BIOMASS AND CLIMATE NEUTRALITY

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Abstract

The use of sustainable biomass will play a considerable role in meeting the 2030 target to reduce greenhouse gas emissions, as well as the objective of climate neutrality by 2050 in the European Green Deal. Biomass can fulfil a plethora of purposes, as a source of renewable energy and material substitution and as a carbon sink. It can even work towards negative emissions with the use of carbon capture and storage. To better understand the degree to which an uptake in biomass would be feasible and desirable, this paper analyses some of the barriers that may restrict its availability and usage. These include the policy and regulatory environment, as well as the many trade-offs associated with the use of biomass and its impact on, among others, greenhouse gas emissions, the environment, biodiversity, land use and food security. Choices of today will affect the available options of future policies. Recognising the complexity of these issues, it will be beneficial to assess biomass use distinctively based on type and end use, especially when it comes to woody biomass, which is associated with some of the most intricate trade-offs. Ultimately, the desirability of further biomass deployment will be determined by a mix of economic, political and technological aspects.

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Abbreviations

AFOLU	Agriculture, forestry and other land use
BECCS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage
CHP	Combined heat and power
ETS	Emissions Trading System
IED	Industrial Emissions Directive
ILUC	Indirect land-use change
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LULUCF	Land use, land use change and forestry
RED II	Recast Renewable Energy Directive

Biomass and climate neutrality

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1. Introduction

Sustainable biomass will play an important role in the EU's attempt to achieve climate neutrality by 2050, alongside other low-carbon technology options. Biomass in a broad sense can contribute to the climate-neutrality objective via sinks, by material substitution, renewable energy, recycling or generating negative emissions through bioenergy with carbon capture and storage (BECCS). On the other hand, the development of the bioeconomy and use of biomass has repercussions for other policy areas, for example biodiversity, local air quality, agriculture or forestry. Extra-EU imports add yet another layer of complexity, such as the assessment and enforcement of sustainability criteria.

Biomass use is likely to change over time. Not every sector is able to immediately make use of every type of biomass for energy. Currently, biomass can contribute to reducing greenhouse gas emissions, being incentivised through the Renewable Energy Directive or the benchmarks under the EU Emissions Trading System (ETS), provided that it is produced sustainably and assuming it is carbon neutral. Biomass use is further regulated by other EU or member state legislation, like local air pollution laws. Biomass production and use needs to find a balance among multiple policy objectives linked with biodiversity, environmental, agricultural and forestry policy.

Material substitution can also produce a positive effect on greenhouse gas emissions. As before, the actual substitution in volume terms needs to be balanced with the objectives of other policies, such as the role of forests as sinks. In the future, the use of biomass through BECCS may enable the achievement of negative emissions. Various scenarios, for example those by the EU and Intergovernmental Panel on Climate Change (IPCC), offer different projections about this potential. Yet the required biomass volumes for BECCS will depend on numerous factors, including public acceptability, the availability of infrastructure for carbon capture and storage (CCS) and CO_2 transport on a large scale, and the availability and costs of competing negative-emissions technologies. Increased afforestation is an alternative pathway to negative emissions.

As part of the ongoing work on carbon neutrality, this CEPS Policy Insight identifies and discusses the principal issues related to EU biomass use and consumption, over both time and geographies. In doing so, it describes and assesses the different ways in which biomass has the potential to contribute to the carbon neutrality objective. It covers a range of perspectives and identifies the trade-offs that policymaking will face. Where possible, the analysis attempts to reconcile the assorted positions. Many decisions of today will have a meaningful impact on the

future trade-offs and the available means to address them, therefore affecting, possibly even narrowing, the scope of future decisions.

Following this introduction, section 2 provides a definition of biomass and a very brief review of accounting issues, before section 3 sketches the main EU legislation affecting biomass sourcing and use. Sections 4 and 5 discuss future potential demand in view of short-, medium- and long-term replacement of fossil fuel energy production, as well as material substitution, contrasting this against the actual availability of biomass in the EU. Sections 6 to 8 provide a more detailed analysis of current and future trade-offs associated with the use of biomass, before the concluding section 9 formulates a number of tentative takeaways and recommendations.

2. Definitions and accounting conventions for biomass

2.1 Defining biomass

Biomass as a larger category is fairly straightforward to define: the IPCC's glossary, for instance, describes it as "[o]rganic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above – and below – ground biomass." This definition sets out just two subdivisions of biomass, above-ground and below-ground respectively.

The taxonomy becomes more complex when considering which types of biogenic material should be included in either of these categories. Above-ground biomass is defined by the IPCC as "all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage".[1] Below-ground biomass is defined as "all living biomass of live roots".

A further possible distinction can be made between 'wet' and 'dry' biomass types.[2] The wet biomass category contains various types of living and dead biomass, including waste from food production and preparation, sewage, agricultural waste streams, grasses and foliage, energy crops and aquatic biomass. Dry biomass is more closely linked to forestry with waste streams and other residues from forests and the paper and pulp industry, but also timber and 'production forests' or wood and grasses sourced from managed landscapes.

Different types of biomass will have different trade-offs and opportunity costs associated with their use, e.g. land use effects. Likewise, the availability of various biomass types may vary significantly, also among regions. This paper refers to these aspects in the relevant sections.

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[1] See https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Glossary_Acronyms_BasicInfo/Glossary.pdf; in both cases minor caveats are added to these glossary definitions.

[2] See DNV GL, 2017 (https://platformduurzamebiobrandstoffen.nl/wp-content/uploads/2020/01/2017_DNV_GL_Rapport_Biomassabeschikbaarheid-in-Nederland_DEF.pdf).

2.2 Can biomass use be carbon neutral?

Whether biomass can be carbon neutral remains contested. Outcomes for 'neutrality' depend on assumptions about the type of biomass used as well as the assumed and acceptable geographies and timescales applied.

The argument in favour of biomass being carbon neutral is that the CO_2 stored in biomass, when harvested, will be counted towards the agriculture, forestry and other land use (AFOLU) emissions of the country producing the biomass. When the biomass is subsequently combusted for energy use, no emissions will need to be recorded as that will already have been done in the land-use sector. Strictly speaking, combusting biomass will result in CO_2 (and in some cases N_2O and CH_4) emissions; however, to avoid double counting they are not considered energy sector emissions. As the CO_2 stored in biomass has been absorbed from the atmosphere before, the total cycle is carbon neutral.

The argument against biomass being carbon neutral is that the immediate release of CO_2 upon combustion of biomass results in a 'carbon debt' that takes time to be paid back. The payback of this carbon debt happens through the regrowth of crops or trees, but this process may take many years. A key assumption when assessing carbon neutrality is the (politically determined) duration of the payback period. The shorter this is, the more difficult it is for certain types of (woody) biomass to be carbon neutral. A rationale for choosing a shorter payback period is that in the context of present climate policy objectives, limiting emissions in the next one or two decades is important to avoid climate tipping points. A rationale for longer payback periods is that they allow for the analysis of a full cycle.

The counterfactual is also a key component in carbon neutrality assessments. What would have happened to the source of the biomass if it had not been combusted for energy purposes? The answer can go either way, i.e. continued higher or lower forest growth or crop growth because there would not have been an investment decision to plant trees.

The IPCC notes that the guidelines on national greenhouse gas inventories do not "automatically consider biomass used for energy as 'carbon neutral'".[3] This reflects that in some cases 'carbon neutrality' depends on sustainability criteria, harvest and removals, land-use changes and additional emissions along the value chain (e.g. transport). As a report on biomass by the PBL research institute summarises, the choice for what is considered a reasonable payback period inherently involves normative considerations and therefore cannot be wholly scientifically determined.[4]

Another consequence of the accounting conventions for biomass is that they can lead to an indirect form of emissions trading if the biomass is imported (and leads to a higher supply in the producing country). Emissions could increase in the exporting country as they are added to the land-use sector's emissions when the biomass is produced, while emissions can decrease

[3] See https://www.ipcc-nggip.iges.or.jp/faq/faq.html.

[4] See https://www.pbl.nl/sites/default/files/downloads/pbl-2020-beschikbaarheid-en-toepassingsmogelijkheden-van-duurzame-biomassa-verslag-zoektocht-naar-gedeelde-feiten-opvattingen_4188.pdf, p. 65.

in the country consuming the biomass, as it is considered carbon neutral at the point of combustion.

Some scientists[5] have challenged the appropriateness of the convention to treat biomass combustion as carbon neutral due to the payback periods and the relatively short timelines associated with meeting the Paris Agreement objectives. IEA Bioenergy, in response, states that 'carbon neutrality' is not a useful moniker[6] as there may be fluctuations over the full life cycle. It emphasises that the key objective is to avoid double counting; that is why biomass emissions are only recorded in the land sector and not in the energy sector. While there may be policy in the future that considers more explicitly what payback periods are desirable, for now the EU accounting convention follows the IPCC guidelines, and thus cannot be seen as aberrant.

In practical policy terms, the sustainability criteria set by the EU in the second Renewable Energy Directive[7] (RED II – see also the next section) should help ensure that the use of biomass is compatible with long-term emissions reduction objectives by limiting the use of biomass types where indirect land use changes (see section 6) can occur. Likewise, the directive stipulates that biomass can only count towards renewables targets if specific emissions reductions are guaranteed (calculated per biomass sub-type in Annex VI).

3. Biomass in European legislation

In the context of the European Green Deal, biomass in its different forms might be a versatile component of a climate-neutral economy. Biomass can directly supply heat, it can be transformed into biofuels and biogas, it can substitute carbon-intensive materials and products, and it can be used in power generation, potentially attaining negative emissions if coupled with a carbon capture technology. At the same time, it is crucial to ensure that its sourcing and use take place in a sustainable manner that is in line with the EU's climate and environmental agendas. For current and potential uses, the production and consumption of biomass are subject to numerous sectoral policies, such as energy, environmental, agricultural and climate policies. The combined effect of these policies can have a significant impact on the availability and use of biomass today and in future.

3.1 Biomass use and potential

Heating and cooling represent about 75% of the bioenergy from biomass used in the EU today. Through its November 2018 so-called long-term climate strategy for 2050, entitled "A Clean

[5] See EASAC, 2020 (https://easac.eu/media-room/press-releases/details/european-national-academies-of-science-easacs-message-to-iea-bioenergy-lets-debate-the-real-issues/).

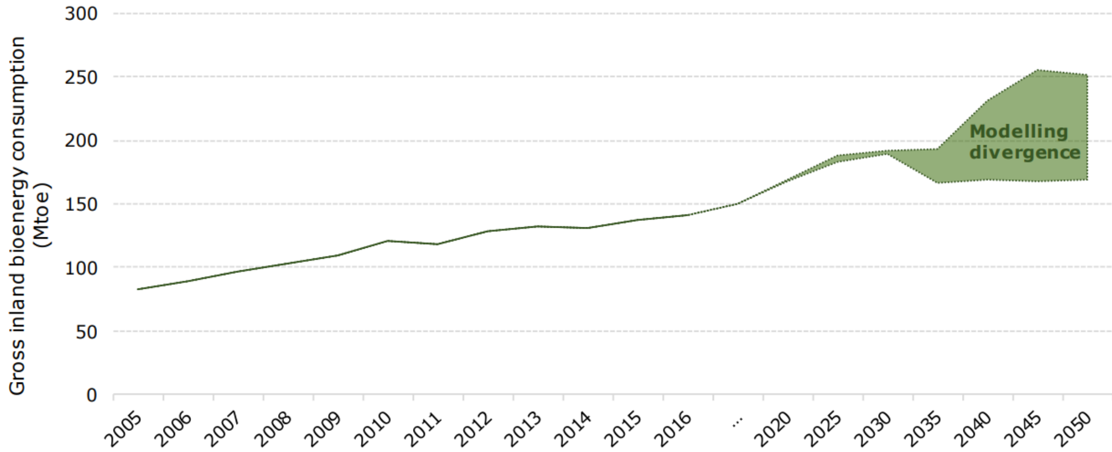
[6] See https://www.ieabioenergy.com/wp-content/uploads/2019/12/WoodyBiomass-Climate_EASACresponse_Nov2019.pdf.

[7] See Art. 29 of RED II and its Annex VI (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 328/82, 11.12.2018).

Planet for all",[8] the European Commission recognises the important role that sustainable biomass will play through its plethora of prospective uses in achieving net-zero greenhouse gas emissions in Europe's economy.

The highest projections of the long-term strategy foresee an increase in bioenergy consumption by around 80% by 2050, compared with today (Figure 1). The strategy also shows that, especially regarding woody biomass, the current EU production trends would be insufficient for covering all future EU needs, so imports will likely be increasingly necessary.

Figure 1. Gross inland bioenergy consumption in the EU



Source: Scarlat et al. (2019) based on European Commission, "A Clean Planet for all" (2018), op. cit.

In light of the projected growth of the sector, the Joint Research Centre's (JRC) Science for Policy Report of 2018 (Camia et al., 2018) on biomass production, supply, uses and flows in the EU highlights the need for knowledge on the potential for sustainable biomass production, its energy sources and impacts on other areas, such as the environment, land use and biodiversity.

Availability of land is a particular concern that can hinder the potential for expanding biomass use and production, as the transition to climate neutrality will require careful consideration of what the best uses of scarce land and limited resources are, in order to maximise efficiency and ensure sustainability.[9]

As part of the European Green Deal, in order to streamline EU policies to reflect the climate objectives of the EU, a number of legislative acts will be revised in sectors such as energy, climate, agriculture, the environment and competition, which will probably influence the expansion of potential uses of biomass, but may also play a role in determining the extent of its of availability.

[8] In this paper, the Commission's long-term strategy refers to European Commission, "A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy", COM(2018) 773 final, Brussels, 28 November 2018.

[9] Ibid., 8.

3.2 Renewable energy policy

Bioenergy represents a contributing source for meeting the 20% renewable energy target by 2020. In fact, biomass[10] for bioenergy represents the main renewable energy source in the EU in terms of final energy consumption for heating, electricity and transport, according to 2016 data (Ecofys, 2019; Scarlat et al., 2019).[11] It will further contribute to the 32% target for 2030 under RED II. It is expected that the level of renewable biomass consumption will likely continue to increase until 2050 and beyond.

Biomass for bioenergy amounted to 140 Mtoe in 2016, sourced mainly from woody biomass, but also from municipal and industrial waste and dedicated energy crops. The latter has an important impact on land use, with about 10% of current productive agricultural land in the EU used for the production of first-generation biofuels.[12]

RED II sets sustainability criteria for biofuels, bioliquids and biomass fuels (see section 6.3 for more details), as well as requirements for greenhouse gas emissions savings. The most stringent criteria are set for installations starting operation from 2021 in the transport sector, which must achieve 65% savings, and for electricity, heating and cooling, which need to achieve 70% savings in the case of installations that become operational between 2021 and 2026 and 80% for new installations starting their operations from 2026. The greenhouse gas emissions savings are estimated by comparing all life cycle emissions (cultivation, processing and transport, but excluding biogenic emissions from growth, decay and combustion) of bioenergy production with the typical greenhouse emissions of the fossil fuels that are replaced. The amendments to the Monitoring–Reporting Regulation and the Accreditation–Verification Regulation, currently under public consultation, will also have implications for the criteria that will be used to determine whether biomass use is sustainable and can thus be considered a carbon neutral source of energy.

In addition, RED II seeks to address the risk of indirect land-use change (ILUC), as a result of increased production of feedstock for biofuels, bioliquids and biomass fuels. Limits on high ILUC-risk feedstock, for which a significant expansion of the production area into land with high carbon stock is observed, affect the total amounts of fuels that member states can count towards their national targets for renewable energy, both overall and for the renewable energy share in transport.

[10] In this context, 'biomass' refers to the biodegradable fraction of products, waste and residues from biological origin from agriculture, forestry and related industries, fisheries and aquaculture, as well as the biodegradable fraction from waste. 'Bioenergy' is the energy produced from biomass (Scarlat et al., 2019).

[11] In terms of end use, the bulk of biomass use, i.e. 75%, comes from heating and cooling, while bioelectricity represents 13% and transport biofuels 12% of the bioenergy use in the EU (Scarlat et al., 2019). In terms of type of biomass used, solid biofuels (excluding charcoal) amounts to about 70%, biogas represents 11.8%, liquid biofuels 10.7% and municipal waste 7.4% (Ecofys 2019).

[12] Ibid., 8.

The directive further calls for member states to take into consideration the biomass cascading principle[13] and requires large-scale bio-electricity generation (above 50 MW) to meet minimum efficiency standards or use of highly efficient combined heat and power (CHP) technology.[14]

3.3 Climate policy

Biomass is covered in all the main climate policy frameworks: the EU ETS, the Effort Sharing Regulation, and the land use, land use change and forestry (LULUCF) legislation.

The EU ETS covers greenhouse gas emissions associated with the power and energy-intensive industrial sectors. Along with potentially higher 2030 targets, the European Commission is assessing whether the system could be further expanded, for example to the transport and building sectors.

In the EU ETS, the accounting convention that treats biomass combustion as 'carbon neutral' leads to biomass being an abatement option that can lower the amount of EU allowances that need to be surrendered. Furthermore, if an installation exclusively uses biomass for combustion, then that installation will be wholly excluded from the ETS and its compliance obligations.[15] Specifically, the EU ETS Directive states that "the emissions factor for biomass shall be zero".[16] This follows the principles of the 2006 IPCC "Inventory Guidelines". Additionally, whenever member states want to exclude small emitters or small installations from the ETS, biomass emissions are not included in the eligibility criteria.

Biomass also plays an indirect role in some of the implementing legislation of the EU ETS, pertaining to (free) allocation. Free allocation is based on a combination of factors, like historical activity levels and product benchmarks, to target the limited allowances available to those installations that are most efficient.[17] Besides product benchmarks, there are separate heat and fuel benchmarks that are used whenever a specific product benchmark has not been formulated (i.e. as 'fall-back'). For phase 3 (2013–20), natural gas was used as a reference fuel (reflecting the energy mix) to establish the fall-back benchmarks. For the revision of the benchmarks for phase 4 starting in 2021 this may no longer be the case. Since the accounting convention for biomass does not lead to recorded emissions under the ETS, any installation using biomass is likely to be among the most efficient, which affects the benchmark updates.

[13] Cascading use of biomass resources, such as wood and agricultural products, means an efficient use of these resources from the point of view of natural resource, material and land consumption.

[14] European Commission, "Guidance on cascading use of biomass with selected good practice examples on woody biomass", Luxembourg: Publications Office of the European Union, 2018 (https://op.europa.eu/en/publication-detail/-/publication/9b823034-ebad-11e8-b690-01aa75ed71a1/language-en/format-PDF/source-80148793).

[15] See Annex I(1) of the consolidated EU ETS Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance), OJ L 275, 25.10.2003.

[16] Ibid., Annex IV.

[17] The original ETS benchmarks reflected the 10% most-efficient installations. For the 4th ETS phase, the benchmarks will be updated to reflect carbon efficiency improvements. See also https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011D0278.

In the case of these fall-back benchmarks for heat and fuel, biomass use can have an impact on a wide range of industries, as the use of biomass in one sector can affect the benchmark update for all sectors to which the benchmark applies. Conversely, product benchmarks are more targeted and can take into account sector specificities.

The *Effort Sharing Regulation*[18] provides a framework for reducing emissions in non-ETS sectors by 2030, based on a set of national targets ranging from 0 to -40% compared with 2005 levels, which differ among member states based on their level of economic development and some further adjustments made to reflect cost-effectiveness. The sectors covered include buildings, agriculture, transport, waste management and some small industrial sectors. The use of biomass represents an important tool for reducing the carbon footprint of these sectors as well. Given that some emissions are not counted in either the EU ETS or the Effort Sharing Regulation (e.g. biomass used for heating households), they can be accounted for as part of the emissions related to land use and change (Runge-Metzger and Wehrheim, 2019).

As part of the EU's commitment to reducing greenhouse gas emissions by at least 40% by 2030,[19] as well as reaching climate neutrality by 2050, agriculture and forestry play a crucial role not only in reducing their greenhouse gas emissions footprint, but also in capturing CO_2 from the atmosphere (Runge-Metzger and Wehrheim, 2019). These sectors are covered under the *LULUCF Regulation*,[20] which concerns emissions and removals resulting from land-use activities involving forests, croplands, grasslands, settlements or wetlands, or from land use changes to these managed lands. To avoid the risks associated with sourcing biomass from countries that do not have a working system for LULUCF accounting, such imports are excluded as renewable energy sources under the Renewable Energy Directive. Under the LULUCF Regulation, the total emissions from the sector must be in balance.

There is also interaction between the three pillars of EU climate policy, as member states can decide to transfer a certain number of tonnes from LULUCF compliance to effort sharing compliance. Similarly, some exchange for flexibility reasons is also possible between the EU ETS and non-ETS.

[18] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013, OJ L 156/26, 19.06.2018.

[19] With a possible upwards revision to 50 or 55%, in the context of the European Green Deal and the new climate law proposed by the European Commission. The European Parliament is debating whether to support a target of 65% reduction by 2030.

[20] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU, OJ L 156/1, 19.06.2018.

3.4 Environmental policy

One of the main areas of environmental policy relevant to biomass for energy is the legislation setting the limits for air, soil and water emissions, covering combustion plants and industrial activities. Air emissions targets have been set for different activities based on the analysis and objectives of the Clean Air Programme.[21] The programme analysed the status of air pollution in the EU, leading to the National Emissions Ceiling Directive.[22] The directive set emissions reduction targets for member states for five air pollutants from 2020. Member states have to achieve these targets with the most appropriate measures determined nationally. The Directive on ambient air quality and cleaner air for Europe[23] also has an impact on indirect emissions through implementing regulations adopted at the national or regional levels.[24]

For emissions of combustion plants, there are two directives in place, one for medium installations up to 50 MW[25] and one for large installations[26] setting the limits for SO_2, NOx and dust emissions. The Industrial Emissions Directive[27] (IED) for larger-scale installations limits the level of air pollutants based on the best available techniques. In theory, permits issued under the IED can also include greenhouse gas emissions limits, but only so far as it is necessary to limit local pollution, or if the installation is not covered by the EU ETS.[28]

In addition to the above directives and regulations, the Ecodesign Directive[29] and Ecolabel Regulation[30] also affect combustion plants. The first sets minimum mandatory requirements for energy efficiency in production, while the second gives voluntary, minimum environmental standards in order to earn the ecolabel. Both include energy efficiency requirements, as well as specific emissions limit values for organic gaseous carbon, CO, NOx and PM.

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[21] European Commission, "A Clean Air Programme for Europe", COM(2013) 918 final, Brussels, 18 December, 2013.

[22] 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, OJ L 344, 17 December 2016.

[23] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

[24] This is the case for example with the Emilia Romagna region's 2020 Integrated Air Plan, which sets emissions limits for PM_{10} and NO_2 at levels where biomass use is rendered unfeasible. See Art. 20 (https://trasparenza.regione.emilia-romagna.it/disposizioni-generali/atti-generali/piano-aria-integrato-regionale-2020-norme-tecniche-attuative).

[25] Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants, OJ L 313, 28.11.2015.

[26] Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants, OJ L 309, 27.11.2001, pp. 1–21.

[27] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions, OJ L 334, 17.12.2010.

[28] See Art. 9 of the Industrial Emissions Directive.

[29] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products, OJ L 285, 31.10.2009, pp. 10–35.

[30] Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel, OJ L 27, 30.1.2010.

Waste management currently has a central position in environmental strategies. The key legislation is the Waste Framework Directive,[31] in which member states are required to design their national renewable energy policies with due regard to a 'waste hierarchy' defined by the directive in order to avoid undue distortive effects on the raw material markets. The new Circular Economy Action Plan[32] envisages a review of the legislation on waste, introducing more stringent requirements.

3.5 Agricultural and forestry policies

Agriculture is the largest source of biomass in the EU – almost two-thirds of the biomass produced – in the land-based sectors (Camia et al., 2018). The agricultural sector provides an estimated 20% of bioenergy feedstock in the form of residues and dedicated energy crops.

Support for energy products are covered by rural development programmes of the EU's Common Agricultural Policy,[33] which include biomass from agriculture and forestry. The support for biomass production for renewable energy is seen as a priority and proposals to reform the rural development policy for the period 2021–17 include a strengthening in this area.

For forestry management and forestry products, the support has to be aligned to the EU forest strategy adopted in 2013[34] and reviewed in 2018,[35] and should lead to a new multiannual strategy starting 2021, namely an afforestation strategy.

Most of the rural development funding for forestry is aimed at the preservation of forests and biodiversity, but it also offers investment support for the management of forests for industrial purposes, such biomass for energy. The support includes specific assistance to forest holders (private or public) for investment in technologies, processing and marketing for forestry products, including for energy use. The rural development programmes also include funds for renewable energy projects to buy equipment in rural areas (including biomass from forestry) and for cooperation and coordination in the supply chain. The rural development policy is under negotiation for the programming period 2021–17 and bioenergy production will likely benefit from increases in support. The policies, however, may be restricted by the work undertaken under the biodiversity strategy (section 3.8).

[31] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, OJ L 312, 22.11.2008.

[32] European Commission, "A new Circular Economy Action Plan for a cleaner and more competitive Europe", COM(2020) 98 final, 2020.

[33] Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005, OJ L 347, 20.12.2013.

[34] European Commission (2013), "'A new Forest Strategy': for forests and the forest-based sector", COM(2013) 659, 2013.

[35] European Commission, "Progress in the implementation of the EU Forest Strategy – 'A new EU Forest Strategy: for forests and the forest sector'", COM(2018) 811 final, 2018.

3.6 Circular economy

The circular economy has become a flagship policy for the EU's Green Deal. The Commission has recently released a new Circular Economy Action Plan[36] that includes the creation of a more coherent and holistic policy framework concentrating on value chains and the circularity of all the stages of industrial processes. It extends to the sourcing and use of biomass products. The action plan is not very explicit in the area of biomass use for energy, but the greater emphasis on the life cycle of all processes and on the protection of biodiversity may affect the biomass sector and its use for energy production.

A 2018 guidance document based on the older 2015 Circular Economy Action Plan[37] presents possible implications for the use of biomass with selected good practice examples on woody biomass.[38] While it predates the present action plan, it does offer insights on the direction policies are taking.

3.7 Bioeconomy Strategy (2018)[39]

The Bioeconomy Strategy is a critical element in defining the use of biomass for energy. The first strategy was published in 2012[40] and was updated in 2018[41] following a progress review published by the European Commission in 2017.[42] The review called for a clearer definition of the concept and more focused, coherent and better supported policy to contribute to the objectives of (i) ensuring food and nutrition security, (ii) managing natural resources sustainably, (iii) reducing dependence on non-renewable, unsustainable resources whether sourced domestically or from abroad, (iv) mitigating and adapting to climate change and (v) strengthening European competitiveness and creating jobs.

The Bioeconomy Strategy considers the role of biomass to be central to achieving the renewable energy, climate and circular economy objectives. Bioenergy is already the EU's largest renewable energy source and is expected to remain a key component of the energy mix

[36] European Commission, "A new Circular Economy Action Plan for a cleaner and more competitive Europe", COM(2020) 98 final, 2020.

[37] European Commission, "Closing the loop – An EU action plan for the Circular Economy", COM(2015) 614 final, 2015.

[38] European Commission, "Guidance on cascading use of biomass with selected good practice examples on woody biomass", Directorate-General for Research and Innovation, Luxembourg: Publications Office of the European Union, 2018.

[39] European Commission, "A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment", Directorate-General for Research and Innovation, Luxembourg: Publications Office of the European Union, October 2018.

[40] European Commission, "Innovating for Sustainable Growth: A Bioeconomy for Europe", COM(2012) 60, 13 February 2012.

[41] European Commission, "A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment", Directorate-General for Research and Innovation, Luxembourg: Publications Office of the European Union, October 2018.

[42] European Commission, "Review of the 2012 European Bioeconomy Strategy", SWD(2017) 374, 13 November 2017.

over the following years. This may cause tension with the forthcoming biodiversity strategy described in the next section.

3.8 Biodiversity Strategy (2020)[43]

A challenge for increasing the use of biomass in the energy sector will be to ensure that it aligns with the EU Biodiversity Strategy.[44] Biomass from agriculture and forestry is an important part of the strategy. For forests, the strategy stresses the need to link the management of forests for biomass to biodiversity considerations. This year, the European Commission is expected to produce a document on the balance between the use of forests for energy biomass and the protection of biodiversity. This may have an impact on an array of policies affecting forestry. In 2021, the European Commission is expected to provide some operational guidance on the sustainability of biomass for energy, including possible measures to phase out biomass energy practices that require extensive land use. The report states that this may lead to "reviews and revision, where necessary, of the level of ambition of the Renewable Energy Directive, the Emissions Trading Scheme, and the Regulation on land use, land use change and forestry (LULUCF) set for 2021".[45] Section 6.3 discusses the biodiversity strategy in more detail.

4. Future demand for biomass to replace fossil fuels in different sectors

As the need for decarbonised energy sources becomes more widespread across EU energy and industrial production, it is important to anticipate what the demand will be in the future in order to better understand the feasibility of such a transition. Estimations are difficult to derive, however, given the properties of different types of biomass, their advantages and disadvantages for deployment in different sectors, as well as the means through which their energy is converted and used.

Generally, the use of biomass-fired systems is more common in the industries that generate solid biomass by-products (e.g. paper and pulp). The penetration of biomass in sectors lacking their own biomass resources will likely encounter more hurdles and could imply additional costs. Even in sectors where biomass use is widespread, actual usage can vary significantly among EU countries. For example, the paper and pulp industry uses biomass to cover 89% of its energy needs in Sweden, while in Italy biomass is virtually unused, with the sector relying mainly on natural gas instead.[46]

[43] European Commission, "EU Biodiversity Strategy for 2030: Bringing nature back to our lives", COM(2020) 380 final, Brussels, 20 May 2020.

[44] Ibid.

[45] Ibid., p. 10.

[46] See Ecofys (2009) 'Methodology for the free allocation of emission allowances in the EU ETS post 2012. Sector report for the pulp and paper industry' (https://ec.europa.eu/clima/sites/clima/files/ets/allowances/docs/bm_study-pulp_and_paper_en.pdf).

The "Masterplan for a Competitive Transformation of the EU Energy-Intensive Industries",[47] developed by the European Commission in 2019, gives an indication of the potential use of biomass in various industrial sectors. While the potential for biomass is identified as high for most sectors (with cement and paper already using biomass on a large scale), it is perceived as low for steel, lime and ceramics (see Table 1).

Table 1. Overview of potential low-carbon solutions in energy-intensive sectors

	Electrification (heat and mechanical)	Electrification (processes: electrolysis/ Electrochemistry excl. H_2)	Hydrogen (heat and/ or process)	CCU	Biomass (heat and feedstock)/biofuels	CCS	*Other (including process integration)*
Steel	**xxx**	xx	xxx	xxx	x	xxx	Avoidance of intermediate process steps and recycling of process gases: xxx Recycling high quality steel: xxx
Chemicals fertilizers	xxx	xxx	xxx	xxx	xxx	xxx(*)	Use of waste streams (chemical recycling): xxx
Cement Lime	xx (cement) o (lime)	o (cement) x (lime)	x (cement) xx (lime)	xxx	**xxx** (cement) x (lime)	xxx	Alternative binders (cement): xxx Efficient use of cement in concrete by improving concrete mix design: xxx Use of waste streams (cement): **xxx**
Refining	xx	o	xxx	xxx	xxx	xxx	Efficiency: **xxx**
Ceramics	xxx	o	xx	x	x	o	Efficiency: **xxx**
Paper	xx	o	o	o	**xxx**	o	Efficiency: **xxx**
Glass	xxx	o	x	o	xxx	o	Higher glass recycling: xx
Non-ferrous metals/ alloys	**xxx**	**xxx**	x	x	xxx	x	Efficiency: **xxx** Recycling high quality non-ferrous: xxx Inert anodes: xxx

o: Limited or no significant application foreseen

x: Possible application but not main route or wide scale application

xx: medium potential

xxx: high potential

***xxx**: Sector already applies technology on large scale (can be expanded in some cases)*

(*) in particular for ammonia and ethylene oxide

Source: European Commission, "Masterplan for a Competitive Transformation of EU Energy-Intensive Industries, Enabling a Climate Neutral, Circular Economy by 2050'" (2019), op. cit.

[47] European Commission, "Masterplan for a Competitive Transformation of EU Energy-Intensive Industries, Enabling a Climate Neutral, Circular Economy by 2050", 2019 (https://op.europa.eu/en/publication-detail/-/publication/be308ba7-14da-11ea-8c1f-01aa75ed71a1/language-en).

Table 2. Indicative figures on annual energy consumption in different sectors with equivalents in solid biomass[48] (the scenario presented is a purely theoretical exploration of a 20% switch to biomass use in the sectors covered in the table)[49] using 2018 emissions data

	Emissions (tCO2e) 2018 (p.a.)	Energy consumption (PJ, p.a.)	Equivalent in pellets 8% moist of a 20% switch (Mt, p.a.)	Equivalent in pile wood 50% moist of a 20% switch (Mt, p.a.)
Power (CHP only)*	126,777,066	1,131–2,535	12.9–29	23.8–53.4
Chemicals (inorganic & organic)	70,319,534	627–1,406	7.1–16	13.2–29.6
Fertilizers	34,522,851	308–690	3.5–7.9	6.5–14.5
Steel	166,249,267	1,484–3,324	17–38	31.2–70
Non-ferrous metals	2,490,767	22–49	0.2–0.5	0.4–1
Cement	115,703,250	1,033–2,314	11.8–26.4	21.7–48.7
Refineries	130,981,084	1,169–2,619	13.3–29.9	24.6–55.15
Pulp and paper	24,814,211	221–496	2.5–5.6	4.6–10.4
Ceramics	12,152,686	108–243	1.2–2.7	2.2–5.1
Lime	26,864,519	239–537	2.7–6.1	5–11.3
Glass	17,356,346	154–347	1.7–4	3.2–7.3

Note: *Part of the power sector (NACE code 35.30) is included here as biomass is used in some combined heat and power (CHP) plants as well as in regular electricity generation for co-firing. It is not intended to purport that biomass will play a dominant role in reducing power sector emissions, which will use a wide range of renewable energy source to decarbonise, such as water, wind, solar, geothermal or tidal energy. About 14% of power sector emissions (126 Mt) can be traced to CHP plants.
Source: Own calculations based on European Union Transaction Log 2018 emissions data.

[48] The calculations of energy consumption equivalent in biomass are worked back from the 2018 European Union Transaction Log of emission data for different sectors. Figures represent one year. The emissions are then converted into energy consumption by using the specific CO_2 emissions associated with methane and peat), for which we estimated the values of 50 $kgCO_2/GJ$ and 112 $kgCO_2/GJ$ respectively, based on available data. The actual energy consumption is within the resulting range, based on the specific energy mix of each industry Then, the equivalent in biomass is calculated based on the calorific value figures of different types of biomass as specified by the European Biomass industry Association (https://www.eubia.org/cms/wiki-biomass/biomass-characteristics-2/). No further assumptions about energy efficiency of energy conversion are made. The table assumes a purely theoretical 20% switch of the energy consumption to biomass in the sectors covered. Therefore, the figures presented in the table are only indicative. The sectors are chosen based on the industries presented in Table 1.

[49] For putting into perspective the scenario of a theoretical switch of 20% of the energy consumption to biomass in the sectors covered in Table 1, this would require a total equivalent of 74.3–166.4 Mt of pellets 8% moist or 136.9–306.6 Mt of pile wood 50% moist, compared with a theoretical 100% switch, which would require a total equivalent of 371.5–832.26 Mt of pellets 8% moist or 684.4–1,533.1 Mt of pile wood 50% moist. This comparison is offered for context and it is not intended to purport that a 100% shift to biomass is realistic, likely or indeed desirable.

Judging the European Commission's long-term strategy, it seems safe to assume that biomass use will become ever more common across multiple sectors of the economy. This may lead to competing interests over a resource that has limits on availability. To illustrate how a broad switch to biomass across multiple sectors could translate into feedstock requirements, Table 2 shows the theoretical equivalent in solid biomass form of 20% of today's energy consumption by different EU sectors covered in Table 1. Woody biomass represents the main source of solid biomass used, with pellets being the most common form of upgraded solid biomass (Malico et al., 2019). Solid biomass can either be used directly (e.g. wood chips, bark, pile wood) or be upgraded for increased efficiency (e.g. pellets, charcoal). Upgrading is needed not only for increasing the energy density of the fuel, but also for easier transport and storage. Therefore, the calculations reflect both the energy consumption equivalents in pile wood and pellet form.

The technical advantages and disadvantages of conversion to biomass differ from one sector to another and depend on the proprieties of different types of biomass, such as elemental composition, ash content, volatile matter content, moisture content, heating value and bulk density, as shown in Table 3. Based on such combinations of desirable properties, different forms of biomass fuels and uses may be useful or not in each sector. The way in which biomass is best utilised and transformed into bioenergy can also vary. Based on different needs, biomass may be used directly, upgraded, gasified or fed into CHP plants, among others. Each of these conversion methods come with associated benefits and disadvantages, have particular economic fundamentals and is at a different stage of technological development and deployment.

Table 3. Comparison of properties among different solid biomass fuels and coal

	Poplar wood	Willow wood	Wood chips (hybrid poplar)	Bark (pine)	Wheat straw	Rice hulls	Pellets (wood)	Wood torrefied at 250-290 °C	Char (willow, 550 °C)	Bituminous coal
Proximate Analysis (wt% dry)										
Fixed carbon	13.71	15.01	20.30	26.60	17.71	37.83	17.58	24.68	82.20	56.18
Volatile matter	85.07	83.40	77.90	71.80	75.27	38.80	82.20	72.20	11.60	34.23
Ash	1.22	1.59	1.80	1.60	7.02	23.37	0.22	3.12	6.20	9.59
Ultimate Analysis (wt% dry)										
Carbon	49.42	50.19	44.00	53.90	44.92	37.86	47.30	53.00	81.70	74.14
Hydrogen	6.00	5.90	5.50	5.80	5.46	4.75	6.76	5.50	2.40	4.79
Oxygen	43.07	42.22	47.70	38.26	41.77	33.49	46.02	37.87	8.60	9.85
Nitrogen	0.23	0.10	1.00	0.40	0.44	0.23	0.15	0.45	0.40	1.27
Sulphur	0.05	-	0.00	0.03	0.16	0.31	0.01	0.04	0.04	0.36
Moisture content (wt%, wet basis, as received)	4.80	43.50	9.20	5.00	8.15	8.00	7.00	8.00	0.10	3.00
Higher Heating Value (MJ/kg) (dry)	19.50	18.56	16.40	21.37	17.94	13.3	19.32	20.70	34.90	30.13

Source: Compilation by Malico et al. (2019) using ECN (2017) data.

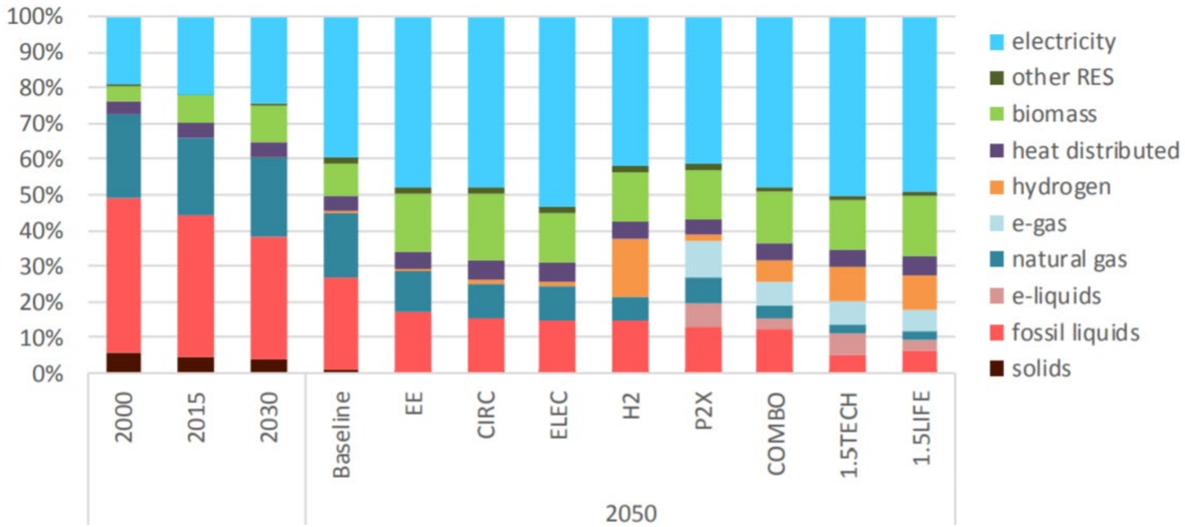
For some industrial processes the direct use of woody biomass may not be a viable option. For example, in the production of tiles and pots, which are usually made in tunnel kilns using natural gas, even minor changes in fired colour can have significant effects on the properties of the end product. Ashes from direct biomass use also become entrained in flue gases, which can make it difficult to meet emissions limits, while dust can interfere or completely disrupt the cleansing process of such tail-end equipment as packed-bed lime scrubbers (Rimpel, 2006). That is why natural gas is currently used. As low-carbon options in the future biogas, biomethane, synthetic methane or other types of biofuels may be alternatives.

In some cases, even if certain types and uses of biomass represent viable possibilities, economic barriers such as high investment costs, availability and security of supply of feedstock or generally the lower costs of fossil fuel alternatives (Malico et al., 2019) hinder the uptake of biomass. The expected increasing use of solid biomass for both energy and non-energy purposes and their competition for limited supply capacity from sustainable domestic production, raises questions about the ability of the future EU biomass production to meet the growing demand. Regulatory restrictions (sometimes regional) can necessitate the installation of dedicated production facilities, which can significantly drive up costs.

5. Biomass availability

As shown in the historic and projected data in Figure 2, biomass and waste are expected to increase their share in all decarbonisation scenarios according to the European Commission's 2018 long-term strategy,[50] partially driven by increased penetration of advanced biofuels, but also through the use of biogas; biomass and waste may thus represent between 14% and 19% of the final energy demand in 2050, starting – according to IEA data[51] – from a share of slightly more than 8% in 2017. Given this growing use of biomass as part of the decarbonisation effort, availability[52] at both the EU and regional level matters.

Figure 2. Historic and projected shares of energy carriers in final energy carriers



Source: European Commission, "A Clean Planet for all" (2018), op. cit.

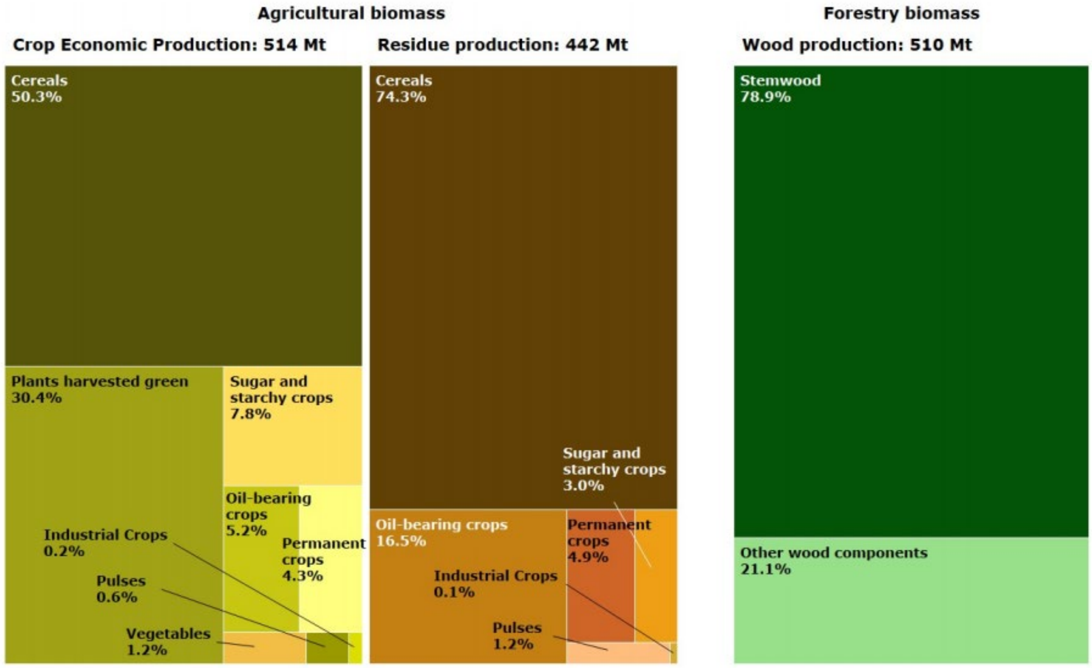
[50] See European Commission "In-depth analysis in support of the Commission Communication, COM(2018) 773 ('A Clean Planet for all'), Brussels, 28 November 2018 (https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf), p. 72.

[51] See https://www.iea.org/data-and-statistics/data-tables?country=EU28.

[52] This section presents some figures that can illustrate this availability, mostly based on data collected and processed for the 2018 JRC Science for Policy Report (Camia et al., 2018).

Biomass for energy purposes is generally obtained from organic matter extracted from forests and uncultivated lands, energy crops, waste and residues from industrial, agricultural and forestry activities, and municipal waste. The agriculture, forest-based and marine sectors represent the main suppliers of biomass in the EU. Production from the land-based sectors (forestry and agriculture, excluding pastures) is estimated at 1.466 Mt of (above ground) dry matter. Figure 3 shows the split of biomass based on source in the EU-28.

Figure 3. EU biomass production from land-based sectors, average (2006–15)

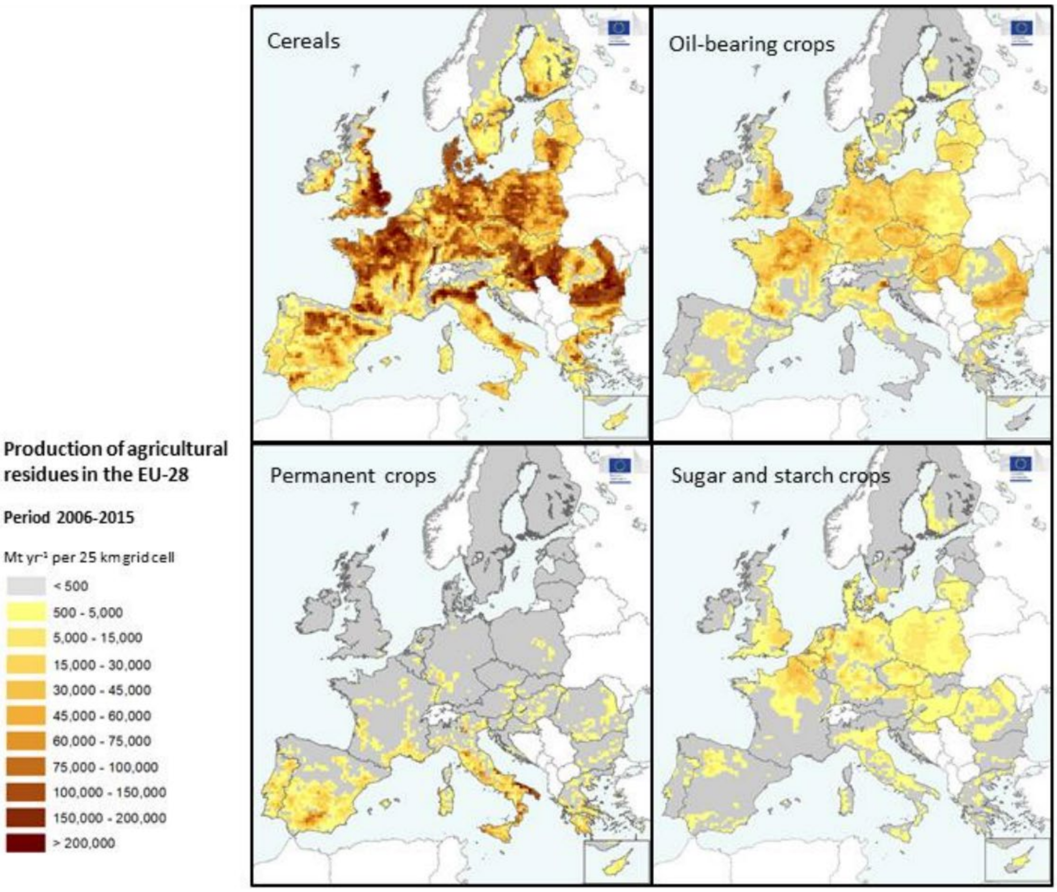


Source: European Commission, "A sustainable Union, Bioeconomy for Europe" (2018), op. cit. and Camia et al. (2018).

Not all biomass is used for the same purpose. According to data presented in the JRC Science for Policy Report (Camia et al., 2018), around 80% of agricultural biomass was used as food and feed. Furthermore, 98 Mt of dry matter of vegetal biomass equivalents were exported, the remainder being used as either biofuel, biomaterial or waste. Meanwhile, 52% of wood primary and secondary sources were utilised for materials and 48% for energy.

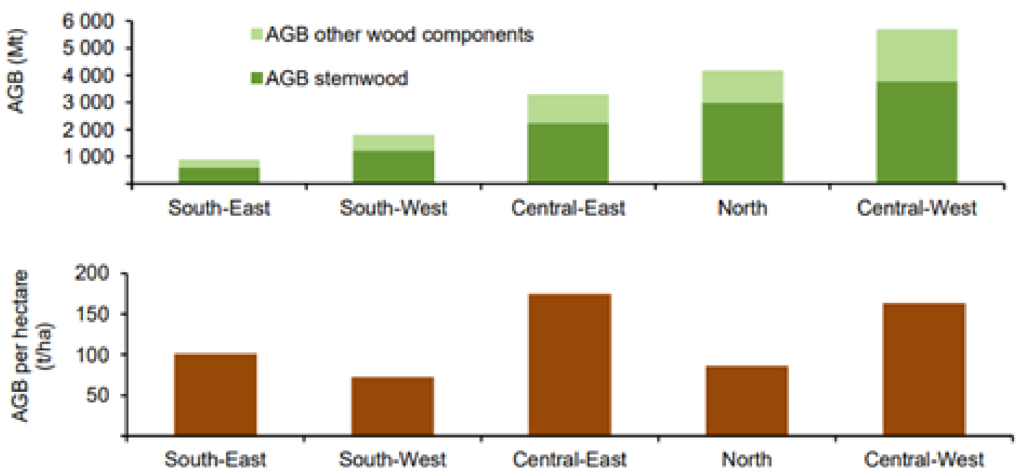
The production and availability of biomass varies significantly among EU countries, creating different opportunities across EU regions. When it comes to economic production of agricultural biomass, France, Germany and Italy are the largest producers. The main sources of waste are France, Germany, Poland and Romania. Whether residues are viable for bioenergy production is usually a function of the associated transport costs (Camia et al., 2018). Figure 4 shows a spatial distribution of agricultural residues across the EU, which play a major role in determining the economic efficiency of using it as a source of bioenergy.

Figure 4. Spatial distribution of agricultural residues from four main crop groups



Source: Camia et al. (2018).

Figure 5. Above-ground biomass in EU regions (in Mt and average per ha)

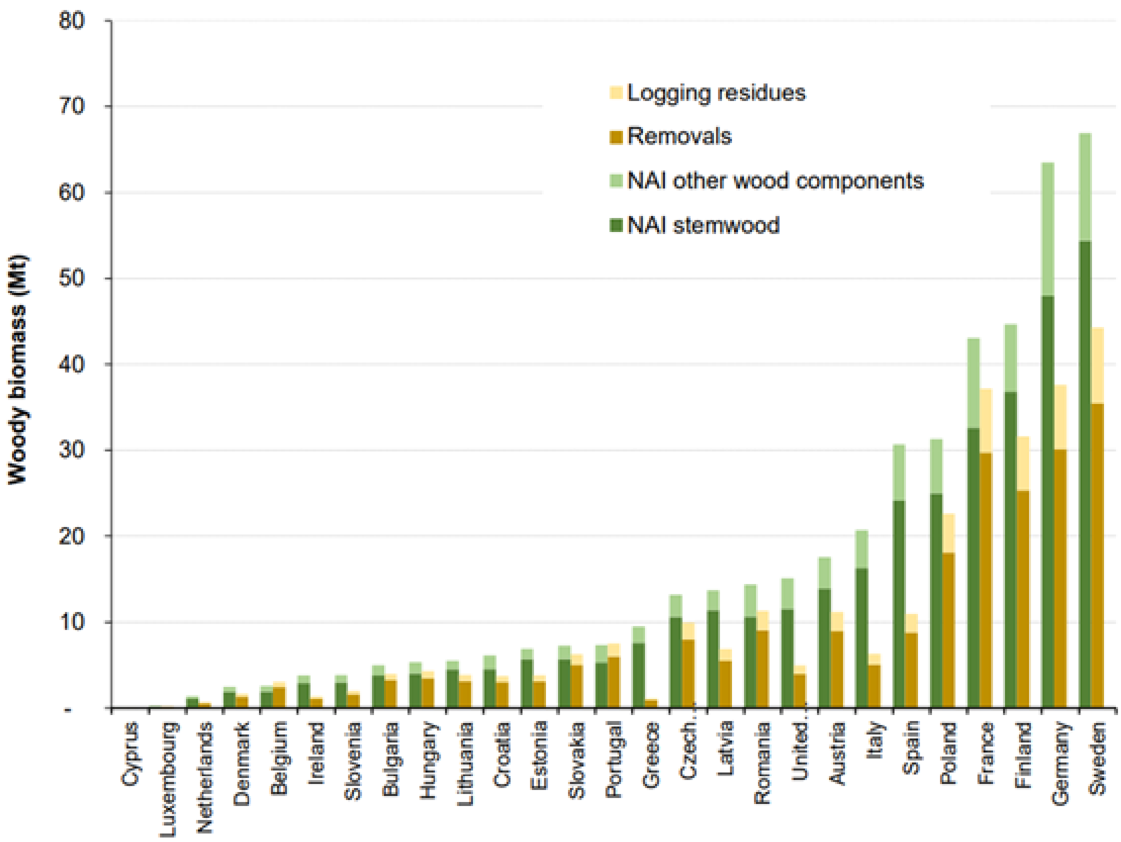


Note: EU regions are split into the following categories: Central-East (Poland, the Czech Republic, Slovakia, Hungary and Romania); Central-West (Ireland, France, Germany, the Netherlands, Belgium, Luxembourg, Austria, as well as the United Kingdom); North (Denmark, Sweden, Finland, Lithuania, Latvia and Estonia); South-East (Slovenia, Croatia, Bulgaria, Greece and Cyprus); and South-West (Portugal, Spain, Italy and Malta).

Source: Camia et al. (2018).

Regarding another major source of biomass, namely forest areas, these cover 38% of EU land, 84% being considered available for wood supply (approximately 134 Mha). While the rate has been decreasing in the past few years, EU forests have been expanding by an average of 0.26% between 2000 and 2015. The total woody above-ground biomass availability in the EU is estimated at 18,600 Mt of dry matter, 32% of which is in the form of stemwood, with the remaining share in the form of other wood components, such as branches, stumps and tops (Camia et al., 2018). Figure 5 shows a distribution of above-ground biomass in different EU regions, as well as the biomass stock per hectare, which is influenced by locally-specific ecological factors and different forest management practices. To better understand availability trends, Camia et al. (2018) also estimate the net annual increment in woody biomass, understood as the annual production minus losses resulting from the natural mortality of trees, as shown in Figure 6.

Figure 6. Harvesting and net annual increment of woody biomass, 10-year average (2004–13)



Note: NAI = net annual increment.
Source: Camia et al. (2018).

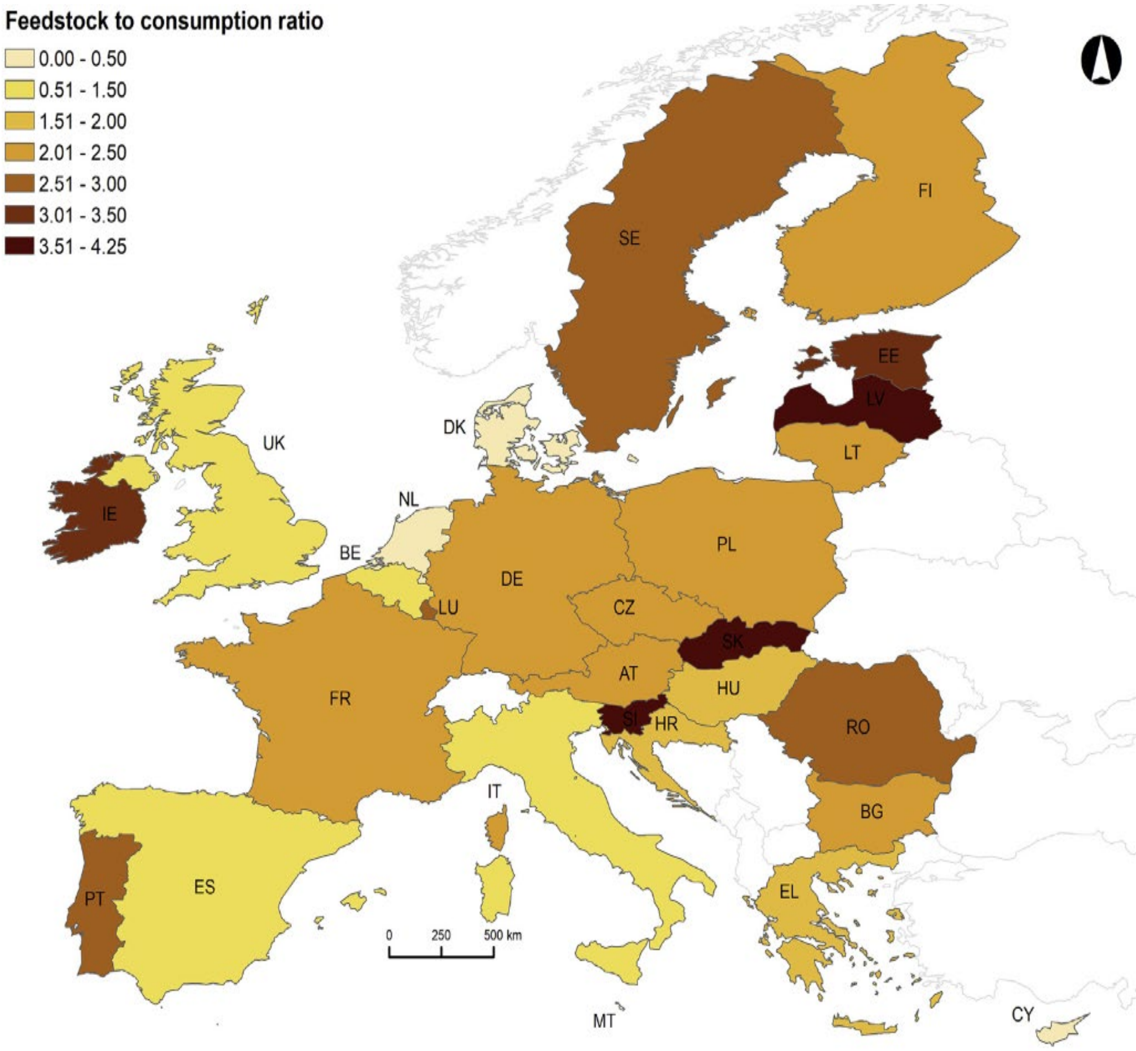
The costs associated with biomass use can vary significantly based on type, quality, local supply chains, resource availability, sustainability criteria and policy choices on competing biomass uses (Malico et al., 2019). This may represent a challenge, especially as most EU countries are net importers of woody biomass. Supply chains in some countries are already stretched by the rising levels of demand. Figure 7 shows the ratio of the biomass potential and the biomass gross

inland consumption. The higher the ratio, the more potential a country has for increasing its biomass consumption by using domestic sources. Countries such as Denmark, however, which cover less than half of their biomass consumption from domestic sources, need to assess the opportunities and costs of imports for expanding their biomass use.

While more difficult to quantify, the economic efficiency of using biomass for energy and industrial processes may be further constrained by regional barriers in the form of local regulatory regimes or natural hazards, such as regulations in the Emilia Romagna region.

Unprecedented and extraordinary events may also cause significant temporary decreases in availability. An example of such a hazard is the recent 'bark beetle calamity', which led to significant losses in tree stocks in the Czech Republic, France, Germany and Sweden, among others. As it also affects young trees, this kind of event is not only detrimental to short-term availability, but it may also have an unpredictable impact on future availability.

Figure 7. Ratio between biomass potential and biomass gross inland consumption



Source: Malico et al. (2019) calculations, based on data from Mandova et al. (2018) and Eurostat.

Similar such examples of regulatory barriers may exist across the EU, but the most significant barrier to switching to renewable biomass remains an economic, rather than simply a regulatory issue. Moreover, a number of trade-offs also need to be considered regarding the most efficient use of land and biomass in the decarbonisation process.

Although initially sustainability criteria like those formulated by RED II may curtail the available supply, there is still the overall aim of expanding the supply of biomass of different types – provided they meet strict criteria — given the importance of the bioeconomy in long-term climate policy. Additionally, strict regulation increases transparency, which may drive both demand and supply as there is more regulatory certainty, despite potentially narrowing the types of biomass that are deemed sustainable.

6. Trade-offs

Biomass and bioenergy are land-intensive resources, which therefore may lead to competition for other uses of land, some of which may play a pivotal role in long-term climate policy. Negative emissions attainment or agriculture are examples. Land use has an influence on biodiversity, the protection of which is a separate environmental policy goal of the EU. Beyond land use, air quality may be affected by various climate and energy policy choices, and there too biomass can have an impact.

It is inevitable that there will be opportunity costs in pursuing climate, energy, environmental and agricultural policy objectives. The trade-offs between these objectives are inherently political. Nevertheless, these trade-offs are not cast in stone. Sustainable land and forest management, as well as deployment at appropriate scale, can mitigate trade-offs (see, e.g. Nabuurs et al., 2007) and generate complementarities, such as those between biodiversity or food security while still using land for biomass or negative emissions. From a global perspective, it is desirable that the scale of land use for climate mitigation purposes is only applied to limited shares of total land.[53]

6.1 Air quality

Biomass combustion may have adverse impacts on air quality (Nussbaumer, 2017). While being a wholly separate environmental issue next to climate policy, air quality and greenhouse gas emissions are often considered in tandem as there may be co-benefits in addressing either. Air quality adds a specific local dimension – in contrast to climate policy, where location does not matter for CO_2 emissions – and one with immediate short-term impacts, also on public health. The main (non-greenhouse gas) pollutants produced during the combustion of biomass are PM, and NO_x,[54] while CO, volatile organic compounds, SO_x and other hazardous air pollutants can also play a role.

[53] See section B3 of the "Summary for Policymakers" in the IPCC Special Report on Climate Change and Land (2019).

[54] See https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf, p. 3.

Compared with natural gas combustion, biomass combustion has a negative impact on air quality. At the same time, the impact on air quality of biomass combustion for energy production, in some cases, depending on the exact pollutant, is limited compared with other sectoral sources of air pollution. These other sources may include road transport and aviation, but also agriculture or household combustion of biomass (e.g. in fireplaces). For NO_x emissions, road transport is the main contributor at 36% in the European Economic Area, while $PM_{2.5}$ is mostly caused through commercial and household use (55%). Conversely, in the case of SO_x, energy production and energy use in industry (where biomass can play a role today) are the main contributors with over two-thirds of the totals.[55]

A study prepared for the UK Department for Environment, Food and Rural Affairs, the Scottish and Welsh governments, and the Northern Ireland Department of the Environment discusses the potential risk of switching from natural gas to biomass combustion in the domestic context. The study describes emissions factors for domestic consumption of fuels, implied by the energy content of fuels (Table 4).

Table 4. Overview of air pollutant emission factors for different fuels

	NO_x (g/GJ)	$PM_{2.5}$ (g/GJ)
Wood	56.5	625
Coal	81.5	387
Burning oil	73.7	3.2
Gas	21.6	0.5

Source: Air Quality Expert Group/DEFRA UK (https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf) p. 36.

The increase in local air pollution levels due to biomass combustion is such that in highly industrialised regions like Emilia Romagna, regional legislation can prevent the switch to biomass combustion for thermal processes. Specifically, industries cannot start using biomass as fuel if they do not guarantee net-zero emissions of NO_x and PM_{10} (Piano Aria Integrato Regionale 2020 – Art. 20).

While particulate matter emissions would likely increase considerably relative to other energy sources, the exact implications depend on the applied technology (e.g. CHP or filters) and the local context (e.g. population density and particulate matter emissions from other sources, notably commercial/household energy use and transport). In order to comply with – sometimes local – air quality standards the use of biomass is likely to require technical adjustment and therefore is more than a simple energy-input substitution.

[55] See https://www.eea.europa.eu/data-and-maps/daviz/share-of-eea-33-emissions-5#tab-chart_1.

There are also NO_X implications. In one example discussed by PBL (2020),[56] the combustion of wood pellets in a CHP plant of 120 MW would lead to negligible increases in particulate matter emissions (0.01 µg/m3) and a more noticeable rise in NO_2 emissions by 2.3%.[57]

In the case of NO_X emissions, in recent years some countries in north-west Europe have faced policy challenges to reduce these emissions in line with EU regulations. Hence, even if the contribution of increased bioenergy use on NO_X emissions is limited, it may nevertheless be politically unwelcome, also in light of the difficulty in reducing similar emissions in the agricultural sector.

It follows from the above that air quality concerns could lead to concerns over (or constraints on) biomass use. Still, the scale of deployment matters, since there are many other sectors likewise contributing to air pollutant emissions, in some cases by greater amounts than the energy and industry sectors.

6.2 Food security

If biomass production competes with agricultural land, an issue with food security may arise. This is potentially a greater issue if large volumes of biomass were imported, because of the prospect of more precarious food-security conditions in some countries and because it may be harder to assess impacts internationally. Due to the food price channel, impacts in one region may have repercussions elsewhere.

The IPCC Special Report on Climate Change and Land (2019) states that increased competition for land is associated with greater risks to food security, which it defines as risks to crop yields or food system instabilities. While the report notes that most climate-mitigation policy options can be pursued without competing for available land, and that land can "make a valuable contribution" to mitigation, there are nevertheless limits to scale if too much land is needed for carbon removal purposes, i.e. afforestation or bioenergy at the level of several gigatonnes a year.[58]

It also follows that the more land is (politically) constrained for negative emissions purposes, the more rapidly emissions need to be reduced to avoid compounding the need to remove carbon. Efficient biomass use is therefore important from the perspective of both potentially enabling rapid emissions reductions where other options are not available, and limiting the volumes of negative emissions.

In the high-level pathways that the IPCC assessed, strategies that prioritise bioenergy and BECCS, along with biochar soil additions, tend to have a lower impact on food security than afforestation, although reforestation can also bring some food security co-benefits.

[56] See https://www.pbl.nl/sites/default/files/downloads/pbl-2020-beschikbaarheid-en-toepassingsmogelijkheden-van-duurzame-biomassa-verslag-zoektocht-naar-gedeelde-feiten-opvattingen_4188.pdf.

[57] Ibid., p. 94.

[58] See https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf, section B3, p. 21.

Afforestation, if pursued at large scale, can lead to food price rises of 80% and increased undernourishment.[59]

6.3 Biodiversity

Ensuring sustainability in sourcing biomass is a key aspect for its increasing use, given its relationship with biodiversity, among others. Activities in the bioeconomy sectors rely strongly on healthy ecosystems and on maintaining the flow of ecosystem services, but such activities can in turn have an impact on the local and global climate (Camia et al., 2018). Climate change itself is a phenomenon that exacerbates biodiversity loss and ecosystem degradation, which can then reduce the ability of ecosystems to capture and sequester carbon.[60] The IPCC Special Report on 1.5°C (2018) estimated that with a 2° C temperature change, 13% of global land area would change from one ecosystem type to another, with 18% of insects, 16% of plants and 8% of vertebrates losing over half their climatically determined geographical range.

The UN Sustainable Development Goal 15 on life on land acknowledges that "[p]rotecting key sites important for terrestrial, freshwater and mountain biodiversity is vital for ensuring long-term and sustainable use of ... various natural resources",[61] which can limit the potential for biomass availability, especially from forests.

Meanwhile, there are some potential trade-offs related to greater use of bioenergy for meeting climate objectives on one hand, and the preservation of biodiversity on the other hand. The extraction of wood is the most significant driver of degradation of biodiversity in forests, while agricultural expansion represents the main driver of deforestation (PBL, 2014). Increased biomass production from wood and lignocellulosic crops are some of the main sources that will cover the uptake in demand, raising the issue of the balance with biodiversity needs. Similar trade-offs lie in the intensification of agricultural production, which can have consequences for biodiversity and other environmental sustainability concerns.[62]

Such trade-offs need to be well-managed, in order to maximise the climate benefits of biomass use, while having a minimal impact on food security, biodiversity and land degradation. Adequate evaluation and monitoring of the environmental effects of the expansion of bioeconomy sectors and the use of bio-based commodities can be a starting point for ensuring the necessary and timely protection of the ecosystems associated with the sourcing and use of biomass (Camia et al., 2018). Ensuring that sustainability concerns are addressed appropriately across the entire value chain of biomass production and use – from the growing and harvesting of feedstock, to processing, conversion and distribution of bioenergy carriers – is another important policy objective (Scarlat et al., 2019).

[59] See https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf, p. 27.

[60] European Commission, "A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy", COM(2018) 773 final, Brussels, 28 November 2018.

[61] See https://unstats.un.org/sdgs/report/2017/goal-15/.

[62] Ibid., 61.

Restrictions on the use of biomass as a renewable energy source based on its impact on biodiversity already exist. Art. 29 of RED II establishes that agricultural biomass should not be made from raw material sourced from land with a high biodiversity value, such as primary forest, highly biodiverse forests and wooded areas, areas protected for the conservation of nature, endangered ecosystems or highly biodiverse grassland.

The abovementioned EU Biodiversity Strategy for 2030 released in May 2020 also establishes general guidelines to put Europe's biodiversity on a path to recovery by 2030. The objectives of this strategy limit the potential production of biomass that will be available for the EU's goal of net-zero emissions. Thus, the EU's primary and old-grown forests are to be strictly protected, while also stipulating that the EU's actions should not cause deforestation in regions outside the EU's border. At least 30% of the EU's land area will be legally protected. The strategy also acknowledges the part that more sustainably sourced bioenergy will play in meeting the climate targets and in preventing biodiversity loss. In this light, the use of whole trees and feed crops for energy production, either produced within EU borders or imported, should be avoided as much as possible.

Further limitations on biomass production will also be put in place though the operational guidance for RED II on the new sustainability criteria on forest biomass for energy, which will be released in 2021. Moreover, the results of an assessment of the sustainability of the EU and global biomass supply and demand, to be published by the end of 2020, will be used as informational input for the planned review in 2021 of the Renewable Energy Directive, the ETS Directive and the LULUCF Regulation.

To address the current deficiencies in protecting biodiversity, the Commission will put in place a novel European biodiversity governance framework. An EU forest strategy, to be released in 2021, will further align the wider biodiversity and climate ambitions.

6.4 Land use

The role of land in climate policy has received more high-level attention in recent years with the release of the IPCC Special Report on Climate Change and Land (2019). Land use affects carbon sequestration and sinks (also for negative emissions), food production and biodiversity, and can support bioenergy production.

These issues may be reflected in possibly (but not necessarily) conflicting political priorities. In addition, there may be a temporal dimension to these priorities, with some taking precedence over others in the context of certain climate policy horizons (e.g. 2050).

The IPCC Special Report lists a number of climate policy options that would rely on (additional) land use and for which there may be significant trade-offs. Some of these directly involve biomass.

The first policy option is the use of bioenergy, perhaps combined with BECCS. This is considered to have potentially large impacts on adaptation, desertification, food security and land degradation. However, the impacts are not easily quantified and much depends on the scale at

which it is applied (globally). If bioenergy were to be primarily produced on marginal lands or abandoned croplands, adverse impacts can be mitigated to a notable extent.

Afforestation and reforestation can be seen as alternative ways to achieve negative emissions, but also carry trade-offs for land use. Large-scale afforestation could push up global food prices due to competition for land, although for reforestation this is much less so. There are also co-benefits in preventing desertification, while small 'best-practice' afforestation can be positive for food security. Finally, the use of biochar could improve the yields of agricultural lands in certain regions, but can also increase competition for land due to the biomass crops needed for biochar production.

While the IPCC warns that biomass production for bioenergy or biochar pursued at scale can have negative consequences for land conversion, endangering other societal goals, limited and sustainable land use for biomass can deliver positive co-benefits. Therefore, the key policy question about biomass is how to deploy it optimally, not how to limit its use to the greatest possible extent. Biomass sourced from residues and wastes largely limit detrimental effects to potential soil degradation and are thus beneficial, but the supply is limited.

Global land use for bioenergy in modelled scenarios ranges from 400,000 (the lower bound for 2° C, slightly larger than Norway's landmass) to 7 million square km (the upper bound for 1.5° C, over two times India's landmass).

7. Can biomass use help deliver negative emissions?

Negative emissions at scale will be an indispensable part of long-term climate policy in the EU. Negative emissions are implicit in the formulation of a net-zero target for greenhouse gas emissions as is being discussed for the EU climate law. Globally, the IPCC Special Report on the 1.5°C (2018) target examines emissions pathways that limit global warming to 1.5° C, which will require negative emissions on a large scale. If there is an overshoot of the temperature target that needs to be compensated later in the century, the volume of negative emissions that needs to be achieved grows. However, even with rapid emissions reductions some negative emissions may be necessary to compensate for residual emissions in hard-to-abate sectors.

Negative emissions (or carbon dioxide removal) can be attained through the agricultural and forestry sector (AFOLU – in IPCC terms) or through BECCS. In the AFOLU sector, if negative emissions are pursued through afforestation, great surface areas of land may need to be converted to forests. This could have implications for food security and other agricultural activities. At the same time, it is possible to combine growing forest areas with co-benefits for biodiversity while also allowing for some degree of wood harvests to expand. Still, as long as negative emissions are needed to compensate ongoing emissions, the land-use implications are vast. Reforestation has fewer land-use impacts. According to the IPCC, a long-term sustainable forest-management strategy that maximises climate mitigation maintains or

increases the forests' carbon stocks, but also produces a sustained yield of "timber, fibre, or energy".[63]

If the use of bioenergy is expanded, the concomitant application of CCS allows for the delivery of negative emissions. However, this presumes the availability of infrastructure for CO_2 transport and storage on an appropriate scale. On the other hand, the land use implications of BECCS can be more manageable for an equivalent volume of negative emissions as the energy crops can be continually harvested and regrown while the CO_2 is stored permanently.

The difference between the two approaches to achieve negative emissions is also highlighted in the European Commission's 2018 long-term strategy ("A Clean Planet for all"), which analyses a number of scenarios, two of which specifically look at 1.5° C. The 1.5° C TECH scenario assumes that BECCS is prioritised while the 1.5° C LIFE scenario prioritises 'nature-based' negative emissions. The total land area required for the BECCS-heavy scenario is lower than for the LIFE scenario, as well as potentially costing less to deliver a tonne of negative emissions (although it does not account for CCS-specific costs).

Biomass for bioenergy production may therefore play a key role in a net-zero, climate-neutrality strategy. This implies that at least some parts of the economy should use bioenergy. Ideally, this would include sectors that also deploy carbon capture technology, so that negative emissions are delivered.

8. Discussion: optimal use of biomass over the long-term

To determine how biomass can be used optimally the principle of cascading can be applied, whereby biomass is prioritised in cases where its use brings the most benefits. This still requires further criteria to determine exactly what is the most beneficial. It also requires normative, political, decisions to prioritise conceivably clashing policy objectives and the degree to which policy or the market should promote certain outcomes.

Examples of criteria that can help determine 'optimal use' include overall volumes or limits on volumes, added value in sectors where biomass would be used, the potential for CO_2 avoidance, the demand for negative emissions, or the availability of alternatives to reduce emissions.[64]

Using wood as a material, as opposed to using it as fuel, is often considered to be one of the highest-value uses of biomass (Churkina et al., 2020) due to the potential for significant avoided CO_2 emissions with lower basic material demand. Nevertheless, some CO_2 is still lost when trees are cut down for harvested wood products.[65] Yet, such material substitution requires a type of biomass (timber from whole trees) that is not necessarily in competition with other uses of biomass, such as for energy, as waste streams or non-woody biomass could also be used for

[63] See https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-chapter9-1.pdf, p. 543.

[64] See https://www.pbl.nl/sites/default/files/downloads/pbl-2020-beschikbaarheid-en-toepassingsmogelijkheden-van-duurzame-biomassa-verslag-zoektocht-naar-gedeelde-feiten-opvattingen_4188.pdf, p. 89.

[65] Harvested wood products and the carbon stock contained therein have their own accounting principles defined by the UNFCCC. See e.g. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf.

this. In the chemical industry specifically, biomass could be used as a feedstock, thereby supporting emissions reductions.

Use of biomass for energy purposes could be regarded as having lower value, as more alternatives often exist, and because of the comparatively low energy density of biomass. But even within this category there are differences, with biomass use for industrial heating being more valuable than residential heating or electricity. Likewise, within transport, lack of alternatives could be seen to increase the attractiveness of biomass, i.e. use in aviation or maritime transport rather than in road transport.

There is agreement that globally, biomass (together with other renewable energy sources) has an important role to play in reaching climate neutrality and it is expected to grow further, as for example has been highlighted by the IPCC. In the EU, both the 2018 long-term climate strategy and the European Green Deal have emphasised the importance of the bioeconomy.

However, there are many trade-offs, for example between land as sinks, biomass for product substitution, energy use or biodiversity, and local air pollution concerns. Pursuing biomass at greater scale invariably involves trade-offs, which require political and sometimes normative choices. Perspectives will evolve over time with regional or member state-wide variation.

If biomass is pursued on a large scale, land-use effects can affect carbon sinks but also other environmental and societal objectives: air quality, biodiversity and food security may be affected. This is partly mirrored in the ongoing scientific controversy on whether biomass can be carbon neutral or not. The outcome of this debate depends, among others, on assumptions on the type of biomass used as well as the geographies and timescales applied. This reflects the fact that while the combustion of biomass is counted as 'carbon neutral', it takes time for the carbon to be reabsorbed from the atmosphere.

The trade-offs for using biomass are highest with woody biomass, mainly because of possible alternative uses of the wood or the land or because sometimes biomass requires further steps, e.g. conversion technologies before fossil fuels can be substituted. Still, some (limited) biomass use would always be beneficial as sustainable forest-management practices enable the availability of both wood harvests while maintaining or growing carbon sinks. Non-woody (wet) biomass from, e.g. agricultural wastes, can also provide energy without impinging too much on land. To not use such forms of biomass could be seen as negative for climate policy, as it requires other decarbonisation options to be pursued on a greater scale, some of which have their own challenges and limitations (e.g. low-carbon gas, or electrification).

The availability and use of biomass may be constrained by different EU policies (climate, the environment, energy or the circular economy). There is also significant regional variation within the EU, which may be caused by both natural availability and national regulatory barriers. Moreover, not all types of biomass are suitable for usage in some sectors and processes. Thus, the future uptake of biomass across economic sectors in the EU will depend on multiple factors, notably costs, local availability, the properties of different types of biomass, technological readiness and the process through which biomass is used (direct combustion, upgraded,

gasified, etc,). Like with other decarbonisation options, innovation may be necessary to enable more sectors to make efficient use of the (bio) resources available.

One of the choices central to long-term climate policy is the demand for negative emissions. BECCS as well as increased afforestation and reforestation can deliver negative emissions. The latter requires more land (to keep reabsorbing ongoing CO_2), possibly with adverse consequences for agriculture, but may also bring some co-benefits for biodiversity.

The key questions are in what sector or application biomass use brings the most value and where volumes are manageable so that the trade-offs, in turn, are also manageable. In all cases, the availability of biomass of different types across different regions is important. Both regulatory and economic barriers may constrain demand.

In the power sector volumes may be significant if biomass is used for combustion, including in CHP plants. Nevertheless, delivering heat in a low-carbon way to all households is a significant policy challenge – not all buildings may be renovated in time, or are suitable for heat pumps.

While most of industry is expected to decarbonise through a combination of electrification, CCS and hydrogen, biomass may still be an option if other abatement options are technically difficult or economically unattractive, for example because the emissions are dispersed over various small installations. Wherever biomass is used, being mindful of the potential scale of deployment matters. As with other abatement options, such as hydrogen or CCS, there are trade-offs for biomass use and these trade-offs become more pronounced as the scale increases. Furthermore, with greater scale, the question of imports becomes more acute, which could bring additional dilemmas to ensure sustainability criteria are met.

9. Conclusions and recommendations

This analysis started from the premise that alongside other climate-neutral technology options, biomass and bioenergy, as part of the larger bioeconomy, will play a larger role in the EU's attempt to achieve the European Green Deal objectives, provided that biomass produced sustainably and assuming it is carbon neutral. All the scenarios in the European Commission's 2018 long-term strategy, which underpin the European Green Deal, foresee an increase in bioenergy compared with 2015 levels. Even the most 'biomass restrictive' scenario (1.5° C LIFE-LB) still leads to a projected expansion in absolute terms.

At the same time there is much discussion about the extent to which biomass may and should represent a widespread solution. Choices made in the industrial sector will be among the determining factors in this conundrum: despite almost all European Commission scenarios in the 2018 long-term strategy projecting higher levels of biomass consumption, there are multiple alternatives to biomass use, in the form of increased deployment of clean hydrogen or electrification. The choice between biomass as a fuel or hydrogen and electricity as energy carriers will depend greatly on availability and relative prices in the future, but also on policy and regulatory choices at both the EU and national levels.

The understanding of the benefits associated with biomass production and use may change over time. Different time horizons affect the usefulness of biomass in reaching the climate-neutrality objectives under the European Green Deal: while from a physical perspective biomass combustion results in greenhouse gas emissions, these emissions are not recorded except as land use emissions in the biomass-producing country, as in the long run the emissions are absorbed from the atmosphere again.

Most importantly, there are multiple trade-offs, such as between forests as sinks, renewable energy, material substitution, recycling, the potential for negative emissions via BECCS, or the need to reconcile biomass with other EU or global policy objectives. Biodiversity, local air pollution, agriculture and forestry policies represent some of the most consequential factors guiding these trade-offs. In view of the various potential benefits that biomass may generate, especially if considered in isolation, a large-scale uptake in its use might raise the risk that biomass volumes may not be sufficient to satisfy demand. Moreover, the aforementioned trade-offs are influenced by the scale at which biomass is deployed.

These trade-offs also vary for different types of biomass, with woody biomass being one of the most controversial. Since the 1990s, the carbon sink of the total EU forest has been stable or even marginally increasing.[66] For the future, the estimations in the 2018 long-term strategy reveal that it should be possible, in principle, to use land for bioenergy production while simultaneously increasing the sink capacity. The forthcoming forestry strategy will be a crucial EU milestone and an opportunity to develop a strategy with a workable definition of what sustainable forestry is. Yet, other trade-offs also need to be taken into consideration for reaching the most desirable option from both a climate and environmental perspective.

Therefore, as the discussion on the sustainability of woody biomass is still underway, it may be worthwhile to expand the use of alternative biomass types, for instance from wastes and residues, especially those that can support the circular economy framework. That being stated, not all sectors are able to immediately make use of any type of biomass for energy; as with other clean energy sources, technological innovation and commercial scale-up may be required to effectively deploy (for both production and consumption) alternative fuels derived from biomass, such as biogas or biomethane.

Recommendations

1) While the European Commission has been recognising the trade-offs that policies concerning biomass face, it should now engage in making the political choices that will be needed for the future development of the bioeconomy, thereby taking into account time and spatial dimensions for all major types of biomass.

[66] See e.g. the European Commission's long-term climate strategy, "A Clean Planet For All: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" (COM(2018) 773 final), Brussels, 28 November 2018. A recent study in *Nature,* however, states that the EU has seen increased forest harvests since 2015 – see https://www.nature.com/articles/s41586-020-2438-y.

2) Given the limited availability of biomass, the European Commission should focus on the analysis of alternative uses to identify the 'optimal' deployment of biomass compared with biomass being combusted in the energy sector, be it for material substitution or feedstock, particularly in those areas where few other climate-neutral alternatives exist.

3) The relative urgency of an EU 'negative emissions strategy' should be acknowledged given its big impact on land use and biomass use and the future development of these areas.

4) The different types of biomass (e.g. woody versus residual and waste types or dedicated crops) should be treated and assessed distinctively when assessing potential merits and risks, as should sectoral and regional limitations.

5) Innovation funding should be provided to ensure that more types of biomass can be efficiently used to replace current carbon-intensive industrial processes, so as to increase the competitiveness of waste and residue biomass types as alternative abatement options.

6) Besides better enabling accessibility to biomass across member states (intra-EU availability), the EU should concentrate on a framework – for example within the forthcoming forestry strategy – that tackles issues related to the imports that will be needed to satisfy demand.

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