentrations. Overall, for few countries, i.e., Croatia, Hungary, Latvia, Romania and Slovenia residential combustion of bioenergy contributes between 40 and 50% of total $PM_{2.5}$ annual mean concentrations in 2020, with few more counties (Bulgaria, Italy, Lithuania, Slovakia) where that contribution is about 30%. Overall, the $PM_{2.5}$ concentrations decline across EU27 in the *Baseline* and a significant part of the reduction in concentrations can be attributed to reduced emissions from bioenergy use, therefore its contribution to concentrations (also relative) declines (Figure 4-12). In the *OPT10* case further decline of concentrations as well as share of bioenergy is expected with only few countries showing about 30% share of bioenergy in total concentrations of $PM_{2.5}$, including Croatia, Latvia, and Slovenia.

29 Years of Life Lost

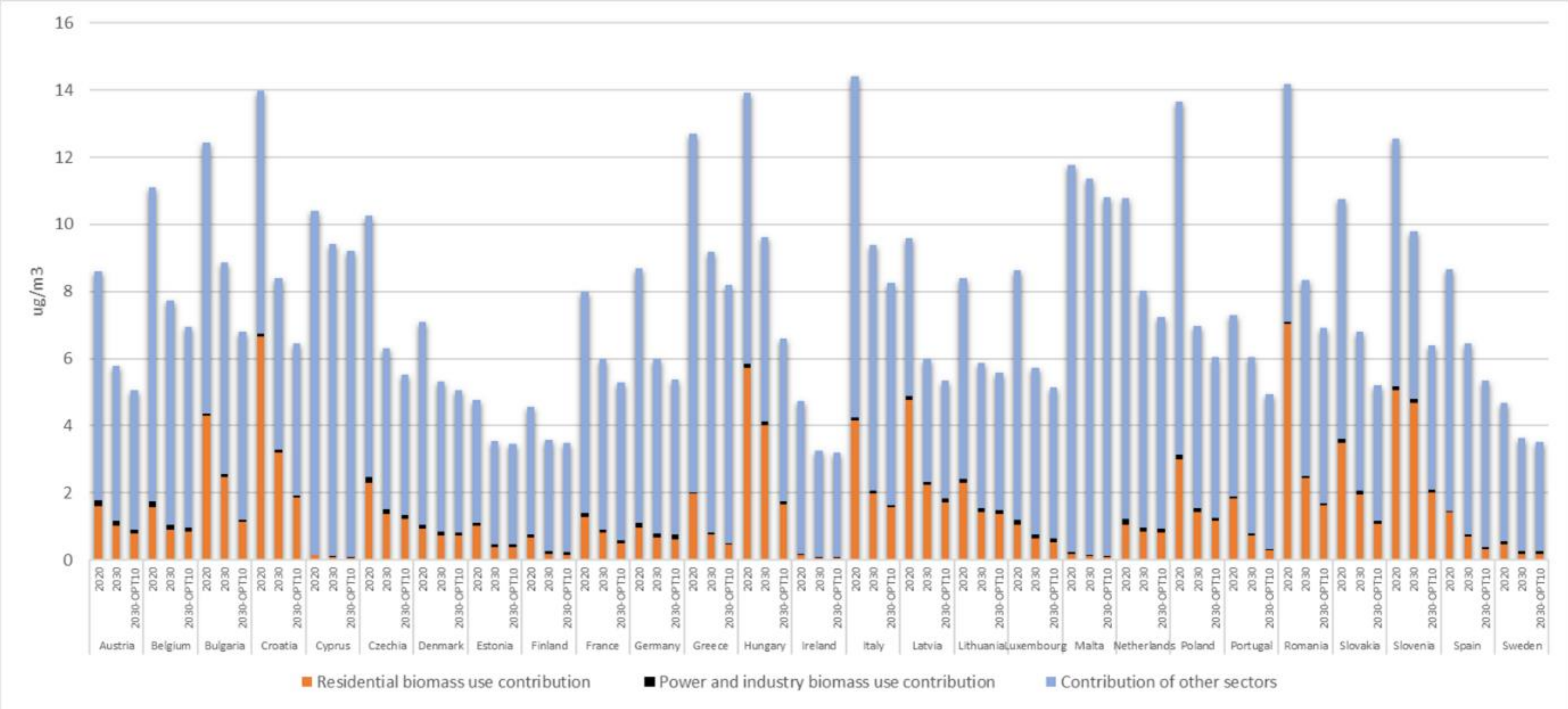


Figure 4-12: Contribution of biomass use in residential, power, and industry sectors to total population weighted annual mean PM2.5 concentrations in the EU27 countries for 2020 and 2030 Baseline and OPT10 scenarios

5 EU Level Bioenergy Drivers and Policy Framework

Summary and outcomes:

- Within the overarching framework of European Union energy, environmental and public health policy, there are both drivers for the increased uptake of renewable energy and heat (including bioenergy), and for improving air quality (and thus public and environmental health)
- The legislative and policy measures for energy and climate on one hand and air quality on the other are, in general, separate and distinct. The only main point of cross-over is the Ecodesign Directive, which seeks to control emissions from new small bioenergy appliances (amongst many other product controls)
- Specific policies to either encourage the use of bioenergy or seek to control the air pollution emissions from small-scale bioenergy largely rest at the Member State level. EU policies provide broad scale drivers and targets for energy, climate and air quality. The separation of policy instruments, e.g. Renewable Energy Directive and Ambient Air Quality Directive, potentially adds to the perception that they are not cohesive and could be seen as driving in different directions

This chapter assesses EU policy and legislation, identifying those areas which act as drivers for the increased use of bioenergy, and those which are aimed at protecting air quality. The latter may have a suppressing effect on bioenergy use, but could also act as a driver for the uptake of cleaner bioenergy, e.g. at the domestic scale through the incentivisation of more efficient appliances. This largely depends on implementation by Member States, but some legislation will have a more direct impact, such as through the Ecodesign Directive emission limits for new stoves and boilers.

Annex 1)a)i)(1)(a)(i)A5 summarises the EU policies, legislation and other regulatory instruments which currently impact on bioenergy use within the EU. It shows both increasing and decreasing pressures on bioenergy use from policy instruments, including within the same instrument. This is tied to the fact that bioenergy is a key source of renewable energy and, in particular, renewable heat. However, it is not the only source of renewable heat and so increases in renewable energy/heat use need not necessarily result in an increase in bioenergy. By the same token, initiatives such as ecodesign, energy labelling and the Medium Combustion Plants Directive can be used to reduce the impact of bioenergy on air pollutant emissions and thus offer the potential to increase renewable heat without degrading air quality, depending however on the scale of this development.

5.1 General policy on energy, climate and the environment

The trade-off between increasing bioenergy use and reducing air pollutant emissions is already well recognised by environmental, health and energy communities alike[30] as well as in European Commission working documents.[31] This trade-off calls for a more integrated approach to meeting renewable energy and air quality targets in the EU as the 2030 Climate Target Plan impact assessment forecasts that the use of bioenergy will increase to 2050.[32] The increase in bioenergy to meet renewable energy targets needs to be considered in the

30 See for instance: https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/renewable-energy-in-europe-2019-recent-growth-and-knock-on-effects and https://www.iea.org/articles/does-household-use-of-solid-biomass-based-heating-affect-air-quality. The scientific evidence on pollutant emissions from biomass combustion and related health is summarised in a report by the UK Air Quality Expert Group for Defra (2017) report on 'The Potential Air Quality Impacts from Biomass Combustion', chapter 3 [https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf]. In a global context, WHO on household air pollution and health summarises the health hazards related to indoor air pollution from biomass burning [https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health].
31 See the impact assessments underlying the Commission's proposals for a revised Renewable Energy Directive (SWD(2021) 621 final) and for a recast of the Energy Taxation Directive (SWD(2021) 641)
32 SWD(2020) 176 final

wider context of the European Green Deal, in particular the Zero Pollution Action Plan and the proposed revision of the Ambient Air Quality Directives (AAQD)[33] and their planned closer alignment to the updated WHO air quality guidelines[34] (and on which a provisional political agreement was reached between the Council and the Parliament in early 2024[35])

The European Green Deal[36] (COM/2019/640) offers an overall framework for EU environment policy. It provides a set of policy initiatives to deliver the overarching goal of climate neutrality to the EU by 2050, supported by initiatives across all sectors of society. The goals included in the deal relate to circular economy, construction, biodiversity, energy, transport, industry, and food. It includes, inter alia, a proposal for a Carbon Border Adjustment Mechanism, a new circular economy action plan, a review of all relevant climate-related policy instruments, a Farm to Fork strategy, a revision of the Energy Taxation Directive, a sustainable and smart mobility strategy, a Biodiversity Strategy and an EU forest strategy.

5.2 Potential legislative/policy drivers for the uptake of bioenergy

5.2.1 Policy and legislation

By the end of 2019, EU Member States were required to submit a ten-year integrated national energy and climate plan (NECP) for the period 2021 to 2030, under the regulation on the governance of the energy union and climate action (EU/2018/199), with an update required by 30 June 2024. These plans contain information on the action of the Member State related to the five dimensions of the energy union: decarbonization, energy efficiency, security of supply, market integration and research, development and competitiveness. PaMs that directly or indirectly impact these dimensions should be reported and the review reports contain an assessment of the adequacy of these policies. As an increase in the use of bioenergy is being used to support decarbonization in the EU, relevant PaMs to increase the use of bioenergy are included in Member State NECPs.

Renewable Energy Directive (RED)

Demand for renewable energy in the EU is increasing as Member States look to meet renewable energy targets as set under the Renewable Energy Directive (RED) in the effort to reach the EU's target of reducing net greenhouse gas emissions by at least 55% by 2030 and achieve climate neutrality by 2050. The recast RED ("RED II")[37] sets a common target for Member States (currently 32% by 2030) for the percentage of energy consumption sourced from renewable energy. Under the *Fit for 55* package of proposals adopted in July 2021, the European Commission proposed an increase in the RED target to 40% by 2030, which will directly transpose to national targets. To accelerate this transition, the REPowerEU plan has proposed further increasing the RED target to 45% by 2030. There is now even greater incentive to reduce the EU's dependence on fossil fuels, particularly those sourced from Russia, as a result of their unprovoked aggression against Ukraine. On 30 March 2023, the European Parliament and the Council reached an agreement and set a binding renewable energy target of a minimum 42.5%, but aiming for 45%, for 2030[38]. The amended REDII[39] entered into force on 20 November 2023 with a transposition deadline by 21 May 2025 (1st of July 2024 for the permitting-related provisions). The amended RED II, among other elements, includes a reinforcement of the sustainability criteria for bioenergy, as well as an

33 https://environment.ec.europa.eu/topics/air/air-quality/revision-ambient-air-quality-directives_en
34 https://www.who.int/publications/i/item/9789240034228
35 https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/air-quality-council-and-parliament-strike-deal-to-strengthen-standards-in-the-eu/#:~:text=Today%20the%20Council%20presidency%20and,in%20the%20EU%20by%202050
36 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
37 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), OJ L 328, 21.12.2018, p. 82–209
38 https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
39 DIRECTIVE (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

obligation to Member States to apply the cascading principle in their financial support schemes. This is likely to have impacts on the availability, price and use of biomass for energy.

5.2.2 Other factors

IEA Bioenergy's Annual Report 2021[40] provides information of the trends of bioenergy in the IEA Bioenergy member countries up to 2019, looking at the role of bioenergy in total energy supply, in electricity use, total fuel/heat consumption, and in transport energy consumption. This includes Austria, Belgium, Croatia, Denmark, Estonia, France, Germany, Ireland, Italy, Netherlands, Sweden and EU as a whole. Individual country reports are also available alongside the main report.

The relative cost of different energy options will be a major driver in their uptake and use. Reporting from the International Renewable Energy Agency (IRENA) shows that, relative to fossil fuelled energy generation, the costs of renewable energy, including bioenergy, have fallen globally[41]. However, the report also notes the wide variation in costs and that, for small-scale use (e.g. domestic), consistent information on feedstock costs is very difficult to identify. In addition, relative costs of different fuels are highly variable and can differ considerably over time. Anecdotal evidence indicates a shift towards bioenergy, especially during times of economic stress, for example, the use of open fires during the economic crash in Greece or a significant rise in the use of wood fuel in the UK during the winter of 2022/23 in response to significant rises in gas and electricity prices. In the latter case, this increased demand also meant an increase in the cost of fuel logs and it is not clear the extent to which shifting to bioenergy was an actual energy saving or a perceived one[42]. This is further complicated by the fact that wood fuel is often acquired for domestic use through informal routes, e.g. foraging, community supplies, local agricultural suppliers, etc.

5.3 Potential legislative and policy restrictions on the uptake of bioenergy

Supporting the European Green Deal, the Zero Pollution Action Plan: "Towards a Zero Pollution for Air, Water and Soil" (COM/2021/400)[43] was adopted on 12th May 2021. It sets out a zero-pollution vision for 2050 and aims to reduce pollution levels in air, water and soil so that they are no longer harmful to human health and natural ecosystems. This is to be achieved through a number of key targets to 2030, including a reduction in premature deaths from poor air quality by 55% compared to 2005 levels.

EU air pollutant emission reduction commitments

Increasing the production of renewable energy in the EU is considered key to meeting the EU's target of a 55% reduction in GHG emissions by 2030 (compared to 1990 levels). However, the conflicting environmental impacts of renewable energy sources need to be considered. Whilst renewable, increasing the use of bioenergy raises concerns for air pollution (amongst other environmental problems), conflicting with emission reduction commitments for air pollutants. In the EU, Member State emission reduction commitments are set out under the National Emission reduction Commitment Directive (NEC Directive[44]) for five key air pollutants: Nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), ammonia (NH_3), and fine

40 IEA Bioenergy (2021). Annual Report 2021. https://www.ieabioenergy.com/wp-content/uploads/2022/04/IEA-Bioenergy-Annual-Report-2021.pdf
41 Report: https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022, infographic: https://www.irena.org/News/articles/2023/Aug/Infographic-Renewable-Power-Generation-Costs-in-2022
42 Evidence on the level of domestic burning in the UK is being developed but had not been published at the completion of this report (March 2024).
43 https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en
44 Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC

particulate matter ($PM_{2.5}$). There has been an identified increase in $PM_{2.5}$ and NO_x emissions since 2005 because of the increase in the use of biomass.[45]

By April 1, 2019, all EU Member States were required to submit a national air pollution control program (NAPCP) report. These reports contain information on the policies and measures (PaMs) that each Member State has implemented to fulfil their commitments to reduce air pollutant emissions from 2020-2029 and beyond 2030. The pollutants in scope under the NAPCP include the five primary air pollutants, NOx, NMVOCs, SO_2, NH_3, and $PM_{2.5}$, as well as PM_{10} and black carbon. Policies targeting bioenergy are likely to be included, as it is a significant source of $PM_{2.5}$, VOCs, and NO_x emissions. Whilst most NAPCP reports give sector-specific PaM details, some do not provide sufficient information for a detailed analysis.

Ambient Air Quality Directives

Directives 2008/50/EC and 2004/107/EC specify air quality standards for the concentration of pollutants in ambient air to be achieved by the Member States for a range of pollutants, of which PM_{10}, $PM_{2.5}$ and PAH are most affected by bioenergy. The Directives also set requirements for assessing and reporting air pollutant concentrations, and for acting on exceedances of the air quality standards. Alongside the NEC Directive and relevant source policies, the Ambient Air Quality Directives are the mainstay of air quality policy across the EU, and a central part of achieving the clean air goals set out in the Green Deal and Zero Pollution Action Plan. In early 2024, a provisional political agreement was achieved on a revised Ambient Air Quality Directive, which will bring EU air quality standards closer in line with the World Health Organization (WHO) Air Quality Guidelines.

According to the provisional agreement, the limit and target values of the revised Directive are to be achieved by 2030, and there is a commitment for regular review of air quality standards by 2030 and every five years thereafter. For the pollutants with the highest well-documented impact on human health, i.e. particulate matter and nitrogen dioxide, the standards have been tightened inter alia for the annual mean limit values of fine particulate matter ($PM_{2.5}$; from 25 µg/m^3 to 10 µg/m^3), and for nitrogen dioxide (from 40 µg/m^3 to 20 µg/m^3).

Under the revised Directive, Member States will be permitted to apply for postponement of attaining some of the limit values for a period of up to 10 years (up until 2040), if they can demonstrate that compliance would not be achievable due to specific conditions, for instance climatic conditions or where the required reduction in emissions could only be achieved with "significant impact on domestic heating systems". For the postponement to be approved, the Member State will need to demonstrate, inter alia, that they will take appropriate measures to ensure they respect air quality standards as soon as possible.

Ecodesign and Energy Performance of Buildings

Some policies have been implemented which begin to address the trade-off and mitigate the amount of air pollution from bioenergy. The Ecodesign regulation for solid fuel boilers and space heaters[46] sets requirements for energy efficiency and air pollutant emissions for solid fuel boilers with a rated heat output of 500kW or less, reducing the emissions produced per unit of energy produced. Alongside this, the energy labelling regulation for solid fuel boilers[47] requires new solid fuel boilers (with a rated heat output of 70kW or less) to be labelled on an energy efficiency scale ranging from A+++ to G. The Energy Performance of Buildings Directive (EPBD) looks to achieve a "highly energy efficient and decarbonized building stock by 2050" through improved building standards, higher efficiency building services and greater information sharing about building energy performance. This will also enable reductions of emissions associated with biomass as residential, commercial and institutional energy consumption is the principal source of $PM_{2.5}$ emissions.[48] The Commission's proposal for

45 European Environment Agency (2023) Briefing on 'Renewable energy in Europe: key for climate objectives, but air pollution needs attention'. Available at: https://www.eea.europa.eu/publications/renewable-energy-in-europe-key
46 Regulation (EU) 2015/1189 and 2015/1185
47 Regulation (EU) 2015/1187
48 https://www.eea.europa.eu/data-and-maps/dashboards/necd-directive-data-viewer-7

a recast of the Directive[49] includes operational $PM_{2.5}$ emissions as an optional indicator on Energy Performance Certificates, which could guide building owners to make renovation choices which will result in reduced $PM_{2.5}$ emissions (see section 7). Political agreement has been reached on the revised Directive[50], although it has not been formally adopted at the time of writing (March 2024).

Land, Land Use Change and Forestry (LULUCF)

Furthermore, the Regulation on Land, Land Use Change and Forestry (LULUCF)[51] provides incentives for Member States to harvest less forest and protect these as carbon sinks. This regulation was updated in 2023 to account for the period up until 2030 and introduces a novel land-based net carbon removals target of 310 million tonnes CO_{2eq} by 2030 for the sector. To enforce this, the regulation's phase 2 (to be implemented 2026-2030) simplifies the reporting standard from accounting benchmarks and towards reliance on actual reported emissions and removals. With this simplification, the regulation prioritises the development of more precise data monitoring, and the utilisation of geographical data and remote sensing.

49 COM/2021/802 final
50 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6423
51 Regulation (EU) 2018/841: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG

6 Member State policy responses

Summary and outcomes:

- The majority of Member States, and other European countries, have put in place measures to control the air pollution impacts of small-scale bioenergy
- These fall into four broad categories: operational measures (including fuel quality), stock replacement measures, use restriction measures and information campaigns. Of the measures assessed through this project, stock replacement measures are the most numerous
- The precise nature of the measures, and the level of ambition shown, varies across Member States, although some general principles can be identified, alongside the key considerations for the development of measures
- Six case studies are presented, to exemplify the range of measures and their application, and a database of arounds 130 measures is presented as Annex A6 to this report

6.1 Approach

The chapter examines how Member States (and their regions and cities) have responded to the challenge of increasing bioenergy use while trying to address concerns relating to air quality. It provides an overview across the EU of measures identified and draws out a series of case studies to illustrate both the potential for action and the features which help achieve successful implementation, as well as highlighting some common barriers. It is based on firstly a literature review and secondly a series of targeted interviews with key stakeholders (see Section 3).

Note that this section deals mainly with the impact of domestic bioenergy use on air quality, rather than the industrial or commercial scale. This approach has been taken for three, interrelated reasons: the domestic sector is by far the largest source of air pollution emissions from bioenergy use; industrial and commercial units are larger, generally more efficient and thus emissions are more easily controlled, allied to the need for regular maintenance to avoid breakdown; and larger commercial and industrial units are subject to EU-wide regulation, through the Medium Combustion Plan Directive and industrial emission control legislation. That said, some of the measures identified in this section do relate to commercial scale units.

6.2 Data sources

To gain an overview of the measures in place and in development in Member States, a literature review was conducted, based on the sources listed in Annex A2. In addition, the submitted National Air Pollution Control Programmes (NAPCPs) and National Energy and Climate Plans (NECPs) for each Member States were also reviewed. A standard data extraction template was used and measures were classified as legislative (e.g. regulations), financial or voluntary. The latter can be defined through legislation but their adoption is non-mandatory. Awareness raising measures, e.g. publicity campaigns, were also included under voluntary measures, although they tend not to be reported on through formal literature; there was very little information regarding these in the documents reviewed.

6.3 Types of measures and strategies employed

Previous sections of this report have detailed both the impacts of bioenergy on air quality and the specific circumstances in which these impacts vary, including the types of fuel used, the types and ages of appliances, and how they are used, as well as the gross quantity of fuel being burnt. The different aspects of the problem have given rise to different types of solutions. These can be divided in a number of different ways but the key is how they fit together to form a strategic whole. Different countries have slightly different types of issue, including the age and size of the appliance stock, availability of other heat sources and the broader socio-economic circumstances. This means that different types of measures will have differing levels of relevance for different countries and will thus be more or less prominent. However, a comprehensive strategy for addressing the air quality impacts of bioenergy use is likely to have the following four elements:

- **Operational measures**: these focus on how appliances are used and other operational elements, such as the quality of the fuel used or the maintenance regimes employed. Such measures can include operational training for users (mandatory or voluntary), maintenance requirements (such as the need to use registered chimney sweeps, and the frequency of inspections), and the regulation of fuel either sold or used, such as a requirement to only sell seasoned wood. Such measures are aimed at ensuring equipment currently in use is operated so as to minimise air pollutant emissions where possible.

- **Stock improvement measures**: These measures focus on the equipment and appliances in use and attempt to shift these towards cleaner combustion or more modern versions, or to remove stock entirely, e.g. by switching to other heating sources. Such measures include imposing emission standards on new appliances or incentivising the sale of cleaner operating stock (e.g. beyond eco-design standards), stove or boiler swap-out schemes (voluntary or mandatory), or incentives for other heating technologies, such as air-source heat pumps or solar PV.

- **Use restriction measures**: This type of measure aims to prevent the use of bioenergy appliances all together. Such restrictions have been used for many years, such as the Smoke Control Areas set up in the UK in the 1950s and 60s, which heavily restricted the use of solid fuels within such areas. However, their application tends to be local and subject to exceptions and exemptions, either for the type of equipment or the times at which restrictions apply.

- **Information, awareness raising and behavioural measures**: Each of the three previous types of measure have a strong behavioural element, be it decisions on how and when appliances are operated, the types of equipment used or compliance with restrictions. Each will thus be improved in terms of their effectiveness if they are underpinned by information and awareness raising campaigns, with a view to encouraging beneficial behaviours. Campaigns could be aimed at the general public but they could also be sector specific, such as the hospitality trade or fuel retailers. Such campaigns may not, in themselves, reduce emissions but they can increase the emission reductions from other measures, if run and targeted effectively.

The following sections of this report provide examples of each type of measure either in place or planned by Member States, regions or cities. They vary considerably in ambition and, inevitably, are tailored towards the prevalent situation in the country and its legislative and governance structures. However, there are common features which could potentially be transferred to other jurisdictions, and these are drawn out in section 6.7. One essential aspect is the development of a strategic approach which addresses several, ideally all four, of the types of measures described above.

While the taxonomy described above is useful in identifying the focus and intent of different types of measures, they are in many ways interdependent. For example, a training programme on how to operate a stove more efficiently, and thus with lower pollutant emissions, would be more effective if the stock of appliances is modern and high quality. Likewise, uptake of an appliance replacement scheme might be higher if awareness of the issues (air pollution and the higher cost associated with running a lower efficiency appliance) is raised among stove owners. Restrictions on use of stove might also be more effective if there is a scheme available for stove owners to swap out to alternative heating technologies.

While the key drivers of air pollution impacts from bioenergy will vary between countries (fuel availability, appliance stock, patterns of use, etc), and so strategies will need to have a different emphasis, the four elements of operational improvements, improved stock, restrictions in sensitive areas and information provision are likely to be common to all. However, the project team found very few examples of coherent, published national strategies to address bioenergy, with that for France[52] being one exception. More common is for measures in bioenergy to be included in a broader air quality plan or strategy although there is a risk that the overall coherence of the approach to bioenergy is lost, especially if links to energy policy are missing.

6.4 Policy development and evaluation

6.4.1 Considerations for developing policies and measures on bioenergy

A key initial consideration in developing an approach to mitigating the air quality impacts of bioenergy use is the nature of the problem to be addressed. In particular, whether the primary issue is local concentrations of air pollutants, including $PM_{2.5}$, or the national or regional emissions of pollutants as a source of regional background concentrations. This balance will be informed by local concentration measurements, emissions inventories, trends in both, compliance with targets or obligations, and the priority which both issues are afforded. A second consideration is the available energy infrastructure, such as connections to electricity or gas grids, district heating, etc. i.e. the extent to which households are dependent on solid fuel or other "delivered" heating fuels, such as oil or bottled gas.

These two issues, namely the nature of the air quality impacts and the available energy infrastructure, will largely drive the balance between restricting the use of solid fuel – and by extension bioenergy – heating and improving the performance of installed appliances. As a broad characterisation, it may be considered that solid fuel heating in urban areas is inappropriate, given the alternative heating methods generally available and the higher concentration of air pollutants locally. However, in more rural areas where the energy infrastructure is less extensive and lower population densities make air pollution concentrations less of a local issue, reducing emissions through improvements to the installed appliance stock, fuel quality or operational practice might be the preferred option. This is, of course, a highly simplified description but it is intended to illustrate the idea that different approaches are required for different circumstances and so a package of measures is likely to be required within a Member State, with implementation driven by local circumstances.

Many further issues will inform the design of measures, including:

- socio-economic factors such as the relative wealth of bioenergy users and consideration of fuel poverty
- cultural issues around the use of solid fuels
- resources available for incentives and replacement schemes
- the degree to which the fuel market is formal or informal (e.g. purchased fuel versus own sourced), and
- the relative economic importance of the fuel or appliance manufacturing and supply sector

Further considerations will include the risk of bioenergy users switching to higher carbon fuels (such as oil) or unregulated fuels, such as waste, with the latter carrying the potential to worsen the air pollution impacts.

As following sections of this report make clear, a large number of measures are already being implemented by EU Member States and other European countries. Drawing from the experiences of others is encouraged, as is the use of policy evaluation processes to help steer policies towards greater effectiveness. A brief introduction to policy evaluation, its main elements, and resources for further support, can be found in Annex 1)a)i)(1)(a)(i)A8.

52 Ministry of Energy Transition (2021) '*The Government presents an action plan to develop more efficient domestic wood heating and reduce PM emissions by 50%*', Press Release, Online. Available at: https://www.ecologie.gouv.fr/gouvernement-presente-plan-daction-developper-chauffage-au-bois-domestique-plus-performant-et

In particular, a strategic approach is needed, with measures aimed at both restriction and improvement and implemented at the correct administrative level (national, regional or local). This will help to mitigate some of the unintended consequences of implementing isolated actions at a national scale.

6.5 Case studies

This section presents a series of case studies to help illustrate the different types of measures implemented by Member States and how they can work as an overall strategy. These examples are not the only instances of such measures being applied, nor are they necessarily the most or least stringent. They do, however, demonstrate that such measures are being implemented at both the national and local scale and that an integrated approach is likely to be more effective than single action approaches.

6.5.1 Case study 1: Denmark

Context: what is the position of bioenergy in Denmark?

Three quarters of Denmark's renewable energy comes from bioenergy[53]. Whilst its predominant application is in district heating, it is estimated that there are approximately 700,000 wood fuelled appliances in operation in Denmark, although this is a reduction from previous years[54]. Furthermore, as of 2021, it has been estimated that there are approximately 130,000 biomass-fuelled boilers, typically in regions with no or limited access to district heating[55].

In terms of reliance on bioenergy for energy consumption, the gross energy consumption of Denmark in 2022 was at a historically high level[56]. Furthermore, Danish households consume one fifth of biomass directly (meaning for heat or for fuel, not including through electricity or district heating). Consumption of wood pellets has been increasing since 1995, while consumption of firewood has fallen sharply since 2018[57].

What are the measures?

In Denmark, there is no energy or CO_2 taxation applied to biomass fuels[58]. According to stakeholders consulted for the purposes of this study, this makes up for the higher Capital Expenditure needed to use biomass fuels instead of fossil alternatives. The predominant pieces of legislation are the **Wood Stove Order**[59] which first entered into force in 2008, and the **Danish Change of Ownership Order of 2021**[60]. The Nordic Swan Eco Label is a voluntary

53 IEA Bioenergy. (2021) *Implementation of bioenergy in Denmark – 2021 update*. Report (10 2021). Online. Available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Denmark_final.pdf. [Accessed: 28/11/2023].
54 Danish Energy Agency (2022). "Firewood Consumption in Denmark 2021," The Danish Energy Agency, Energistyrelsen, Miljoministeriat and Wilke. Available at: https://ens.dk/sites/ens.dk/files/Statistik/braendeundersoegelsen_endelig_rapport.pdf. [Accessed: 08/02/2024].
55 The Danish Technological Institute (2021). The boiler of the future emits almost no particles. [online] State of Green. Available at: https://stateofgreen.com/en/news/the-boiler-of-the-future-emits-almost-no-particles/. [Accessed 8 Dec. 2023].
56 Schultz, K. (2023) "Denmark's consumption of biomass for energy maintains historically high level," *Danmarks Statistik*. Available at: https://www.dst.dk/da/Statistik/nyheder-analyser-publ/bagtal/2023/2023-08-23-Danmarks-forbrug-af-biomasse. [Accessed: 08/02/2024].
57 Ibid.
58 IEA Bioenergy. (2021) *Implementation of bioenergy in Denmark – 2021 update*. Report (10 2021). Online. Available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Denmark_final.pdf. [Accessed: 28/11/2023].
59 *The Wood Stove Order (2022)*. Denmark. Available at: https://www.retsinformation.dk/eli/lta/2022/199. [Accessed 8 Dec. 2023].
60 *The Danish Change Of Ownership Order (2021)*. Denmark. Order on the replacement or decommissioning of certain solid fuel combustion plants under 1 MW in the event of a change of ownership of real estate. Online. Available at: https://www.retsinformation.dk/eli/lta/2021/1449. [Accessed 08/12/2023].

label which can also be applied to woodstoves of an appropriate operating standard[61]. A scrapping scheme for old wood stoves was launched in 2015[62]. Several web-based information campaigns designed for public education are currently in operation[63].

What will they do?

Denmark's **Wood Stove Order** empowers municipalities to increase restrictions and enforcements on the use of wood for heating and impose additional regulations on wood use in their jurisdiction, under §17. The Danish Environmental Protection Agency has published a list of municipalities implementing the restriction, which shows the Municipality of Rebild is the latest adopter[64]. The Order also empowers citizens file complaints with their municipal representatives about smoke from wood fuel used for heating. Furthermore, its annexes specify limit values and test methods for appliances which implement the quality standards outlined in the EU Ecodesign Directive.

Executive order No. 64 from 24 May 2023 allows municipalities to place a ban on the use of wood-burning stoves and fireplaces produced before June 2008 in areas with district heating or natural gas from 1 January 2023. On the 17th of June 2022, the Decree on the replacement or decommissioning of certain solid fuel combustion plants below 1 MW in the event of a change of ownership of immovable property came into force under the **Danish Change of Ownership Order**[65]. It stipulates that all wood stoves and fireplace inserts produced before 2003 must be replaced or discontinued when selling a house. If the appliance was produced after 2003, it must be documented with a test certificate showing compliance with the Nordic Swan Ecolabel, a conformity assessment, or a signed statement from a verifier. This information is held by the Danish EPA. Due to shortages in supply of new stoves and inserts, the Danish EPA had issued a dispensation order. In November 2023, the EPA announced that the dispensation option would terminate on 1st January 2024[66]. Other exemptions are listed under §2 of the order and include antique appliances, appliances in listed buidlings, built-in fireplace inserts and more.

The **Nordic Swan Ecolabel** is a voluntary certification applicable to fireplaces, stoves, etc. and solid fuels. For stoves, etc. it prohibits the use of hazardous production chemicals when manufacturing the appliance, requires strict pressure testing of appliances labelled to monitor leakages and inefficiencies, and sets emission limits for organic gaseous carbon (OGC) and carbon monoxide (CO) and particulate matter[67]. For solid fuels (pellets, wood briquettes, wood chips, firewood), there are stringent requirements for quality properties to ensure efficient combustion including compliance with the EN ISO 17225 part 1-5:2014 standard. Wood fuels must be made from 100% renewable sources. For pellets and wood briquettes, a minimum of 95% of raw wood materials must be

61 Nordic Ecolabelling (2022) Nordic Ecolabelling for Stoves version 4.6 until 31 December 2025. Online. Available at: https://www.nordic-swan-ecolabel.org/495e7f/contentassets/df55b91410e5472480635a54b10c7aa2/criteria-document_078_stoves-078_english.pdf. [Accessed 08/12/2023].
62 The Danish Environmental Protection Agency. (n.d.). Air pollution from stoves. [online] Available at: https://eng.mst.dk/industry/air/air-polluton-from-stoves. [Accessed: 08/12/2023].
63 Danish Ministry of Environment (2022): Fire correctly: Smoking cessation guide for wood-burning stoves. Online. Available at: https://braendefyringsportalen.dk/borger/rygestop-guide-for-braendeovne/. [Accessed 08/12/2023].
64 See https://braendefyringsportalen.dk/kommuner/udvalgte-eksempler/eksempler-paa-kommunale-forskrifter-om-brug-af-braendeovne
65 *The Danish Change of Ownership Order (2021)*. Denmark. Order on the replacement or decommissioning of certain solid fuel combustion plants under 1 MW in the event of a change of ownership of real estate. Online. Available at: https://www.retsinformation.dk/eli/lta/2021/1449. [Accessed 08/12/2023].
66 https://mst.dk/nyheder/2023/november/ophoer-af-midlertidig-dispensationspraksis-for-braendeovne-og-pejseindsatse?utm_medium=nyhedsmail&utm_source=20231106_Oph%C3%B8r%20af%20midlertidig%20dispensationspraksis%20for%20br%C3%A6ndeovne%20og%20pejseindsatse&utm_campaign=Oph%C3%B8r%20af%20midlertidig%20dispensationspraksis%20for%20br%C3%A6ndeovne%20og%20pejseindsatse
67 Nordic Ecolabelling (2022) Nordic Ecolabelling for Stoves version 4.7 until 31 December 2026. Online. Available at: https://joutsenmerkki.fi/wp-content/uploads/2022/06/078e_4_7_CD.pdf. [Accessed 08/12/2023].

residues from the wood processing industry. For wood chips, firewood and firelighting products, a minimum of 70% of wood raw materials must be certified as sustainably forested under the FSC or PEFC schemes[68].

Who is implementing them?

At the municipal level, some authorities have implemented measures on wood combustion. For example, Lejre Municipality set regulations for the use of wood-burning stoves, pellet stoves and other stoves for solid fuel. The regulation details what can be burnt, chimney height and design requirements and implements the Danish Wood Stove Order. A list of municipalities implementing this order can be found online[69]. According to stakeholders, during the development of Wood Stove Order 2023, Copenhagen has taken steps to move closer to a ban on wood combustion, and at time of writing, four municipalities in the capital region are developing a ban[70]. Public information campaigns have been run at national levels by both public authorities and industry. For an example of the latter, the Danish Association of suppliers of fireplaces and woodstoves (DAPO) provides information regarding the choice and operation of stoves[71].

What issues and obstacles have had to be overcome?

Much of Denmark's air pollution is transboundary, which means that any national measures will have a relatively small mitigation effect on air quality in much of Denmark (Green Transition Denmark, 2022)[72]. There may be less motivation to reduce emissions domestically if this ambition is not matched at the international level. Furthermore, through stakeholder engagement activities conducted for the purpose of this study, a common theme noted amongst multiple respondents has been that political incentive to introduce restrictive legislation in Scandinavian countries could be particularly low due to the popularity of 'cosy' heating. This may mean that industry, in turn, faces fewer incentives to invest in innovative appliance design.

Is there an estimate of effectiveness?

Denmark committed to, and achieved, a 33% reduction of fine particulate matter emissions by 2020 based on 2005 levels according to the NEC Directive. This has been attributed predominantly to a reduction in wood combustion and replacement of inefficient wood stoves. However, the opposite trend was observed for soot (black carbon) particle emissions, which increased[73] over the same period.

Since the 2023 usage ban is an optional policy, its environmental impact cannot yet be determined.

There is a risk of a lack of public transparency associated with industry-led information campaigns, such as some led by DAPO, on appliance use. For example, if the requirements for the design of an environmentally sound appliance do not coincide with popular, aesthetic design priorities (such as the use of glass for burners, for

68 Nordic Ecolabelling (2021) Nordic Ecolabelling for Solid fuels and firelighting products version 3.4 until 30 June 2025. Online. Available at: https://joutsenmerkki.fi/wp-content/uploads/2022/05/087e_3_4_CD.pdf . [Accessed 08/12/2023].
69 https://braendefyringsportalen.dk/kommuner/udvalgte-eksempler/eksempler-paa-kommunale-forskrifter-om-brug-af-braendeovne
70 Holst, N and Raarup, M. (2024) "Hans wonders How can wood stoves be allowed in cities?" *Kosmopol.* Online. Available at: https://www.tv2kosmopol.dk/spoerg-os/hans-undrer-sig-hvordan-kan-braendeovne-vaere-tilladt-i-byerne. [Accessed: 13/02/2024].
71 The Association of Danish Suppliers of Fireplaces and Wood-burning Stoves (DAPO) (n.d.). *Choosing a Woodburning Stove*. [online] DAPO. Available at: https://dapo.dk/braendeovnen/ [Accessed 8 Dec. 2023].
72 Green Transition Denmark (2022). *Pollution from Residential Burning: Danish experience in an International perspective.* Green Transition Denmark, Clean Heat and Deutsche Umwelthilfe. Online. Available at: https://rgo.dk/wp-content/uploads/GTD_Pollution-from-wood-burning_2022-1.pdf. [Accessed: 08/11/2023].
73 Green Transition Denmark (2022). *Pollution from Residential Burning: Danish experience in an International perspective.* Green Transition Denmark, Clean Heat and Deutsche Umwelthilfe. Online. Available at: https://rgo.dk/wp-content/uploads/GTD_Pollution-from-wood-burning_2022-1.pdf. [Accessed: 08/11/2023].

example), public information surrounding the improvement seen with environmentally sound appliances may not be found on these websites.

Comparing the Nordic Swan Eco Label with the EU Ecodesign Directive requirements, the European Environmental Bureau concludes that both fail to reduce new stove PM emissions to an acceptable level.[74] It is important to note that stakeholders contacted for the purpose of this case study question the methodology of this conclusion, so it should be noted that a full comparative evaluation of these standards is not available.

What are the lessons which could be applied elsewhere?

Denmark is unusual among EU Member States in that its predominant heat supply is district-based, which removes a lot of the user impact when it comes to air quality concerns from biomass heating. This is allied with high home insulation standards, with a similar energy context seen in Sweden. This places small-scale domestic bioenergy very much in the secondary heating category, with usage for "cosy" purposes rather than as a necessary supplementary heat source. Conversations with key stakeholders in both Sweden and Denmark indicated that there is an issue in terms of the public perception of small-scale wood-fired heating, with little recognition of the potential impact on air quality. This lack of recognition of the problem, and a perceived lack of issue associated with it, as well as the cultural significance of 'cosy' firing, addressing air pollutant emissions from bioenergy combustion is not a perceived environmental policy priority in Scandinavia, according to stakeholders. Raising awareness of the issues, as well as the potential solutions, is necessary for the successful implementation of a programme of measures to mitigate the air quality impacts of domestic biomass burning.

6.5.2 Case study 2: Germany (national)

Context: what is the position of bioenergy in Germany?

Bioenergy is highly regarded as a sustainable source of energy in Germany, and dependence on the fuel is quite high with over half (55%) of renewable energy across all uses in the country being biomass[75]. Germany is the largest consumer of solid biomass in the EU and second largest consumer of solid biomass used in the residential sector, second to France[76]

The German Environment Agency estimates that there are currently more than 11 million wood stoves in Germany[77]. Furthermore, it is estimated that over 27% of households in Germany have a stove as a supplementary heating appliance[78].

74 European Environmental Bureau and Green Transition Denmark (2021). Where there's fire, there's smoke: Emissions from domestic heating with wood. [online] Brussels: European Environmental Bureau, pp.1–13. Available at: https://eeb.org/wp-content/uploads/2021/09/Where-theres-fire-theres-smoke_domestic-heating-study_2021.pdf [Accessed 8 Dec. 2023].

75 IEA Bioenergy (2021) 'Implementation of bioenergy in Germany – 2021 update', IEA, Pelkmans, L. Report no. 102021. Online. Available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Germany_final.pdf. [Accessed: 19/12/2023].

76 European Commission (2024). "Union Bioenergy Sustainability Report Study to support reporting under Article 35 of Regulation (EU) 2018/1999," Luxembourg: Publications Office of the European Union. Available at: https://op.europa.eu/en/publication-detail/-/publication/96d671c9-c719-11ee-95d9-01aa75ed71a1/language-en/format-PDF/source-305260384. [Accessed: 14/02/2024].

77 Thieringer, J. R. D., *et al.,* (2022). *Impact of residential real-world wood stove operation on air quality concerning PM2.5 imission',* Karlsruhe Institute of Technology, 10:545. Online. Available at: https://doi.org/10.3390/pr10030545. [Accessed: 19/12/2023].

78 Umwelt Bundesamt (2019). "Emissions from wood and coal burning stoves in residential areas", online. Available at: https://www.umweltbundesamt.de/en/topics/health/environmental-impact-on-people/special-exposure-situations/emissions-from-wood-coal-burning-stoves-in#use-of-wood-and-coal-stoves-in-residential-areas. [Accessed: 19/12/2023].

What are the measures?

The German **Ordinance on Small and Medium Firing Installations** (1. BImSchV) is the main piece of operational legislation in Germany[79]. It first entered into force in 2010 and sets out the quality conditions for small and medium sized firing installations.

The German **Energy Act for Buildings**[80] and the VDI-Standard 4207-2[81] implement the requirements of the 1. BImSchV. There are also regional financial support schemes[82] to promote compliance with 1. BImSchV and there are further incentives to encourage technological improvements and innovation for ultra-low emission stoves which are better than the legal minimum[83].

There is user training program designed to raise public awareness of efficient wood combustion practices[84].

Germany is one Member State with an above-average number of policies and/or schemes in place to address air quality concerns related to domestic wood-burning. This is shown not least through their use of four different voluntary eco-labels; Blue Angel, EN*plus,* DIN*plus,* and a TÜV-Süd-certificate for stoves.

What will they do?

The German **Ordinance on Small and Medium Firing Installations** governs the installation and operation of such appliances, covering both installations for solid fuels and oil and gas. It sets out permissible fuels, monitoring requirements and the standards to which these should be met. For solid fuel installations, it also sets out emission limit values for particulate matter and carbon monoxide (Section 5)[85]. The monitoring requirements of the 1. BImSchV are then operationalised under the VDI 4207 series of standards. Part 2 lays out how to measure emissions from small firing installations burning solid fuels and primarily addresses chimney sweeps who undertake these monitoring activities, also implementing the **German Chimney Sweeping and Inspection Code** (KÜO)[86]. For these appliances, any wood pellets must be of A1 quality according to ISO 17225-2 and an emission measurement of CO and PM must be undertaken. If an appliance fails an inspection, a second measurement will be taken 6 months later following a service, repair, or procurement of more suitable fuel. There is one more

79 *The German Ordinance on Small and Medium Firing Installations* (2010). BMUV. Online. Available at: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Gesetze/1_bimschv_en_bf.pdf. [Accessed: 19/12/2023].
80 Gebäudeenergiegesetz (2020). Federal Ministry of Economic Affairs and Energy and the Federal Ministry of the Interior and Community. Online. Available at: https://www.bmi.bund.de/EN/topics/building-housing/building/energy-efficient-construction-renovation/buildings-energy-act/buildings-energy-act-node.html. [Accessed: 19/12/2023].
81 Technical Division Environmental Measurement Technologies (2016). VDI 4207 Blatt 2. Emission measurements at small firing installations – Measurements at installations for solid fuel. https://www.vdi.de/en/home/vdi-standards/details/vdi-4207-blatt-2-emission-measurements-at-small-firing-installations-measurements-at-installations-for-solid-fuel. [Accessed: 19/12/2023].
82 See, for example: https://sdg21.eu/en/blog/scrapping-pay-for-old-wood-stoves; https://www.rundumwarm.de/Downloads/Infolinks/FBStVO_foerderrichtlinie_2011-01-26.pdf.
83 Bundesministerium für Wirtschaft und Energie (2021). *Richtlinie für die Bundesförderung für effiziente Gebäude – Einzelmaßnahmen (BEG EM)*. Bundesanzeiger. Online. Available at: https://www.bundesanzeiger.de/pub/publication/WvQ8k3f3hl7npi5nNo9/content/WvQ8k3f3hl7npi5nNo9/BAnz%20AT%2007.06.2021%20B2.pdf?inline. [Accessed: 19/12/2023].
84 Shared in email contact with stakeholder.
85 *The German Ordinance on Small and Medium Firing Installations,* Division 2, section 5. (2010). BMUV. Online. Available at: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Gesetze/1_bimschv_en_bf.pdf. [Accessed: 19/12/2023].
86 Technical Division Environmental Measurement Technologies (2016). VDI 4207 Blatt 2. Emission measurements at small firing installations – Measurements at installations for solid fuel. https://www.vdi.de/en/home/vdi-standards/details/vdi-4207-blatt-2-emission-measurements-at-small-firing-installations-measurements-at-installations-for-solid-fuel. [Accessed: 19/12/2023].

inspection chance after this, but if the boiler fails three times, a replacement or shut down of the appliance may be decreed.

Furthermore, chimney sweeps in Germany must go through an intensive, three-year training program to become qualified. They are obliged to test fuels, something which is not within the scope of chimney sweeps in other Member States, such as France. The chimney sweep in Germany is regarded with high authority, and citizens cannot opt out of appliance or fuel inspections. Furthermore, all data kept by the chimney sweep is entered into a harmonised database of chimney sweeps nationwide, which works to generate data on national fuel statistics and numbers of appliances. On top of this ambitious inspection and reporting system, emission testing equipment is required to be inspected annually, to maintain the accuracy of emissions values.

There are numerous national information campaigns aimed specifically at promoting household shift towards more efficient appliances. The **HKI quality label** can be awarded to room heaters, inset appliances and slow heat release appliances. The emissions limits detailed by the HKI quality label for CO and PM are the same as those specified in 1. BImSchV, and for NOx and OGC, the limits applied in the EU Ecodesign Directive apply[87]. The HKI certification goes beyond efficiency requirements mandated by national legislation, with the stated aim of increasing the market share of lower-emission heating appliances for solid fuels. The HKI, in partnership with the Federal Association of Chimney Sweeps have developed a traffic light classification system for estimating appliance emissions, which are communicated to households with the aim of promoting a replacement of old appliances. The **user training program** is an initiative of the German Environment Agency and comprises a course focusing on the correct lighting procedure for wood combustion appliances. The **EU-funded BEREAL project** (2013-2016) sought to investigate the difference in performance between firewood and pellet room heaters under test type conditions and real-life conditions. It found a significant difference between the test and practical operating conditions[88].

The most widely used ecolabel in Germany is the **Blauer Engel** (Blue Angel), having been the ecolabel of the German Federal Government for almost half a century. To be certified with the Blue Angel, appliances are subject to a stricter testing procedure than is the case in the current type testing process[89]. Whilst the statutory limit for PM emissions under the 1. BImSchV is 40 mg/m3, heating appliances holding the Blue Angel must comply with a limit of 15 mg/m3, which is predominantly achieved using innovative technology. Germany also has the TÜV-Süd-certificate for stoves, which is a new label being promoted by the German Stove Association that applies to space heaters[90]. This certificate applies to appliances in compliance with improved emission performance in real-life installations. It requires that the appliance has proof of conformity with the requirements of regulation EU 2015/1185 and Regulation EU 2015/1186, which detail energy labelling and the requirements of the EU Ecodesign Directive for solid fuel local space heaters.

87 IEA Bioenergy (2022) 'Inventory of national strategies for reducing the impact on air quality from residential wood combustion', *Technology Collaboration Programme.* (eds) Hans Hartmann. Online. Available at: https://task32.ieabioenergy.com/wp-content/uploads/sites/24/2022/10/NationalStrategies_Report-final.pdf. [Accessed: 19/12/2023].
88 Hartmann *et al* (2017). *Advanced Testing Methods for Better Real Life Performance of Biomass Room Heating Appliances.* Project Summary. European Union. Online. Available at: https://cordis.europa.eu/article/id/207390-new-real-life-test-method-for-biomass-heating-appliances. [Accessed: 19/12/2023].
89 Blue Angel (2020). 'Stoves for Wood: Basic Award Criteria – Version 7', DE-UZ 212. Online. Available at: https://www.blauer-engel.de/en/productworld/stoves-for-wood#:~:text=Heating%20appliances%20holding%20the%20Blue,limit%20of%2015%20mg%2Fm3. [Accessed: 19/12/2023].
90 TÜV SÜD Industrie Service GmbH (2021). 'Certification scheme for heating appliances fired by wood logs', Certification document. Online. Available at: https://www.tuvsud.com/de-de/-/media/de/industry-service/pdf/broschueren-und-flyer/is/real-estate/technische-gebaeudeausruestung-und-aufzuege/feuerungstechnik-waermetechnik-abgastechnik/is-taf-certification-procedure-for-heating-appliances-fired-by-wood-logs.pdf. [Accessed: 19/12/2023].

Who is implementing them?

Whilst the 1. BImSchV is a national level, it is the federal states (Lander) that implement and enforce it. Stakeholders indicated that Bavaria (Munich), Aachen and Stuttgart are implementing usage restrictions (see below), allowed for under the legislation. The Blauer Engel certificate is a label used and dispersed by the Federal Government (federal environment ministry), with different actors involved in the development of criteria and actual award of the label to products.

What issues and obstacles have had to be overcome?

It is important to note the cultural significance associated with wood combustion in Germany, and its overall positive image. One problem identified through conversations with stakeholders, is that it is hard to regulate what individuals are entitled to do with the forest reserves they own (in the case of private or community owned forests). Other challenges relate to enforcing fuel quality standards and making sure individuals do not burn wood with a high moisture content, for example.

Furthermore, concerns relating to air quality tend to be focussed on urban areas and far less on rural areas, despite wood combustion having a proportionately higher impact in rural areas (both in terms of the number of users and the reduced presence of other sources). This is exacerbated by the small number of monitoring points located in rural areas, sited to capture regional background concentrations rather than local conditions. As a result of this, many, especially rural, citizens do not associate the use of wood fuel for home heating with impacts on air quality, and there is often a higher level of acceptance of the practice as there are more users (more "normalised" behaviour). According to a survey on wood burning and perceived nuisance, 80% of all respondents indicated that they typically did not feel affected by nuisance caused by smoke and the smell of wood-burning stoves in the neighbourhood. In these results also, there was a split picture between perceptions of impaired air quality because of heating with wood, between those in semi-urban areas (41% of the opinion that this was the case) compared to only 29% of those from rural areas[91].

Is there an estimate of effectiveness?

The user training program mentioned above has been evaluated in terms of reduced emissions before and after training. After training, results indicated an estimated 11% carbon monoxide (CO) and 36% total particulate matter (TPM)[92] emission decrease during ignition and an average 57% CO and 82% TPM emission reduction during reloading[93].

Furthermore, following findings from the EU funded BEREAL project, researchers have developed new testing methods for biomass room heating appliances reflecting real-life operation, rather than optimistic type-test conditions[94]. Because of this, real-life operating conditions can now be used as the baseline level of fuel or appliance efficiency when displaying quality standards associated with different ecolabels meaning there is less room for over-reporting on efficiency standards of these.

In relation to Germany's advanced inspection procedures and the authoritative role of the chimney sweep, broadening the chimney sweep's remit beyond fire safety to include an inspection of the quality of fuel has resulted in a much more efficient use of wood in Germany. Whilst the 1. BImSchV states that moisture content for wood fuels must not exceed 25%, recent study results show that the average moisture content was around

91 Umwelt Bundesamt. (2023) "Environmental Awareness in Germany 2020: Results of an additional survey on the topic of 'heating with wood stoves'". Online. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/auswertungsbericht_heizen_mit_holzoefen.pdf. [Accessed: 14/02/2024].
92 Total Particulate Matter, equivalent to Total Suspended Particulate (TSP) or total mass of particulate matter.
93 Shared in email contact with stakeholder.
94 Hartmann *et al* (2017). Advanced Testing Methods for Better Real Life Performance of Biomass Room Heating Appliances. Project Summary. European Union. Online. Available at: https://cordis.europa.eu/article/id/207390-new-real-life-test-method-for-biomass-heating-appliances [Accessed: 19/12/2023].

13%, with some recorded fuels having only an 8% moisture content. The study concludes that problems with moisture content are scarcely relevant in Germany anymore, since the implementation of the legislation (UBA, 2022/2023)[95].

Are there any other measures being implemented?

There are no other national measures being implemented, but for a detailed overview of measures in Bavaria specifically, see section 6.5.3.

What are the lessons which could be applied elsewhere?

There are two key messages from the measures described above: firstly that "on the ground" operators make an effective means of spreading good practice, and that user training can make a measurable difference to emissions, especially in those areas heavily reliant on bioenergy. While few countries have in place mandatory training for chimney sweeps to the depth shown in Germany, many Member States have specific requirements for mandatory chimney sweeping or maintenance. Even where these are not in place, regular chimney sweeping is required by users to maintain the effective operation of their heating appliances and for fire prevention. Chimney sweeps are thus very well placed to deliver messages on good practice regarding appliance maintenance and fuel used.

In addition, while Germany's user training program has been criticised by stakeholders contacted for this study as being too detailed (and thus too long), it has been shown to be effective at reducing emissions from bioenergy through improved operation. Such courses may be most effective when conducted online, to decrease the burden of attending sessions. This could be implemented in Member States who do not have the capacity nor resources to conduct user training programs in person.

6.5.3 Case study 3: Bavaria

Context: what is the position of bioenergy in Bavaria?

As shown in section 6.5.2, Germany is one of the main consumers of woody biomass for heating in the residential sector. Whilst the project group have identified no information on state-level bioenergy reliance for heating in the residential sector, according to key informants interviewed for the purposes of this study, Bavaria is the leading state in Germany in terms of wood stove usage and is where the greatest share of these appliances are located.

What are the measures?

There was a utilisation ban on appliances non-compliant with emissions limits in Munich as of the 31st of December 2018, which implements the Federal Emission Control Act of 1974. The State Capital Munich Department for Climate and Environmental Protection implements the 1. BImSchV through requiring the declaration on the decommissioning of a single-room combustion system for solid fuels in the state capital Munich[96]. Between 2014 and 2017, a timebound subsidy scheme was implemented to shorten the transition period from older to new stoves[97].

95 UBA (2022/2023). "Staub- und CO-Messungen an Einzelraumfeuerungen im Realbetrieb", Unpublished report. Project number: 170766. Eds. Kristina Juhrich. Shared in email contact with key stakeholder.
96 Municipality of Munich (2021) "Merkblatt und Erklärung zur Stilllegung einer Einzelraumfeuerungsanlage für feste Brennstoffe auf dem Gebiet der Landeshauptstadt München". Online. Available at: https://www.muenchen.de/rathaus/dam/jcr:fa244625-fd16-41a1-a9b2ec2d101bf5ea/merkbl_stillegung.pdf. [Accessed: 19/12/2023].
97 Municipality of Munich (2017) Incentive program of the city of Munich for log wood stove replacement. Online. Available at: https://docplayer.org/59137101-Richtlinie-staedtisches-foerderprogramm-2017-fuer-den-austausch-alterfestbrennstoffbefeuerter-oefen.html. [Accessed: 19/12/2023].

There is also a Bavarian-specific version of the wood stove operation training course, which has been shortened and streamlined to better reflect the local desires of users.

What will they do?

The local utilisation ban of appliances stipulates that combustion appliances installed before October 30, 1999, that do not meet the emission limits for PM at 40 mg/m3 and CO at 1250 mg/m3 can no longer be used, as of December 31st 2018[98]. In addition, all older appliances in the city had to be retrofitted with a dust precipitator[99]. The subsidy scheme granted 30% of eligible costs for appliance replacement (or max. 300€ for each replacement of an older log wood stove). It lasted until 2017, when the total budget of 100,000 euros was utilised. New appliances had to comply with the limit values in the BIm.SchV.1, and a letter of commitment was needed declaring that the owner would not resell the new stove[100].

What issues and obstacles have had to be overcome?

As mentioned in section 6.5.2, stakeholders interviewed for the purposes of these German case studies have mentioned the cultural significance of wood combustion (and forestry) and thus the difficulty in regulating the quality of fuels used for burning. There are some 2 million private and community forest owners in Germany, 700,000 of which are Bavarian. Bavaria is the most densely wooded federal areas, with 2.56 million hectares which equates to around a third of the whole state[101], which has the potential to exacerbate the difficulties associated with implementation of policies, particularly around the restriction of inefficient fuel usage outside of the city.

Is there an estimate of effectiveness?

There are no publicly available evaluations of any of the measures detailed in this case study.

What are the lessons which could be applied elsewhere?

The measures in Munich to aid in the implementation of 1. BIm.SchV, added to localised support for the national information and training programme, show an apparently rare example of a Member State locality implementing all four types of policy (operational, changing stock, restriction of use and support from national information campaigns) together to achieve transition. Bavaria exemplifies how national measures can be adapted to the regional scale; reflecting the priorities and perceptions of wood usage in localities, compared to on a broader, national level.

6.5.4 Case study 4: Sweden

Context: what is the position of bioenergy in Sweden?

In Sweden, there is not a strong dependency on bioenergy at the household level since most homes are either connected to district heating or have changed to alternative sources such as electric boilers and heat pumps.

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98 Ramboll (2023). 'EU Clean Air Technology Hub Final Clean Air Tech Report on Development And Greater Uptake Of Cleaner Solid Fuel Household Heating Solutions', *European Commission.* Luxembourg: Publications Office of the European Union. DOI: 10.2779/6522. [Accessed: 19/12/2023].
99 IEA Bioenergy (2022) 'Inventory of national strategies for reducing the impact on air quality from residential wood combustion', *Technology Collaboration Programme.* (eds) Hans Hartmann. Online. Available at: https://task32.ieabioenergy.com/wp-content/uploads/sites/24/2022/10/NationalStrategies_Report-final.pdf. [Accessed: 19/12/2023].
100 IEA Bioenergy (2022) 'Inventory of national strategies for reducing the impact on air quality from residential wood combustion', *Technology Collaboration Programme.* (eds) Hans Hartmann. Online. Available at: https://task32.ieabioenergy.com/wp-content/uploads/sites/24/2022/10/NationalStrategies_Report-final.pdf. [Accessed: 19/12/2023].
101 Bayerische Landesanstalt für Wald und Forstwirtschaft (n.d.). Forest ownership, counselling and forest policy. [online] Bayerische Landesanstalt für Wald und Forstwirtschaft. Available at: https://www.lwf.bayern.de/en/221952/index.php [Accessed: 19/12/2023].

The small-scale market of bioenergy use for heating in single-family houses reached historically low levels of around 8 TWh in 2020[102]. However, when it comes to using wood as a secondary heating source, as a "cosy" fireplace for aesthetic and comfort purposes for example, there has been an increase in the last 15 years. According to data from a yearly survey made by the Swedish Civil Contingencies Agency (MSB), all biomass appliance quantities have reduced between a 2012 and a 2021 stock take, apart from local fireplaces which increased by almost 260,000 units in the 9-year period[103]. In addition, due to recent shocks in energy prices, these secondary heating appliances are expected to sell even more than usual, based on the perceptions of stakeholders interviewed for this case study[104].

In Sweden, wood combustion is the largest source of emissions of Black Carbon (BC) and accounts for ca. 30% of $PM_{2.5}$ emissions[105]. The extent of the problem regarding the air quality impact of using wood- is not well-known in Sweden. Work is ongoing to investigate how information on the location, type and use of wood stoves can be collected and made available, to facilitate more effective assessments of air quality and identify areas with the highest concentrations of the most problematic woodstoves. As in most, if not all, Member States, there are significant shortcomings in the currently available data, resulting in PM emissions estimates relating to bioenergy which carry a high level of uncertainty.

What are the measures?

There are many municipalities that do not have restrictions on wood combustion, but do have recommendations to limit usage[106]. In Sweden, the regulation **(1998:899) on environmentally hazardous activities and health protection** empowers municipalities to issue a temporary ban on small-scale combustion with certain solid fuels within specially defined areas. The strictest measure is related to the city of Malmö, where there are some restrictions on biomass combustion under the **City of Malmö's local environmental regulations**, paragraphs 10 to 12[107]. There is also the regulation by the Swedish National Board of Housing Building and Planning that limits the boilers and stoves that can be installed for residential heating in new buildings[108]. Information campaigns are relatively infrequent, with the last national campaign occurring in 2019, with no follow up besides annual social media information campaigns.

What will they do?

Since the scale of the problem is relatively unknown in Sweden, and more than half of the domestic heating is district-based, there are only a handful of national or local measures in Sweden. Most of these are used to implement EU policy to adhere to Ecodesign regulations. The usage ban in Malmö under the local environmental regulations, which is the most prescriptive of the local policies, however, only allows 'cosy' firing to take place during the coldest months (October to March), and on top of this, they recommend that fires in tiled chimneys are also lit no more than twice per week[109].

102 The Swedish Energy Agency (2023) '*An Overall Picture of the Energy Situation in Sweden,*' ET 2023:01. Available at: ISBN (pdf) 978-91-7993-103-2. [Accessed: 19/12/2023].
103 Information provided via email with key stakeholders.
104 Information provided via email with key stakeholders.
105 Bodin, S. (2017) "Evaluation of the Swedish Communication Campaign "Lighting in the Top," 2017-18 Woodburning Season Summary and Conclusions," International Cryosphere Climate Initiative. Online. Provided through Email contact with stakeholder.
106 International Cryosphere Climate Initiative (2013) "Legislation and Regulations in Nordic Countries to Control Emissions from Residential Wood Burning: An Examination of Past Experience," Report to the Nordic Council of Ministers. Online. Available at: https://iccinet.org/wp-content/uploads/2012/03/Nordic-Woodburning-Review-Draft-130911.doc. [Accessed: 19/12/2023].
107 Malmö stad (2023) '*Elda med ved*', online. Available at: https://malmo.se/Bo-och-leva/Bygga-och-bo/Inomhusmiljo/Elda-med-ved.html. [Accessed: 19/12/2023].
108 Boverket (2019). *Boverkets föreskrifter om ändring i Boverkets byggregler (2011:6) - föreskrifter och allmänna råd.* Available at: https://rinfo.boverket.se/BFS2011-6/pdf/BFS2019-2.pdf. [Accessed: 19/12/2023].
109 Malmö stad (2023) '*Elda med ved*', online. Available at: https://malmo.se/Bo-och-leva/Bygga-och-bo/Inomhusmiljo/Elda-med-ved.html. [Accessed: 19/12/2023].

Who is implementing them?

As abovementioned, municipalities can impose general or temporary bans on small-scale combustion with certain fuels within certain areas. The most prescriptive, general ban is shown in the example of Malmö. According to stakeholders consulted, this is the only general ban in the country. However, the recommendation to limit biomass combustion for recreational purposes (not as a primary heating source) to twice per week, four hours at the time, has become practice and is recommended by many municipalities. The Swedish Environmental Protection Agency (SEPA) has developed information on best practice fire-lighting and this is disseminated annually to the public. There are information videos on boilers[110], fireplaces[111] and a "Light at the Top" best practice tutorial[112]. The latter is the second-most viewed video that the Swedish EPA posted between November 2022 and November 2023, according to interviewees.

What issues and obstacles have had to be overcome?

Homes that use solid fuel for heating, and typically the homes with the old inefficient stoves, are mainly in rural areas, outside of the city. As a result of this, where there is capacity and resource to measure air quality impacts of wood combustion (typically in cities), there is less of a need to do so, since homes in these areas are predominantly reliant on district heating or electricity. There is also a hint that there is a general lack of political incentive to reduce wood firing, due to the cultural significance of wood combustion and previous resistance from the public, which led to a cancellation of an old wood stove regulation in 2019[113]. According to interviewees, there have been attempts to set a target for the exchange of boilers, with some financial backing to do so, but it was never put in place, and remains on the government's list of potential actions. Stakeholders indicate also that there is less of an incentive to tackle wood combustion since there is no pending risk of EU infringement proceedings and fines due to exceedances of the EU air quality standards.

Is there an estimate of effectiveness?

Where there is an estimate of effectiveness available for any action on air quality, it comes from the information campaigns disseminated by the Swedish Environmental Protection Agency. The evaluation report of the "Light it from the top" campaign in 2017 concludes that it was the most comprehensive campaign to change attitudes and behaviour. As a result, two-thirds of people interviewed who received the campaign brochure said they paid attention to it, and of these, almost three-quarters (73%) said they applied the guidelines stipulated in the brochure. However, only 79 out of 290 municipalities in Sweden participated in the campaign[114].

There have been no other evaluations of measures on wood combustion.

Are there any other measures being implemented?

One program which ended in 2008 in Sweden, provided financial incentive for people who undertook training on how best to light a wood-fuelled boiler, when they exchanged for an old fossil-fuel burner. There is an estimate of effectiveness with this scheme, outlined by the International Cryosphere Climate Initiative. The scheme is estimated to have reduced PM emissions by 6% in a 10-year period up to 2008, however it is likely that this is due to the transition away from fossil fuels rather than the training provided on proper lighting[115].

110 See https://youtu.be/FCjJbcVXVII
111 See https://youtu.be/MwSWkZX-xOw
112 See https://www.youtube.com/watch?v=am3495wKa_E
113 Sahlberg, A., et al., (2022) 'Don't extinguish my fire – Understanding public resistance to a Swedish policy aimed at reducing particle emissions by phasing out old wood stoves,' *Energy Policy*, 167, 113017. Available at: https://doi.org/10.1016/j.enpol.2022.113017 . [Accessed: 19/12/2023].
114 Bodin, S. (2017) "Evaluation of the Swedish Communication Campaign "Lighting in the Top," 2017-18 Woodburning Season Summary and Conclusions," International Cryosphere Climate Initiative. Online. Provided through Email contact with stakeholder.
115 International Cryosphere Climate Initiative (2013) "Legislation and Regulations in Nordic Countries to Control Emissions from Residential Wood Burning: An Examination of Past Experience," Report to the Nordic

What are the lessons which could be applied elsewhere?

There is a similar landscape in Sweden as seen in Denmark, related to the fact that most of the country relies on district heating, and there is a similar cultural significance of wood combustion, which to many people is considered 'cosy' and an important right.

The **Regulation (1998:899) on environmentally hazardous activities and health protection** and its implementation by municipalities allows neighbourly complaints to spark an inspection could be a useful device for other Member States where restrictive policy is currently not possible. For example, this does not exist in Sofia, and has been suggested by interviewees as a reason why a total ban on wood combustion in the city's jurisdiction would not be enforceable.

6.5.5 Case study 5: Sofia

Context: what is the position of bioenergy in Sofia?

Woody biomass makes up a large proportion of home heating across Bulgaria. A survey in 2018 indicated that electrical heating was the most used (38% of households), with wood fuel, in the form of wood logs, making up 33% of household heating; wood pellet heating added a further 3%. Coal and manufactured solid fuels contributed 7.5% and district heating just over 14%. Heating with gas made up only 2-3% of households.

While the use of wood fuel in Sofia is lower than the national average, it still accounts for a very large proportion of heating. The national census in 2011 indicated that around 50,000 households across the city are reliant on solid fuel heating, with wood logs being the most common fuel. In addition, it has been indicated that domestic solid fuel (though this also includes coal) use for heating make up around 56% of all PM_{10} emissions[116].

What are the measures?

Sofia Municipality has an ambient air quality program which is implemented by the project "Bulgarian Municipalities Working Together to Improve Ambient Air Quality" under the LIFE Programme of the European Union - **LIFE17 IPE/BG/000012** - LIFE IP CLEAN AIR. The main project under the program is the development of an appliance replacement scheme.

Additionally in the municipality of Sofia, there is a **Low Emission Zone** (LEZ) for transport and household heating.

What will they do?

The LEZ for household heating is expected to be in action as of 1st January 2023[117]. This will not span the entirety of the city but will cover mostly central areas. There will be a ban on solid fuel heating (wood and coal, but not wood pellets). The European Commission contributes 60% of the EUR 16.7 million budget, which is set to expire in 2024. The scheme aims to transition from heating with wood and coal towards pellets, gas or use of the central heating network.

Council of Ministers. Online. Available at: https://iccinet.org/wp-content/uploads/2012/03/Nordic-Woodburning-Review-Draft-130911.doc. [Accessed: 19/12/2023].
116 Tcolova, K and Vladimirov, M. (2023) 'Reversing the Trend Smart Enforcement of the Low-Emission Zone in Sofia, Bulgaria', *Center for the Study of Democracy*. Online. Available at: https://csd.bg/fileadmin/user_upload/publications_library/files/2023_03/Reversing_the_trend_Smart_Enforcement_of_the_LEZ_in_Sofia_WEB.pdf. [Accessed: 19/12/2023].
117 Tcolova, K and Vladimirov, M. (2023) 'Reversing the Trend Smart Enforcement of the Low-Emission Zone in Sofia, Bulgaria', *Center for the Study of Democracy*. Online. Available at: https://csd.bg/fileadmin/user_upload/publications_library/files/2023_03/Reversing_the_trend_Smart_Enforcement_of_the_LEZ_in_Sofia_WEB.pdf. [Accessed: 19/12/2023].

Who is implementing them?

Municipalities are responsible for developing air quality plans in Bulgaria, the support of which is a priority of the LIFE-IP Clean Air program. In Sofia, a combination of funds channelled through the Life IP program and the Operational Program for the Environment in Sofia (2007-2013, 2014-2020 and currently 2021-2027) have been enabling the exchange of inefficient appliances.

What issues and obstacles have had to be overcome?

There are control issues associated with the informal collection of wood for heating. For example, whilst it may be possible to control the quality of fuels imported or sold formally, this might not be the same for those living in rural areas outside of the city. This makes the enforcement of fuel restrictions very difficult to oversee, and due to this, fuel restriction has largely remained outside of Bulgarian bioenergy policy landscape.

Is there an estimate of effectiveness?

The rate of exchange for boilers has been extremely slow. Since the start of the exchange program, there have been ca. 7000 appliances exchanged. Whilst all new appliances must follow the general EU Ecodesign regulations, there is no control over the circulation of substandard stoves on the market since there are no restrictions on this in Bulgaria. The LEZ, though not yet implemented, has had criticisms that it may not be an effective measure since the majority who use wood for heating do not live in the central parts of the city, where the ban will be applicable[118].

Bulgaria's NAPCP (dating from 2019) described policies which aimed to develop standards for the quality of wood and coal, however these were only developed for the latter at the time of writing (March 2024). The program has thus far only led to recommendations being made for use of wood heating, and these recommendations are tailored towards the end-user, which makes them harder to enforce.

Are there any other measures being implemented?

It is expected that a total ban on wood heating from the 1st January 2029 will enter into force, however this remains to be seen since there are some enforceability issues which are not covered in existing legislation. For example, one stakeholder mentioned the lack of structure in place to report a neighbour's property if reasonably suspicious, as happens in Denmark and Germany, as a barrier towards more ambitious legislation detailing widespread usage bans.

What are the lessons which could be applied elsewhere?

The landscape for domestic use of wood in Eastern Europe is very different than in Western Europe or Scandinavia. In Eastern Europe, there is demand for the fuels as a primary source of heat, as opposed to a supplementary source or use of wood for 'cosy' firing. The inclusion of wood heating within an LEZ is a relatively new initiative; and Sofia is among the first of any city in Central and Eastern Europe to introduce a LEZ[119]. However, there have been no lessons-learnt analysis conducted here because it is yet to be implemented. Learning from the difficulties in developing the policy, and its subsequent push back, however, ex-post findings argue for the importance of engaging with the public through formal, in-person consultations which should be an approach taken when developing an LEZ in any city[120].

118 Tcolova, K and Vladimirov, M. (2023) 'Reversing the Trend Smart Enforcement of the Low-Emission Zone in Sofia, Bulgaria', *Center for the Study of Democracy.* Online. Available at: https://csd.bg/fileadmin/user_upload/publications_library/files/2023_03/Reversing_the_trend_Smart_Enforcement_of_the_LEZ_in_Sofia_WEB.pdf. [Accessed: 19/12/2023].
119 Ibid.
120 Ibid.

6.5.6 Case study 6: France

Context: what is the position of bioenergy in France?

According to the IEA[121], around 60% of renewable energy in France is from biomass. In domestic heating, 6,725,000 domestic wood appliances produced 75,700 GWh of renewable heat in 2020[122]. According to one study conducted by IFOP and Cheminées Poujoulat, 75% of wood heater owners use another source of energy alongside wood, and wood-based domestic energy covers 24% of the population's heating needs in the residential sector[123].

What are the measures?

There are **two restriction of use policies** operating in France: The **Ministerial Decree** of 7 April 2016[124], and the **Atmosphere Protection Plan**[125]. In April 2021, Deputies to the National Council voted on a commitment to reduce fine particle emissions by 50% in highly polluted areas in France between 2020 and 2030 and developed and agreed to implement this in areas covered by an Atmosphere Protection Plan[126].

What will they do?

The **Ministerial Decree of 2 April 2016** authorises prefectures to temporarily suspend the use of inefficient biomass combustion devices. There are further geographical bans under the Atmosphere Protection Plan applicable in agglomerations < 250000 inhabitants where air quality standards are not respected.

The efficient domestic wood heating action plan[127] is a systematic approach to reducing particulate matter across the country, by speeding up the replacement of old stoves and fireplaces with efficient equipment. It covers six integrated approaches to abating air quality impacts of residential wood combustion. These are raising public awareness of the impact on air quality of using inefficient appliances and fuels, strengthening, and simplifying support schemes to speed up the replacement of inefficient appliances, extension of the **Green Flame label** beyond a 7-star threshold to showcase best available technology and appliances, and to develop a label indicating high quality fuels regarding their moisture content and origin. The approach will be tailored to each region to reflect public awareness and potential reception of air quality measures.

Additionally, **mandatory chimney sweeping** has recently entered into force by decree (Decree No. 2023-641)[128]. These inspections cover not only sweeping, but also the maintenance of appliances. The chimney sweep acts

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121 IEA Bioenergy (2021). *Implementation of bioenergy in France.* Country Report No. 10 2021. Online. Available at: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_France_final.pdf. [Accessed: 19/12/2023].
122 Ibid.
123 Cheminees Poujoulat (2022) '*Study Report: The Place of Wood Heating in the Home'*, study summary Online. Available at: https://www.ifop.com/wp-content/uploads/2022/12/25605-Rapport-Cheminees-Poujoulat-diffusion-site-internet-IFOP.pdf. [Accessed: 19/12/2023].
124 *Order relating to the triggering of prefectural procedures in the event of episodes of ambient air pollution (7 April 2016)*. Available at: https://www.legifrance.gouv.fr/loda/id/JORFTEXT000032376671/. [Accessed: 19/12/2023].
125 Direction Regionale et Interdepartementale de l'Environnement et de l'Energie (2017). *Atmosphere protection plan for Ile-de-France 2018-2025*. Paris: France. Online. Available at: https://inis.iaea.org/search/search.aspx?orig_q=RN:51070016. [Accessed: 19/12/2023].
126 Ministry of Energy Transition (2021) '*The Government presents an action plan to develop more efficient domestic wood heating and reduce PM emissions by 50%'*, Press Release, Online. Available at: https://www.ecologie.gouv.fr/gouvernement-presente-plan-daction-developper-chauffage-au-bois-domestique-plus-performant-et. [Accessed: 19/12/2023].
127 Ibid.
128 Decree No. 2023-641 on the Maintenance of Fireplaces and Appliances for Heating, Cooking, Combustion, hot water production and the chimney sweeping of Flues (2023). Available at: https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000047867286?fbclid=IwAR3b0G4sPQAvT5723ZB8NxxPmAwxrMVe7kL71EpJ1O_RfDNbwdLVCqaEU6E. [Accessed: 19/12/2023].

as a consultant and is required to advise their customers about operational aspects related to best practice wood combustion, advise on the need to replace or update appliances, as well as inform customers about subsidies available for replacing their appliances.

Who is implementing them?

France's action plan, whilst a national initiative, is enacted at the regional level. Having local plans (in addition to the overarching national plan) is designed to better reflect the consensus and understanding of wood combustion and its impacts amongst a diverse population. These will reflect the general level of understanding of the negative air quality impacts from wood combustion in the region. The benefit of the regional APPs also, considering Grenoble as an example, mean that regional emissions limits can be developed based on ground research of the most important pollutants in the area. For example, in Grenoble, the most recent update to the plan notes that PM emissions have not exceeded regulatory thresholds for half a decade, however these thresholds are still much higher than those recommended by the WHO. This, including the overarching aim of the plans detailed in the 2021 vote to reduce fine particulate matter emissions, provides a strong evidence base for justifying the newly introduced plan for post-2025 (Regional Directorate for the Environment, Planning and Housing, 2023)[129].

Whilst there is a national government level funding pot, it is up to state authorities to define the amount of funding available for households to access to upgrade their appliances. In states where there are usage bans (such as in Grenoble and Auvergne-Rhône-Alpes, for example) there are usually subsidies available for appliance replacement.

What issues and obstacles have had to be overcome?

Key interviewees informed us that the current log market only accounts for approximately 20% of logs being used in France for domestic heating, which means that there is a large portion of wood fuel that is not regulated, nor can its moisture content be enforced. Fuel restrictions also stipulate that moisture of wood fuel must be known, for whatever quantity it is sold in. However, only wood sold in small quantities (i.e., where it is assumed that none will be stored before use), has a requirement of a moisture content <23%, according to conversations with stakeholders.

Is there an estimate of effectiveness?

The local plans required under the Atmosphere Protection Plan must be evaluated every two years, meaning the first will take place in 2025. Therefore, there will be estimates of effectiveness going forward, which can be regarded as best practice given the widespread lack of evaluation for such measures.

The Green Flame Label is only slightly more stringent than the requirements laid out by the EU Ecodesign Directive. There are plans for a revision of the label in 2025, however. It is important to note that the label does not require the use of catalysts, nor installation of particle filters. The predominant difference between the Green Flame Label and the EU Ecodesign requirements is that Green Flame requires emissions certification to be confirmed at two separate laboratories. While this will be more burdensome for manufacturers, it will provide additional assurance that emissions levels can be replicated in real-world use.

Are there any other measures being implemented?

France Bois BÛche is a fuel quality mark. It also acts as an advice column and a public information source for details regarding upcoming subsidy schemes and changes to legislation. For example, whilst not a measure specifically, there is an upcoming reform of the main government subsidy scheme for replacing fossil fuel-based

129 Regional Directorate for the Environment, Planning and Housing (2023). *Plan de Protection de l'Atmosphère de Grenoble Alpes Dauphiné 2022-2027*. Préfet De L'Isère. Online. Available at: https://www.auvergne-rhone-alpes.developpement-durable.gouv.fr/le-plan-de-protection-de-l-atmosphere-de-l-a22941.html?lang=fr. [Accessed: 19/12/2023].

appliances with wood-based ones. The reform will be implemented as of April 2024, and will cut the available funds for households looking to switch to wood-fuelled appliances. This will have implications for the uptake of wood-burning appliances[130]. This decision has allegedly been due to the necessity to preserve France's forests.

What are the lessons which could be applied elsewhere?

The case study of France showcases a potential policy option which accommodates regional differences of public perception and understanding of air pollution issues related to wood combustion. For example, through tailored Atmosphere Protection Plans, stringent measures are introduced only in areas with particularly high exposure to poor air quality. France's Atmosphere Protection Plan model also promotes the equitable division of financial resources amongst regions.

6.6 Analysis of measures

Annex A6 (spreadsheet) provides a reference table for the policies and measures aimed at reducing the air pollution impact of bioenergy at national, regional or local/city level. It has been drawn together from a number of different sources, as well as primary research. The measures listed cover 18 different countries (mainly EU Member States), and while the search for measures has been extensive, it was not necessarily exhaustive: where Member States are not listed, it does not necessarily mean that no measures are being undertaken, simply that they did not feature in the information sources the project was able to access. In particular, information and awareness campaigns are likely to be far more numerous than those listed. For example, only two campaigns sponsored by local authorities in the UK are listed, whereas there are in reality many more. Adding further examples to the list would not necessarily add value to the overall database given that many draw on the same sources of information. Moreover, in terms of policy interventions, they all refer to the same two or three policy measures available nationally in the UK.

6.6.1 Prevalence of measures across Member States

Around 120 measures are listed in Annex A6, split between operational, stock change, restriction, and information.

Operational measures

As noted above, these measures are aimed at improving the operation of bioenergy appliances, by improving the quality of fuel used or improving maintenance regimes. Of the 17 listed, 7 are related to inspections, whereby mandatory inspection of units is required, usually on a one-to-three-year basis, and often by chimney sweeps. Note that "chimney sweep" is the English term for the function but it captures a wide variety of professionalisation and training. In some countries, chimney sweeps simply clean chimneys, whereas in others (such as Germany) they are appliance technicians, trained in solid, liquid and gaseous fuel appliances and equipped to undertake detailed technical inspections.

However, **mandatory chimney cleaning/inspection** is in place in several countries, although usually for fire safety reasons. This not only provides a potentially useful source of information on installed appliances, but chimney sweeps have also been shown to be a very useful way of advising users on good combustion practice. Their advice and guidance is often more effective than generalised advice from either regulators (i.e. government or municipal sources) or manufacturers/suppliers. As the case study from Germany shows, they can be effective in changing consumer behaviour to the extent that burning unseasoned, or "wet", wood is no longer seen as a significant issue.

130 France Bois Buche (2024) " 2024 subsidies for the purchase of a wood-burning appliance." Online. Available at: https://www.franceboisbuche.fr/choisir-mon-appareil/les-aides-2024-pour-lachat-dun-appareil-de-chauffage-au-bois/. [Accessed: 15/02/2024].

The remainder of the measures are focussed on **fuel quality**. They generally seek to limit the supply or use of wet wood, with the maximum moisture content of 20-25% (where specified). Where these are legislative requirements, there are some exemptions in terms of the volume of wood supplied or the locations they apply to. However, most of the measures listed are related to labelling schemes and are not mandatory. The key weakness of almost all of the fuel quality measures is that they only apply to fuel sold, whereas in many areas wood fuel is either own sourced or supplied through the grey market, e.g. a local tree surgeon supplying friends and family. This emphasises the importance of user behaviour and knowledge, such as the importance of using seasoned wood, how to recognise seasoned wood and how to season at home, if necessary.

Stock change measures

This is the most numerous category among those identified through this project; it is also the most diverse. Over half of those identified are **schemes aimed at replacing old appliances with newer**, less polluting versions or even with non-combustion heating systems, including two scrappage schemes (i.e. aimed at fully removing appliances from the stock, not just replacing them) such as in the Netherlands or Aachen, Germany. They all involve some form of subsidy, either as a direct payment or through subsequent tax relief. They vary in the level of subsidy, including some which cover 100% of purchase and fitting costs for new appliances, although this level of subsidy is rare (it was also criticized by one stakeholder for limiting the coverage available to the scheme as a whole). In some countries, e.g. Denmark, the subsidy scheme was linked to a time expiry for older stoves, and in fact a similar scheme ran in the UK following the Clean Air Act 1956 and the introduction of Smoke Control Areas, which directly supported the uptake of gas heating systems in the 1950s and 60s. Thus, subsidised replacement schemes are an effective way to facilitate both stock renewal and restriction programmes.

A further 21 measures are **product standards**, applying emission limits to new appliances. In many cases, they have been superseded by the requirements of the Ecodesign Directive (2009/125/EC), but many are still more stringent. This includes the testing regime required for certification, such as the requirement to have results certified by a second testing laboratory (France) or to include start up emissions as part of the test (Germany). The standards which are more stringent than the Ecodesign Directives tend to be **voluntary labelling schemes**, and while they are not mandatory, they do provide some leverage for local authorities to specify higher minimum standards in building codes, etc.

The remaining three measures are **building standards**. Two restrict the types of appliances which can be installed in new buildings, with one, in Denmark, also specifying a maximum age for stoves to be included in house sales. The third measure, in Germany, includes the listing of biomass heating as part of the Energy Performance Certificate (EPC) which potentially paves the way for the inclusion of a $PM_{2.5}$ metric in EPCs (see section 7).

Restriction of use

This is also a varied category of measures, with 9 identified schemes applied at a national level and the remainder at a regional or local level. Of the national measures, five are enabling (i.e. allowing municipalities to take certain actions but not mandating such action), while the others mandate either a product or building standard, and are thus very similar to equivalent stock change measures.

The regional or local measures vary quite considerably in their specification and include:

- Absolute bans on solid fuel heating in some cities (e.g. Krakow and Sofia) although these are very locally focussed
- Temporary bans on wood or solid fuel heating depending on conditions, including high air pollution episodes (e.g. in Graz, Austria or the Po Valley region in Italy)
- Bans on the installation of appliances, either based on emission performance or location, or both (such as in Riga, Latvia)
- Fuel quality requirements (such as the Domestic Solid Fuel Regulations in the UK), and

- 1 instance, from Denmark, of a ban on chimneys for new buildings, to restrict the uptake of bioenergy

The limited geographical extent of these measures will mean that they also have a limited impact on total regional or national emissions. However, their intent is to reduce local concentrations, especially of PM_{10} and $PM_{2.5}$. The project team was unable to identify any evidence of their effectiveness in this, although the future (at the time of writing) evaluation of regional plans under the French strategy should be an opportunity to demonstrate this.

Information campaigns

As noted above, the extent of information campaigns is very likely much higher than those listed in this project. However, the broad themes are likely to be the same. Of the 32 measures listed, 22 are **aimed at stove (and other wood fuel appliance) users**, mostly to provide advice and information on how to operate a solid fuel appliance correctly. This advice ranges from the type of appliance to choose, the type of fuel, how to light it and how to operate the appliance most efficiently. The approaches vary from simple website campaigns through to television advertisements and ultimately to full training and certification courses (non-mandatory). While these approaches will assist in reducing emissions from existing appliances, stakeholders have commented that they could legitimise solid fuel (or bioenergy) use where the local aim is to reduce it, e.g. in more urbanised settings.

A further 10 campaigns are **more general awareness raising**, highlighting the impact of solid fuel/woody biomass use on air quality, as well as the themes mentioned above. They tend to be either leaflet or website campaigns and have been used in conjunction with more direct intervention.

Once again, it has not been possible to identify evidence on the effectiveness of such campaigns, at either reducing bioenergy use or improving practice, although they are seen as a necessary facilitating action alongside other, more direct, interventions.

6.6.2 Effectiveness of measures and barriers to uptake

One of the main gaps in the information gathered for this project is the quantified effectiveness of measures. This is largely because policy evaluation, either *ex ante* or *ex post* appears to be undertaken rarely and published even more rarely. This is especially the case for measures undertaken at local level, but national level policy evaluation is also still in its infancy in many Member States. Formal evaluations are either underway or planned in several countries, and evaluation of the impacts of the regional plans is mandated through the French Atmosphere Protection Plan[131], although this won't be undertaken until 2025. There is some evidence that the programme of inspections undertaken by chimney sweeps in Germany has resulted in improvements in the quality of fuel being burnt (i.e. lower moisture content). A reduction in the use of wood logs has been reported in Denmark, with users switching to wood pellets or non-combustion heating.

Barriers to the uptake of measures to control the impact of woody biomass used for heating on air quality, and which limit the effectiveness of those that are implemented, are multiple and overlapping. From the research undertaken for this project, they tend to be political, cultural and socio-economic, rather than technical in nature: applying emission limits on appliances, for example, appears to be relatively straightforward and, indeed, they already apply across the EU in the form of the Ecodesign Directive requirements. There are also technical controls applied to both medium and large bioenergy units, through the MCPD and IED, receptively. The key issue, as highlighted throughout this report, is the application of controls on the domestic use of bioenergy, generally in the form of wood combustion.

131 Direction Regionale et Interdepartementale de l'Environnement et de l'Energie (2017). *Atmosphere protection plan for Ile-de-France 2018-2025.* Paris: France. Online. Available at: https://inis.iaea.org/search/search.aspx?orig_q=RN:51070016

Political barriers

The reluctance to impose controls on people's activities in their homes – the key political barrier – is not unique to bioenergy/woody biomass used in households for heating purposes, and extends to a number of potentially "polluting" activities, such as the use of high solvent products. These are usually controlled through product standards, making the polluting product or material less available (or by banning it). However, such controls are far less effective where the product is sourced either outside the normal market, e.g. through local suppliers with extremely short supply chains, through grey markets or even self-sourced (e.g. foraged). Controls can be applied within the more formal retail settings, such as the labelling of wood logs sold in supermarkets, DIY stores or garden centres, but that only addresses a part of the supply: estimates in France, for example, are that only 20% of the wood logs used for heating come from such formal sources. There is therefore a strong reliance on consumer behaviour, such as the proper storage and seasoning of fuel or correct lighting procedure, which is politically and socially unattractive to regulate.

Product control processes can, of course, be used to specify emission standards for new appliances, hence the approach used in the Ecodesign Directive. However, this only addresses new appliances and not appliances already installed. While replacement of old appliances with new will, eventually, reduce air pollution emissions, stock turnover is often very slow due to both the longevity of combustion units and the costs (and inconvenience) often associated with replacement. The application of emission controls to already installed appliances is usually associated with an expectation of financial support or compensation to address either the cost of the new appliance, or its installation, or both. This brings, in turn, further potential issues, depending on the local circumstances. For example, in some countries, especially where bioenergy is not a principal source of space or water heating, the use of log burning stoves is associated with relatively wealthy households. Thus, any subsidies could be seen as subsidising the already well off. Moreover, securing significant funding for any compensation scheme will be at the detriment of other public funding areas. Finally, the effectiveness of emission controls on appliances is still dependent on user behaviour, including the operation of the appliance and the quality of the fuel used.

Socio-economic barriers

Socio-economic factors which limit either the uptake or effectiveness of measures to reduce air pollution from domestic use of woody biomass for heating will depend on both the wider socio-economy of the Member State (or region) and the prevailing energy infrastructure. Where the predominant issue is the use of appliances using wood (and/or other solid fuels such as coal or MSF) as a supplementary space heating source, a significant proportion is likely to be "aesthetic" or "cosy" burning. This means that householders decide to use a supplementary heating source when it is neither necessary nor economical to do so; a recent analysis in the UK suggested that the use of wood fuel is significantly more expensive than relying on natural gas[132] (by far the most common heating fuel in the UK). This in turn means that household value the "cosy" atmosphere and the aesthetics of a wood fire above the additional cost of running such an appliance, voluntarily incurring additional costs. This makes it very difficult to use economic signals or market mechanisms to influence their behaviour.

By contrast, reliance on solid fuels, including the use of woody biomass/fuelwood in households, is also associated with more economically deprived households, with the proportion varying in different Member States. Such households may also have more limited access to alternative energy sources. Thus, the use of economic drivers to change behaviour may be viewed as regressive, penalising those who are least able to afford alternatives.

Cultural barriers

The impact of cultural influences on the use of woody biomass/fuelwood in households is more difficult to quantify, and evidence is limited. However, anecdotal evidence from interviews conducted as part of this study

132 https://urbanhealth.org.uk/wp-content/uploads/2023/11/Relight-my-fire-investigating-the-true-cost-of-woodburning-stoves-impact-on-urban-health.pdf

has indicated that, in some countries and regions, there are strong cultural and traditional associations with the use of bioenergy, especially locally sourced wood fuel. In parts of Germany, for example, private and community ownership of forests is common, and the expectation is that wood from such forests can (and should) be used as a heating fuel. Links between the use of wood-fuel and "traditional" lifestyles in some countries may make political decision makers reluctant to intervene, particularly in the current political climate, where environmental issues are being employed as a "wedge" issue.

All of these issues overlap to present a significant challenge to the successful implementation of measures to reduce the air pollution impact of fuelwood use for heating in households. They emphasise the need to be clear about the nature of the issue to be addressed (e.g. patterns and location of woody biomass use for energy) and the intended outcome of a measure (e.g. reduction in use or change in behaviour), and the use of multiple measures within a wider strategic framework.

6.7 Principles for successful measures

Reviewing the measures that have been implemented by Member States, their regions and cities highlights some broad principles which could aid the successful development of new measures:

The measures need to fit the issues

It is clear that there is not a "one size fits all" solution to addressing the air quality impacts of biomass use for energy. In some circumstances, biomass may be the most effective source of renewable heat, and the air quality impacts may be of lower importance, such as in low population density, rural areas. In such cases, ensuring equipment and fuels are of high quality is likely to be the main aim of local interventions. However, in high density, urban areas, where there are multiple alternative energy sources, encouraging users to use less or move to non-combustion heating systems is likely to be a more preferable policy aim. These are simply two examples and there are many other circumstances, each requiring a slightly different policy approach. The main point is that the measures should be developed and implemented with the specific issue to be addressed, and the outcome desired, as the key guiding principle.

A variety of measures is likely to be required, at different administrative levels

Following on from the previous point, reliance on centrally implemented solutions is likely to be less successful than locally implemented solutions which meet local needs and circumstances. However, a national level framework will be required, to ensure consistency and avoid confusion among suppliers and consumers alike. This could include fuel quality standards, appliance emission limits or labelling, the provision of powers to local enforcement authorities or funding for appliance replacement schemes. This will then enable the implementation of local measures ranging across the types described in this report, i.e. operational changes, stock changes, use restrictions, and information campaigns.

Measures need to be bound together in a coherent, publicly accessible strategy

A coherent strategy, which sets out the national framework and the roles and responsibilities of local enforcement or planning authorities is required to ensure maximum visibility of the overall policy aims. A publicly available strategy will provide a focal point for action and allow local authorities, producers, suppliers and consumers to understand what is expected of them.

Measures need to include both suppliers and consumers

The importance of the informal market, and non-market supply of fuel, means that measures which only address the formal market are unlikely to be effective, or at least unlikely to be effective on their own. Changing the level of understanding of air quality impacts among consumers, as well as upskilling in the use of woody biomass-using appliances, will help create upward pressures on suppliers, changing the market. The example from Germany, where the combustion of unseasoned wood is no longer considered an issue, came as a result of directly changing consumer behaviour which in turn has changed the demands those consumers make on fuel suppliers.

Information is a key component, as is the way in which information is presented

The provision of information, both on the potential impact that the use of biomass for energy has on air quality and on the correct use of it (including appliance choices) is crucial for the successful implementation of other measures, e.g. on use restriction or fuel quality. There have been successful national and local information and training campaigns, implemented by national and local authorities. However, consideration also needs to be given to other information sources. Specifically, chimney sweeps have been shown to be a crucial link in providing information to consumers, being both more personal and, potentially, more trusted than either authorities or manufacturers/suppliers. In countries where chimney sweep services are mandatory, they have also been shown to be an excellent source of information on the domestic appliance stock, thereby helping to improve air quality emissions estimates.

Measures need to take into account both fuel poverty and the access to alternatives

Every Member State, to a greater or lesser degree, will have households dependent on non-grid energy. Care is needed in the design and implementation of measures to avoid extending or exacerbating fuel poverty, for example by increasing fuel costs where no alternatives exist, given that fuel poverty is also linked to significant public health impacts. Other unintended consequences, such as forcing people to switch from regulated fuels to unregulated fuels, such as waste construction timber (which could in turn make air pollutant emissions worse), must also be considered within the measure design.

Cultural drivers need to be taken into account

Potential cultural drivers for the use of bioenergy need to be understood and sensitively handled in the design of measures. Not to do so risks popular backlash and a distrust of those implementing the measures, undermining their effectiveness. Popular and stakeholder engagement are therefore important in the measure design process, as is the provision of clear, unbiased information on both the issues to be addressed (e.g. air pollution or fuel poverty) and the aims of the policies being developed.

7 Enabling action through policy development

One of the initial components of this study was the provision of support to the European Commission in securing policy coherence around the issue of bioenergy and air quality. In particular, measures in development which could, potentially, promote or enable the use of bioenergy needed to be aligned with the goals of improving air pollution and thus public health. During the project, two measures in particular were under development, namely the revision of the Regulations relating to solid fuel boilers and local space heaters, made under the Ecodesign Directive (2009/125/EC), and the revision of the Energy Performance of Buildings Directive (EPBD, 2010/31/EU).

7.1 Ecodesign Directive

The Ecodesign Directive has provided a significant driver for the improvement in the energy performance, and other environmental metrics, of a wide range of consumer products. Of relevance for this study, this includes space heaters and boilers, and the setting of mandatory air pollution emission limits for bioenergy appliances. However, these standards have lagged behind those set in some Member States and so a tightening of the standards has been proposed.

An initial information exchange between this project team and the team supporting the revision of the Ecodesign criteria for solid fuel boilers and local space heaters has been undertaken. However, other than a broad alignment of objectives (i.e. the minimisation of air quality impacts from bioenergy use), there was little commonality found between the specific aims of the projects. This project sought to summarise the air quality impacts of bioenergy and analyse the range of measures being developed in this space by Member States. It does not address the specifics of emission standards or testing procedures to the level of detail required by the Ecodesign Directive revision team. Therefore, no more work was undertaken under this sub-task, but the results generated here on the air quality impacts of bioenergy will be available to inform the preparation of the revision of Ecodesign criteria for solid fuel boilers and local space heaters.

7.2 Energy Performance of Buildings Directive

The EPBD is the main EU instrument targeted at improving the overall energy performance of buildings in Europe. It includes requirements for Member States to improve the energy performance standards for new and renovated buildings and mandates the issuing of Energy Performance Certificates (EPCs). EPCs must include a standard set of performance metrics, with additional, optional indicators listed in Annex V of the Directive. One of these optional indicators relates to operational emissions of fine particulate matter ($PM_{2.5}$), although this is not further defined in the Directive.

Given that bioenergy, and solid fuel use more broadly, is the principal source of domestic $PM_{2.5}$ emissions, the development of an initial format for the $PM_{2.5}$ indicator for potential inclusion in EPCs was undertaken as part of this project. The resulting proposal is based on EMEP Guidebook[133] emission factors for different heating appliance types and uses an A-F scale similar to that already used for the energy performance indicators in EPCs. It is explained further in Annex 1)a)i)(1)(a)(i)A7 to this report. The proposal is the preferred option of three initially considered, and would need further refinement and testing using real-life examples before it is ready to roll out.

133 https://www.eea.europa.eu//publications/emep-eea-guidebook-2023

8 Conclusions

8.1 Key emerging messages

Small-scale bioenergy use presents a significant barrier to meeting clean air ambitions in the EU

Bioenergy use in small combustion appliances makes up around half of the $PM_{2.5}$ emissions in the EU27 (see Figure 4-4). This presents a risk to the EU's ability to meet both air pollutant emission reduction commitments and concentration targets. Given the scale of emission reductions from all sectors required to meet the recently agreed air quality standards under the revised Ambient Air Quality Directive[134] significant reductions in $PM_{2.5}$ emissions from bioenergy use will be necessary for full compliance.

Bioenergy is also a significant part of the energy supply landscape in almost all EU Member States

Bioenergy is the main source of renewables in the EU in terms of gross final energy consumption, representing almost 60% of renewable energy sources[135]. Its main use is for heating and cooling (around 75%). In the EU, the use of bioenergy increased very rapidly between 2005 and 2020, although in recent years the growth has levelled out, potentially due to uncertainty in policies and debates about sustainability of bioenergy[136]. Germany, France, Italy and Sweden are the EU27 Member States with the highest bioenergy consumption in absolute terms, although it makes a significant contribution to energy consumption in all but a few Member States. At the EU collective level in 2021, the industry sector consumed 21.1 Mtoe of solid biomass (8.8% of final energy consumed in the industry sector), the residential sector 45.2 Mtoe (17.3%) of final energy consumed in the residential sector), and the energy sector 33.0 Mtoe (2.6% of transformation input in the energy sector)[137].

Controlling air pollutant emissions from domestic-scale bioenergy use is a key challenge for clean air policy

Small-scale biomass combustion, using solid fuel, makes up the great majority of bioenergy emissions for the five pollutants covered by the NEC Directive. There are significant contributions from bioenergy use in the energy and manufacturing industry sectors for NO_X and SO_2. However, the stricter emission limits included in the updated LCP BAT conclusions, in place from 2021, will likely result in bioenergy emissions from these sectors decreasing in the near future. Moreover, bioenergy is a minority contributor (2-8%) to EU emissions of NO_X, SO_2 and NH_3. This is not the case for $PM_{2.5}$ where, as noted above, emissions from small-scale bioenergy combustion make up around 50% of the total.

There are drivers to both increase bioenergy use and control its impacts within EU policy, and greater coherence is needed especially around domestic heating

Policy and legislation to control air pollution have been in place at EU and Member State levels for a considerable time and the area is relatively mature. Such legislation should act to control the air pollution impacts of bioenergy use. However, climate policies (and associated messaging) in general, and renewable heat policies in particular, have tended to promote an image of bioenergy as "green energy". The attendant potential negative impacts on air quality have not had much prominence. This was born out by comments made by some of the stakeholders interviewed for this project.

134 https://environment.ec.europa.eu/topics/air/air-quality/revision-ambient-air-quality-directives_en, see in particular the impact assessment underpinning the proposal for more details on the required reductions of emissions
135 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130730/2022.5470_kjna31283enn.pdf
136 Ibid.
137 https://op.europa.eu/en/publication-detail/-/publication/96d671c9-c719-11ee-95d9-01aa75ed71a1/language-en/format-PDF/source-305260384

There are measures to address the air quality impacts of bioenergy use in most, if not all, Member States, following a similar pattern

The potential air pollution impacts of domestic solid fuel use, be that bioenergy (wood) or coal, have been well known for many decades. As such, most Member States have some measures in place, and are also covered by EU scale legislation through, for example, the Ecodesign Directive. However, as other sources of air pollution, notably industry and transport, have been subject to increasingly stringent emission controls, the impact of bioenergy use in particular has come to the fore. Moreover, the focus on non-domestic and mobile sources has coincided with the uptake of domestic fuelwood use, often for "aesthetic" purposes, in many countries. This has changed the nature of the issue and has meant that many measures are overdue for update and revision.

The precise nature of the primary issues vary between Member States, as does the level of ambition shown

As noted above, the status of domestic woody biomass/fuelwood use varies between different Member States. In some, solid fuel use, including bioenergy, is still a staple component of domestic space and water heating. Of those, some have transitioned strongly towards cleaner, pellet fuelled boilers (if not necessarily stoves) whereas others, notably in Central and Eastern Europe, still retain a strong reliance on older log wood and coal fired appliances. In other countries, where gas and other energy networks are more extensive, the use of wood stoves as a supplementary heating source, often for aesthetic reasons, has increased over recent years. Added to this is the difference between rural and urban populations, both in terms of heating behaviour and access to alternative heating sources. This means that measures need to be carefully designed and complementary, in order to address the different circumstances, drivers and solutions each variant requires.

What is certainly the case is that the level of ambition shown by different Member States also varies significantly. Germany, Denmark and France appear to be the most active in this space, although many other countries and cities are taking progressive action, such as Sofia's low emission zone for both transport and domestic heating.

There are good examples of measures already introduced from a variety of Member States, at local, regional and national scale, although more work is needed to evaluate their effectiveness

In broad terms, the measures to address the air quality impacts of bioenergy undertaken by Member States, regions and cities fall into four categories: **operational** (addressing things like maintenance regimes or fuel quality), **stock changes** (upgrading the stock of appliances to cleaner burning versions), **use restrictions** (restricting the areas or times in which bioenergy can be used) or **information and training** (mainly aimed at users, although not exclusively). In addition to Sofia's low emission zone, mentioned above, Denmark's requirement to upgrade stoves before a house can be sold, Germany's work with information provision by chimney sweeps and France's strategic approach to the control of domestic bioenergy emissions stand out as innovative (and replicable in other countries). However, there is very little information about the effectiveness of such measures. Impact and process evaluation appears to be particularly rare in this space but could help refine and direct measures to ensure they achieve their desired outcomes and avoid unintended consequences.

National strategies to address domestic solid fuel use, including bioenergy, are likely to be needed in order to meet EU air quality and climate ambitions, as well as to address social issues such as fuel poverty

As noted above, domestic woody biomass use accounts for around half of the $PM_{2.5}$ emissions in the EU and is likely to act as a barrier to achieving the EU's Clean Air ambitions unless addressed. As also noted in this report, this is a complex problem, with links not only to climate policy and the promotion of renewable heat, but also social issues such as fuel poverty. A dedicated strategic approach to addressing the air pollution impacts of bioenergy is likely to be needed within each Member State. The aim is to ensure that a range of measures is available, to be implemented in different areas to address the different nature of the issues (e.g. urban and rural situations), and that account can be taken of wider issues such as fuel poverty. It is also more efficient to evaluate the effectiveness of a strategy, rather than of each individual measure, and allows the enabling nature of information campaigns to be more fully assessed.

8.2 Recommendations

8.2.1 EU Level

- Greater consistency is required from the **European Commission** as to the expected role of bioenergy and solid fuel use more generally, within the overall energy, climate and clean air policies for the EU. Differentiation is needed between large and medium scale bioenergy use (e.g. in power generation or district heating) and small-scale domestic use, and on suitable locations for use. In particular, any policy or legislation which promotes the use of bioenergy needs to include a full impact assessment of likely effects on air quality and public health. Moreover, measures to protect air quality should be built into policies and legislation which incentivise or drive the uptake of renewable heat in particular, attempting to avoid widespread uptake of small-scale bioenergy in urban areas. While it is for **Member States** to determine their energy policies and strategies, the Commission has a role in coordinating across policy areas and helping to set expectations

- More needs to be done, by the **EU institutions**, to realise the $PM_{2.5}$ emission reduction potential in source legislation, such as the EPBD and Ecodesign Directive. The former includes an optional indicator for operation $PM_{2.5}$ emissions from buildings but this needs to be developed into a workable metric for use by Member States. In the case of the Ecodesign Directive, mandatory PM emission standards for bioenergy appliances need to be tightened, bringing them into line with more progressive Member State standards. Consideration should also be given to developing even more stringent, non-mandatory standards, for use by Member States in labelling and incentive schemes. This will allow the manufacturers and suppliers to better coordinate their approaches to bringing lower emission appliances to the market

- Further, coordinated support is needed from the **European Commission** for schemes to replace older wood combustion appliances (with lower emission appliances or, preferably, non-combustion heating), especially in less wealthy Member States. There is a risk that this "legitimises" bioenergy use in situations where it may not be appropriate, such as urban areas, and so such support needs to be contingent on location

- Given that achieving compliance with EU goals on clean air is contingent on local level action, the **European Commission** could develop, and encourage the use of, tools for policy evaluation at local levels, for use where they do not already exist at Member State level

8.2.2 Member State level

- **Member States** should develop a coherent plan for addressing the air quality impacts of bioenergy, in particular the use of biomass for domestic-scale energy purposes (and, by extension, domestic solid fuel use[138] more generally), within their overall air quality and energy strategies. This will require coordination across Government Departments or Ministries to ensure a consistency of messaging for the general public and the bioenergy supply industries

- Drawing on the research to support this project, a mix of measures is required, including:

    - Operational and fuel quality improvements

    - Stock improvements, removing older appliances (including open fireplaces) and upgrading the emission performance of installed appliances

138 Coal, lignite and other solid fuels remain widely used as a domestic heating source in many Member States.

  - Restrictions on use where other forms of heating are readily available, and local air quality impacts more significant, and

  - Information and training, both on the use of appliances and their potential impacts on local environments (and public health).

- In accordance with the principles set out in section 6.7, such strategies need to consider the country's specific domestic-scale bioenergy picture and develop a suite of measures accordingly, deploying (or facilitating) measures to suit local circumstances, with use restrictions being more appropriate for urban areas and stock changes elsewhere

- Within their overall strategies, **Member States** should include a plan for the evaluation, revision and refinement of their measures over time, utilising good practice evaluation techniques. This should include the building in of evaluation processes from the start, such as the development and testing of theories of change

- **Member States** should actively collate, publish and exchange information on their measures to mitigate the impact of the use of biomass for energy on air quality. This project has identified a number of good practice and innovative measures which appear to be unknown outside their country or region of implementation. Given the transboundary nature of air pollution, it is in the interests of all Member States, and their citizens, to ensure that efforts to improve air quality are coordinated across different countries

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10 Annexes

A1: Measurement standards

A2: Literature review

A3: Stakeholder Interview Guides

A4: Stakeholder survey

A5: Summary of the EU policies, legislation and other regulatory instruments which currently impact on bioenergy

A6:Policies and Measures at Member State, regional or local level

A7: Proposed metric for operational $PM_{2.5}$ emissions from buildings

A8: Policy Evaluation

A1 Measurement standards

This section provides more technical background of the different measurement methods, and also describes how the appliance type test operating procedures fit in there. The section covers two areas:

- Procedures for appliance tests (i.e. concerning combustion phases tested, types of nominal or reduced combustion speed, fuel quality) and how these relate to real-life emissions
- The pollutant sampling method (with or without condensables for particulate emissions) used to determine the emissions

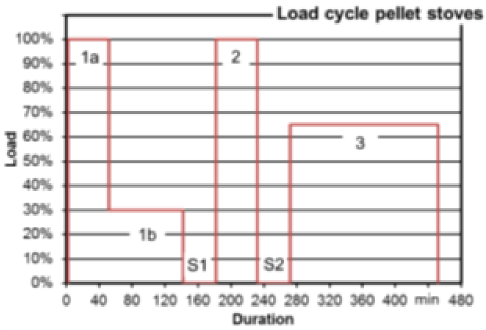
Appliance test operating procedures compared to real-life emissions

For type testing of appliances, operating procedures have historically been set as optimal operating conditions (e.g. the procedures EN 13240, EN 13229 and the draft European standard prEN 16510-1). In addition to this, the latest version of the European standard proposes optional tests at nominal power and at partial load, the latter however upon the discretion of the manufacturers. No standardized documentation exists which describes combustion conditions with limited air intake, whereas these conditions are particularly representative for overloading or night use, hence useful to simulate. In real life conditions, combustion conditions described in standards are often relatively far from the real operating conditions where the user will often have to operate his appliance at low output (with a combustion air intake limited, with a variable wood load and quality, under natural draft which is generally different from the fixed 12Pa flue draft of the standards, etc.).

Wohler et al. (2016) investigated real life operation of biomass room heating appliances in Europe, it was based on a survey performed in 16 European countries amongst which the most represented were Italy, Germany, Austria and Sweden. The results of this paper showed important differences between how room heating appliances are operated in the field and type testing protocols. The authors mentioned that these differences might be responsible for higher emissions in the field and that survey results may support further developments of type testing standards.

Several alternative testing protocols describing real life use have been imagined in different countries, amongst which the BeReal protocol proposed by the European BeReal Project (BeReal: Advanced Testing Methods for Better Real-Life Performance of Biomass Room Heating Appliances)[139]. The protocols proposed for pellet and woodlog stoves are presented in Figure 10-1.

139 BeReal final publishable report, available from https://cordis.europa.eu/docs/results/606/606605/final1-bereal-final-publishable-report.pdf



	Operational mode	Load level	Duration
1a	Cold start	Nominal load: 100 %	50 min
1b	Load change	Partial load: 30 %	90 min
S1	Standby	0%	40 min
2	Warm start	Nominal load: 100 %	50 min
S2	Standby	0%	40 min
3	Warm start	Partial load: 65 %	180 min
Total duration: 7.5 h			

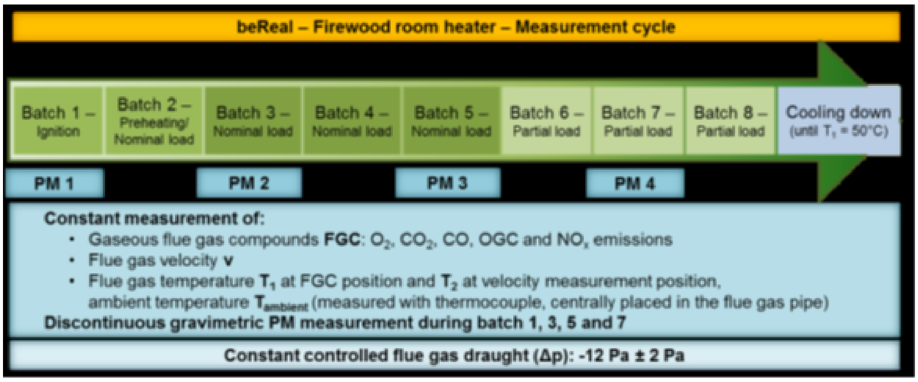


Figure 10-1: "BeReal –Firewood" – test procedure and measurements (from BEREAL final report)

According to the BeReal[140] study, performing tests according to the conditions described in standards could lead to strongly underestimating the real emissions of PM from woodlog stoves emitted essentially during the ignition and extinction phase and when low output combustion conditions are used and to overestimating the energy efficiency by 16%. A similar trend was observed within the Afac[141] project with an overestimation of the energy efficiency by 5% when using combustion conditions described in standards compared to using "real-life" combustion conditions.

Another study performed in the UK[142], gathered results of several studies that showed that real-world emissions can be higher than legislated limits due to a number of factors including fuel quality and operator behaviour. This study also recommended to reduce uncertainties in inventory estimates particularly around small-scale burning, by including the assessment of real-world emissions.

The Real-life project[143] aims at continuing the work initiated within the BeReal project by determining EFs of several appliances in Europe using real-life protocols.

Emissions from biomass combustion and how these are measured using different methodologies

140 BeReal 2016, Deliverable D7.1, Documentation and evaluation of field data demonstration.
141 AFAC, Détermination de facteurs d'émission de polluants des foyers domestiques alimentés au bois, Etude ADEME, rapport Ineris 2016
142 Air Quality Expert Group, The Potential Air Quality Impacts from Biomass Combustion, Prepared for: Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland
143 Real-LIFE emissions project, Harmonizing reliable test procedures representing real-LIFE air pollution from solid fuel heating appliances, LIFE Preparatory Project 2020, 01/05/2021 – 30/04/2024 https://sites.uef.fi/real-life-emissions/

This section discusses provides more a more in-depth description of the different types of particles and gases emitted by biomass combustion appliances and to what extent these are measured by the different measurement methods.

The particles present in ambient air, resulting directly or indirectly from wood combustion processes, can be divided into two categories[144]:

- Primary particles include those present in the solid state in the chimney flue and, by convention, the so-called condensable fraction. The solid particles emitted form mainly in the coldest areas of the combustion chamber. The condensable fraction is made up of semi-volatile species (SVOCs) with a high molecular weight which, when cooled outside the flue, form particles by condensation. The concentration of the solid fraction can be quantified by simple collection on a heated filter, while the concentration of the condensable fraction can be quantified using a method involving trapping in an appropriate cooled liquid (impinger or washing bottle method) or on a filter after dilution of the gases (dilution methods including dilution tunnel method)
- Secondary particles (Secondary Organic Aerosols) are formed in the atmosphere after emission by photooxidation phenomena, mainly from the most reactive gaseous precursors (semi-volatile and volatile organic compounds). To date, there is no standardised method for characterising the potential of a source to form SOA

During combustion, biomass decomposes, forming a wide variety of organic compounds with very different characteristics in terms of chemical structure and vapour pressure. The more incomplete the combustion, the greater the quantity of volatile organic compounds formed. These compounds are present in large numbers and, after nucleation, coagulation and condensation, form aerosols. Depending on their boiling point, these compounds can be divided into two main families: Volatile Organic Compounds (VOCs) and Semi-Volatile Organic Compounds (SVOCs).

Depending on temperature and flue gas dilution, the latter compounds can change phase. Initially present in gaseous form in the flue, they can be transformed into liquid aerosols by condensation, or solid aerosols by adsorption onto fine particles.

These compounds form the condensable fraction and their inclusion in reported emissions is very much method dependent, as explained earlier in this report. Existing methods for the determination of residential wood combustion PM emissions are presented in a report published by RISE during the IMPRESS 2 project[145].

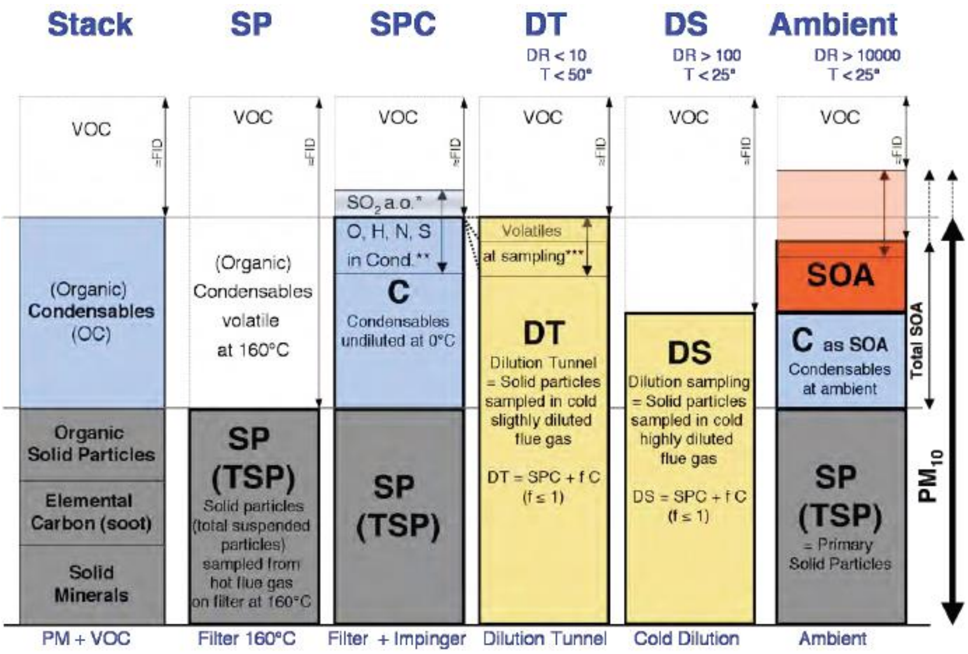
As already mentioned, sampling on a heated filter (HF) and sampling in a dilution tunnel (DT) are the two main methods that have historically been used in Europe to characterize emissions. Three other type of measurement methods, more marginally used, involve either sampling through an electrostatic precipitator, combining the heated filter (HF) to condensation of organic using a solvent (HF+impinger method, for example US EPA 5H) or diluting using higher dilution ratios.

A study published in 2017 (Seljeskog et al. 2017) compared the two main measurement methods of PM (HF and DT). In average, the mass of particles collected at the outlet a the tested appliances with the full flow DT method was about 6.5 times the mass of particles collected using the Heated Filter method.

This situation has an impact on both performance testing and the determination of emission factors, since the results presented in the inventories are necessarily linked to the measurement methods used and the associated measurands. Indeed, the quantities measured by these methods may differ: the SP method specifically

144 SYNTHESE DES ETUDES A L'EMISSION REALISEES PAR L'INERIS SUR LA COMBUSTION DU BOIS EN FOYERS DOMESTIQUES, Avril 2018, [Synthèse des études à l'émission réalisées par l'Ineris sur la combustion du bois en foyers domestiques | Ineris]
145 Emissions of particles and organic compounds from small and medium scaled biomass combustion Sara Janhäll, Daniel Bäckström and Lennart Gustavsson, RISE Report : 2018:57, Impress 2 EMPIR Project

determines the solid fraction of the aerosol, whereas the DT method also includes the condensable fraction. The following diagram (Figure 10-2) summarizes the parameters that can be measured at emission and contribute to particulate levels in ambient air.



SP: Filter (Method a) resulting in solid particles SP (total suspended particles TSP).
SPC: Filter + Impinger (Method b) resulting in solid particles and condensables SPC.
DT: Dilution Tunnel (Method c) with typical dilution ratio (DR) in the order of 10 resulting in a PM measurement including SPC and most or all C. DT is identical or slightly smaller than SPC + C due to potentially incomplete condensation, depending on dilution ratio and sampling temperature (since dilution reduces not only the temperature but also the partial pressure of contaminants).
DS: Dilution Sampling with high dilution ratio (DR > 100).
PM_{10}: Total Particulate Matter < 10 microns in the ambient including SP and SOA
SOA: Secondary organic aerosols, consisting of condensables C at ambient and SOA formed by secondary reactions such as photochemical oxidation.

*SO_2 and other soluable gaseous compounds in the flue gas may be dissolved in the impingers.
**In case of determination of TOC in impingers, the mass of O, H, N, S and other elements contained in the organic condensables needs to be accounted for separately.
***Organic compounds that are liquid or solid at partial pressure in the flue gas and ambient temperature but volatile at sampling due to reduced partial pressure by dilution and temperature above ambient.

Figure 10-2: Comparability of results obtained by existing methods in relation to concentrations emitted and measured in ambient air (source: after Nussbaumer, 2010)

Emissions from solid fuel space heaters, such as wood stoves, are regulated in the Ecodesign Regulation (EU) 2015/1185, and the Construction Product Regulation 305/2011 which regulates woods stoves as a construction product, while solid fuel boilers are regulated according to Ecodesign Regulation (EU) 2015/1189 The 1185 Ecodesign regulation, refers to three sampling methods (the HF method, the DT method, and a method based on the use of an electrostatic precipitator) that can be used by notified laboratories to determine the performance of equipment to be placed on the market from 2022 onwards; with distinct limit values depending on the methods used.

In a study[146] published in 2016 The Danish Ecological Council recommends harmonization of particle measurements from stoves and boilers by using methods that include condensates (smoke temperature 25-30 °C) per energy unit (joule) or per standard fuel unit (kg dry wood). Furthermore, in 2020 an international expert group convened by the EMEP programme recommended the inclusion of condensables in emission inventories (Simpson et al., 2020).

In 2021, the French Energy management and Environment Agency (Ademe) carried out a study of international benchmarks on heating appliances and air quality[147]. The aim of this study is to identify the policies put in place in various countries to limit the impact of domestic combustion heating on air quality, as well as their assessment methods, and to gain a better understanding of the emission factors used in these countries for this activity sector. This study shows that it is essential to work towards harmonizing emission measurement methods on a European scale, in order to limit the methodological impact on the heterogeneities observed. This harmonization work is particularly important in the case of particulate matter, in order to decide how the condensable fraction should be taken into account, and how it should be measured.

In 2022 CEN TC295 in charge of Residential solid fuel combustion appliances published an updated heated filter method for determination of dust emission (PM) as part of the non-harmonized part 1, EN16510 standard known as EN-PME method and based on the recommendation formulated following the EN_PME_TEST project. The idea of the EN-PME method is to make a clear distinction between solid particles and VOCs, with both components being measured separately. This method was intended to be used for the evaluation of new stoves, but as a result emissions derived from this method do not include the condensables.

There has been much scientific activity going on with regard to measuring condensables in Europe in recent years. A simplified version of the US EPA 5H method, combining a heated filter to washing bottles containing isopropanol as solvent has been developed by INERIS (e.g. HF-IPA impingers) and successfully compared with the dilution tunnel method by Fraboulet and al (2016). More recently, a simple method of dilution aiming at taking into account condensables has been developed by ENEA4/ISSI5 and evaluated using wood log and pellet stoves within the EMPIR Impress 2 project by five European partners (ENEA/ISSI,DTI, RISE and INERIS). Results are presented in a paper published by Cea et al. (2021). Finally, a method combining the EN_PME_TEST method to a dilution device positioned at the outlet of the EN-PME probe and heated filter is being developed within the Real-life on-going project. This method will be tested in comparison with the DT and HF-IPA impinger methods and its performance will be evaluated through an intercomparison, for which first results are expected at the end of 2024.

146 Pollution from residential burning – Danish experience in an international perspective, Green Transition Denmark, 2016, https://www.ccacoalition.org/en/resources/pollution-residential-burning-danish-experience-international-perspective
147 Domestic heating and air quality, international benchmarks. French Ademe Report (2021), https://librairie.ademe.fr/air-et-bruit/4208-chauffage-domestique-et-qualite-de-l-air-benchmark-international.html

A2 Literature review

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
NEC Directive	Legislation	European Commission	2016	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L2284&from=EN	05.01.2023
Ambient Air Quality Directive(s)	Legislation	European Commission	2008	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN	04.01.2023
Renewable Energy Directive(s)	Legislation	European Commission	2018	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN	04.01.2023
Industrial Emissions Directive	Legislation	European Commission	2010	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0075&from=EN	04.01.2023
Medium Combustion Plant Directive	Legislation	European Commission	2015	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L2193&from=EN	04.01.2023
Energy Performance of Buildings Directive	Legislation	European Commission	2018	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN	04.01.2023
Ecodesign Regulation	Legislation	European Commission	2022	https://environment.ec.europa.eu/system/files/2022-03/COM_2022_142_1_EN_ACT_part1_v6.pdf	04.01.2023
Energy Labelling Regulation	Legislation	European Commission	2017	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1369&qid=1672841306552&from=en	04.01.2023
Monitoring Mechanism Regulation	Legislation	European Commission	2013	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0525&from=EN	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
Regulation on Land Use, Land Use Change and Forestry	Legislation	European Commission	2018	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0841&from=EN	26.01.2023
Zero Pollution Action Plan	Legislation	European Commission	2021	https://ec.europa.eu/environment/pdf/zero-pollution-action-plan/communication_en.pdf	26.01.2023
European Green Deal	Legislation	European Commission	2019	https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF	26.01.2023
Investigation of real-life operation of biomass room heating appliances – Results of a European survey	Scientific Literature	Wohler et al.	2016	https://www.sciencedirect.com/science/article/pii/S0306261916301076	04.01.2023
Impact of fuel moisture, charge size, feeding rate and air ventilation conditions on the emissions of PM, OC, EC, parent PAHs and their derivatives from residential wood combustion	Scientific Literature	Shen et al.	2013	https://www.sciencedirect.com/science/article/pii/S1001074212602587	04.01.2023
Bottom-up inventory of residential combustion emissions in Poland for national air quality modelling: current status and perspectives	Scientific Literature	Gawuc et al.	2021	https://www.researchgate.net/publication/355938899_Bottom-Up_Inventory_of_Residential_Combustion_Emissions_in_Poland_for_National_Air_Quality_Modelling_Current_Status_and_Perspectives	04.01.2023
Annual exposure to polycyclic aromatic hydrocarbons in urban environments linked to wintertime wood-burning episodes	Scientific Literature	Tsiodra, et al.	2021	https://www.researchgate.net/publication/356848263_Annual_exposure_to_polycyclic_aromatic_hydrocarbons_in_urban_environments_linked_to_wintertime_wood-burning_episodes#:~:text=Tsiodra%20et%20al.%20%282021%29%20found%20that%20local%20winter,contributor%20%28	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
				76%25%29%20to%20increased%20excess%20lifetime%20cancer%20risk.	
Sustainability constraints in determining European bioenergy potential A review of existing studies and steps forward	Scientific Literature	Kluts et al.	2017	https://www.sciencedirect.com/science/article/pii/S1364032116307638	04.01.2023
Indoor air pollution from residential stoves: examining the flooding of particulate matter into homes during real-world use	Scientific Literature	Chakraborty et al.	2020	https://www.researchgate.net/publication/346715580_Indoor_Air_Pollution_from_Residential_Stoves_Examining_the_Flooding_of_Particulate_Matter_into_Homes_during_Real-World_Use	04.01.2023
Particle emissions from residential wood combustion in Europe – revised estimates and an evaluation	Scientific Literature	Denier van der Gon et al.	2015	https://www.researchgate.net/publication/307823348_Particulate_emissions_from_residential_wood_combustion_in_Europe_-_revised_estimates_and_an_evaluation	04.01.2023
The influence of residential wood combustion on concentrations of $PM_{2.5}$ in four Nordic cities	Scientific Literature	Kukkonen et al.	2020	(PDF) The influence of residential wood combustion on the concentrations of PM 2.5 in four Nordic cities (researchgate.net)	04.01.2023
Residential wood combustion in Finland: $PM_{2.5}$ emissions and health impacts with and without abatement measures	Scientific Literature	Savolahti et al.	2019	(PDF) Residential Wood Combustion in Finland: $PM_{2.5}$ Emissions and Health Impacts with and without Abatement Measures (researchgate.net)	04.01.2023
Cleaning the flue in wood-burning stoves is a key factor in reducing household air pollution	Scientific Literature	Rahman et al.	2022	https://www.researchgate.net/publication/364382745_Cleaning_the_Flue_in_Wood-Burning_Stoves_Is_a_Key_Factor_in_Reducing_Household_Air_Pollution	04.01.2023
Health-related social costs of air pollution due to residential heating and cooking in the EU27 and UK. CE Delft	Scientific Literature	Kortekand, M. et al.	2022	https://cedelft.eu/publications/health-related-social-costs-of-air-pollution-due-to-residential-heating-and-cooking/	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
Health Impacts of Anthropogenic Biomass Burning in the Developed World. European Respiratory Journal 46: 1577-1588	Scientific Literature	Sigsgaard, Torben et. al.	2015	https://www.researchgate.net/publication/282278252_Health_impacts_of_anthropogenic_biomass_burning_in_the_developed_world	04.01.2023
The Lancet Countdown on Health and Climate Change: Policy Brief for Europe.	Scientific Literature	Van Daalen, Kim.	2021	https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)01787-6/fulltext	04.01.2023
Commission Report COM/2021/3 final 'The 2nd Clean Air Outlook' and forthcoming 3rd Clean Air Outlook	Commission/ EEA reports	European Commission	2021	(3rd outlook) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=comnat:COM_2022_0673_FIN24	26.01.2023
Renewable energy in Europe 2019 - Recent growth and knock-on effects	Commission/ EEA reports	EEA	2019	https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/renewable-energy-in-europe-2019-recent-growth-and-knock-on-effects	26.01.2023
ETC/ATNI Report 2020/6 on the Development of renewable energy and impact on air quality: co-benefits and trade-offs	Commission/ EEA reports	Couvidat et aql.	2021	https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-6-2020-development-of-renewable-energy-and-its-impact-on-air-quality-co-benefits-and-trade-offs	04.01.2023
Managing Air Quality in Europe	Commission/ EEA reports	EEA	2022	https://www.eea.europa.eu/downloads/801821f1df9d4591a149ae8f1c8845b2/1656665799/managing-air-quality-in-europe.pdf	04.01.2023
EU Clean Air Technology Hub - Final Report under request for services in the context of Framework Service Contract EEA/ACC/18/001/LOT2	Commission/ EEA reports	Ramboll	2022	EU clean air technology hub - Publications Office of the EU (europa.eu)	
Healthy environment, healthy lives: how the environment influences health and well-being in Europe. European Environment	Commission/ EEA reports	EEA	2020	https://www.eea.europa.eu/publications/healthy-environment-healthy-lives	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
Agency (EEA) Report No 21/2019, European Union, Luxembourg					
The impact of residential heating and cooking on air quality in Europe: The health argument for clean heating and cooking. European Public Health Alliance (EPHA) Position paper, Brussels	Commission/ EEA reports	EPHA	2022	https://epha.org/wp-content/uploads/2022/03/epha-position-paper-clean-heating.pdf	04.01.2023
The use of woody biomass for energy production in the EU	Commission/ EEA reports	European Commission, Joint Research Centre	2021	https://op.europa.eu/en/publication-detail/-/publication/7120db75-6118-11eb-8146-01aa75ed71a1/language-en	04.01.2023
National Air Pollution Control Programmes (NAPCPs) for all Member States (as submitted to EEA's Common Data Repository, CDR) (and their evaluation by the Commission)	National Reports	European Commission		Located in NAPCP review tab	
National Energy & Climate Change Plans for all Member States and their evaluation by the Commission	National Reports	European Commission		Located in NECP review tab	
Revising $PM_{2.5}$ emissions from residential combustion 2005-2019, implications for air quality concentrations and trends. Report for Nordic Council of Ministers	National Reports	Simpson, Kuenen et al.	2022	temanord2022-540.pdf (norden.org)	04.01.2023
Pollution from residential burning – Danish experience in an international perspective	National Reports	Green Transition Denmark	2016	https://www.ccacoalition.org/en/resources/pollution-residential-burning-danish-experience-international-perspective	04.01.2023
Report on 'Potential air quality impacts from biomass combustion'	National Reports	UK Air Quality Expert Group for Defra	2017	Report: The Potential Air Quality Impacts from Biomass Combustion - Defra, UK	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
Impact of fossil fuel usage reduction policy on $PM_{2.5}$ level changes in a Lesser Poland Area	National Reports	Dąbrowski K.M.	2022	Impact of fossil fuel usage reduction policy on $PM_{2.5}$ level changes in a Lesser Poland Area | Elsevier Enhanced Reader	04.01.2023
Ref2 alternative emission inventory: alternative PM estimates for small combustion (including biofuels) consistently including the condensable component of PM	Relevant Datasets				
National emission inventories and accompanying Informative Inventory Reports (IIRs) which describe the methodologies used in each Member State to estimate emissions in their national inventories	Relevant Datasets				
LIFE Clean Heat	LIFE Projects				
Real-LIFE emissions (uef.fi), especially the results of the first project workshop which took place 9 November 2022	LIFE Projects				
PrepAIR (biomass pillar in this project)	LIFE Projects				
LIFE Green Stoves	LIFE Projects				
Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. WHO Regional Office for Europe, Copenhagen	Other Sources	WHO	2015	https://www.who.int/europe/publications/i/item/WHO-EURO-2015-4102-43861-61759	04.01.2023
Factsheet: Slashing Emissions from Residential Wood Heating. Available at Switch4Air website of Bioenergy Europe	Other Sources	Bioenergy Europe	2019	https://epc.bioenergyeurope.org/wp-content/uploads/2021/01/Air-Emissions.pdf	04.01.2023
Residential heating with wood and coal: health impacts and policy options in Europe and North America	Other Sources	WHO	2015	https://apps.who.int/iris/bitstream/handle/10665/153671/9789289050760-eng.pdf?sequence=3&isAllowed=y	04.01.2023

Document Title	Data Source	Author	Year of Publication	Access Location	Access Date
Out of the woods: Using ecodesign to reduce the negative impacts of solid fuel heating	Other Sources	Coolproducts & ECOS	2022	https://www.coolproducts.eu/wp-content/uploads/2022/03/ECOS_Out-of-the-woods_final.pdf	04.01.2023
Where there's fire, there's smoke. Emissions from domestic heating with wood	Other Sources	EEB and Green Transition Denmark	2021	Where-theres-fire-theres-smoke_domestic-heating-study_2021.pdf (eeb.org)	04.01.2023
UNECE LRTAP Stage 3 Review Reports 2022	Other Sources				
Health-related social costs of air pollution due to residential heating and cooking in the EU27 and UK	Other Sources	CE Delft	2022	CE_Delft_210135_Health-related_social_costs_of_residential_heating_and_cooking_Def_V1.2.pdf (cedelft.eu)	04.01.2023
Wood burners cause nearly half of urban air pollution cancer risk – study	Other Sources	The Guardian	2021	Wood burners cause nearly half of urban air pollution cancer risk – study | Air pollution | The Guardian	04.01.2023
Code of Good Practice for Solid Fuel Burning and Small-scale Combustion Installations; TFTEI/LRTAP submission to WGSR 2019.	Other Sources	TFTEI	2019	PowerPoint Presentation (unece.org)	04.01.2023
Reduction of emissions of black carbon and $PM_{2.5}$ from domestic heating and open agricultural burning	Other Sources	Bodin, S.	2017	EECCA_TFTEI Berling 20190514 Reduction of BC and $PM_{2.5}$ from OB and DH (unece.org)	04.01.2023
Climate Change Mitigation of Climate Change	Other Sources	IPCC	2022	IPCC_AR6_WGIII_FullReport.pdf	04.01.2023
Annual Report 2021	Other Sources	IEA Bioenergy	2021	IEA-Bioenergy-Annual-Report-2021.pdf (ieabioenergy.com)	04.01.2023
Inventory of national strategies for reducing the impact on air quality from residential wood combustion	Other Sources	IEA Bioenergy	2022		

A3 Stakeholder Interview Guides

A3.1 Introduction

The European Commission has commissioned a consortium led by Logika Group to deliver a project on *Increasing Policy Coherence between Bioenergy and Clean Air Policies and Measures*, in which stakeholder interviews form an integral part of the study. You have been invited to participate in these interviews due to your experience and expertise in this area, but participation is completely voluntary. Further detail about the study and the interview, including interview questions, are provided below.

A3.2 Project Context

Bioenergy, in the form of woody biomass, constitutes a significant part of the energy mix for many EU Member States and the use of wood and other biomass fuels offer a renewable, relatively low-cost combustion fuel. However, it carries with it the risk of greatly increased air pollutant emissions. This problem is not a new one and not all forms of bioenergy have the same impacts. Potential solutions exist to help mitigate the negative effects of bioenergy on air quality, and to increase policy coherence between bioenergy and clean air policies in the EU. The aim of this project is to gather evidence to identify and reduce unintentional trade-offs between different objectives found in EU law (existing or forthcoming) and related policy documents.

A3.3 Interview Context

Stakeholders have been identified to provide input in the format of targeted interviews, to discuss the identification of relevant policies and measures in place in Member States to mitigate the air quality impacts from bioenergy use. The key aim of these interviews is to supplement our literature review which aimed to identify relevant policies and measures at a national and sub-national level.

The focus of the discussion will be on:

- Identification of relevant measures to mitigate trade-offs
- Their application and location
- Any information on effectiveness which may be available
- Possible contacts for further research

The target time for the interviews is around 45 minutes. Participation in this interview is voluntary and you may decline from answering any of the questions.

A3.4 Confidential Information

You will have been sent a participant information sheet and consent form. At the start of the interview, we will ensure that you are happy to proceed and full consent will be obtained. However, if at any point after agreeing to proceed with the interview you would prefer to not answer a particular question(s) or stop the interview, please let us know.

The information that we collect from your interview will be combined with information gathered from other interviews for the purpose of the study. Responses will not be attributable to individuals and no names will be referred to in any reports produced.

All information that you provide will be held confidentially by the study team, in accordance with GDPR requirements and our contract with the European Commission. We will provide you with a copy of the written notes from the interview so that you can check these for both accuracy and sensitivity.

In order to capture the full detail of the information you provide during the interview, it would be beneficial to record the discussion. The recording will be used to enable us to produce accurate summary notes of the discussion and will be deleted once these notes have been agreed. We recognise that you may not wish the discussion to be recorded, so please let us know if you would prefer to proceed without recording. In that case, we will take written notes during the interview and share these notes with you after the interview for confirmation. Interview Questions

We have requested this interview because of your and your organisation's expertise regarding bioenergy use and its potential impacts. Note that the main aim of the interview is not to establish the advantages and disadvantages of bioenergy *in general*. The purpose of the interview is to identify and examine measures implemented to address the impacts of bioenergy on air quality by Member States and/or their regions or cities, and what evidence there may be on the effectiveness of such policies or actions.

A3.4.1 You and your organisation

1) What is the role/function of your organisation?

2) How does this relate to the use of bioenergy?

3) What is your role within the organisation?

A3.4.2 Bioenergy and clean air

4) The introductory sections above gives an overview of the scope of the study in relation to the use of bioenergy and the challenges it can bring for clean air objectives. Would you like to add any general observations on the link between bioenergy use and air quality?

5) Would you like to add any observations on the consistency between bioenergy and air quality in the EU policy framework? [*if aware – perhaps not relevant for interviewees in Third countries*]

A3.4.3 National scale actions (in EU countries)

We have provided a data collection proforma in **Annex 1**. Any/all of it can be pre-filled with existing knowledge you have on policies and measures in order to guide the conversation. Alternatively, we complete this during the interview if you prefer.

6) Are you aware of any EU Member States where the issues identified above [i.e. Q4] are either seen as more prevalent, or are a more pressing environmental concern?

7) What leads you to this view?

8) Are you aware of any particular actions being undertaken by Member States to address air pollution from bioenergy, or their regions or cities?

9) For each policy or measure targeting limiting air pollution from bioenergy that you are aware of:

   a) Where and at what scale (e.g. local, national, regional?) is this measure/policy applied?

   b) What is the primary aim of the measure/policy?

   c) Is this a legislative measure, or a 'soft' measure (for example, non-legislative awareness campaigns)

   d) Are you aware of any evidence of its effectiveness, or impacts on bioenergy use/emissions?

   e) Are you aware of any obstacles or barriers that may be preventing the effectiveness of these measures?

f) Do you know who is responsible for the implementation of the policy/measure? Do you have any contact details for further discussion?

10) What brought these to your attention?

A3.4.4 Actions outside the EU

11) Are you aware of any countries outside the EU where the issues identified above [i.e. Q4] are either seen as more prevalent, or are a more pressing environmental concern?

12) Are you aware of any particular actions being undertaken in these countries, which are designed to address such issues?

13) Do you have any information or evidence on how effective these measures have been?

Contacts for follow-up

14) If we wanted to investigate any of the measures mentioned further, do you have any contacts we could utilise, which you would be willing to share?

15) Are there any other organisations which you would recommend we speak to?

Thank you for your time today. We will be in touch to share the notes from the meeting for your comments and approval. **Are there any further questions for us?**

A4 Stakeholder survey

Bioenergy and Clean Air Polices and Measures

* Required

1) Your name *

2) Name of organisation *

3) Email (this will not be shared with any other organisation) *

4) We are aiming to examine the overlaps between the use of bioenergy, specifically biomass heating, and clean air objectives. Would you like to add any general observations on the link between bioenergy use and air quality? *

5) Are you aware of any EU Member States where issues relating to the impact of biomass on air quality are either seen as more prevalent, or are a more pressing environmental concern? *

6) Are you aware of any particular actions being undertaken by Member States, their regions or cities, to address air pollution from biomass use? *

7) Are you aware of any studies into, or evidence of, the effectiveness of those actions? *

8) Are you aware of any countries outside the EU where the challenges related to biomass use and air quality are either seen as more prevalent, or are more a more pressing environmental concern, and whether specific actions have been undertaken? *

9) Are you happy for us to contact you with follow up questions? *

Yes ○

No ○

A5 Summary of the EU policies, legislation and other regulatory instruments which currently impact on bioenergy

Legislation/Policy	Summary	Likely impact on bioenergy use	Timelines
Air Quality			
Ambient Air Quality Directives (AAQD) Directives 2008/50/EC and 2004/107/EC	Sets air quality limit and target values (i.e. concentration limits) to be achieved in Member States for a range of pollutants, of which PM_{10}, $PM_{2.5}$ and PAH are most relevant for bioenergy, alongside assessment, reporting and mitigation requirements.	Key driver for actions to reduce local/urban emissions from any source, including (biomass) combustion	Political agreement on revision reached in Feb 2024
National Emissions reduction Commitments Directive (NECD) Directive 2016/2284/EC	Sets emission reduction commitments at the Member State level of a range of pollutants, including $PM_{2.5}$ and NMVOC, to 2020-29 and 2030 onward. Among the obligations under the NECD is the requirement to prepare and report National Air Pollution Control Programmes (NAPCPs), which must include mitigation actions where the emission reduction commitments are projected not to be met.	Key driver for actions to reduce national air pollutant emissions, including from (biomass) combustion	entered into force on 31st December 2016
Industrial Emissions Directive Directive 2010/75/EU, and BAT conclusions	The main EU instrument regulating pollutant emissions from industrial installations. The Directive sets out the main principles for permitting and controlling large industrial and livestock (hereafter agro-industrial) installations based on an integrated approach and the detailed permit conditions are defined in the **BAT conclusions**, adopted by the Commission as implementing decisions. Best Available Techniques (BAT) as defined in BAT Reference documents (BREFs) should be applied to reach a high level of environmental protection. The IED covers around 50,000 agro-industrial installations in the EU.	Key driver to reduce air pollutant emissions from industrial sources	Entered into force on 6th January 2011. Proposed revision adopted on 5th April 2022
European Pollutant Release and Transfer Register (E-PRTR) Regulation (EC) No 166/2006	Outlines the legal reporting requirements of the E-PRTR regulation, which provides easily accessible environmental data from industrial facilities across EU Member States, Iceland, Liechtenstein, Norway, Switzerland, Serbia and the UK. Annual data is reported by around 34,000 industrial facilities across 65 economic activities. The data covers 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins.	Key driver to reduce air pollutant emissions from industrial sources	Entered into force on 24th February 2006. Proposed revision adopted on 5th April 2022.

Legislation/Policy	Summary	Likely impact on bioenergy use	Timelines
Climate and Energy			
Renewable Energy Directive (RED) Directive 2018/2001/EU, amended by Directive (EU) 2023/2413	Sets a common target for the proportion of renewable energy in EU total consumption (of at least 42.5% binding at EU level by 2030 - but aiming for 45%, following the 2023 amendment). It also contains measures to support renewables uptake in transport, heating and cooling, to create an energy efficient and circular energy system that facilitates renewables-based electrification and promotes the use of renewable and low-carbon fuels, including hydrogen, in sectors where electrification is not yet feasible. Note that while the RED does not address air quality, the impact assessment for 2018/2001/EU notes that poor quality biomass combustion can have a negative impact on air quality.[148] It further notes that there is EU legislation in place to address poor air quality (citing the AAQDs and NECD) and that the eco-design directive is best placed to address the poor performance of appliances.	Driver for uptake of renewable heat, including bioenergy + electricity	Revised Directive adopted in October 2023 and entered into force in all EU countries on 20 November 2023, with a transposition deadline of 21 May 2025 (1st of July 2024 for the permitting-related provisions).
Regulation on the governance for the energy union and climate action Regulation (EU) 2018/1999	This regulation aims to ensure that the EU's energy union strategy is implemented effectively and to ensure that the EU achieves its objectives for climate including those under the 2030 policy framework for climate and energy and the Paris Agreement. It requires EU Member States to develop integrated national energy and climate plans based on a common template, covering decarbonisation, energy security, energy efficiency, internal energy market, and research, innovation and competitiveness.	Governance framework to ensure delivery of energy and climate targets	Entered into force on 24th December 2018
Regulation on Land Use, Land Use Change and Forestry Regulation (EU) 2018/841	Requires EU Member States to ensure that GHG emissions from land use, land use change or forestry are offset by at least an equivalent removal of CO_2 from the atmosphere in the period 2021 to 2030. Introduces a standardised system of accounting rules, as well as flexibility mechanisms for transferring accounted emissions and removals with the Effort Sharing Regulation. It is the third pillar of the EU's 2030 climate and energy framework.	Mandates that GHG emissions from biomass are accounted for in MS climate commitments (and thus could impact bioenergy demand)	Adopted on 30th May 2018
REPowerEU Plan COM/2022/230	Plan to make Europe independent from Russian fossil fuels before 2030, in light of Russia's invasion of Ukraine. It contains a series of measures to reduce dependence on Russian fossil fuels and	Driver for a faster transition to renewable energy (including bioenergy)	Presented on 18th May 2022

148 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0621&qid=1682590610107

Legislation/Policy	Summary	Likely impact on bioenergy use	Timelines
	accelerate the green energy transition. Some of the measures look to boost investment in renewable energy and the adoption of more ambitious renewable energy targets.		
Energy Efficiency Directive Directive (EU) 2018/2002, Directive on energy efficiency and amending Regulation (EU) 2023/955 (recast)	Sets out binding measures to reach the EU's energy efficiency targets. The recast Directive, adopted in July and set to come into force in September or October 2023, mandates an additional 11.7% reduction in final energy demand by 2030 (based on 2020 projections). This is on top of the target in the 2018 amending Directive of a 32.5% reduction by 2030, over a 2007 baseline. The revisions aim to ensure that the 2030 target of GHG emission reduction by 55% (by 1990) is met by the EU. Additional specific measures are aimed at the public sector, industry and at alleviating fuel poverty.	Driver to reduce overall energy use	Recast Directive adopted July 2023.
Product specific emission control			
Ecodesign Directive (2009/125/EC and currently under revision) and associated Regulations	Sets environmental performance standards for consumer products, covering (currently) some 31 product groups, including domestic heating appliances. By introducing mandatory, minimum standards, the product Regulations aim to improve the environmental performance of products and to eliminate the least performing products from the market.	Includes product level emission limits including on air pollutants	Amended on 25th October 2012. Currently under revision (proposal for a new Regulation on Ecodesign for sustainable products adopted on 30 March 2022).
Energy Labelling Regulation Directive 2017/1369 and associated Regulations	Sets up a framework for energy labelling and repeals the previous Directive 2010/30/EU. It lays down a framework for the labelling of energy-related products placed on the market or put into service. It standardises the display of product information regarding energy efficiency, the consumption of energy and of other resources by products during use and supplementary information about the product. The aim is to allow customers to clearly understand the energy efficiency of their products and encourage them to purchase more efficient ones. Requirements for specific products are set out in product Regulations.	Driver to increase energy efficiency, reducing overall energy use	Entered into force on 1st August 2017
Installations and buildings			

Legislation/Policy	Summary	Likely impact on bioenergy use	Timelines
Medium Combustion Plant (MCP) Directive Directive 2015/2193	Limits the emissions of certain pollutants into the air from MCPs by regulating pollutant emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 Megawatt thermal (MWth) and less than 50MWth.	Includes emission limits for the emission of SO_2, NO_x and 'dust' from MCPs but not relevant for small domestic units	Approved on 25th November 2015
Energy Performance of Buildings Directive (EPBD) Directive 2010/31/EU	Main legislative instrument aimed at improving the energy performance of buildings in the EU. This is key for achieving the EU's 2030 and 2050 decarbonisation objectives, as buildings account for 40% of energy consumed and 36% of energy-related direct and indirect greenhouse gas emissions. The EPBD takes into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.	Driver to reduce overall energy use in buildings	Entered into force on 18th June 2010. Revised in 2018 by the Directive amending the Energy Performance of Buildings Directive (2018/844/EU). In December 2021, the Commission proposed a revision of the directive (COM(2021) 802 final).[149] Agreement reached on revision, due for adoption in early 2024[150].
Construction Products Regulation Regulation (EU) 305/2011	Initiates the development of harmonised European standards/technical specifications which provide a common language for assessing the performance of construction products, including space heaters.	Driver to reduce air pollutant emissions from space heater appliances	Approved on 9th March 2011. proposal for a revised Construction Products Regulation (CPR) was adopted on 30 March 2022.[151]

149 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0802&qid=1641802763889
150 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6423
151 https://ec.europa.eu/docsroom/documents/49315

A6 Policies and Measures at Member State, regional or local level

Annex 6 is published separately, here.

A7 Proposed metric for operational $PM_{2.5}$ emissions from buildings

A7.1 Energy Performance of Buildings Directive (EPBD): potential metrics for $PM_{2.5}$

A7.1.1 Introduction

The Energy Performance of Buildings Directive (EPBD, 2010/31/EU) is the main EU instrument targeted at improving the overall energy performance of buildings in Europe. The Directive was amended in 2018 (along with the Energy Efficiency Directive in 2019) as part of the 'Clean energy for all Europeans' package. In October 2020, the Renovation wave strategy was published by the Commission, as part of the European Green Deal. This includes an action plan with a series of regulatory, financing and enabling measures to enhance building renovation with one of its key initiatives being a revision of the EPBD.

In December 2021, the Commission proposed a review of the Directive (COM(2021) 802 final) to update the existing regulatory framework to reflect higher ambitions and more pressing needs in climate and social action, with flexibility to account for the differences in the building stock across Europe. This revision is part of the 'Fit for 55' package and looks to help the EU meet its objective of a minimum 55% reduction in greenhouse gas emissions by 2030 compared to 1990. The proposed updates include[152]:

- A new EU definition of a 'zero emissions building' which applies to all new buildings from 2027 and to all renovated buildings from 2030
- The acceleration of energy-efficient renovations through Minimum energy performance standards
- Improvements in the reliability, quality and digitalisation of Energy Performance Certificates (EPCs)
- A revised A-G scale of EPCs (based on common criteria)
- EPCs to include calculated figures for, *inter alia*:
  - Energy performance (in kWh(m^2.year))
  - Operational greenhouse gas emissions (in kg CO_2/(m^2.year))
  - Renewable energy production
- The end to subsidies for fossil fuel boilers

Of particular relevance to this project, Annex V of the proposed revised EPBD includes an optional indicator on operational emissions of fine particulate matter ($PM_{2.5}$) for inclusion in an EPC (Annex V, 2(q)). Buildings contribute around half of primary $PM_{2.5}$ emissions in the EU and are a significant cause of premature death and illness[153]. The application of such an indicator in the Member States' implementation of the Directive could be important for driving building owners and developers towards measures that reduce $PM_{2.5}$ emissions.

A7.1.2 Challenges

For such an indicator to be useful (assuming it is applied by the Member States), there would need to be some consistency in how emissions are calculated and reported. This needs to start with a clear definition of what should be considered within scope of "operational emissions". For greenhouse gas emissions, this is defined as

152 https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698901 Note that agreement has been reached on the proposal: https://www.consilium.europa.eu/en/press/press-releases/2023/12/07/fit-for-55-council-and-parliament-reach-deal-on-proposal-to-revise-energy-performance-of-buildings-directive/
153 cf Recital 10 of the recast EPBD proposal

"…emissions associated with energy consumption of the technical building systems during use and operation of the building" in the proposed recast of the Directive. It is assumed that for $PM_{2.5}$ emissions this should be consistent, i.e. that the emissions estimate should only include combustion systems associated with heat and power generation and not, for example, cooking operations or transport (which could both be significant emission sources for $PM_{2.5}$).

EPCs also include a requirement for reporting annual operational CO_2 emissions (as mass per unit area per year). However, calculating such a figure for $PM_{2.5}$, for reasons summarised below, is likely to require more information than is routinely available for the compilation of EPCs. In addition, a mass emission figure is unlikely to be meaningful for prospective building users and would thus fail to act as a driver for improvement. Therefore, a greatly simplified metric is proposed, based on an A-G scale which consumers will be familiar with due to is existing use for energy performance, both in EPCs and for consumer products.

The primary challenge relates to how operational $PM_{2.5}$ emissions can be estimated for a particular building in a consistent and robust manner. For CO_2, the calculations are much simpler, based directly on energy usage (which has to be captured already) and using standardised emission factors. Whilst a similar framework can be applied for $PM_{2.5}$ emissions, there are a number of variables that need to be considered which influence emission factors and overall emissions. These include:

- Type of appliance, including its age and mode of operation
- Fuel type(s) and quality – for biomass the fuel type is important for emissions including e.g. logwood vs pellets, moisture content of wood
- Activity levels i.e. fuel consumption (this may be estimated if forward looking and/or based on actual usage when retrospectively estimating emissions)

To an extent, all of these factors will also impact on the CO_2 emission calculation. However, CO_2 emissions are likely to be determined by the main source of heat (space and water) for the building and for which the necessary data (or standard emission checklists) will generally be available. However, emissions of $PM_{2.5}$ can often be dominated by secondary heating appliances, such as fireplaces or stoves, for which data, especially on use, will be much less accessible.

It should also be noted that all solid combustion fuels, including coal, lignite, manufactured solid fuels (MSF), peat, etc. will give higher $PM_{2.5}$ emissions than natural gas, often by several orders of magnitude. Thus, any $PM_{2.5}$ metric needs to consider all combustion fuels and not just wood or woody biomass.

Each of these factors will need to be considered in turn to understand how information on operational $PM_{2.5}$ emissions could be incorporated into the EPC. Furthermore, it is assumed that the metric will need to be formulated on the basis of the information currently required by the EPC compilation process (Annex I):

- Annex I, paragraph 1, states that "energy performance of a building shall be determined on the basis of calculated or actual metered energy". Metered energy generally refers to grid electricity or mains gas, although deliveries of other fuels, such as bottled gas, wood pellets or coal, could also be taken into account. However, in practice, delivered fuel use is usually accounted for by using standard usage checklists, based on the average use for that type of heating source, in that type and size of building, in a given Member State. Wood fuels obtained through informal routes (e.g. self gathered or small suppliers) make up a significant proportion of wood fuel used in many, potentially all, Member States. It is thus unlikely to be included as a delivered fuel even where this is taken into account. Moreover, as noted above, PM emissions are often dominated by secondary heating sources, and for which there are multiple variables which greatly effect such emissions, i.e. fuel type and quality, frequency of use and operator practice. This would render any "average use" statistics highly uncertain, to the extent that they are likely to be misleading
- Annex I, paragraph 4, sets out the aspects to take into consideration in determining energy use. This includes *inter alia* the heating installation and hot water supply. Thus, bioenergy installations used as the primary heat

or hot water supply will be listed, including bioenergy boilers. However, it is not certain that supplementary heating installations, such as stoves or fireplaces, are also included. As one of the key drivers of bioenergy air quality emissions in many Member States, i.e. the use of log burning stoves as a supplementary heat source, guidance should be strengthened to ensure supplementary heating sources are accounted for in EPCs

- The Annex I calculation does not take account of issues which have a significant impact on bioenergy $PM_{2.5}$ emissions but which are far less relevant for, say, gas or electrically powered heating, such as fuel quality (e.g. moisture content of wood), fuel type (e.g. logs or pellets), or operator actions (including maintenance regimes). Thus, any proposed indicator can only be a rough estimate of probable emissions, within a wide band of potential emissions

Therefore, any indicator proposed will necessarily be fairly broad and not fully reflective of actual $PM_{2.5}$ emissions. Given the difficulties in estimating actual emissions, as noted in the third point above, the metric can only reflect *potential* $PM_{2.5}$ emissions rather than actual. The $PM_{2.5}$ emission factors for stoves, fireplaces and boilers, taken from the 2023 EMEP Guidebook[154], are shown in Appendix 1. These reflect one half of the standard emissions calculation of *activity x emission factor = emission*. It should be noted that the values shown are a midpoint, and the guidebook provides upper and lower confidence levels. For example, the Tier 2 emission factor for residential gas boilers – 0.2 g/GJ $PM_{2.5}$ – has a confidence range of 0.12-0.28, which is fairly narrow. By contrast, the emission factor for a simple wood stove – 740 g/GJ – has a range of 370-1480, i.e. the actual emissions could differ by 100%, based on tests using the correct fuels. Using unseasoned wood, for example, will increase this range even further.

A7.2 Options for an EPC metric on $PM_{2.5}$ emissions

The following option is presented as the preferred option for Member States to consider when opting to add a metric of operational $PM_{2.5}$ emissions to their EPC. It strikes a balance between being overly simplistic, risking presenting misleading messages, and overtly complex, which would reduce the likelihood for adoption. Crucially, it provides an indicator which does not require activity data, such as frequency of use, which is not normally gathered through the EPC process. The other two options considered, and rejected, are presented in Appendix 2.

A7.2.1 Option 1: A-G rating based on emissions factors

The use of an A-G rating, rather than an emission figure, has two main attractions:

1) It avoids the need to gather usage data or to calculate an average use default value for the Member State. Emission estimates for small combustion are notoriously uncertain, with most Member States lacking reliable data on either the extent of appliance use or the amount of fuel used. While this can be worked around at a national level, reducing the national statistics to individual households is likely to be so uncertain as to be effectively meaningless

2) Even if total emissions on $PM_{2.5}$ were calculated for each building, they are not likely to carry any context or significance for householders and other users. However, the A-G rating is familiar from other consumer product labelling and provides an easy relative comparison between different buildings

Splitting out the installations into an A-G rating, based on their class emission factors, would be consistent with the overall approach to energy performance ratings for EPCs. This would allow differentiation between appliance and fuel types, and also allow more efficient appliances of different sizes to be combined. Crucially, it avoids the need to gather usage data:

154 https://www.eea.europa.eu//publications/emep-eea-guidebook-2023

Rating	EF range (g/GJ)	Appliance type	
		Residential buildings	**Commercial buildings**
A	0	Non-combustion heat	
B	0.1-1.0	Boiler, gas	Boiler, gas Gas turbine, gas
C	1.1-10.0	Boiler, liquid Stove, liquid Fireplace, gas	Boiler, > 50 kWth to ≤ 1 MWth, liquid Reciprocating engine, gas Gas turbine, gas oil
D	10.1-100	Stove and boilers, wood pellet Eco-stoves and boilers, wood	Boiler, > 1 MWth to ≤ 50 MWth, liquid Boiler, > 50 kWth to ≤ 1 MWth, wood Boiler, > 1 MWth to ≤ 50 MWth, coal Boiler, automatic, wood Advanced boiler, auto, coal Reciprocating engine, gas oil Boiler, > 1 MWth to ≤ 50 MWth, wood
E	101-200	-	Boiler, manual, wood Boiler, > 50 kWth to ≤ 1 MWth, coal Advanced boiler, manual, coal
F	201-500	Boilers and stoves, coal Advanced stove, coal Open fireplace, coal High efficiency stove, wood Boiler, wood	-
G	500-1000	Stove, wood Open fireplace, wood	-

This system is relatively complex but still simple enough to be used with the information available through the EPC process[155], e.g. through the provision of checklists for assessors. The emission factors used have been drawn from the 2023 EMEP guidebook, shown in Appendix 1, although other emission factors could be substituted. For example, if the pellet fed boilers generally in use in a Member State are of higher (or lower) quality than the EU average, a Member State specific emission factor could be used for these[156]. The scales could also be drawn differently for commercial/institutional and residential, so that each rating category is covered.

Note that this scale only considers the potential emission level from the building, and also that it is independent of the energy performance of the building. Thus, a highly insulated house, fitted with solar panels and air source heating could still be rated G for $PM_{2.5}$ emissions if it had an operational wood burning stove[157], regardless of how often that stove is actually used.

A7.3 Appendix 1: $PM_{2.5}$ emission factors, 2023 EMEP guidebook

155 The definitions for the different appliance types could also be taken from the EMEP guidebook
156 This is already standard practice in the calculation of national emissions inventories, where national level data can be substituted for standard emission factors, supported by relevant evidence.
157 Allowance would need to be made for appliances, such as fireplaces, which have been rendered inoperable and are retained for decorative purposes only.

Tier 1 Emission factors

Category	Type	Unit	Value
Residential combustion	Hard coal and brown coal	g/GJ	398
	Gaseous	g/GJ	1.2
	Liquid	g/GJ	1.9
	Solid biomass	g/GJ	740
Commercial/institutional	Hard coal and brown coal	g/GJ	108
	Gaseous	g/GJ	0.78
	Liquid	g/GJ	18
	Solid biomass	g/GJ	160

Tier 2 emission factors, arranged by ascending emissions

Category	Range	Type	Value (g/GJ)
Res	0.1-1.0	Boiler, gas	0.2
Com		Gas turbine, natural gas	0.2
Com		Boiler, > 50 kWth to ≤ 1 MWth, gas	0.45
Com		Boiler, > 1 MWth to ≤ 50 MWth, gas	0.45
Res	1.1-10	Boiler, liquid	1.5
Com		Reciprocating engine, natural gas	2
Res		Open fireplace, gas	2.2
Res		Stove, liquid	2.2
Com		Boiler, > 50 kWth to ≤ 1 MWth, liquid	3
Com		Gas turbine, gas oil	9.5
Com	10.1-100	Boiler, > 1 MWth to ≤ 50 MWth, liquid	30
Com		Reciprocating engine, gas oil	30
Com		Boiler, > 50 kWth to ≤ 1 MWth, wood	37
Com		Boiler, automatic, wood	37
Res		Stoves and boilers, wood pellet	60
Com		Advanced boiler, auto, coal	70
Com		Boiler, > 1 MWth to ≤ 50 MWth, coal	72
Res		Eco-stoves and boilers, wood	93
Com		Boiler, > 1 MWth to ≤ 50 MWth, wood	98.5
Com	101-200	Advanced boiler, manual, coal	130

Category	Range	Type	Value (g/GJ)
Com		Boiler, manual, wood	160
Com		Boiler, > 50 kWth to ≤ 1 MWth, coal	170
Res	201-500	Boiler, solid (not biomass)	201
Res		Advanced stove, coal	220
Res		Open fireplace, solid (not biomass)	300
Res		High efficiency stove, wood	370
Res		Stove, solid (not biomass)	450
Res		Boiler, wood	470
Res	501-1000	Stove, wood	740
Res		Open fireplace, wood	820

A8 Policy Evaluation

Policy evaluation provides an analysis of how existing measures and spending programs have been performing, to check that they are efficient, effective, relevant and coherent, and that the intervention is actually adding value. By establishing the extent to which the aims of the intervention are being delivered, and specifically which aspects are working and which are not, and why, it is possible to adjust measures to be more cost effective (or just more effective) over time. Different Member States may have different approaches to evaluation, in addition to the European Commission's Better Regulation Guidance[158], although all will have common elements as described below. The Better Regulation Guidance is aimed mainly at evaluation of policies at an EU or national level. Nevertheless, the principles are universal and references to specific parts of the toolbox are referred to below.

Theory of change: Key to any policy evaluation is understanding the expected causal effects and intervention logic of a policy. A first step to an evaluation will be reviewing the intervention logic that was previously developed, or developing a new one in the absence of one. The intervention logic frames the evaluation questions the study seeks to answer, and it will be used to define the scope and depth of the analysis. The intervention logic starts with the rationale and objectives of the policy ("objectives") and the problems ("needs") it was designed to address. It then describes the activities required under the policy ("actions"), the expected effects (including "outputs", "results" and "impacts"), and "external factors", including related policies, that may impact on the overall performance of the intervention, both positive and negative. An evaluation aims to explore each of the steps in the intervention logic and the movement from one step to the next e.g. how effectively and efficiently actions have been translated into results.

Baseline and/ or points of comparison: An ex-post evaluation seeks to look back on what has occurred in practice and ideally makes a comparison against a hypothetical scenario of a counterfactual baseline. Where possible, the baseline provides a quantitative counterfactual for the main points of change identified by the intervention logic. Where prior impact assessment exists, the evaluation baseline will simply refer to the impact assessment baseline. In cases where there is no prior impact assessment, it will be necessary to develop a baseline. Where it is not possible to establish a quantitative counterfactual, in line with Tool #46 of the Better Regulation Guidelines, a "point of comparison" approach can be used, through identifying key variables for the intended effects of the legislation which have been influenced by the actions of the legislation.

Evaluation questions and matrix: All evaluations and fitness checks base their analysis on the evaluation criteria of effectiveness, efficiency, coherence, relevance, and added value of the intervention, or provide due justification why this is not the case. Thus, it is necessary to develop an evaluation question matrix that can frame the analysis. The purpose of this analysis will be:

- Effectiveness: assess the extent to which the measure is achieving its intended effects
- Efficiency: review the main costs of implementing the actions of the measure and review whether it is being implemented efficiently and fairly across all stakeholder groups
- Relevance: review whether the objectives of the measure are consistent with the current, new and emerging needs, and other related issues
- Coherence: assess the consistency and risks of conflict in the way the measure is implemented, within the measure itself and with other related policy areas
- Added value: review the extent to which the measure would be effective and efficient in the absence of related actions or measures, including national and EU level measures

158 https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en

The evaluation question matrix then establishes the specific questions and sub-questions that will be answered by the analysis. For each sub-question, operational criteria are needed for how an assessment will be made, indicators for how to measure the impacts that will be used as evidence to underpin the analysis, the approach to analysis and the identification of key data sources and collection methods that will underpin the evidence collection. Guidance on the approach that could be used is set out in Tool #46 "Design the evaluation" and Tool #47 "Evaluation criteria and questions" of the Better Regulation Guidelines.

Research tools: A number of research tools and methods could be used to support the analysis, including:

- Policy, literature and data review, drawing on available data sources and existing analysis (qualitative and quantitative) to establish a robust evidence base
- Case studies and/or focused analytical assessments of specific themes to describe, explore and categorise in detail key outcomes
- Stakeholder consultation will be performed in accordance with the Better Regulation Guidelines (Tools #51 to #55)

Developing conclusions: The final part of the evaluation needs to show a clear and transparent approach to the analysis and development of conclusions. The evaluation matrix should be updated based on all the findings and evidence gathered throughout the process. The analysis should highlight where the evidence has been sourced and, as far as possible, aim to triangulate the conclusions from multiple sources. Any discrepancies or biases should be clearly identified and discussed.

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