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Sustainable use of biomass in the residential sector

A report prepared in support of the European Union Strategy for the Danube Region (EUSDR)

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This report provides a synthesis of the current knowledge, leading the reader from problem formulation, to impact analysis and suggested solutions, both from the technical and regulatory points of view.

Contents

Abstract

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Authors

Fabio Monforti-Ferrario, Claudio Belis. JRC C.5

Executive summary

This report is intended to be read by policy makers and technical staff in research and regulatory bodies in the countries of the Danube-macro region dealing with the problem of finding a better balance between "decarbonisation" benefits and negative impacts on air quality, the environment and human health, connected with its excessive or unregulated use.

Policy context

The EU Strategy for the Danube Region (EUSDR) has identified energy as a key issue to be addressed in order to support sustainable growth throughout the region. In particular, domestic biomass burning has been identified as a topic to be further investigated. Consistently with its role of supporting decision-makers and other stakeholders to identify the policy needs and actions for the implementation of the strategy, the Joint Research Centre (JRC) has acted both as knowledge producer and knowledge manager for addressing the issue. This report is based on this scientific work performed by JRC, its local partners in the EUSDR and several other research and policy making institutions.

Key conclusions

The climate legislative framework of the EU and the non-EU countries of the Danube region for energy and climate is leading to increased use of biomass for energy purposes, including domestic heating. This trend, if not properly governed, could to pose risks for the human health and the environment mainly because of emissions of air pollutants and overexploitation of resources. Governance is then needed, aiming at both improving the technologies used and optimising the management of biomass resources.

Main findings

Key messages coming from the actual experience and scientific investigation are conveyed in chapter 4 of this report.

Here in synthesis:

- The energy and climate legislative framework of the EU, fully adopted by the Energy Community Treaty signatories, is pushing for an increased use of biomass for energy purposes, including domestic heating where **solid biomass is and will remain a pivotal fuel**. Unfortunately, biomass burning in domestic appliances is known to **release substantial quantities of air pollutants**. Data from the Emissions Database for Global Atmospheric Research (EDGAR) show that in the EUSDR area, emissions of biomass-related $PM_{2.5}$ in the sector "Energy in buildings" have increased by more than 60% since 1990.

- The use of the Screening for High Emission Reduction Potential on Air (SHERPA) air quality model has shown that for the major cities in the EU28 part of the Danube macro-region, **emissions from the residential sector usually account for a share between 5% and 25% of $PM_{2.5}$** with emissions originating from domestic heating in the city itself rarely exceeding 10%. For this reason, **policies limiting domestic heating emissions should not be limited to cities**, but must involve a wider geographic context, e.g., regional.

- The policy framework of the EU **offers several instruments for putting emissions under control**, starting from the EcoDesign and energy labelling directives or, on the energy demand side, the directive on energy efficiency in buildings and the smart grids concept. The bioeconomy and circular economy concepts also offer a frame for a suitable management and optimisation of biomass utilisation.

- The **EU Strategy for the Danube Region (EUSDR) has offered an ideal framework** in which issues related to the use of biomass for domestic heating have been discussed and practical initiatives have been taken. **The Joint Research Centre (JRC) provided scientific support to the EUSDR** both by backing decision-makers and other stakeholders to identify the policy needs and actions for the implementation of the strategy and by promoting cooperation across the scientific communities of the Danube Region.

Foreword

The EU Strategy for the Danube Region (EUSDR) [European Commission 2010], launched in 2010 and approved by the Council in 2011 involves 14 EU and non-EU countries[1] with 115 million inhabitants and aims to promote the sustainable development of the Danube macro-region by tackling key issues that require working across borders and national interests: mobility, energy, water, biodiversity, socio-economic development, education, culture and safety.

The Joint Research Centre (JRC) contributes to the EUSDR both by supporting decision-makers and other stakeholders to identify the policy needs and actions for the implementation of the strategy and by promoting cooperation across the scientific communities of the Danube Region. JRC Scientific Support to the Danube Strategy initiative is sub-divided into different flagship clusters and activities among which there are the Danube Air Nexus (DAN) and the Danube Bioenergy Nexus (DBN). DAN aims at protecting human health, ecosystems and climate from the impacts of atmospheric pollution while DBN focuses on the high potential of the Danube Region for developing renewable energy from materials derived from biological sources.

Biomass burning for heat production in households has emerged as a major issue in both the Nexi: while DAN has identified it as a major source of emissions, DBN has worked to investigate how bioenergy, and bioheat in particular, can provide Danube countries an opportunity for clean and sustainable growth. This report provides a synthesis of the efforts of both Nexi, integrated with other elements of knowledge originating from other JRC activities, the scientific literature and the work of other ongoing initiatives addressing the Danube area.

The ideal readers of this report are policymakers and the technical staff of policy support and research bodies, involved in the debate on the sustainability of the energy system in general and the heating and cooling sector in particular. The report addresses the EUSDR area, but we believe it could provide insights of interest even outside the Danube basin. For the benefit of the reader, the report is structured to follow from problem formulation, to impact analysis and suggested solutions.

In the first chapter, the scene is set presenting the current and foreseen use of biomass for heat production in households on the basis of the data provided by Danube countries and other wider scenarios. Feedstock categories employed are also presented together with the types of devices actually used for biomass combustion. This introductory chapter ends with a review of the existing schemes supporting biomass use in households in the target countries.

The second chapter focuses on impacts, starting from air quality, then touching greenhouse gases savings related to bioenergy and concluding with other environmental impacts such as soil fertility and water quality and use.

Chapter three enters in the fields of policies and strategies, presenting and identifying tools, practices and solutions aimed at finding an equilibrium between opportunities for development and environmental challenges. Technological improvements and the potential added value arising from the bioeconomy concepts are especially discussed, while the final paragraph focuses on the role and activities of the Danube macro-regional transnational structures.

Key messages are summarised in the final chapter.

[1]Nine EU Member States: Germany, Austria, the Slovak Republic, the Czech Republic, Hungary, Slovenia, Croatia, Romania and Bulgaria, and 5 non-EU countries: Serbia, Bosnia and Herzegovina, Montenegro, the Republic of Moldova and Ukraine.

1 Introduction – setting the scene.

EUSDR countries have fully adopted the EU policies towards renewable energy, a policy framework that stems from the 2020 energy and climate strategy and requires a gradual shift from fossil fuels to renewable energy sources. The Renewable Energy Directive 2009/28/EC (RED) sets a general binding target for the European Union to derive 20 % of its final energy from renewable sources by 2020 and requires the EU Members States to submit a national renewable energy action plans (NREAP) and, starting from 2011, to submitted every two years a progress report (PR) detailing their state of advancement in actually deploying renewable energy. PRs submitted so far cover the period 2009-2016.

The rest of the Danube countries are Contracting Parties to the Energy Community (EnC) that comprises the Western Balkan countries (Albania, Bosnia and Herzegovina, Kosovo, Former Republic of Macedonia, Montenegro and Serbia) as well as Moldova and Ukraine. In 2012 the Energy Community Treaty (EnCT) adopted the relevant *Acquis Communautaire* including the Renewable Energy Directive and the Contracting Parties committed both to binding renewable energy targets by 2020 and to prepare NREAPs outlining the scenarios and policies they intend to pursue to meet these binding targets. These countries also committed themselves to submit periodically progress reports following the same scheme adopted by EU countries.

Data from these NREAPs and progress reports provide the scene setting analysis presented in the first two sections of this chapter. Reference data for domestic biomass combustion technologies are provided in the third section, together with a critical assessment of their representativeness of reality across the macro-region. The final section introduces a summary of the main financial and market tools used by the Danube countries to practically support domestic biomass heat production.

1.1 Biomass domestic heating in the context of bioenergy deployment in Danube macro-region – present state and projections

A complete discussion of renewable energy and bioenergy status in the Danube area can be found in and [Hujber and Szilágyi, 2014], [Banja et al. 2014] and [Banja et al. 2016]. The relevant findings are summarised in order to pave the way for the following discussions.

The NREAPs submitted by the both the EU and non-EU Danube countries depict an energy mix in which bioenergy is and will remain a major source of renewable energy. Indeed, the final renewable energy from bioelectricity, bioheat and biofuels (bioenergy) totalled 36.7 Mtoe in 2013 and is expected to reach 48.6 Mtoe in 2020. In percentage terms, in 2013 bioenergy provided almost 62.7 % of the final renewable energy in the Danube region, a contribution that is expected to decrease to 59 % in 2020. Solid biomass was the main source of bioenergy covering more than three quarters of final bioenergy consumption, a contribution that should drop to 68 % in 2020.

Heat generation (bioheat) accounts for the main use of bioenergy[2] in the Danube region, with 27.85 Mtoe (almost 76% of total bioenergy) produced in 2013 in the Danube region equivalent to nearly 13 % of the gross final energy consumption of the heating and cooling sector. By 2020 bioheat in the Danube region is expected to reach 32.8 Mtoe, or 14.9 % of the overall gross final energy consumption in the heating/cooling sector.

Growth in bioheat has been extremely fast and Germany, Austria, Romania and Slovenia already reached their 2020 indicative targets for bioheat in 2010. In several non-EU Danube countries, biomass in the heating and cooling sector is also planned to increase in order to contribute to the renewable energy targets. For instance, in Ukraine, the installed capacity of biomass in the heating systems is planned to double between 2010 and 2020, while in Serbia the increase should be of about 15%.

For some countries bioheat is and will remain the main, if not the only, way in which renewable capacity is deployed. For example in 2013 Moldova produced 0.25 Mtoe of

[2] Bioenergy accounts for by bioheat, bioelectricity and biofuels for transport.

bioheat, representing 97.2 % of its total renewable energy production. Thanks to the expected installation of some electricity generating wind and hydro plants, this share is expected to slightly decrease but bioheat will still account for 0.33 Mtoe or 89 % of the total renewable energy produced in the country in 2020.

Solid biomass was the main source of bioheat in the Danube region in 2013, with 26 Mtoe (93% of bioheat produced) with the remainder largely biogas and other bioliquids. This situation is expected to remain substantially unchanged in 2020 when solid biomass should provide 29.8 Mtoe of bioheat, 91% of bioheat expected to be produced in the Danube macro-region. 67.1% of bioheat consumption in the Danube region in 2013 (equivalent to 18.7 Mtoe) took place in households, while 1.9 Mtoe of bioheat (6.8% of total bioheat) was generated for use in district heating. In 2020, bioheat use in households is expected to slightly increase to 19.3 Mtoe (+3%) while biomass fed district heating systems are planned to reach 10.7 Mtoe (+460%).

For post-2020, on 30 November 2016, the European Commission published a proposal for a revised Renewable Energy Directive as part of the Clean Energy for All Europeans package [European Commission 2016a].

The proposal covers the decade 2021-2030 and suggested an overall objective of 27% of Final Energy Consumption from renewables by 2030. Following extensive discussions, on June 2018 the Commission, the Parliament and the Council reached a political agreement which includes an increase of the binding renewable energy target for the EU for 2030 to 32%, with a clause for a further possible upward revision by 2023. In the framework of the Governance of the Energy union, Member States will then have to develop Integrated National Energy and Climate Plans covering the period 2021-2030 and to report on the progress they make towards them on a biennial basis.

Official plans from EU and non-EU countries on RES deployment are thus still currently limited to the 2020 horizon. Nevertheless, scenarios prepared for the Renewable Energy Directive update provide an insight of the possible future development of biomass use in the residential sector, although without a high level of detail. Although no scenario has been yet developed for the finally agreed target of 32%, scenarios based on both a 27% and a 30% renewable target were developed[3] to be compared with a reference scenario based on current global and EU market trends and adopted EU and Member States' energy, transport, climate and related relevant policies with a cut-off date at the end of 2014. [European Commission 2016b] [European Commission 2016c]

In the reference Current Legislation (CLE) scenario, the share of renewables in the EU heating and cooling sector (H&C) increases from 17% in 2015 to 22% in 2020, and reaches 25% in 2030, while in the EUCO27 and EUCO3030 scenarios the share of renewable in the heating and cooling sector reaches 27% and 30% respectively. Absolute RES consumption in 2030 the H&C sector amount to 123.8 Mtoe, 128.0 Mtoe and 132.9 Mtoe in the reference, EUCO27 and EUCO3030 scenarios respectively, to be compared with a reported consumption of 94.1 Mtoe for 2015 and 111.8 Mtoe expected for 2020. Although the scenarios do not provide details on the expected penetration of fuels and technologies in the heating and cooling sector, solid biomass consumption in the households will remain critical in achieving the envisaged targets.

From a global perspective, the Global Energy and Climate Outlook (GECO)[4] scenarios foresee an increase in the use of biomass for energy in the future, with a global growth of 30% to 44%, in 2030, compared to 2014 (depending on the scenario) with the largest increase coming from cellulosic sources: forestry residues and dedicated energy crops. [Kitous et al. 2017] [Kitous and Keramidas 2017]

[3] The 27% scenario for Renewable Energy Sources (EUCO27) also supposes the fulfilment of a 27% energy efficiency target for 2030, while the Renewable Energy Sources 30% scenario (EUCO3030) supposes a more ambitious target of 30% primary energy consumption reduction is set

[4]The "Global Energy and Climate Outlook" is a recurring publication of the JRC. Based on quantified assessment by the JRC's internal energy-economics teams, GECO provides a global picture of energy markets as they transform over the next decades, under the simultaneous interactions of economic development, technological innovation and climate policies.

Biomass use is expected to increase beyond 2030, to even tripling the current level of exploitation in 2050, according to GECO INDC scenario. Nevertheless, over this longer term, the use of biomass will change radically: while in 2010 80% of biomass consumed was used to generate heat, this share will decrease in favour of a higher use of biomass for power production and for second-generation biofuels, aimed at substituting fossil fuels in the transport sector.

1.2 The main biomass feedstock categories and their origin

Data provided in progress reports do not allow a detailed description of the types of biomass used in the heating and cooling sector, because of the increasing use of Combined Heat and Power. For this reason, the amounts consumed for different feedstock categories are available for the total production of electricity and heat.

Accordingly, domestic woody biomass originating from both forestry and wood industry residues was the main biomass feedstock categories used for electricity and heat purposes in the Danube in 2013 region, accounting for 24.5 Mtoe, equivalent to an estimated 86.2 Million m^3 of which about 39% were wood residues. About 8.8 Million m^3 of woody material used for bioheat production, was imported mainly from EU countries. The other sources of domestic biomass used in energy production were agricultural by-products (7.0 Mtoe), biomass wastes (2.3 Mtoe) and a little dedicated energy crops (0.24 Mtoe). [Banja et al. 2016]

Use of biomass for energy in the Danube region is expected to increase by 37.8 % between 2013 and 2020 to reach 47.6 Mtoe. The largest increase in biomass categories up to 2020 is expected to occur in agriculture residues supply with +149 % (+10.5 Mtoe) whereas waste and forestry should increase by 44 % and 20.8 % respectively.

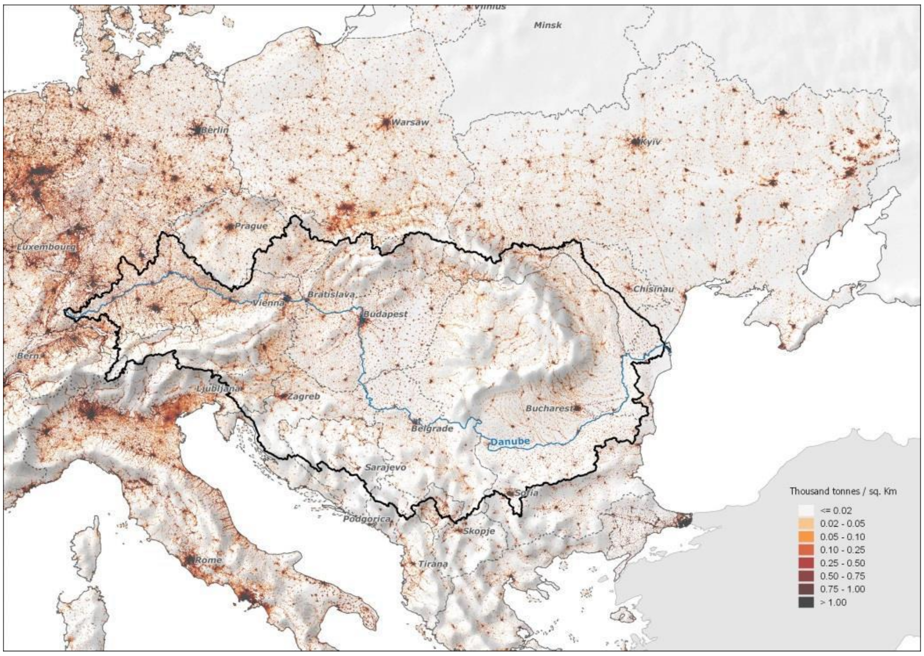
Clearly, the planned increase in biomass use needs to be consistent with the actual available potential of primary feedstock categories, with the distance between supply area and final users being the shortest possible in order to avoid transport costs and emission increases. For this reason, detailed spatially explicit estimates of actually available biomass fraction of Municipal Solid Waste (MSW) (Figure 1 - top) and agricultural residues (Figure 1 - bottom) have been produced. These spatially explicit datasets can be of great support to planners needing to create a supply chain for appropriate heat generation.

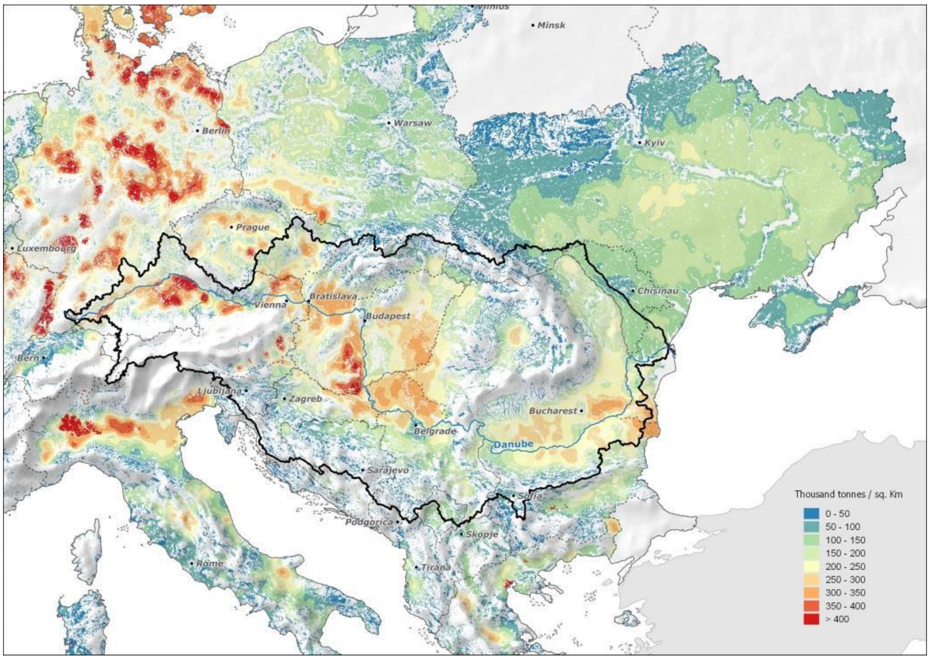
The expected increase in biomass use in the macro-region will have impacts on sustainability. For instance, the large increase foreseen in the use of crop residues needs nevertheless some attention to avoid impacting in an unforeseen way desirable features of the soil such as soil quality and productivity. Similarly, woody biomass must be collected and transported to heat facilities in the full respect of sustainable forestry principles in order to maximise the decarbonisation potential. Chapter 2 will provide more insights.

It is worth noticing that in some areas, an important share of biomass consumed in domestic heating is unregistered and escapes from official statistics. For instance [World Bank 2017] estimates that in 2013, in the Western Balkan area, 58% of the biomass use for energy purposes came from unregistered consumption, mainly consisting in the very local and spontaneous collection of woody biomass by private house owners and small communities located close to forests or woody zones.

Nevertheless, biomass collection and transport for domestic heating is not necessarily a local business, in particular when it is traded in the form of pellets. According to [IEA 2017] wood pellet consumption for both industrial and heating purposes increased by 60% during 2010-16. Global wood pellet production in 2016 reached 28.5 million tonnes, of which 15 million tonnes were consumed in the building sector. A more detailed analysis [Thran et al. 2017] shows that several Danube countries are net exporters of pellets, further increasing pressure on their natural resources (See Table 1). The transnational nature of biomass trade makes this an ideal topic to be addressed at least at the macro-regional level (see section 3.3).

Figure 1: Municipal Solid Waste (top) and crop residues (bottom) potentials in the Danube region.





Source: JRC – Courtesy of Nicolae Scarlat and Fernando Fahl.

Table 1 Pellet production, net export and main customers for some Danube countries.

Country	Domestic production (1000 t/year)	Net Export (1000/year)	Main customers and share	Reference year
Austria	1000	200	IT (87%)	2015
Czechia	200	160	AT (35%) IT (35%)	2012-14
Germany	2000	220	UK(25%) AT(21%)	2015
Romania	420	310	AT (40%) IT (30%)	2015
Slovakia	100	80	IT and AT	2014
Ukraine	350	140	PL (33%) IT (18%)	2015
Bulgaria	140	130	IT (N/A)	2014

Note: data refer to whole countries, not only to their sectors belonging to the Danube basin)

Source [Thran et al. 2017]

1.3 Typical and actually available biomass burning technologies

Excluding the advanced district heating systems, biomass consumption for domestic heating utilises different types of devices, ranging from open fires heating a single room to advanced boilers used by large condominiums.

Biomass burning generates substantial quantities of different kind of pollutants, such as particulate matter (PM_{10}, $PM_{2.5}$), CO, polychlorinated dibenzo-p-dioxins (PCDDs)/ polychlorinated dibenzofurans (PCDFs), black carbon (BC), organic carbon (OC) and polycyclic aromatic hydrocarbons (PAHs), depending on the technologies applied. Smaller and less technologically advanced systems generally have less efficient energy conversion and produce higher emissions.

Indeed, the main cause of harmful emissions from domestic and residential heating systems fuelled with solid biomass is the incomplete combustion of solid fuels and the consequent dispersion in the atmosphere of particles of ash and dust containing dangerous pollutants. For this reason, the combustion process in a heating device is crucial to controlling the resulting emissions. The device size, combustion technology, combustion control measures, end of pipe controls, fuel quality, temperature control and air distribution operational practices and maintenance all contribute to emissions mitigation.

Source [Muntean et al, 2017]

shows some of the emission factors for the $PM_{2.5}$ for domestic appliances used in the development of the Emissions Database for Global Atmospheric Research (EDGAR) (See paragraph 2.1) where emissions from biomass are compared with factors from equivalent devices fuelled with coal, liquid fuels and natural gas.

Table 2 $PM_{2.5}$ emission factors for heating appliances using different types of fuels in g/GJ.

Appliance	Biomass	Coal	Natural gas	Liquid fuels
Stove – conventional	740	450		
Stove – advanced	370[5]	220		
Boiler < 50kW	470	201	0.2	
Boiler (50 kW to 1 MW)	86.5	170	0.45	30
Boiler (1 MW to 50 MW)	33	72		3
Fireplace	820	330	2.2	

Source [Muntean et al, 2017]

The table shows clearly that apart from larger boilers, the emissions from conventional biomass in state of the art devices are more than from coal and it is much less clean than natural gas and in some cases, liquid fossil fuels. It is thus evident that biomass burning in domestic appliances will contribute to air pollution.

Moreover, the actual situation in reality could be very different from the typical values contained in Table 2. For instance, it has been reported [Martinov 2017] that in some countries or areas, appliances are self-made, or produced by local handcrafters, with low price the main production criteria at the expense of efficiency and higher pollutants emission rate. For this reason, a policy framework pushing for an adoption of the most advanced technological as fast as possible is absolutely crucial. Tools and strategies available are further discussed in paragraph 3.1.

1.4 Relevant support schemes and incentives

The European Commission has issued a set of guidelines on State aid for environmental protection and energy that provide the framework in which Member States can design appropriate support schemes for renewables, stating that "under certain conditions State aid can be an appropriate instrument to contribute to the achievement of the Union objectives and related national targets" and that "Market instruments" […] should normally ensure that subsidies are reduced to a minimum in view of their complete phasing out. However, given the different stage of technological development of renewable energy technologies, these Guidelines allow technology specific calls for tender to be made by Member States, "on the basis of the longer-term potential of a given new and innovative technology and the need to achieve diversification" [European Commission 2014].

Given this framework, which is also followed also by the non-EU EUSDR countries, Member States can use different kinds of incentives and market tools to support the deployment of biomass sources in the heating market. Table 3, based on the comprehensive analysis of [Banja et al. 2017], updated with information from the latest published progress reports (2015-2016) and the RES-legal database[6], summarises the main support schemes involving the biomass use in the residential sector.

The list is nevertheless not exhaustive and is limited to support schemes explicitly targeting explicitly this specific use of biomass. In several cases support could be indirectly awarded through more general comprehensive schemes, such as generic "emission cutting" or "renewable energy sources promotion" programmes allowing different renewable sources to be incentivised. In some other cases, incentives are linked to other specific parts of legislation. For instance, programs supporting the fulfilment of requirements from the Directive on energy performance of buildings (2010/31/EU) could also support the

[5] Emission factors are as low as 29 g/GJ for the most efficient pellet stoves and boilers
[6] www.res-legal.eu

installation of renewable heat production devices (e.g., biomass boilers) by owners and builders.

Table 3 Main support schemes and incentives applicable to biomass use in domestic heating.

Country	Target group	Support scheme
Austria	Private households Local Public building managers: municipalities, Community-owned enterprises, other commercially active organisations, public institutions, associations, religious denominations.	Support is granted for newly installed pellet- and wood chip-fired central heating that replaces one or several existing fossil fuel boilers. Support is also available for replacing wood-fired heating systems which are at least 15 years old with pellet- and wood-chip fired central heating or for reducing the fuel consumption of 15-year-old wood heating systems by constructing pellet-fired stoves. Funding is granted in the form of a non-repayable investment grant for pellet- or wood-chip fired central heating to replace existing fossil fuel boilers: EUR 2,000. Funding of EUR 800 is provided if an old heating system is replaced by pellet- or wood-chip fired central heating. Lump-sum support of EUR 500 is available for pellet-fired stoves. In the Climate and energy model regions 2015 and 2016 support was provided as a non-repayable net investment subsidy depending on the installed system performance (kW) and amounts to EUR 120 per kW for the first 50 kW (0–50 kW) and EUR 60 per kW for each further kW (51–399).
Bulgaria	households, associations of condominium owners or service companies	The Energy Efficiency and Renewable Energy Credit Line provides households, associations of condominium owners or service companies the possibility to obtain dedicated loans and grants via a network of Bulgarian commercial banks. The funds are provided for the implementation of energy saving and energy efficiency including efficient cookers and boilers and burning biomass;
Czechia	Various actors	Operating support for heat originated from biomass combustion based on the difference of fuel costs. Buildings are exempt from real estate tax following a change of heating system from solid fuels to a system using renewables, for a period of five years.
Hungary	Various actors	Utilisation of biomass (agricultural by-products, horticultural by-products, energy crops, forestry products and by-products, wood industry and other industry wastes and by-products) for heating is supported in a number of programmes such as: - Development of the energy performance of public buildings - Development of the energy performance of ecclesiastical buildings
Romania	Households, local administrations, public institutions and religious entities.	Programme regarding the installation of heating systems that use renewable energy, including the replacement of or addition to traditional heating systems (segment for natural persons also known as ‘Green House’ Programme) Finance of 1 314 € for installations that generate thermal energy based on pellets, briquettes, sawdust, as well as any other plant, agricultural and forestry residues and waste). The installation or replacement of heating systems based on renewables for administrative units, public institutions and religious entities is also funded by the Environment Fund.

Country	Target group	Support scheme
Slovenia	Households	The Eco Fund provides non-repayable financial incentives for investments in the use of RES in single- and two-dwelling buildings, including wood biomass combustion installations. Support for biomass use in heating and cooling is provided within different streams targeting specific subcategories: wood biomass boilers in households, wood biomass and geothermal district heating systems and wood biomass boiler equipment. In 2015, the Eco Fund also published a public tender for non-repayable financial incentives for the replacement of old solid fuel combustion installations with new WBCIs in residential buildings, intended for socially-disadvantaged individuals.
Slovakia	Public buildings	Support for the installation of equipment using renewables in public buildings, improving the thermal characteristics of structures and upgrading heating and air-conditioning systems particular emphasis on ensuring that the various measures proposed complement each other in order to make the best possible use of energy saving potential. The priority is to reduce energy consumption and cover the unavoidable consumption with efficient district heating systems or by installing equipment using renewables in or very near the building itself.
Germany	Households	The principal instrument to support heating/cooling sector in Germany is the "Market Incentive Programme (MAP)". This scheme consists of investment subsidies that trigger loans to facilitate the investment in solar thermal installations, biomass boilers and heat pumps. The investment support is divided into basic support (e.g., 80 EUR/kW for pellet stoves or a lump sum of 3500 EUR for wood-chip devices and 2000 EUR for log-wood) bonus support (e.g., 500 EUR is a solar collector and/or a heat pump is combined to the new biomass device) and innovation support (e.g., 3500 EUR for pellet stoves with secondary particles separation) Installations need to supply heat or cold predominantly in Germany and have to be operated for at least 7 years.
Moldova	Various	The 2016 Law on Promotion of Energy from Renewable Sources introduces support measures for including renewable energy technologies when planning, constructing and renovating buildings or industrial sites. Other measures are foreseen under the Law on Energy Performance of Buildings.
Serbia	Various	A project "Promotion of Renewable Energy Sources Utilization – Biomass Market Development" has been launched. The aim of this project is the biomass utilization in heating plants in the Republic of Serbia for the production of heat energy or combined heat and power production. The Project budget amounts to around 110 million EUR
Ukraine	Households	A government program to support purchase of "Non-gas" boilers is in place to encourage boilers generating heat from electricity and alternative types of fuels.
Montenegro	Households	The programme ENERGY WOOD II provides interest-free credit for the installation of household heating systems using modern biomass fuels (pellets, briquettes).

Sources [Banja et al. 2017]

2 Biomass burning sustainability – a multi-faced challenge

Using biomass to provide domestic heating is a practice that has consequences and produces pressures on the environment, not only when combustion takes place, but all along the production chain spanning different time and space scales. Some of these impacts are discussed in this chapter, starting from, but not limited to, the tangible impact on air quality.

The most evident and immediate impact of biomass-fed heat production consists in the emission of smoke. Smoke from biomass burning contains substantial quantities of pollutants including particulate matter (PM_{10}, $PM_{2.5}$), CO, polychlorinated dibenzo-p-dioxins (PCDDs)/ polychlorinated dibenzofurans (PCDFs), black carbon (BC), organic carbon (OC) and polycyclic aromatic hydrocarbons (PAHs), caused by inefficient combustion of solid fuels, that can have an important impact on ecosystem and human health. [WHO 2013a, 2013b]

The first two sections contain data on emissions from domestic biomass burning in the Danube macro-region and show the extent to which these emissions contribute to problems in air quality for the population of the macro-region.

The third section investigates the overall carbon balance of biomass burning practices considering greenhouse gases emissions taking place all along the production chain, while the final part examines other relevant impacts, e.g., on soil carbon and water use.

2.1 Estimating the emissions arising from residential biomass burning in the Danube area

Residential heating is known to be an important source PM in Europe and in Eastern Europe, with particular reference to wood burning and other solid fuels [Mira-Salama et al. 2008] [Vossler et al. 2016]. This sector is of particular considering that it is associated with emissions of carcinogenic compounds (i.e. polycyclic aromatic hydrocarbons, PAHs) and black carbon [Belis et al. 2011].

According to [EEA 2017], in 2014, emissions from small combustion activities sector in the EU28 accounted for 50% of $PM_{2.5}$, 35% of PM_{10}, 38% of CO, 36% of PCDDs/PCDFs, and 52% of total Polycyclic Aromatic Hydrocarbons.

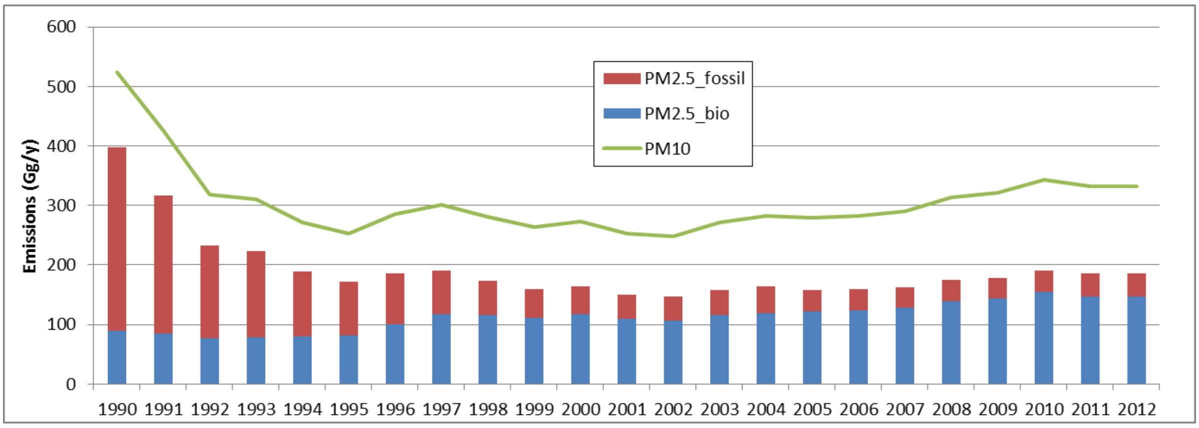
Emissions from residential biomass burning in the Danube area have been estimated in [Muntean et al 2017] on the basis of the methodology used in the Emissions Database for Global Atmospheric Research (EDGAR). As far as activity data are concerned, EDGAR (release v4.3.2, 2017) relies on the data on fuel consumption in residential subsector from International Energy Agency for which the time span 1990-2012 was analysed.

In the residential sector, according to IEA data, in 1990 coal accounted for 14% of energy consumption in Austria and 22% in Germany, falling to shares of less than 3% in Germany and 1% in Austria, by 2012. At the same time, Hungary, Croatia, Romania, Slovenia, Slovakia and Ukraine also reduced coal use in household heating to less than 4% while in Bulgaria (22%), Czech Republic (14%) and Serbia and Montenegro (16%) it remained important and in Bosnia Herzegovina increased to 34% by 2012.

By comparison, biomass consumption in the same sector generally increased in the last two decades to 38% in Austria and 15% in Germany while some Central European countries of the Danube macro-region reached very high shares such as in Bulgaria (70%), Serbia and Montenegro (68%), Romania (55%), Slovenia (53%), Bosnia Herzegovina (53%), Croatia (34%) and Czech Republic (31%). It has to be reminded (see paragraph 1.2) that figures relate to traded biomass only, home produced or foraged biomass is not included and thus values for rural communities in these countries are likely to be even higher.

Figure 2 shows the sum of national emissions of PM_{10} and the $PM_{2.5}$ emitted by biomass and fossil fuels burning in the Danube Countries estimated by EDGAR for the sector 1.A.4 – "Energy in buildings". The trend clearly shows a sharp decrease of emissions of both PM_{10} and $PM_{2.5}$ in the first part of 1990s while the emissions seem to stabilise along the years 2000s with a slight increase in the early 2010s. The decrease of the fossil-related $PM_{2.5}$ is all along the last decades is quite evident and counterbalanced by the clear increase of the emissions related to biomass burning.

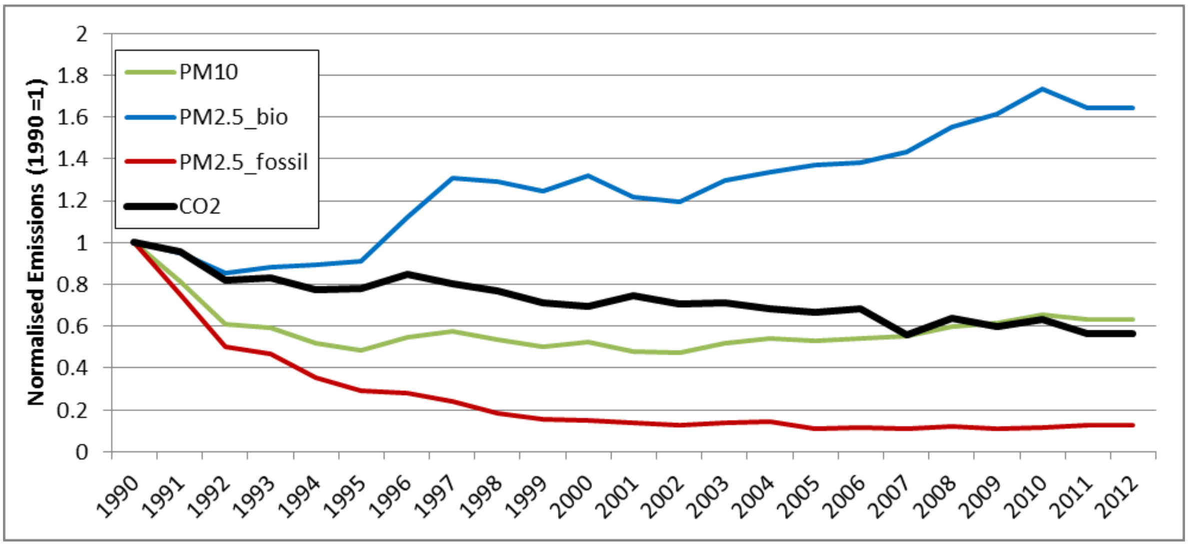
Figure 2 Emissions of sector "of PM_{10} and the fossil and biogenic components of $PM_{2.5}$ in the sector "Energy in buildings" in the Danube countries from 1990 to 2012.



Source EDGAR (release v4.3.2, 2017) – Units in Gg/year.

In Figure 3 1990-2012 normalised trends for the same pollutants are compared with normalised CO_2 emissions from the same countries, again in the building sector, in order to make evident how the PM component dynamics compares with the general frame of steady CO_2 emission reduction in the same sector. In comparison to the reductions of 40% for CO_2 and PM and of more than 80% for $PM_{2.5}$ from fossil fuels, biomass-related $PM_{2.5}$ has increased by more than 60% in the latest 23 years.

Figure 3 Normalised trends for PM_{10} (green), biogenic $PM_{2.5}$ (blue), fossil $PM_{2.5}$ (red) compared with normalised CO_2 emissions (bold black) in Danube countries between 1990 and 2012



Source EDGAR (release v4.3.2, 2017) – Normalised units (1990 = 1).

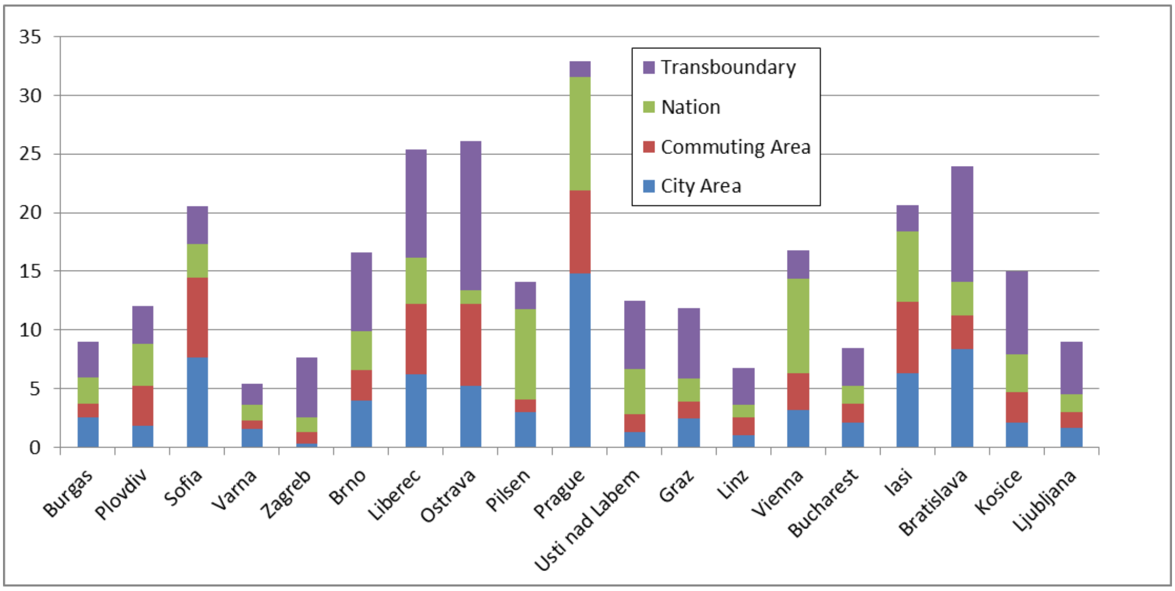
This trend suggests that in the latest decades, efforts in controlling emissions related to fossil fuel combustion in domestic heating have been quite successful, while biomass related emissions still need to be more strictly controlled.

2.2 Residential biomass burning – urban dimension

The previous section shows that biomass burning accounts for a significant part of emissions from residential heating. In order to assess the final impact of biomass burning on human health, a further analysis step is needed to link emissions with actual concentrations directly impacting human health. In 2016, JRC has performed an analysis to quantify the contribution made by sources to PM2.5 and the geographic areas from where the pollution originates. The SHERPA tool developed by the JRC was used to model PM2.5 concentrations in the 150 largest EU28 cities, including several cities in the Danube macro-region. [Thunis et al. 2017].

Figure 4 reports the percentage of $PM_{2.5}$ that this study found to be attributable to residential heating in the analysed cities, taking into consideration four types of geographical origin: the city area itself, its commuting zone, the rest of the city's country and the emissions situated outside the country.

Figure 4 Percentage of $PM_{2.5}$ attributable to residential heating in cities analysed in [Thunis et al. 2017] located in the Danube area, detailed for geographical origin: city area (blue), commuting zone (red), rest of the city's country (green), transboundary (purple).



Source: own elaboration of data from [Thunis et al. 2017]

Figure 4 shows that residential sector usually accounts for a share between 5% and 25% of $PM_{2.5}$ in the studied cities. Although the study has demonstrated a quite diverse geographical origin of the particulate matter impacting the cities analysed, the share of $PM_{2.5}$ originating from domestic heating located in the city itself rarely exceeds 10% in absolute terms and never accounts for the majority of $PM_{2.5}$ attributable to domestic heating.

Consequently, policies aiming to reduce the impact of domestic heating in urban areas should not be restricted to just the urban emissions: cities are the most important areas where population exposure takes place, but are not the only areas were the emissions related to domestic heating seen in the cities are produced.

It is important to note that while the last two sections show how biomass burning is a significant problem, estimations of its contributions can still be improved. In fact, there are considerable uncertainties in the emission factors and limited knowledge of the behaviour of the organic compounds emitted and how they condense to create additional particulate matter or how they react with other pollutants (e.g. O_3) [Piazzalunga et al. 2011].

2.3 Carbon neutrality and GHG emissions along the biomass production chain

Biomass burning could be considered "carbon neutral" on the basis of the reasoning that the CO_2 emitted in combustion is recaptured by new biomass growth as part of the "natural" biosphere carbon cycle and does not lead to any increase in atmospheric greenhouse gas concentrations. Nevertheless, when the whole biomass production chain is considered other emissions originating e.g., from raw material transport and processing enter in the picture.

For instance, [Giuntoli et al. 2015] investigated three different ways of providing heat to households by means of solid biomass: log wood residues burned in a stove, a pellet domestic stove, and a district heating plant using forest chips. The supply chain Greenhouse Gas emissions are estimated by means of a Life Cycle Assessment, compared with a reference fossil fuel system, based on Natural Gas combustion. GHG savings obtained by means of biomass burning overcome in all cases 80% and are very close to 100% (i.e., full "carbon neutrality") in the case of logwood residue burning. Results are nevertheless sensitive to the assumed pattern of trade of these biomass products (see table 1), due to the different transport distances involved.

Camia et al. (2018) analysed a wider set of feedstock categories, including agricultural and forest logging residues and several types of chips and pellets, confirming the overall advantage of biomass over fossil fuels from the point of view of GHG emissions.

The picture becomes more complicated if the analysis is extended to include considerations related to the overall ecosystem from which the biomass originates. For instance, in the case of wood residues, it is necessary to consideration the alternative fate of the residues, if they were not collected and combusted. Under certain scenarios they could store the emitted carbon for very long time. Thus if the use of woody biomass is part of a cycle where the burnt wood is rapidly replaced in its carbon storage function by newly planted biomass, the net production of energy is actually obtained without altering the overall carbon cycle. Otherwise, the "burst" of carbon emitted by combustion can take a long time to be recaptured. In addition it has also been seen [IEA 2017] that while the biogenic carbon cycle for some forests and forestry materials can be long because of slow forest rotations and biomass decay, annual crops and their residues have a much shorter carbon life-cycle, and this introduces a time element that is not always taken into consideration when assessing carbon savings benefits of bio-based solid fuels.

On the other side, solid biomass used in heat production is generally free from the ILUC (Indirect Land Use Change) effect, caused by the displacement into the fuel market of biomass stock originally intended for food and feed use. Nevertheless, in some cases of residues overexploitation, farmers could receive an incentive to expand crops beyond necessary, ending up in unnecessary change of land use. More details about ILUC factors for different feedstock categories are available in [Woltjer et al. 2017]

It is therefore very important to approach the exploitation of biomass carefully. Energy uses should be based on choosing production chains and feedstock types that maximize actual advantages in terms of environmental impacts, starting from GHG and air quality, but without forgetting other relevant impacts that will be considered in the next section.

2.4 Biomass burning and ecosystems.

Carbon related issues and pressures on air quality are not the only potential consequences to be considered when considering the overall sustainability of biomass use for domestic heating, especially if all the environmental, social and economic aspects of sustainability are considered. A full discussion of all these aspects is outside the scope of the present report and other sources such as [IEA 2017] provide a more complete framework. The following topics have been found relevant for Danube regions in the framework of JRC support to Danube strategy.

- *Maintaining soil fertility*

Biomass, including biomass residues, is a part of the natural carbon cycle. Whenever a part of this cycle is modified to provide a service, in this case domestic heating, it should avoid major disturbances and preserve as much as possible the capacity of the ecosystems to provide their services.

A major example is the role played by agricultural residues in maintaining the levels of Soil Organic Carbon (SOC) and consequently soil fertility. Although beneficial from the point of view of providing additional income to farmers and a relevant source of renewable heat (see section 1.2), excessive removal of residues could in principle reduce SOC content and lead to loss of fertility in the long run.

For this reason, [Monforti et al. 2015] investigated the actual potential for agricultural residues available for heat production, when constrained by the need to maintain the SOC level in the soils. Results of the study show that in general agriculture residues can play a role in the renewable heat arena, but countries in the Danube area are among those where particular care must be taken to adjust residue collection rates to maintain soil fertility. More details can be found in the cited study.

- Potential impact of climate change on biomass productivity

The impact of climate change on the potential production of biomass for energy purposes should be considered for at least two reasons. First, from a sustainability point of view, the amount of material that can currently be sustainably extracted from a forest could be too much for the same forest under a different climate, which could in turn make the development of a biomass supply chain unviable.

[Garbolino et al. 2017] show that Mediterranean forests may be more vulnerable: temperature increases may affect the mortality of the trees and shrubs and the structure of the ecosystems due to the colonization of more xerophilous species in valleys and hills. Conversely, mountain areas become more suitable for the development of forests, although several of these areas are either protected or logistically more difficult to exploit for biomass production. The extension of this analysis to the Danube area would be extremely useful as a base for appropriate policy development.

- Competition with food

There has been much discussion in recent years on the use of feed and foodstuffs for first generation biofuels. Considering the very limited use of biofuels for heating purposes, this topic remains outside the scope of this report. It is nevertheless useful to remember that domestic heating systems can be fed with agricultural crop residues in the form of briquettes. Moreover, some species of energy crops (e.g., mischantus) could in future become more important for bioheat provision and could in principle compete for land use with agriculture crops. Although for the moment these aspects are secondary in comparison with other issues, it is worthwhile to monitor their development.

- Other issues

Following IEA (2017) other aspects to be considered include water use both in the phase of feedstock production and transformation, water quality, mostly related again to feedstock transformation by means of industrial process such as torrefaction, waste management (e.g., ash disposal) and biodiversity preservation. Further details are found in [Dallemand and Gerbens-Leenes 2013] and [Fritsche et al. 2010].

3 Finding an equilibrium. Strategies and policies

To find the right balance between the advantages and disadvantages of biomass use in the domestic sector policy makers and citizens can follow two main strategies: technology improvements and efficient and integrated resource management. Of course, these lines of action are not mutually exclusive and can in principle be blended in function of priorities and political visions and deployed in a large variety of ways.

In this chapter, the main ingredients for policy developments touching biomass use in the domestic heating are presented. The first section focuses on issues for which technological improvement has shown to be a valuable tool: for instance, controlling the emissions from heat production devices, improving their efficiency and decreasing the demand of energy in the heating sector. The second section discusses how integrated policies can be also an efficient tool, from enhancing renewable alternatives to biomass burning to appropriate economies of scale. In the final section, examples coming from the Danube macro-region will complete the policy discussion.

3.1 A path to sustainability: pushing for technology improvements

Technology is a powerful tool for addressing sustainability issues, including the challenges posed by the use of biomass for bioenergy described in the previous chapter.

Improving and optimising technology can have a beneficial impact on any of the links of the supply chain leading from raw material to the final service provided. Moreover, focusing on the major issue of air pollution, technological improvement can have a major role in the mitigation of final pollutant emissions. Technologies are known to improve and evolve mostly under market forces, driven by consumer demand for even better and more "accessorised" products, but this is not the only way technologies reach and flourish in the market and in some cases they have to be pushed by appropriate legislative frameworks and incentives, some of them are described in the following for the case of domestic heating systems.

- *EcoDesign.*

The Eco-design directive (2009/125/EC) states the principle that energy-related products circulating in the EU should comply with standards aimed at improving their environmental performance. The benchmarking criteria used usually include, but are not limited to, energy efficiency and where relevant, pollution emissions. Each category of products is the object of specific technical legislation and most of the biomass-fed domestic heating systems fall in the categories considered in Regulation 2015/1189 on eco-design requirements for solid fuel boilers with a rated heat output of 500 kW and less[7]. The regulation also defines indicative benchmarks for best-performing solid fuel boilers available at the time of entry in force in order to provide a guidance to best available feasible technologies.

Table 4 and Table 5 show the specific criteria and benchmark values on energy efficiency and pollutants emissions set for this type of appliances that should be met by new products entering the market from 1st January 2020.

Table 4 Minimum and benchmark values of seasonal space heating energy efficiency for biomass boilers below 500 kW.

<table>
<tr><th>Rated heat output</th><th>Threshold efficiency</th><th>Benchmark values</th></tr>
<tr><td>≤ 20kW</td><td>75%</td><td rowspan="2">96% (co-generation)
90% (condensation)
84% (other boilers)</td></tr>
<tr><td>> 20kW</td><td>77%</td></tr>
</table>

Source: EC regulation 2015/1189

[7] The non-woody biomass boilers are not yet included and the first review of the regulation (before end 2022) will assess whether to set eco-design requirements for their specific types of pollutant emissions.

Table 5 Minimum and benchmark values of pollutants emissions for biomass boilers below 500 kW (in mg/m3)

Pollutant	**Threshold emissions (Automatically stocked)**	**Threshold emissions (Manually stocked)**	**Benchmark Values**
Particulate Matter	40	60	2
organic gaseous compounds	20	30	1
carbon monoxide	500	700	6
nitrogen oxides	200	350	97

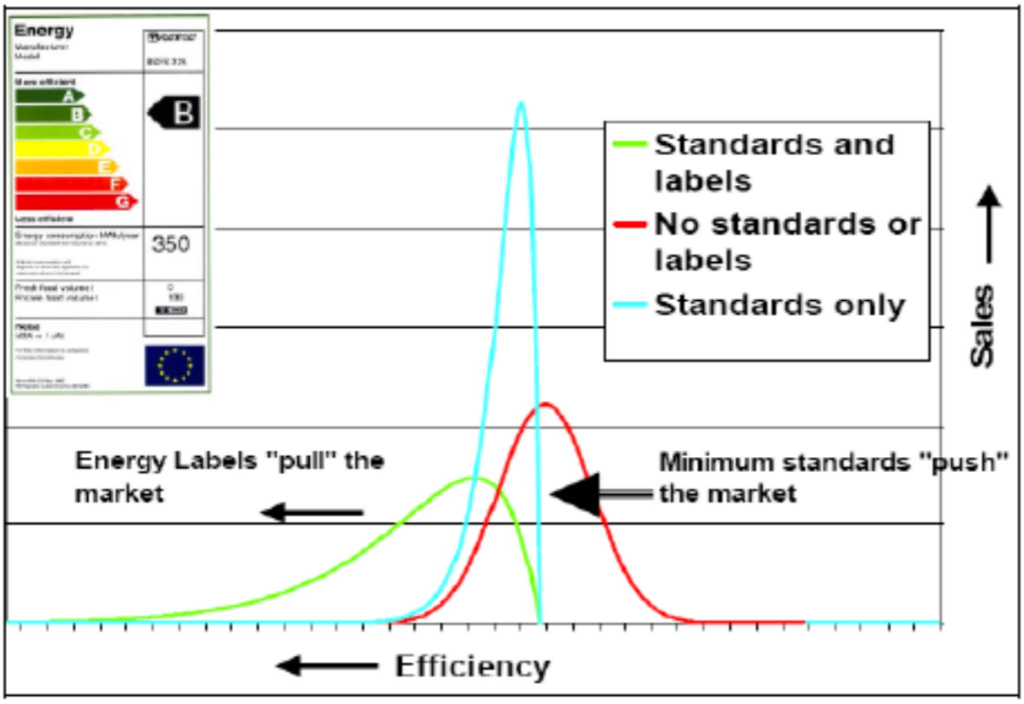
Source: EC regulation 2015/1189

The directive is however expected to have a limited impact in the short-term because of the long transition periods and long lifespans of the appliances covered by the Eco-design Commission Regulation 2015/1189 and related ones (813/2013 814/2013 on water heaters and 2015/1185 and 2015/1188 on space heaters) and for this reason needs a complementary legislation with a more direct market impact.

- Energy labelling

Generally speaking, the more efficient a boiler is, the lower is its environmental impact, in terms of emissions, raw material consumption and other end points. The energy label regulations are meant to influence the market and to stimulate a "pull" towards more efficient appliances. From this point of view the energy labelling philosophy is complementary to eco-design and other similar measures setting minimum acceptable standards (see Figure 5).

Figure 5 The combined effect of Eco-design and energy labelling regulations.

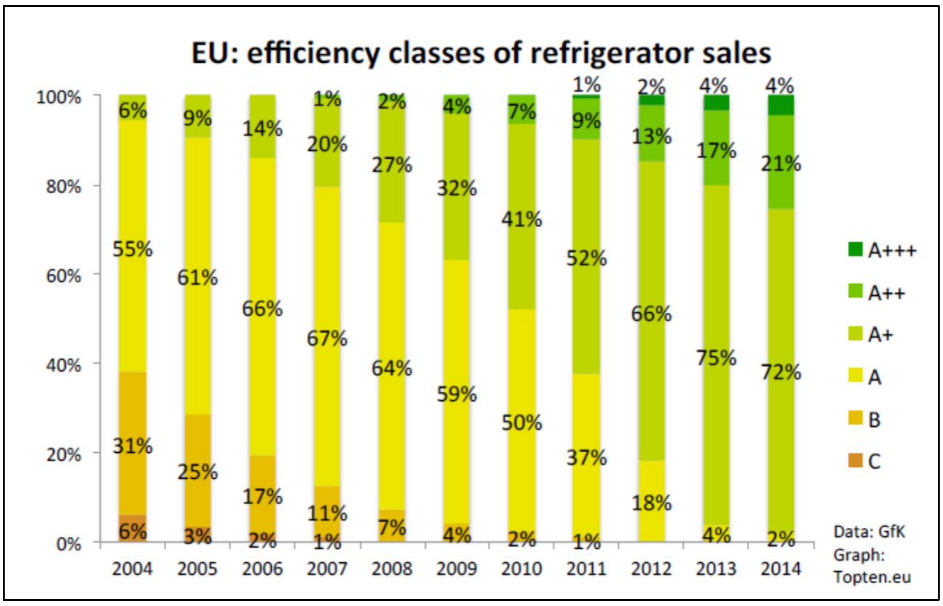


Source: [European Commission 2015a]

Regulation 2015/1187 on energy labelling of solid fuel boilers targets the same category of products considered by Eco-design regulation, although limited to domestic appliances below 70kW of rated heat output. This regulation requires that, as of 1st April 2017, boilers put on the market are provided with a label specifying the efficiency class, ranging from G (least efficient) to A+++ (most efficient). Efficiency class is determined for each type of the appliance on the basis of the Energy Efficiency Indicator (EEI), an indicator combining actual combustion efficiency with other parameter such as internal energy consumption, efficiency of electricity co-generation and others.

The combination of energy labelling and eco-design has been shown be very efficient in supporting the market penetration of increasingly efficient devices (see e.g. Figure 6 for the cases of refrigerators sales).

Figure 6 Evolution of market shares of refrigerators sold in the EU in function of their energy labelling.



Source[European Commission 2015a]

The application of both eco-design and energy labelling regulations to biomass-fed boilers are still too recent to see an impact on the European market, but the Impact Assessment for Regulations 2015/1187 and 2015/1189 and [European Commission 2015b] foresees their combined effect generating annual energy savings of approximately 18 PJ (0.4 Mtoe), carbon dioxide emission reductions of approximately 0.2 Mton and reductions of 10 kton of particulate matter, 14 kton of organic gaseous compounds and 130 kton of carbon monoxide emissions by 2030.

- Control policies.

Apart from the eco-design requirements for new appliances, European legislation does not impose maximum emission values for biomass-fed heating appliances. Under the pressure of the Air quality legislation, several countries heavily affected by pollution from domestic biomass burning have nonetheless imposed stricter requirements. For instance, Table 6 presents the updated limits to be respected by domestic appliances in Serbia, while in Germany, since January 2015, new stoves and boilers have to comply with Particulate Matter threshold emission concentrations ranging between 20 mg/m^3 and 40 mg/m^3, depending on type of appliance and fuel used.

Table 6 Emission limits for domestic combustion appliances in Serbia.

Pollutant	Fuels	Thermal power (kW_{th})	Limits(mg/Nm^3)
Particulate Matter (PM)	Coal	≥4	90
	Wood, excluding wooden briquettes and pellets	≥4	100
	Wooden briquettes and pellets	≥4	60
Carbon Monoxide (CO)	Coal and Wood, excluding wooden briquettes and pellets	4-500	1000
	Wooden briquettes and pellets	4-500	800
	Coal and Wood, wooden briquettes and pellets	≥500	500

Source:[Martinov 2017]

Imposing stringent limits on new appliances is usually the most effective policy strategy, but the positive impact is dependent on the time taken to renew existing appliances with those meeting the new limits. This may be too slow to cope with very high pollution levels and in some areas specific stricter legislation has been designed to increase the abandonment of older polluting devices. For example, the northern Italian regions have agreed on a common approach aimed at decreasing biomass burning emissions in the Po Valley, still one of the most polluted areas in Europe. Boilers and stoves, both new and existing, are now required to be classified on a scale of "stars" ranging from 1 (most pollutant) to 5 (least pollutant) on the basis of a combination of emissions and efficiency. Starting from 1st October 2018 1-star devices may no longer to be used, while new heaters have to be rated 3-star or higher. Limits are expected to become more and more stringent in successive years and can be temporarily increased in case of "emergency" high pollution episodes.

Control policies may also be twinned with incentive schemes to further encourage the transition to the new generation of appliances and counter any opposition from citizens requested to invest sometimes important amounts of money into the upgrade. Supporting schemes and funding schemes should not focus on single emission values, but should be based on the performance and parameters of real importance and on the evaluation of real-life operation.

- Demand side measures: Energy Efficiency in buildings and smart grids.

Another way to decrease the emissions of heating systems is by reducing the demand for heat. Building technology has also noticeably improved and the European legislation has since 2010 pushed for a full exploitation of the possibilities offered by means of the Energy Performance of Buildings Directive (2010/31/EU). Following the introduction of energy efficiency requirements in national building codes in line with the Directive, new buildings today consume half as much as typical buildings from the 1980s.

The rate of renewal of building stock is nevertheless even slower than for appliances and a newly revised Directive (2018/844/EU) aims to accelerate the cost-effective renovation of existing buildings. It worth noting that the revision also supports electromobility infrastructure deployment in buildings' car parks, preparing the European building stock for the foreseen transition in the transport sector. It also introduces new provisions to enhance smart technologies and technical building systems, including automation. Indeed, in the vision proposed, buildings can benefit from being more and more integrated in the "smart grid" concept, where supply and demand of energy are automatically monitored and adjusted to achieve the highest possible efficiency and when coupled with smart meters, price optimisation. [Filiou 2016]

3.2 Integrated polices

In order to better control impacts related to domestic biomass burning, approaches other than the direct control of emissions or decreasing heat consumption are also possible. Taking a wider systemic view, some strategies have shown to be effective in improving the environmental profile of the whole domestic bioheat supply chain.

- Enhancing alternatives: heat pumps and solar heating.

As seen in Chapter 1, bioheat production is the most popular way to increase the penetration of renewable energies in the heating and cooling sector, but it is not the only one. Other fossil-free technologies are increasingly available as domestic heating systems, among which heat pumps and domestic solar heating systems are increasingly successful[8]. A proper integration at the building level of these technologies is a powerful tool for decreasing the demand for other sources of heat and, as a consequence, limiting the needs for solid fuels, including biomass.

- Economy of scales: district heating and Combined Heat and Power.

Although domestic-scale appliances are the main object of this study, it is worth mentioning that another solution to the proliferation of small and inefficient heating systems could be to move towards a physically more integrated system based on the District Heating (DH) paradigm. The idea is that a biomass-fed DH system, including just one or very few combustion units allows a more efficient management of the energy produced, avoiding losses and optimising combustion.

Large DH boilers are also suitable for the combined production of heat and power (CHP), while plants could in principle be built to allow a certain fuel flexibility and co-burning of different types of biomass or even non-biomass fuels.

- Bioeconomy and Circular economy

Resource-efficiency is the main road to a sustainable society laid down by the interplaying bioeconomy and circular economy strategies. [European Commission 2012] [European Commission 2015c] and [European Commission 2018]

Driven by global challenges like climate change, land and ecosystem degradation, coupled with a growing demand for food, feed and energy, the bioeconomy looks for new ways of producing and consuming and focuses on a proper management of the supply chain for bio-based products. Bioeconomy aims at reconciling demands for sustainable agriculture and fisheries, food security, and the sustainable use of renewable biological resources for industrial and energy purposes, while ensuring biodiversity and environmental protection. The circular economy promotes the transition to an economy where the value of products, materials and resources is maintained in the economy for as long as possible and waste generation minimised. Based on these concepts, supply chains getting the highest value from materials that are originally seen as "secondary" should be further explored and exploited.

In the case of biomass domestic use for heating, a widely known example consists in the use of wood and agricultural resides residues for domestic heating purposes, more and more often in the form of pellets or briquettes, as already discussed in Chapter 1. Other forms of recirculation of materials are nevertheless possible, again more easily at the district heating or industrial scale.

3.3 Tools for multi-dimensional policy design. The role of the macro-regions

The EU Strategy for the Danube Region (EUSDR) offers an ideal framework in which issues related to the use of biomass for domestic heating could be discussed.

[8] According to [Eurobserv'er 2016] there were more than 25 million heat pumps installed in the EU at the end of 2015, 10% of which were newly installed in 2015 itself. The large majority (95%) are aerothermal pumps, with geothermal covering the remaining 5%. Together, heat pumps have provided in 2015 8.8 Mtoe, 20% more than planned in the EU NREAPs.

As already discussed, the EUSDR aims to promote the sustainable development of a macro-region with 115 million inhabitants, by tackling key topics that require working across borders and national interests. The transnational nature of most of the impacts of biomass burning (e.g., air quality, pressure on natural resource) and the increasing trade across both EU and non-EU countries, makes such a strategy particularly suitable. Moreover, key issues identified by the EUSDR are mobility, energy, water, biodiversity, socio-economic development, education, culture and safety and most of them are very relevant to the trans-sectorial nature of energy uses of biomass.

The EUSDR is structured in four pillars: "Connecting the region", "Protecting the environment", "Building prosperity" and "Strengthening the region" subdivided in 11 priority areas (PA) and topics discussed in this report lay at the intersection of the themes treated in the second priority area (PA2) "To encourage more sustainable energy" and the sixth priority area (PA6) "To preserve biodiversity, landscapes and the quality of air and soil". In particular, Danube countries are realising one of the main actions foreseen under PA2 "To extend the use of biomass (e.g. wood, waste), solar energy, geothermal, hydropower and wind power" as far as the biomass component is concerned and biomass use in domestic heating in particular.

Due to the complexity of air quality, health and climate change challenges, coordinated actions should be taken at different levels: local, regional, national, EU and non-EU. To improve the effectiveness of such measures, it is essential to involve all the relevant actors and assess possible interactions between sectorial policies.

Supporting the development of a strategy to achieve the standards laid down in the EU legislation and the EUSDR objectives requires appropriate diagnosis with the most suitable tools to support the definition of the strategies. From the source in Baden-Württemberg to the Danube delta in Romania the Danube macro-region encompasses countries with very different levels of economic development and consequently emissions, due to the different kind of technologies and fuels used and different levels of implementation of environmental policies. In addition, within each sub-basin, gradients from rural–mountainous areas to flat populated areas impacted by different types of sources are present.

- EUSDR policies for addressing the biomass burning issue

As described in chapter 2, there is scientific evidence about the impact of residential heating on PM in Europe and in Eastern Europe. Apart from the general framework offered for the emissions from new boilers and stoves, partially addressed by the Eco-design, Energy Labelling Directive and the other policies cited in paragraphs 3.1 and 3.2, policies in the Danube macro-region are quite heterogeneous as a consequence of the different legislations in force.

For instance, Montenegro and Serbia have started to implement provisions concerning air quality plans. In general, PM_{10} exceedances were the main target of AQ Plans with the exception of Bor (a hot spot in Serbia) where the breach concerns SO_2. According to the enlargement progress reports for Bosnia and Herzegovina, air quality plans for the areas where pollutant levels exceed limit values are still to be adopted.

Measures to improve the energy efficiency of buildings were implemented in almost all the countries. Extensive use of wood for household heating in winter has been associated with air pollution in Slovenia and Croatia. This source contributes to the exceedances of the European air quality limit values for PM. Moreover, in some Western Balkan countries coal fired residential heating also contributes to both PM and SO_2 emissions. Schemes to promote replacement of obsolete appliances and for the development of district heating networks were adopted in Slovenia, Serbia Montenegro and Croatia. Among the non-technical measures, information campaigns about the proper use of the stoves and boilers fuelled with biomass were launched in Croatia and Slovenia.

3.4 EUSDR experiences and JRC support for policy design and implementation

The Danube macro-region encompasses regions from EU and non-EU countries that have different legislative and institutional frameworks. This can be an obstacle to the implementation of macro-regional actions. Nevertheless, the long-term experience of EU Member States in pollution reduction policies can inform those countries that started to deal with the same challenges more recently. Transfer of knowledge and experience from EU Member States regarding air pollution abatement policies and measures would facilitate a faster adoption of new standards in accession and neighbourhood countries. Furthermore, considering the transboundary nature of air pollution, such cooperation would also contribute to a faster compliance with the air quality standards in the EU. A comprehensive analysis of the biomass potential, legal framework and regulatory environment of biomass utilisation in the Danube Region, as well as good practice projects are available in the Danube Region Biomass Action Plan drafted in 2014 under the EUSDR Priority Area 2 [Hujber and Szilágyi 2014].

The Joint Research Centre (JRC) provides scientific support to the EUSDR both by backing decision-makers and other stakeholders to identify the policy needs and actions for the implementation of the strategy and by promoting cooperation across the scientific communities of the Danube Region. The Scientific Support to the Danube Strategy initiative is subdivided into different flagship clusters and activities. Different aspects of residential biomass burning issue were was addressed under two flagship projects: the Danube Air Nexus (DAN) and the Danube Bioenergy nexus (DBN). Since 2016 the activity continued under the JRC project on Macro-regional Strategies that also included other European macro-regions (EUSAIR and EUSALP).

- *Task force activities*

Task Forces have proved to be efficient working structures for the implementation of the EUSDR policy priorities by gathering representatives from different fields with a joint thematic focus.

In order to take action regarding the many challenges identified in Danube Air Nexus studies and to link scientific research with policy level and civil society in the Danube Region, a Task Force on Air Quality (TFAQ) was created in May 2016. The TFAQ is coordinated by the JRC and works in close collaboration with the PA6 coordinators and participates in the PA6 steering committee meetings it aims to promote concrete actions for the reduction of air pollution in the Danube region, in collaboration with other Priority Areas.

Between 2016 and 2018, there were six TFAQ plenary meetings in: Ispra, Bratislava, Belgrade, Prague, Sofia and Bucharest leading to the creation of a network of more than 50 experts from all the Danube countries. In addition, the TFAQ involved: national authorities (the ministries for the Environment of Croatia and Czech Republic), local authorities (the municipalities of Zagreb - HR and Sofia - BG), small enterprises (SCIENCE IN s.r.o. - CZ, Bioenergy2020+ GmbH –A), and NGOs (Energy Agency of Plovdiv – BG). TFAQ members are running the project CONSPIRO[9] that has been funded under the Danube Strategic Project Fund (DSPF).

The TFAQ has organised several capacity building activities for the Danube countries and its studies have been published as JRC reports [Belis et al. 2016] [Belis et al. 2017] and scientific publications [Perrone et al. 2018].

[9] https://www.danube-capacitycooperation.eu/uploads/files/DSPF_KickOff_project_posters_06_ECVII_PA06_CONSPIRO.pdf

Box 1. Other recent activities and relevant initiatives

- On 5-6 February 2018 a high-level conference on eco-innovation for air quality took place under the sponsorship of Bulgarian Presidency of the EU Council. 18 case studies were presented with a special emphasis on the relationship between Energy and Air quality. The report of the conference is available at:

http://ec.europa.eu/environment/ecoinnovation2018/1st_forum/report_en.html.

- On 9-10 October 2017 a workshop on "Clean Growth in bioenergy in the Alpine and Adriatic-Ionian regions" took place at the JRC in Ispra where the issue of biomass use in domestic appliances was also discussed with experts coming, inter alia, from several EUSDR countries.

http://edgar.jrc.ec.europa.eu/working_group_bioenergy_2017.php

In addition to the dedicated initiatives at the Danube level the issue of biomass combustion is addressed by different European public and private communities:

- The European networks on air quality measurements and modelling: AQUILA (https://ec.europa.eu/jrc/en/aquila), FAIRMODE (http://fairmode.jrc.ec.europa.eu/) and EIONET (https://www.eionet.europa.eu/).

- In the private sector the companies dealing with bioenergy, including the domestic heating sector, are gathered under different associations such as the Bioenergy Europe Association (https://bioenergyeurope.org) or EUBIA (http://www.eubia.org).

4 Conclusions and key messages

This report has provided an overview of the issues related to use of biomass fuels in the frame of domestic heating systems, starting from an analysis of drivers, then moving to consequences and impacts and finally discussing solutions and mitigation strategies offered by the scientific research and the multinational policy framework of EU and EUSDR.

The ideal readers of this report, i.e., policy makers and their technical support staff dealing with the sustainability of the heating and cooling sector could find the following summary of the key messages encountered throughout the report useful.

The context

- The energy and climate legislative framework of the EU, fully adopted by the Energy Community Treaty signatories, is pushing for an increased use of biomass for energy purposes, including domestic heating. This increasing trend is confirmed in the 2030 energy and climate strategy, at least in absolute terms.

- Solid biomass is and will remain a pivotal fuel in this context. Moreover, because of some feedstock categories (e.g., pellets), biomass use in the domestic heating systems is less and less a local issue and assumes transnational characteristics that need super-national strategy to be addressed.

- Several types of incentives for biomass use are available in most of the EUSDR countries, often embedded in general schemes targeting climate change and energy saving on a wide basis.

The pressures

- Biomass burning in domestic appliances can however release substantial quantities of different kinds of pollutants, such as particulate matter (PM_{10}, $PM_{2.5}$), CO, polychlorinated dibenzo-p-dioxins (PCDDs)/ polychlorinated dibenzofurans (PCDFs), black carbon (BC), organic carbon (OC) and polycyclic aromatic hydrocarbons (PAHs), depending on the technologies used.

- Data series extracted from the EDGAR emission inventory show that, since 1990, in the EUSDR area, emissions of biomass-related $PM_{2.5}$ in the sector "Energy in buildings" have increased by more than 60% while at the contrary, CO_2 and PM emissions in the same sector have decreased by 40% while $PM_{2.5}$ related to fossil fuels has decreased by more than 80%. This suggests that fossil fuel emissions have improved, while biomass related emissions still require careful control.

- The use of the SHERPA air quality model has shown that in the major cities in the EU28 part of the Danube macro-region, the residential sector usually accounts for a share between 5% and 25% of $PM_{2.5}$, with emissions originating from domestic heating in the city itself rarely exceeding 10%. For this reason, policies aiming to reduce the impact of domestic heating should not be limited to urban emissions alone: cities are the areas where population exposure predominantly takes place, but are not the only areas were the emissions from domestic heating are generated.

- Biomass use in domestic heating can result in savings of carbon emissions of the order of 80%. Unfortunately, the benefits become less certain when the analysis is extended to include considerations related to long distance transport of the biomass products, the overall ecosystems from which biomass originates and the time scales of their recovery. Detailed case-by-case analysis should be carried whenever possible.

- Environmental pressures from domestic-scale biomass burning are not limited to air quality, but include other aspects, such as soil fertility, ecosystems preservation, water quality and availability, biodiversity preservation. Again, specific studies should be carried whenever possible.

The policy tools available

- The policy framework of the EU offers several instruments for dealing with emissions of domestic biomass burning, starting from legislation stimulating technological improvement such as the EcoDesign and energy labelling directives, that can be combined into effective control policies.

- On energy demand side, the directive on energy efficiency in buildings and the smart grids concept provide additional room for assuring a more efficient use of biomass as final energy source.

- The development of renewable heat sources not based on combustion processes (e.g., solar heating, heat pumps, geothermal) and their blending with more traditional stoves and boilers can be a further way to manage the demand for domestic bioheat.

- The bioeconomy and circular economy concepts also offer a frame for a suitable management and optimisation of biomass utilisation.

The EUSDR action and the JRC support

- The EU Strategy for the Danube Region (EUSDR) has offered an ideal framework in which issues related to the use of biomass for domestic heating have been discussed and practical initiatives have been taken, ranging from air quality plans (e.g., Montenegro and Serbia) to measures to improve the energy efficiency (almost all EUSDR countries) and schemes to promote replacement of out of date appliances and for the development of district heating networks (e.g., Slovenia, Serbia Montenegro and Croatia). Among the non-technical measures, information campaigns about the proper use of the stoves and boilers fuelled with biomass were also launched in Croatia and Slovenia.

- The Joint Research Centre (JRC) provides scientific support to the EUSDR both by backing decision-makers and other stakeholders to identify the policy needs and actions for the implementation of the strategy and by promoting cooperation across the scientific communities of the Danube Region. Different aspects of residential biomass burning issue were was addressed under two flagship projects: the Danube Air Nexus (DAN) and the Danube Bioenergy nexus (DBN). Since 2016 the activity continued under the JRC project on Macro-regional Strategies that also included other European macro-regions (EUSAIR. EUSALP).

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