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Policy report

Biomass in the EU Green Deal

Towards consensus on sustainable use of biomass for EU bioenergy?

Institute for European Environmental Policy

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SUMMARY FOR POLICYMAKERS

With forests being so crucial to mitigating climate change, and so vulnerable to the effects of a changing climate, what role does forest biomass have in the EU Green Deal and, more specifically, does it make sense to take biomass out of forests and use it for energy generation? At a fundamental level the debate here is **whether it is appropriate that the EU continues to rely on carbon-based fuel sources of any kind (living carbon in the form of biomass or fossil carbon in the form of coal, gas, and oil), rather than moving further and faster in favour of genuine renewables (solar, wind, hydro).** To explore these issues, this report provides a state-of-the-art meta-review of the sustainable use of biomass (from forests, agriculture, and waste sources) within biophysical limits in the context of the EU Green Deal. It builds on and contributes to a series of recently published studies on biomass availability, sustainability, and bioenergy in Europe. It explores the uncertainty and divergence of opinion on the role of biomass for energy (and wider bioeconomy) in the context of supply and demand estimates. Finally, it provides policy recommendations to narrow down the role of biomass within the EU's decarbonisation agenda.

Avoiding catastrophic climate change requires society to avoid emissions wherever possible, reduce emissions where they cannot be avoided altogether, and recover emissions where possible (Lóránt & Allen, 2019). Forests (alongside oceans and other natural ecosystems) are natural carbon sinks, and a natural and cost-effective mechanism for carbon removals that are essential to addressing the climate challenge (both mitigation and resilience). EU forests represent a net-sink of around -315 ktCO_2 of GHG emissions (2019). Damage to these ecosystems has a big impact on the climate. Emissions are released during the combustion of biomass for energy generation – exacerbating climate change; and the sink and sequestration capacity of the living biomass is lost during harvesting – preventing the opportunity for natural mitigation to take place from that same biomass. Climate change is intensifying this impact through feedback loops, such as forest fires or storms. With these natural disturbances included, the total carbon stock of EU forests has been declining over the last decade (EEA, 2021). Whilst the world's forests remain carbon sinks for now, this is quickly being undermined by human activity (Harries et al., 2021; Harris & Gibbs, 2021) and a changing climate. Ten of the world's most protected forests have become net emitters of carbon, as they are degraded by human activity and climate change (Gill, 2021), and only one of the major tropical rainforests remains a strong carbon sink, with others subject to illegal logging, drainage, and fires.

Biomass in context

Biomass is a term used to describe the organic material arising from living ecosystems, including forests, cultivated land and oceans. It can be extracted directly from ecosystems, such as the harvesting of timber, or by taking biomass residues and wastes that have been through previous use- or production-phases. This report concerns itself mainly with forest or woody biomass as a convenient and widely used resource in the EU economy. This is a result of availability, the capacity of biomass to replace fossil fuels in existing infrastructure, its (at least on paper) zero-carbon rating[1] in the EU's Emissions Trading Scheme (ETS) and the variety of end uses biomass can supply. In energy terms, biomass provides the major share (75%) of the bioenergy component (~60%) of the EU's renewable energy mix (European Commission's Knowledge Centre for Bioeconomy (2019) and is a convenient and widely used resource in the EU economy.

The harvest and re-growth or replacement cycle that is common to most living biomass, has earned biomass the label 'renewable', yet in practice it is functionally finite and can be exhausted before it can be replaced. The regrowth period of some forest biomass can be upwards of 100 years, meaning a substantial difference from the emissions at the point of combustion, and when they are eventually re-sequestered. This is recognised in the EU's bioeconomy strategy, which requires biomass to be used only within safe ecological limits (action 3.3) in order for it to "*strengthen the resilience of land and sea ecosystems, ensuring their contribution to climate mitigation, and enhancing their biodiversity*" (EC 2019 a). Once these ecological limits are breached, the ecosystem itself may start to decline, alongside the services that it provides. This also undermines the ability of that system to (re)sequester carbon (replacing that emitted in the consumption of the harvested biomass) and regrow material that can be used in future years.

The unreliability of biomass estimates

Despite a wealth of studies, the numbers indicating the exact amount of biomass that can be harvested sustainably (before generating more GHG emissions than it saves, undermining the zero-carbon-rating of biomass in accounting systems and leading to ecosystem decline) remain uncertain. The meta-review undertaken here points to a common pattern across a range of studies that call for a more serious and precautionary look at how we view biomass for energy.

[1] The assumption that the carbon released from the combustion of biomass is equal to that which has been absorbed and accounted during the growth phase.

Natural carbon sinks are essential for Europe's climate commitments (sequestration and resilience), yet the ecosystems from which biomass is harvested continue to decline. At present, the average amount of forest biomass that is supplied to meet existing demands is 12% higher for 2030 and 17% higher for 2050 *than the average amount of 'sustainably' available biomass (corresponding to 170 Mtoe for 2030 and 163 Mtoe for 2050 compared to 190 Mtoe)*. This suggests that that the intensity of biomass harvesting from these ecosystems is currently 'unsustainable' and needs to be reduced.

Looking ahead, the various EU demand scenarios set out in the studies assessed in this report, envision a *"near-doubling to a tripling in bioenergy by 2050"* and "foresee use that is around 50% higher than can be served by EU resources" (Material Economics, 2021).

The studies in this meta-review have a wide-ranging view of 'sustainable' which makes future supply estimated unreliable and difficult to compare. One common pattern appears to be the potential to increase the supply of biomass from secondary and tertiary sources, (i.e. from wastes and residues that have already been cascaded and used in their material form in the wider bioeconomy), rather than from primary sources, such as timber and crops.

The carbon-benefits of keeping biomass in its original form are rarely included in the sorts of assessments reviewed here, which focus rather on an expected use of biomass for a material or energy purpose. **In order to get a more reliable picture of the genuine sustainability of extracting and using biomass for energy, it is essential to contrast any harvesting with the climate benefits of keeping that biomass in its living form** (i.e., avoided GHG emissions, increased absorption of carbon from the atmosphere). Functional and resilient ecosystems also provide a much wider suite of environmental and social benefits to society than just climate, and these should also be considered. Building an effective counterfactual scenario to highlight these benefits may call into question the logic or scale of biomass use for energy as it is today or expected in future.

Recommendations for policy

There is a significant divergence of opinion between stakeholders on how to treat biomass within EU policy, and it is important to recognise those who will be impacted by future policy changes. Nonetheless, **sustainable bioenergy and the wider bioeconomy transition must recognise and take responsibility for its reliance on natural capital and prioritise management options that *maintain or enhance* ecosystem conditions and the delivery of ecosystem services.** The most obvious of routes to address the impact of over-exploitation of biomass for energy production is to **take a precautionary approach and limit its use whilst**

focusing more on genuine and renewable alternatives which are already common but relatively under-utilised in the EU's energy mix. Setting a clear and long-term trajectory for the use of biomass and its role in the EU's Green Deal will help all stakeholders to recognise the opportunities, plan, invest and benefit.

The current deployment of nearly 60% of renewable energy from biomass is not in line with the goals of the EU Green Deal – particularly when considering future demand scenarios. For biomass to continue to have a role in the EU's sustainability transition its use will need to be limited, and that this limited sustainable resource to be targeted towards high-environmental-value applications in those areas where there are no suitable or more sustainable alternatives. Wind and solar power are good examples of alternatives that have minimal impact on the environment whilst providing genuinely renewable sources of energy without impacting natural carbon sinks or necessitating a recovery period, in order to capture emissions. As such, there **is a need to promote, develop and scale-up alternative sustainable and renewable energy sources, deploying those first before turning to biomass as a source of energy**.

All policy scenarios need to include a robust counterfactual assessment of the ecosystem and carbon benefits of not using the biomass and the land associated with its production for energy purposes. This would serve to identify what contribution such biomass and land would make towards the EU's climate goals through its sequestration and sink potential, as well as through avoided emissions (from harvesting and combustion), whilst other sources of renewables are scaled up.

Stakeholders who are responsible for the ownership or management of bio-resources and the ecosystems from which they arise, such as forests, will need support in this transition. This can in-part be achieved by **recognising and incentivising the value of the in-situ benefits of biomass to the climate (retaining carbon in its living form) and the environment, rewarding those who protect and enhance the resource over those who extract and exploit it.** This could be achieved, for example by paying directly for the carbon value of forests, avoided emissions or carbon sequestered (akin to emerging carbon farming initiatives promoted in the EU's Farm to Fork strategy); or through other income mechanisms for forests associated with tourism. The full modalities of such an approach would need to be researched and developed,

The prioritisation of biomass towards where it provides the most added value to climate and environmental objectives (even if this means that it remains *in situ*), will **require the introduction of complementary policy measures of circularity**

(recovery and re-use) and cascading (sequential use phases) to maximise resource efficiency, with energy recovery only as a final step.

Focussing on alternatives and prioritising biomass use touches on a wide range of different and existing policies. **The addition of an overarching biomass and bioeconomy governance mechanism within the EU policy framework would help to guide biomass use in a consistent and coherent way towards the EU's climate and environmental goals**. This should include the restructuring of policies to focus on the contribution to achieving the EU's 2030 and 2050 biodiversity and climate objectives as set out in the EU Forest Strategy. Specifically, the overarching biomass framework should:

- **provide** a clear future trajectory for those sectors that currently manage and use biomass
- **prevent** system lock-in that would prolong the use of unsustainable biomass streams
- **ensure** that anything that releases carbon into the atmosphere and contributes to climate impacts is disincentivised
- **promote** only the ecological high value use of biomass, including the value of biomass in its living and natural form
- **re-establish** the economic, environmental, and social value of natural ecosystems and their protection
- **ensure** that trade and import policies are aligned with the EU's internal goals based on the above, and thus avoiding the export of environmental and social impacts beyond the EU's borders.

1. INTRODUCTION: BIOMASS IN THE SUSTAINABILITY TRANSITION

The use of bioresources is an essential part of our society and our economy. Biomass is the cornerstone of the bioeconomy in providing sources or organic materials (feedstocks), such as plants, trees, algae, and organic wastes (Bioenergy Europe, 2021). As a part of the European Green Deal, the European Commission raises the prospects of increased reliance on biomass sources for energy – and hence biomass use. Bioenergy is already making a substantial contribution in meeting energy demands and reaching EU, as well as global, renewable energy targets and decarbonisation pathways. In 2019, bioenergy accounted for around 55% of the renewable energy in the EU, with woody biomass providing the lion's share (75%) of bioenergy consumption (Smith et al., 2021), followed by agricultural biomass (crops and residues) and biowaste. Energy-and climate policies and strategies foresee a substantial increase in the use of biomass and demand for bioenergy, largely due to policy priorities, GHG accounting rules, and biomass subsidies.

The capacity of biomass to replace fossil fuels in existing infrastructure and the variety of end uses bioenergy provides (e.g., for electricity, heating, and fuel for transportation), makes biomass an attractive and convenient energy resource towards the decarbonisation transition. Further, the zero-carbon rating[2] of biomass in the EU's Emissions Trading Scheme (ETS) means that it can be utilised with limited attention given to the impact of emissions. However, the production and extraction of biomass has profound implications for natural ecosystems such as declines in biodiversity and ecosystem function, and the reduction in natural carbon sinks and stocks that are essential to maintaining a climate balance, thus potentially causing conflict between EU policy objectives. Furthermore, larger uncertainties exist on the actual climate gains of biomass extraction and on how much biomass can continue to contribute in a sustainable way. This makes bioenergy and its use of biomass for the wider bioeconomy subject to complex debates that encompasses various, often polarised rationales or visions (Smith et al., 2021).

There is a recognition in the EU's bioeconomy strategy that the EU bioeconomy and use of biomass for energy needs to be sustainable and operate within ecological limits. This identifies a fundamental premise of biomass use – that it is functionally finite and needs time to regrow and recover, and as such cannot be

[2] The assumption that the carbon released from the combustion of biomass is equal to that which has been absorbed and accounted during the growth phase.

harvested at scale without some impacts on the ecosystems or carbon balances from which they have been extracted. Despite a wealth of studies, the exact amount of biomass that can be harvested sustainably before impacting carbon performance, undermining the zero-rating of biomass in accounting systems and leading to ecosystem decline remains uncertain.

Addressing the issues of tackling climate change and ongoing declines in ecosystems and ecosystem services while ensuing a sustainable use of biomass, requires us to acknowledge this uncertainty and shift how we understand, approach, and utilise bioresources for bioenergy within ecological boundaries. The success with which we will be able to meet the European Green Deal objectives and take the path of green recovery towards a climate neutral Europe in 2050, depends largely on the way we utilise our natural resources, including biomass, to produce energy, materials, and food. If biomass is to be utilised for energy, it needs to be produced, processed, and used in a sustainable and efficient way to address needed wide-scale and real-time GHG emissions savings while maintain crucial ecosystems and ecosystem services. It is essential that both carbon and ecosystem impacts are well addressed for biomass to have any credible role in the EU's decarbonisation agenda. This is particularly important as bioenergy is still foreseen as playing a substantial role in decarbonisation pathways to 2030 and 2050, as highlighted again in the recently released International Energy Agency (IEA) Net Zero 2050 report[1], and as other policy files such as the EU Taxonomy Regulation are looking to the REDIII revisions to potentially update its biomass energy climate mitigation criteria for private finance.

This report is based on and contributes to a series of recently published studies on biomass availability, sustainability, and bioenergy in Europe, including for example the Material Economics (2021) and the Imperial College London (2021) report – though with differences in e.g. feedstock types, end-uses of biomass, sustainability understanding and views on EU bioenergy going forward. The overall purpose of this report is to provide a review of the scientific basis on sustainable biomass use regarding biophysical limits, and to include perspectives from different corners of the debate and policy recommendations on the use of biomass in the EU, with a particular focus on bioenergy. The latter is informed through interaction with stakeholders (researchers, CSOs, industries, and decision-makers) to understanding different perspectives.

Therefore, the objective of this report is to provide **a state-of-the-art meta-review of the sustainable use of biomass (from forests, agriculture, and waste sources) within biophysical limits in the context of the Green Deal. It explores the uncertainty and divergence of opinion on the role of biomass**

for energy (and wider bioeconomy) in the context of supply and demand estimates. Lastly, it provides policy recommendations to support the role of biomass within the EU's decarbonisation agenda. Specifically, the report focuses on:

1. Chapter 2 presents the policy context in which bioenergy (and the bioeconomy) operates in the EU (section 2.1), and the functional and finite nature of biomass (section 2.2), as well as explores different understandings of the terms ´sustainability 'and perspectives of what constitutes ´sustainable´ biomass.
2. Review of the current and future biomass supply (section 3.1) and demand of biomass (section 3.2) for EU bioenergy, as we present the supply versus demand challenge (section 3.3).
3. Understanding the importance of consensus of the risks and uncertainties associated with biomass supply and demand, and how to reduce biomass demand ensure biomass use within ecological boundaries (Chapter 4).
4. Chapter 5 provides policy recommendations that are to support the development in the decarbonised European energy system (and bioeconomy) within a sustainable pathway respecting ecological boundaries.

Box 1: Scoping biomass sources and end-uses

Overall, the review includes all **biomass sources** to ensure a richer and more complete discussion around the environmental sustainability of biomass use in general, as well as to include necessary considerations about transferability between biomass sources and demands. However, a special focus on woody biomass is given in this review due to its:

i. substantial and increasing contribution to EU-27 and the UK bioenergy production;
ii. often-quoted significant supply potential;
iii. forests as important carbon sinks with potentially high degree of trade-offs when trying to achieve carbon mitigation;
iv. potential alternative uses of forest biomass in the wider bioeconomy; and
v. substitution with wood fibre is significant in the bioeconomy and circular economy narrative illustrating a high degree of competing demands.

These factors are set in the broader context of current EU policy developments in areas covering forests and forest biomass, reflected for example with the EU Forest Strategy and the likely reliance on woody biomass in the EU's revised Renewable Energy Directive following the Fit for 55 Package (COM(2021)557[3]) REDIII.

End-uses are focussed primarily on bioenergy, but also consider the wider bioeconomy to understand the biomass demand and competing uses in low-carbon transition pathways. The review focuses the end-use of where forest biomass can play a significant role – power and heat, bioeconomy (fibre, wood products etc), but to a lesser extent liquid biofuel.

[3] European Commission (2021; 577 final). https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

2. BIOMASS IN CONTEXT

Understanding the implications of using biomass to meet EU objectives, and how biomass rests within the EU policy framework requires a look across the nature of biomass itself, the various legislation that influences biomass use and a closer examination of what we understand to be 'sustainable' biomass. This section introduces these elements in turn to help understand how policy should develop and what it needs to account for in the future use of biomass in the EU – particularly for bioenergy. In this, it presents the functional and finite nature of biomass, including ecosystem resilience and biophysical limits, and in which way carbon is accounted for in the context of biomass used for energy. Lastly, this section presents different understandings and perspectives on the term 'sustainability' and sustainable biomass supply and use going forward.

2.1 EU legislation and biomass

The resolution on the European Green Deal was adopted by the European Parliament in January 2020, emphasizing the need for more ambitious actions to address European, and global, climate change and meeting environmental objectives. The July 2021 ´Fit for 55` Legislative Package sets a target of reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels. The package includes 13 cross-cutting legislative proposals, including for example revisions of the EU ETS and the LULUCF regulation, as well as new proposals, such as an amendment on the Energy Efficiency Directive (EED) to the RED to implement the ambitions of the new 2030 climate target.

The new EU Forest Strategy for 2030, a flagship initiative of the European Green Deal, contributes to the greenhouse gas emission reduction targets of the 'Fit for 55 Package'. It further helps the EU deliver on its commitment to enhance carbon removals by natural sinks as per the Climate Law. The new EU Forest Strategy for 2030 aims at ensuring the multifunctionality of EU forests (including as a source of biomass) and sets visions and concrete actions for increasing the quantity and quality of European forests through protection, restoration, and sustainable management of forests (European Commission, 2021 a).

Below **Error! Reference source not found.** provides an overview of key EU policies and strategies with specific relevance for EU biomass and bioenergy. The purpose of the table is to understand the political sphere in which EU bioenergy operates and develops, and how the legislative instruments are influences EU biomass supply and demand.

Annex 1 Table 1: Overview of key EU legislative instruments and their influence and relevance on biomass

Policy/strategy	Summary of EU legislation	Relevance for biomass production and use
Renewable Energy Directive II and III	The 2018 recast of the Renewable Energy Directive (REDII) established a common framework for the promotion of renewable sources for energy in the EU and a part of the 'Clean energy for all Europeans package' beyond 2020. The 2021 revision of RED confirms the EU's objective of sourcing 38-40% of its energy from renewable by 2030. Further, the revised directive provides an increase in the renewable target for transport from 14-16% (European Commission, 2021)[4].	- The REDII revisions implicitly recognise that biomass use is not sustainable by default, and that sustainability criteria are a necessary tool to mitigate the risk of unsustainable use of biomass in the EU. - Lays down rules on financial support to enhance the use of renewable energy, such as bioenergy. - Drives biomass use for energy with sustainability criteria to mitigate the risks of unsustainable biomass use. - Includes caps on the use of stem wood above a certain size for energy purposes, applying existing agricultural biomass no-go areas for forest biomass. - Cap on high indirect land use change-risk biofuels. - Sets out biodiversity risks.
Land Use, Land Use Change and Forestry (LULUCF) Regulation	The LULUCF Regulation (2017) aiming to incorporating GHG emissions and removals due to LULUCF into the EU's 2030 Climate and Energy Framework. The Regulation introduced binding commitment to GHG emissions in forestry and land use for all EU MSs, as well as related compliance rules for the 2021-2030 period.	- Accounts for carbon emissions from biomass harvesting in land use. - Emissions from bioenergy are assumed to be zero in the energy sector, while accounted in the LULUCF sector in the form of harvested biomass. - Imported biomass and biofuels, for example, do not add emissions in the LULUCF sector and can contribute to deforestation at global scale.

[4] https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

EU Forest Strategy for 2030	Highlights the need to sustainably manage forests to support biodiversity goals alongside the development of the circular bioeconomy.	- Commits to strictly protecting primary and old-growth forests, restoring degraded forests, and ensuring they are managed sustainably. - Actions include increasing carbon sequestration through enhanced sinks and stocks, as well as protection, restoration, and actions towards sustainable management of forests. - Promotes climate and biodiversity friendly management practices. - Emphasises the need to keep the use of woody biomass within sustainability boundaries. - Encourages resource-efficient wood use in line with the cascade principle (European Commission, 2021 a). - Announces a legal proposal to step up monitoring, report, and data collection of forest in the EU, including harmonisation of data.
EU Biodiversity Strategy 2030	The main objective is to "put Europe's biodiversity on a path to recovery by 2030". To achieve this, the strategy sets out a long-term plan which includes the expansion of the EU network of protected areas, the proposal of legally binding targets for nature restoration, the creation of a governance framework that helps better integrate biodiversity into all relevant parts of society, and the promotion of EU action for global biodiversity challenges. Several of these actions are relevant to biomass and bioenergy.	- As part of the EU Nature Restoration Plan, the Strategy highlights the need to assess the biodiversity and climate risks of the EU and global biomass supply. - Aims to improve the sustainability of agricultural practices which will in turn affect EU agricultural biomass supply. - The headline target of placing 30% of EU area under protection will have implications for the bioeconomy as it will further constrain the land area available for biomass production.
EU Bioeconomy Strategy	The EU Bioeconomy Strategy (2012) was developed in the context of the Europe 2020 Strategy emphasising the need for smart, sustainable, and inclusive growth to	- Contributes to the increasing demand of biomass for bioeconomy purposes by providing concrete measures to scale up the bio-based sectors

	improve Europe's competitiveness and productivity (European Commission, 2012) Updated in 2018 as a respond to new European policy priorities, such as the Circular Economy Action Plan and the Communication on Accelerating Clean Energy Innovation (European Commission, 2016) highlighting the importance of a sustainable and circular bioeconomy for the EU to maximise its Sustainable Development Goals and Paris Agreement commitments (European Commission, 2019 b).	- Recognizes and acknowledges the ecological boundaries of the bioeconomy
The EU Taxonomy on Sustainable Finance	The EU's sustainable finance taxonomy is part of a wider package of measures to help 'improve the flow of money towards sustainable activities across the European Union.' The Delegated Acts on technical screening criteria arising from the Taxonomy Regulation ((EU) 2020/852) set out the technical screening criteria, thresholds and metrics that define whether an economic activity (such as forest management) is delivering a substantial contribution to the climate mitigation objective.	- The first Delegated Act (European Commission, 2021 b) arising from the Taxonomy Regulation) includes economic activities linked to biomass production and use. Notably: **forestry** (afforestation, reforestation, forest management, conservation forestry); and the **production of energy from biomass**. - The Delegated Act criteria for Forestry and for Bioenergy are foreseen for review 'based on upcoming Commission policies and considering legislation (including the revision of the Renewables Directive), in accordance with the biodiversity and climate neutrality ambitions of the Union (European Commission, 2021)[5]. The current criteria make a number of references to national law and the sustainability criteria of the current RED II. It is critical to both public and private finance how REDII evolves,

[5] European Commission (2021). Questions and Answers: Taxonomy Climate Delegated Act and Amendments to Delegated Acts on fiduciary duties, investment, and insurance advice. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_1805

		and how MSs policies address the sustainability limits of biomass extraction and use.
Governance Regulation and National Climate and Energy Plans (NECP)	MSs were obliged to submit integrated 2030 NECPs and required to describe their national contributions towards the binding EU energy-climate targets, as well as foreseen energy-climate measures and policies with the Energy Union dimensions to be implemented over a period of 10 years (2020-2030) to reach the proposed national targets (European Commission, n.d.)[6].	- The plans include MS's reliance on bioenergy, estimated trajectories on bioenergy demand, end uses, and biomass feedstock and origin. - For forest biomass, the plans should include the role of biomass in different sectors and identify possible trade-offs, such as the contribution to the LULUCF sector (Smith et al., 2021)[7].

[6] European Commission (n.d.). National energy and Climate plans: EU countries' 10-year national energy and climate plans for 2021-2030. https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en
[7] Smith et al., (2021) Trinomics, B.V. https://www.fern.org/publications-insight/analysis-on-biomass-in-national-energy-and-climate-plans-2326/

Other policies such as the EU forest strategy, or the Common Agricultural Policy (CAP), as well as national policies and laws further influence how biomass is grown and processed, how land use systems are governed, and the requirements placed on individual actors. Further down the supply chain, there are policies and standards that govern material content for products, energy sustainability criteria, etc. which further influence biomass supply and demand. Member States (MSs) continue to rely heavily on the use of biomass to reach climate targets, either through the energy sector where biomass continues to account for more than 50% of renewable energy (almost 60% in 2020) (European Commission's Knowledge Centre for Bioeconomy (2019), or through the bioeconomy where material substitution is increasingly being seen as a means to reduce dependency on fossil products. The zero-rating of biomass in the EU ETS further encourages, or rather does not provide a clear rationale to limit its use, despite the uncertainties and impacts on the wider ecosystem.

2.2 Understanding the functional and finite nature of biomass

Biomass use is embedded in natural systems and must remain within safe ecological boundaries to ensure its long-term sustainability.

2.2.1 Biomass and ecosystem resilience

Biomass harvesting depends on healthy ecosystems while simultaneously having significant impact on them. These impacts must be considered and adequately managed both to ensure biomass use is not at odds with biodiversity protection goals and to secure its future viability. Ecological boundaries refer to the environmental limits beyond which ecosystems become destabilized. For biomass, these limits include (i) the regeneration rate of biomass, (ii) the renewal of other resources needed for biomass growth, (iii) the availability of land and, underpinning the rest, (iv) losses of biodiversity and ecosystem services from areas from which resources are extracted (Székács, 2017).

Biomass resources are renewable, yet they are also functionally finite in that they need time to regrow or recover. This constrains the availability and sustainability levels of biomass resources. It is therefore essential that the harvesting of biomass does not exceed the natural regeneration rate needed to maintain biodiversity and ecosystem structure, functioning, and productivity (Camia et.al., 2021).

Natural resources needed for biomass growth, such a soil and water, are also renewable but functionally finite. Soil fertility and productivity are vital to biomass supply, biodiversity and ecosystem functioning as soils underpin the delivery of a range of regulating ecosystem services (e.g. nutrient cycling and water regulation). Soils themselves are influenced by the ecosystem around them, the decaying and dead matter from the forest helping to improve soil functionality. Biomass demand can lead to soil degradation (e.g. through selective logging and conversion of grassland and cropland). Since soils have limited renewal capacity, meaning their restoration is slow and often spans over that of a human lifespan, degradation beyond certain thresholds can result in the loss of their key ecosystem function (Székács, 2017)

Biodiversity underpins ecosystem processes needed to deliver the vital ecosystem services which sustain biomass production and societal well-being (e.g. climate regulation, pollination and hazard risk mitigation) (Cardinale et al., 2012). Moreover, functional, genetic, and taxonomic biodiversity supports ecosystem resilience to external pressures (Jucker et al., 2014). The EU Biodiversity Strategy for 2030 aims to put biodiversity on a path to recovery, and under the Nature Directives, MS have a legal responsibility to ensure favourable conservation status for protected habitats and species. To achieve these goals and to safeguard the benefits biodiversity delivers, natural resources, including biomass, must only be used sustainably.

However, the use of biomass is not sustainable by default and changes in land use and management (even where the land cover remains the same, e.g. forest) can push ecological boundaries such as through unsustainable agriculture and forestry practices which are the largest threat to biodiversity in the EU (EEA, 2020). Direct and indirect land use changes (ILUC) can have profound impacts on biodiversity. For example, the conversion of semi-natural landscapes such as grasslands to cropland can lead to habitat loss and changes in associated species communities. Management practices, such as the removal of logging residues for biomass use, clear-cutting and whole-tree-harvesting also threaten common woodland species as well as specialist species with important ecological roles such as those that feed on dead wood (saproxylic species) (Camia et al., 2021). Changes in land use and management practices impact biodiversity and ecosystem resilience through multiple, complex mechanisms which we do not fully understand. As a result, there is uncertainty regarding at which points these impacts become critical and irreversible. A precautionary approach should be followed in response to this uncertainty to avoid serious and permanent losses in biodiversity.

Finally, land is needed to produce biomass, particularly for primary bioresources, creating additional pressures on the finite land resource. Substantially increasing the EU's biomass supply could require the cultivation of new energy crops since importing biomass has large environmental costs, and the potential for additional sustainable supply from other sources within the EU (e.g. forests, waste and residue streams) is limited at present. Increased biomass use could require an area of around 20% of all current EU cropland (Material Economics, 2021). The feasibility of meeting this demand without exceeding environmental and biophysical limits is doubtful considering existing biomass use already exceeds biocapacity in the EU and land use intensity must be reduced to achieve land use within safe planetary boundaries (UNEP, 2014). Moreover, meeting environmental goals set out in EU policies will require changes in land use, such as setting aside 30% of land for biodiversity conservation and 10% for strict protection, which increasingly constrain land availability. Direct trade-offs can therefore occur with biodiversity objectives requiring the modification of forestry and agricultural land-use and practices which affect potential biomass supply (e.g. halving mineral fertiliser use and having 25% of agricultural land under organic farming).

2.2.2 Biomass and carbon accounting

In addition to biomass as a functionally and finite resource and the ecological perspective (as above), there are other ways in which biomass is viewed in EU legislation, potentially confusing what 'sustainability' means in practice. One such example is the way in which carbon is accounted for in the context of biomass used for energy. Under EU carbon accounting rules, once a tree is harvested that embedded carbon is assumed to be lost immediately to the atmosphere – instant oxidation. If the biomass is then used to produce energy, it is technically 'zero-carbon rated', as the carbon lost from the tree has already been accounted for in the forest and does not need to be accounted for again in the energy sector. Whilst the accounting approach is intended to be consistent across economic sectors, it does not fully address the difference between the emissions of carbon at the point of combustion and the removal of atmospheric carbon through the past growth and assumed future growth associated with the supply chain for the feedstock. This time difference varies substantially and can be as little as a few years to beyond 100 years, depending on the source of the biomass - a measurement referred to commonly as the 'carbon debt period'[8]. There are two principal issues that risk the use of biomass for energy running counter to the EU's climate goals:

- The perception that the whole forest is available to offset the biomass extracted and used for energy – to balance the books. To deliver low-carbon economies, forests, and their potential to remove and store carbon are becoming increasingly relied upon by society to counterbalance emissions

[8] i.e. the imbalance between the carbon emissions generated by a particular use of biomass (in this case energy) and the removals or sinks that can be used to counteract these generated emissions (in this case forests). https://ieep.eu/uploads/articles/attachments/b01428ef-d75c-462a-9d3c-bfef4a4fb37d/IEEP_2016_Carbon_sustainabilty_of_Bioenergy_Web.pdf?v=63664509991

from other sources. In current accounting frameworks, the carbon sequestered in existing forests may have already been used to balance removals in other sectors. Only if it has been 'banked' for energy use, can it be used legitimately to account for the emissions released at the point of burning, or if the carbon would have been lost through combustion without energy recovery.

- The need to reduce real-world emissions in absolute terms now and for the next 10-30 years. The carbon repayment period for the oxidised biomass could be upwards of a period of 60 years, depending on forest growth rates, meaning that whilst GHG emissions are 'accounted for', the impact on the climate will be negative during a period whereby emission reductions is essential.

To address these carbon and biodiversity issues through policy requires an understanding of the level of carbon removals and sequestration that can legitimately be used to counterbalance the emissions from energy production. These in turn require a reasonable understanding of what would happen if the biomass and the land associated with its production were not used for energy (the counterfactual) and the relevant characteristics of the types of biomass being used (definitions) (IEEP, 2012). Further, the uncertainty around the various tipping points where ecological boundaries are breached or where carbon impacts undermine the anticipated GHG savings, means it is likely that a much more precautionary approach is needed to biomass use.

Some Member States have recognised the functionally finite nature of biomass and the importance of retaining living biomass, particularly that of forests, in addressing the climate challenge. The Danish Council on Climate Change, for example, has recognised in its 2018 report (Klimarådet, 2018) that the role of biomass in the green transition needs to be questioned in the context of the green transition, with suggestions on how its sustainability could be ensured. There are two decisive reasons for doing so. Questions are often raised about whether the carbon footprint of biomass is as low as commonly perceived, and Denmark's consumption of solid biomass as a source of energy is relatively significant and is expected to continue to increase.

2.3 Understanding 'sustainability'

Currently, no uniform or common framework exists on what constitutes sustainability, which makes the interpretation of sustainability highly subjective to the variety of different actors in the biomass supply chain. It is understandable that any given point in the supply chain could consider themselves as operating sustainably as their scope and control over sustainability is naturally limited and often, they lack the bigger picture perspective across the whole supply chain and its implications. It is only when the whole biomass supply chain is considered, and its estimated future level of demand, that the broader sustainability issues start to become apparent – even where some sustainability criteria are in place. **The lack of a governing framework for biomass use remains an issue, particularly in giving clear market signals to suppliers and users of biomass, as is the lack of common terminology that relate to sustainability.** Therefore, there is a need for a unilateral standard that resolves the issues of variation. In this report we have not determined a specific definition for sustainability, rather we have adopted and used the definitions provided in the various reports so as to highlight the variation in supply potentials as a result of different definitions of sustainability.

One of the major considerations around biomass sustainability is therefore associated with scale. With the net-zero emissions target in 2050, competition between multiple uses of biomass utilisation and sectors to claim benefits of the carbon sequestration in land is increasing. In accounting terms, the EU's forest carbon sink (part of the LULUCF sector accounting) is the largest land-based source of negative emissions in the EU available to offset any emissions in other sectors that cannot be reduced. Although the forest sink is declining as a result of over exploitation, natural disasters and climate change. The question of who and which sector can appropriate these forest carbon sinks (in accounting terms), and what happens to them (in real terms) when there is an increasing demand for biomass, remains. Demand scenarios foresee a near-doubling of bioenergy use and a roughly 50% increase in biomaterial production, resulting in a biomass demand up to around 19 EJ by 2050 (Material Economics, 2021). The proposed increase spans a wide range of sectors, and includes demands for bioenergy, biomaterials (e.g. pulp and paper, timber and other fibre-based products)[9], bio-feedstocks (e.g. for chemical production) as well as utilisation of biomass for conventional food and feed.

In considering the multiple demands for biomass, it is important to recognise that they are not all additive, and that principles such as cascading use or the utilisation of residues, wastes and materials at the end of a given use phase mean that the same biomass can be utilised for different demands in sequence, with the final use of biomass resulting in energy recovery. At present this more resource-efficient way of utilising biomass, as part of a circular-bioeconomy, is

[9] Demand for solid wood products and pulp and paper is expected to grow in the EU to replace more carbon-intensive materials, such as cement and steel in construction or plastics in packaging. New uses of biomass are also expected to rise, including for example textiles from manmade cellulosic fibres created from dissolved pulp, chemicals produced using biomass or biogenic CO2 as a feedstock, as well as new bio-based materials created from fibres.

still developing, and typically primary biomass supplies continue to be important in many cases. In considering competing uses or demands for biomass, cascading use or circular-bioeconomy principles applied to biomass use can lower the resource footprint of any given sector, including energy, but this requires a systems-view of biomass use, which remains rare, with different policy interests and initiatives leading to isolated incentives and demands.

The question should then not be what an environmentally sustainable use or supply level of biomass is, but rather how and in what way can biomass (in its various forms) support the EU's green deal objectives, and what role within that is there for a use of biomass for material and energy purposes. It should not be pre-assumed that biomass needs to be harvested and used to be part of the sustainability picture.

Environmental sustainability is therefore understood in this report in the context of two fundamental principles: the first is to recognise and reward biomass left in its living form (for ecosystem resilience and natural carbon sinks) as providing an important contribution to the EU's green deal objectives; the second is where biomass is harvested and used, to ensure the protection of the ecosystems from which that biomass arises and without which there would be no enduring supply. This is both a recognition of the ecological limits of biomass supply as well as the ecological contribution to climate and environment goals. Respecting the second of these principles Box 2 sets out considerations for the use of biomass in an environmentally sustainable way – to aid in the interpretation of existing supply estimates which almost universally focus on using harvested biomass rather than rewarding in-situ benefits.

Box 2: Considerations for environmentally sustainable biomass supply potentials

The key condition for bioenergy development is the availability of reliable, economically viable, and environmentally sustainable biomass. The scale of biomass potentials is affected by all three factors – with the focus of this review on the environmental criteria that would ensure sustainability of the supply.

Each step in the biomass supply chain poses different sustainability challenges that need to be managed to ensure long-term availability and sustainability of biomass for energy and material use. Based on several existing assessments of understanding and estimating the sustainable biomass supply (e.g., Kluts et al., 2018; Faaij, 2018; Material Economics, 2021), the following conditions need to be considered when mobilising biomass resources in a sustainable manner:

1. **Land availability** and competing land uses, as well as land management, such as intensity of production. This includes indirect land use changes through displacement. Areas dedicated to food, feed and fibre production should be excluded.
2. **Impact on carbon cycles,** by removing biomass that would otherwise continue to accumulate **carbon** in situ.
3. **Impact on other environmental objectives (other than climate mitigation)** through biomass cultivation and extraction, such as water requirements for growth, **or** loss of soil nutrients and structure where excess residues are removed.

2.3.1 Different perspectives and lack of consensus

Box 3 summaries areas of disagreement (or lack of common ground) on sustainable biomass supply and the role of EU bioenergy going forward identified during an EU workshop (16th of September 2021). The workshop invited several stakeholders, such as research institutions, civil society organisations, industries, and policy makers to understand the different perspectives and interests shaping the EU bioenergy discussion today.

Box 3: Key areas for non-consensus identified based on an EU workshop

1. **Factual disagreements between different stakeholders due to differences in terms and their definitions.** The impact of which is a lack of common ground on which to debate a way forward in the use of biomass. This includes for example, forest stocks versus forest area, or the definition and scope of 'residues', such as those arising as part of harvesting, or the consideration of trees from the forest thinning process, as residues.
2. **Multiple drivers of biomass demand** exist; however, their contribution and importance are highly contested. Some stakeholders argue that subsidies play a small role in driving demand, and that harvesting for by-products does not have a big impact on biomass and bioenergy demand and instead the market will dictate in what direction the bioenergy industry will go. Others

argued that it is difficult to say that subsidies do not have an impact when looking at the billions of Euros provided annually, but that making a causal link between subsidy payment in increased harvesting is challenging. Further, some questioned the need for subsidies at all and that some existing incentives are incoherent with the EU's green deal objectives and cannot be justified in climate terms – whereas a focus on recognising and remunerating the environment and climate value provided by healthy forest ecosystems would be aligned. Another contested term is whether the demand for wood pellets drives biomass harvesting.

3. **Addressing sustainability through criteria for multiple end-uses:** Sustainability criteria were also discussed with calls to ensure criteria across different EU policy areas and instruments are coherent. This could help reduce administrative burdens which participants mostly agreed are important to reduce as they can have important economic consequences, particularly to SMEs. Setting priorities for one biomass use over another depends on the different perspectives, interests, and policies in place, and a prioritisation or hierarchy of uses based on their environmental performance and/or alternatives. Different stakeholders hold opposing views on the importance of regulating the use of certain feedstocks. While some stakeholders believe the criteria set by the REDIII regulation do not go far enough, particularly for woody coarse biomass, others argue we should rather focus on sustainably sourcing all feedstocks through better monitoring and enforcement.
4. **Perspective on the impact of harvesting of biomass on the environment.** The literature and evidence on the health of natural resources, particularly in Europe, is clear and largely unchallenged. The decline of biodiversity and impact on natural resources is evident from over extraction of biomass and management intensities beyond the natural carrying capacity (ecological boundaries) of the system. However, there is a lack of agreement between stakeholders on the cause and further the management response to those causes. Some argue that, for example, forest management is part of the solution to improving biodiversity whilst wood extraction continues, others argue that forest management should change to focus on the goal of delivering ecosystem health as a primary concern, even if in cases this means the cessation of

biomass extraction. Both groups agree that the management effort to protect and maintain healthy ecosystems should be recognised and remunerated, although some do not see this as the role of forest management and would not wish to be paid to do 'nothing'.

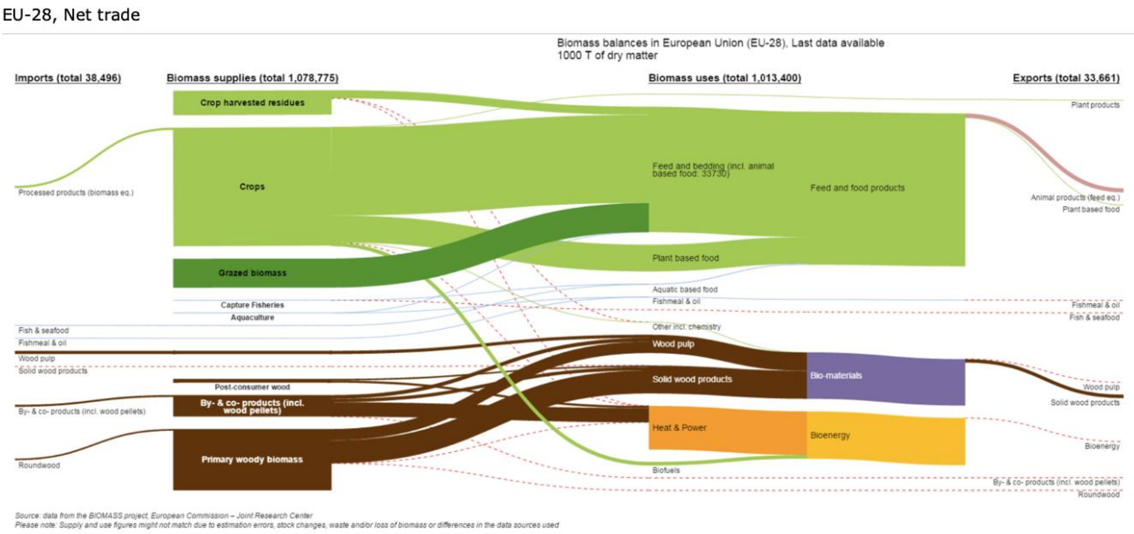
5. **Data, assumptions, and biomass models** used to estimate sustainable future biomass availability and demand emerged as a key point of discussion between different stakeholders. Understanding between stakeholders that disagreements and uncertainties over numbers can be largely attributed to their underlying assumptions and biomass models used. For example, some models only consider carbon impacts which will differ to calculations including other dimensions of sustainability such as biodiversity. Differences also arise from the use of future scenarios, especially long-term ones. Some of these might become quickly outdated with changes in the policy landscape and availability of future technologies. The discussion revealed that many factual disagreements between stakeholders are rooted in uncertainties in numbers due to differences in the underlying assumptions, models, and definitions. Therefore, the conversation should focus on interrogating these and reaching a common understanding.
6. Uses for biomass can be prioritised according to their value, and there was a common understanding among stakeholders that markets will shift to high value uses of biomass. However, how this "value" should be defined is more controversial among the participants. The value of biomass can be economical, environmental, or social, and this value is perceived differently between stakeholders. Therefore, when thinking about value we must ask "to whom?". For example, although harvesting biomass might be economically valuable, the value of its in-situ benefits (e.g., to soil health), might outweigh these. Some agreement exists that the **different values should be better captured to help the decision-making process about how and in what way biomass can support the EU's green deal objectives and make a substantial contribution to the society both in the EU, and globally**.

3. BIOMASS SUPPLY AND THE DEMAND FOR BIOENERGY IN THE EU

This section provides an overview of the main sources of bioresources and presents the current and future biomass supply potentials (and the assumptions that underpin them) based on existing literature. Further, the section looks at where there is a biomass demand and how much is required, before comparing supply and demand in the context of sustainable use.

Understanding the available supply, uses and perceived demand for biomass and bioenergy in the EU helps to determine how much and in what form biomass use can and should play a role in the EU's green transition. Bioenergy currently represents around 60% of the renewable energy mix and is one of the main relied sources for the EU's net-zero carbon transition (Faaij, 2018). However, the exact role of bioenergy in this transition remains uncertain and depends inter alia on the biomass supply available, their sustainability and wider environmental implications beyond climate (e.g., biodiversity) and actual climate benefits, and future biomass uses and demands. Central to this is the type of biomass which has a marked impact on both sustainability and supply potentials (**Error! Reference source not found.**).

Figure 1: Sankey biomass diagram depicting net trade in biomass for the EU-28



Source: Gurria et al., 2017. https://publications.jrc.ec.europa.eu/repository/handle/JRC106502

Note: This report does not attempt to provide a detailed description of the complex flow of biomass between source and end use, as these are covered well in other reports (e.g. Gurria Albusac et al, 2017), and do not illustrate the assumptions that underpin supply and demand figures that lead to the significant variation in quoted figures.

3.1 Biomass supply: How much is out there?

Bioenergy is the use of biomass (in the form of biomass fuels, biogas, and biofuels) to produce power, heating or cooling or transport fuels. It is generated by using heterogeneous feedstocks primarily from the agriculture and forestry sectors. This creates a demand for biomass from land-based sources. The need to cultivate, extract, and produce bioenergy feedstocks therefore influences land use and land management decisions, which in turn has impacts on a range of environmental objectives.

Not all biomass for energy comes from primary sources (crops, trees, grass, algae) but arises in the form or residues from other processing of biomass (such as sawdust, pitch, etc.), or as wastes (such as food waste, sewage, etc.) (see **Error! Reference source not found.**). Residual biomass is a result of biomass production and management as a product of the primary resources, while biomass waste is generated as an artefact on consumption or discard and does not drive biomass production from land. Many of these biomass types have existing and other uses than energy generation, such as materials and industrial use (Camia et al., 2018).

Figure 2: Types of bioresources

Forest biomass	•Stemwood production •Primary forestry residues (e.g. bark, pitch, logging, pre-commercial thinning •Secondary forestry (industrial by-products), residues (e.g. wood pellets, sawdust, black liquor)
Agricultural biomass	•Primary agricultural crops •Dedicated energy crops (incl. perennial linocellulosic and grassy crops) •Primary residues (e.g. straw, cobs, manure) •Secondary and solid residues from processing of harvest products (e.g. bagasse, rice husk)
Waste biomass	•Tertiary residues (e.g., municipal solid waste, vegetal wastes, paper and cardboard, sewage sludge, animal-based waste (manure) and mixed food waste, wood waste)
Algae*	•Algae •Seaweed

Source: EC, 2017; Camia et al.,, 2018; André P.C. Faaij (2018); Material Economics (2021); Ruiz et al., 2015.

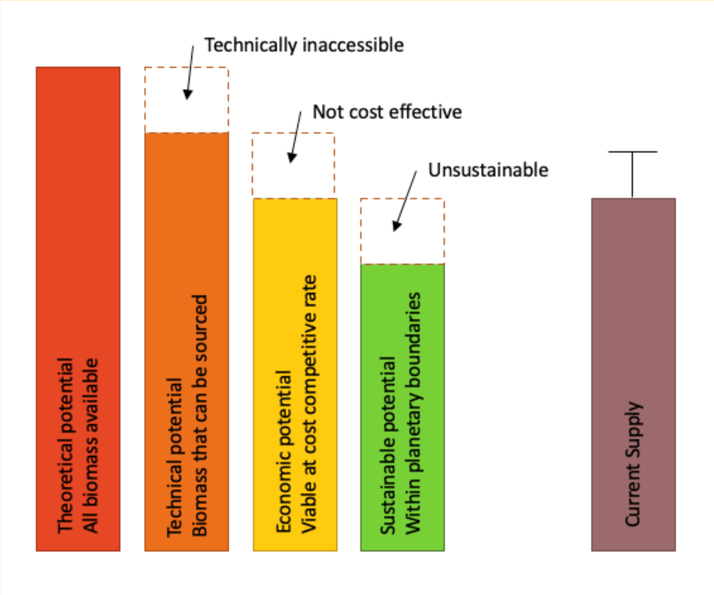
*Not included further in biomass supply estimates as currently limited use in the EU. However, algae is covered in the DG RTD study and in the recent overview from JRC.

Scale of biomass sources

Existing literature on the scale of biomass sources and potential biomass supply for bioenergy (and the wider bioeconomy) varies widely due to e.g., the heterogeneity and inconsistency of methodologies and terminology, what constitutes sustainability, use of different conversion efficiencies, assumptions (e.g., regarding forest and farming practices) and datasets employed. This lack of harmonisation makes it particularly challenging, complex, and uncertain to compare and estimate the scale of biomass sources that could be sustainably available – making it almost impossible to reach consensus and develop long-term and effective policies for sustainable biomass use in the EU. Nevertheless, an effort is made in this section to compile most recent estimates of the current biomass supply and future potentials, and the ecological/environmentally sustainable (where possible) in the EU and illustrate the reasons underpinning any significant variation. Supply data has been extracted from recent literature (see Annex X) and potentials are both primary and secondary biomass resources, for example potentials for the entire forest sector and flows that results from integrated forestry practices. Furthermore, the biomass supply estimates are not limited to potentials for energy purposes only but covers supply for the wider bioeconomy as well. The understanding and approach to the biomass potentials used in this report are explained in below Box 4.

Box 4: A theoretical presentation of how different biomass supply potential are represented

The general approach and understanding of sustainable biomass supply potential and other biomass potentials used in this report is illustrated in below figure.



Source: Own production (authors), 2021

- Review of available and recent literature and data on the existing and technical biomass supply potentials, this includes identification of the theoretical (maximum supply potential within fundamental biophysical limits), the technical potential supply (the fraction of the theoretical potential available under current technology) of EU biomass, and that which is economically viable to obtain.
- These four different types of potential vary with decreasing levels as further *'limitations'* are taken into account. The current supply operates in a space below the technical potential limit, but often above the sustainable potential.
- Within each potential, the actual potential figures are determined by the assumptions on limiting factors. These may be the technology that can be deployed to prospect certain biomass types, whether or not it is cost effective for the price that can be obtained for such biomass, the policy incentives that give certainty to the demand, or the different

types of sustainability considerations (e.g. Climate, Biodiversity, Water, etc.).

- In this meta-review we focus primarily on constrains related to ecological limitations and environmental sustainability, including competing land uses, GHG emission reductions, and implications on biodiversity and ecosystem services.
- Estimates of the biomass supply potential vary substantially, driven by differing understanding, inclusion and emphasis on sustainability and sustainability criteria, preconditions, assumptions, and methodologies.

Total EU biomass supply

The supply of biomass comes from three main sources: forests, agriculture, and waste streams. The total of each of these types are illustrated in Figure 3 (and in Annex A) for current, technical (potential), and 'sustainable' supply estimates.

The total technical supply potentials range from 391 Mtoe (16.4 EJ/yr) to 448 Mtoe (18.8 EJ/yr) with an average of 420 Mtoe in 2030, and from 196-737 Mtoe (6-30 EJ/yr) with an average of 461 Mtoe in 2050 (see below **Error! Reference source not found.** and Annex A). This is compared to a total current biomass supply between 148-434.4 Mtoe (6.2-18.2 EJ/yr) and with an average of 277.2 Mtoe, which suggests a technical growth potential in the use of biomass in the EU when comparing average figures. However, what is a realistic biomass supply is highly uncertain and contested, as estimates differ between limited increase beyond current levels in conservative assessments, to high theoretical estimates. This Illustrates that comparison between figures is challenging even with EU-level datasets. A similarly confusing picture with large ranges of biomass supply estimates emerges in the aggregate 'sustainable' supply potentials. The total 'sustainable' potential of biomass supply in 2030 is estimated to be between 191-409 Mtoe (8-17.1 EJ/yr) with an average value of 295 Mtoe, and between 206-478 Mtoe (8.6-22.3 EJ/y) with an average of 232.8 Mtoe in 2050 (notably lower than the 2030 figure). Whilst this shows a considerably smaller upper figure in the range compared to technical potentials, the lower estimates are still higher or similar to the current supply figures. This however should not be understood as the current biomass supply as being sustainable as we already see extensive environmental implications of biomass sourcing. Whilst the figures may look similar, they do not show the type of biomass being included or where it originates from. A sustainable supply stream of biomass could (in theory) be the same amount or more than the current supply, but from different and more sustainable sources, replacing primary biomass with that of waste streams. The sustainable supply and potential biomass supply figures are therefore not directly comparable from a feedstock perspective, presenting an unclear picture for decision makers.

It appears evident from **Error! Reference source not found.** below that for 2050, the average supply level within the ranges for total forest and total agriculture are lower in the sustainable supply estimates than either the potential supply or current supply. The opposite however can be observed for 2030. A different picture is seen with waste biomass, where the sustainable average figure is higher than current supply and similar to the potential supply. When aggregated the total figures appear confusing as the average sustainable supply level is higher than current supply but lower than the technical potential. Yet if we consider the information in its components, a picture does begin to emerge.

On the basis of the average figures alone, both the agriculture and the forestry biomass totals suggest that current supply is higher than the sustainable supply potential and can thus be considered as unsustainable (see below **Error! Reference source not found.**). The reverse is true of the waste biomass where the sustainable supply level is higher than the current supply, suggesting that there are further sustainable resources that can be accessed from waste streams. When brought together the higher average total biomass supply potential compared to current total biomass can be (in part) explained as a result of a reduction in the forest and agriculture streams, and a compensatory increase in the waste streams. There is also likely to be some variance in the types of biomass changes within both the agriculture and forestry data.

Waste biomass estimates seem to be difficult to estimate and currently only limited data could be found on waste biomass. There are several reasons for why it remains difficult to find a realistic waste range and reach consensus on the potential biomass waste supply. These includes for example:

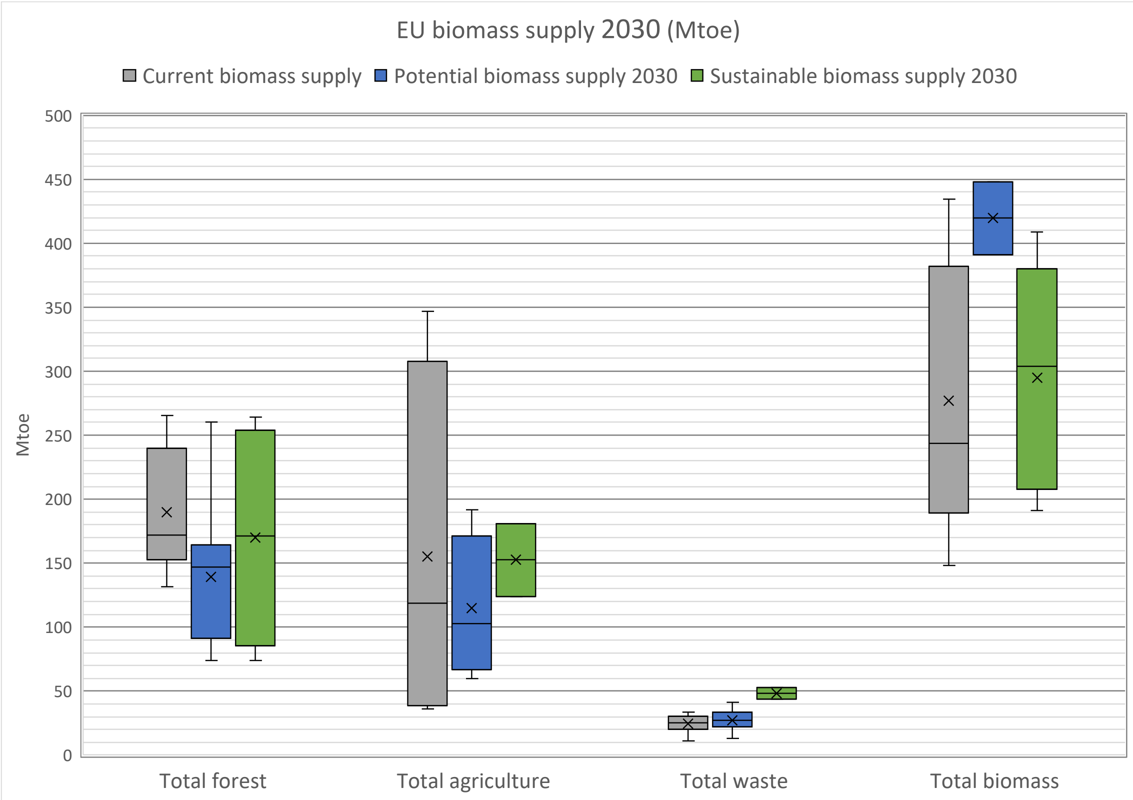
- Waste categories are more diverse than other biomass types and categories are more likely to overlap due to different understandings of types of biomass waste. For example, some of the high-end estimates includes wood waste, while other excludes wood waste as covered under forest biomass.

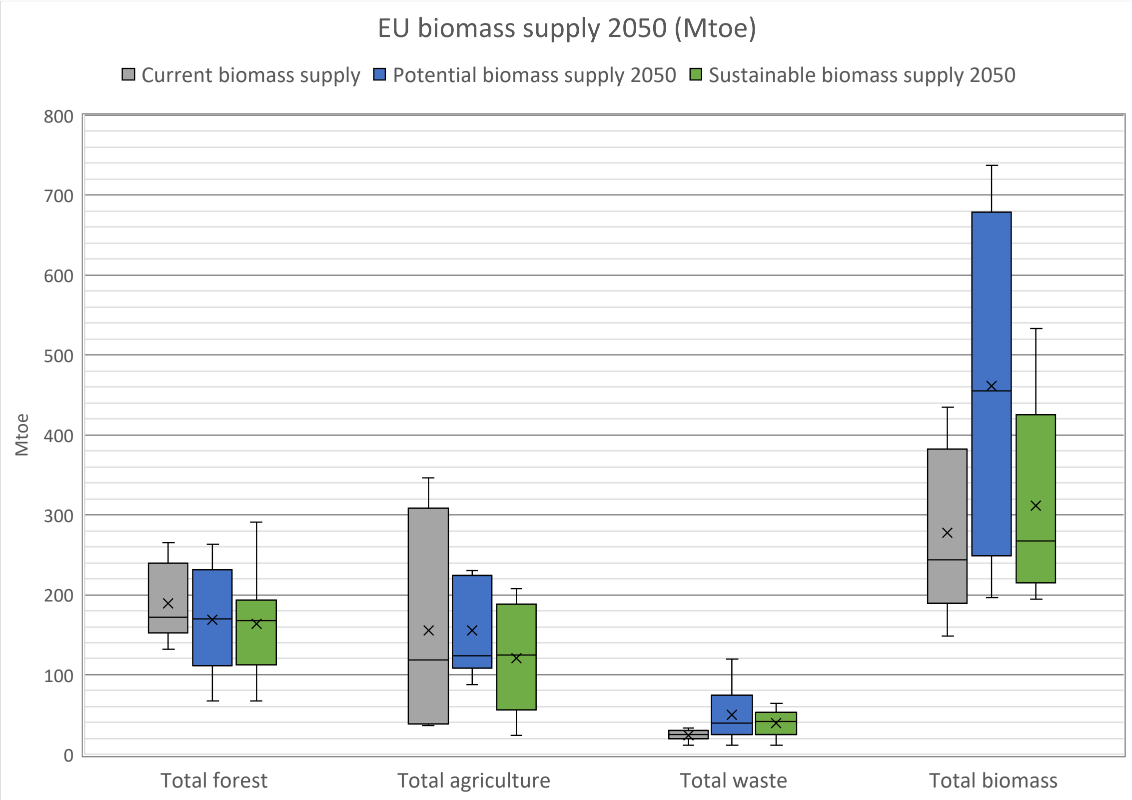
- The supply of such waste streams is directly related to economic activities, markets and technologies and can be highly fluctuate over time. Technological developments can potentially increase the use and efficiency if waste streams – and potentially reducing the costs associated with the collection and usage of waste.

- Fewer materials on biomass waste potentials and mobilisation estimates than for other biomass types.
- Overall, in reaching consensus we need to agree on the definitions and assumptions on biomass waste.

This is an ordered list

Figure 3: Total current*, potential and sustainable EU biomass supply (in Mtoe) in 2030 and 2050 based on recent literature on EU biomass supply





Notes: The potential and current biomass supply includes different potentials, including theoretical and technical potential, but excludes ecological/(environmental) sustainability potentials covered in separate boxes.

*The current biomass supply covers a range of years from 2010-2020 due to limited data. The cross the lines represent the average values, while the box inside the boxes represents the median (50th percentile). The arms from the boxes illustrate the minimum and maximum values, while the top and the bottom of the box represents the 25th and 75the percentile.

In understanding the data presented here, we may be seeing differences in figures from several causes. The following bullets identify some of these potential reasons for the differences in these and other figures hampering comparability.

- Sustainable supply levels could be higher than current supply as a result of changing biomass types and sources;
- As a result of the geographic coverage of the underlying data, such as EU-28, EU-27, Europe (including a wider country set beyond the EU);
- As a result of focusses assessments for just certain end-uses in the supply chain, such as potentials only for bioenergy use, rather than total biomass supply;
- As a result of a change in biomass types and sources between current, technical, and sustainable potentials, so that the same type of biomass is not

being compared. For example, current supply could be 100% woody biomass from primary sources, but the sustainable supply may be 50% woody biomass from waste and 50% agricultural residues; and

- As a result of increased technological recovery or innovations that enable different biomass extraction or more sustainable sourcing.

Unpacking the reason for these variations is possible but requires a much deeper understanding and interrogation of the data and the assumptions that underpin it. From a policy perspective, this reduces the useability of the information and introduces uncertainty around the figures. As such, biomass use and the policies surrounding it should proceed only on a precautionary basis, with a focus on sustainability, whilst the monitoring and data to support such assessments improves.

3.2 Biomass demands and needs

Since 2000, EU bioenergy use has increased by 150%. The demand has been partly driven by policy incentives and commitments towards a net-zero GHG and sustainable economy with more efficient use of our resources[10]. In the EU, bioenergy demand is particularly linked with the renewable energy targets currently set under the REDII(I) and commitments in the NECPs, as well as a growing focus on material substitution in the bioeconomy. The use of biomass to provide renewable materials, fibre, and chemicals is expected to increase in the transition to net-zero. The various policy and strategy targets listed here and earlier in the report are part of the driver of biomass use, but they do not explicitly provide subsidies. These are provided as a response to the policy incentive and targets that Member States are asked to commit to and provide, such as the share of renewable energy in the total energy mix of a country, or the EU as a whole. In order for this to happen, subsidies in various forms (such as feed in tariffs, or exemptions) create then financial incentives to utilise renewable energy. The zero-rating of biomass in the EU's climate accounting approach for energy, allows for the use of biomass to meet these targets, and thus benefit from subsidies, providing it satisfies the sustainability criteria of the RED II.

The increasing demand and the dynamics in different sectors of the economy are putting pressure on the natural environment to provide bioresources and risk increasing import of bioresources from non-EU countries, exporting our material footprint. At the same time, carbon sinks and protection of ecosystem services

[10] Material Economics (2021). EU biomass use in a net-zero economy – a course correction for EU biomass. https://materialeconomics.com/latest-updates/eu-biomass-use

continue to grow in importance as they are increasingly recognised as the essential basis for a sustainable society (EU Green Deal (COM/2019/640 final); EU Biodiversity Strategy (COM(2020) 380 final); EU's 8th EAP (COM(2020) 652 final)), yet their protection is at risk.

3.2.1 Energy demand for biomass resources

The EU's demand for renewable energy is set to increase considerably in the gradual phase-out of fossil fuels in the EU's energy mix and the targets set for renewable energy sources. Currently energy and material consumption accounts for between 48% (JRC, 2018) and 60% (Material Economics, 2021) of the EU's woody biomass consumption providing around 11.6 EJ of energy output (in material and energy forms) (average from a range of 6.2 – 18.2 EJ/yr). The energy sector is by far the largest user of EU internal wood processing residues and by-products, and the heating and cooling sector the largest end-use of bioenergy in general, using about 75% of all bioenergy consumed. Bioelectricity and transport fuels account for 13% and 12% respectively (JRC, 2018).

To 2050, energy consumption from biomass is expected to rise at a sustained rate with estimates varying from a near doubling (Material Economics, 2021) to a tripling (Faij et al., 2018). When material use is included, the consumption figure rises further with a 50% increase in material consumption alone expected as they replace other more carbon-intensive materials.

The expanding growth of demand from both energy and material uses will, to some extent, be mitigated with an increasing move towards a circular-bioeconomy and cascading use (Vis et al, 2016). However, even with the most circular system and greatest level of cascading use, energy recovery is a final step without further potential for re-use of the original fibre. Therefore, whilst the material demand can be mitigated to some extent through greater recovery and re-use, the energy demand cannot.

Currently the majority (96%) of EU's biomass demand is met from domestic sources, while only around 4% is imported from non-EU countries with varying approaches depending on the Member State (Box 5) (EU Science Hub, 2019). Biomass use patterns typically develop based on the available and residual biomass streams present in a country. For example, Spain has a high potential to utilise agricultural residues from its permanent crops (olives, fruit trees), Denmark utilises a significant amount of straw from its agriculture sector, whilst Finland focuses on solid biomass from forest sources. Yet the scale of demand required is leading some countries (such as Denmark and the Netherlands) to look beyond domestic supplies to increase imports. This approach further increasing the EU's material footprint to third countries. The dependence on material consumption is recognised by and addressed in part through the EU's Circular Economy Action Plan, which notes that "The EU needs to....keep[ing] its resource consumption within planetary boundaries, and ... to reduce its consumption footprint and double its circular material use rate in the coming decade" (EC, 2020).

Box 5: Examples of EU Member State approaches in meeting biomass demand

Demand scenarios foresee an EU increase in biomass for energy (and material purpose) related to the gradual phase-out of fossil fuels. According to a recent study (Fern, 2021), electricity and heat produced from biomass is expected to increase overall through implementation of the planned additional measures but decline in proportion to other renewable sources by 2030. This is explained by the fast technological development in other renewable sources, such as wind and solar power for electricity. Nevertheless, in the heating and cooling sector, biomass, and especially solid wood-based biomass, is still planned to provide the majority of renewable energy in the coming years. However, the demand and use trajectories of biomass and approaches to meet such demands vary between Member States.

Solid biomass is most important for electricity production in Nordic countries, such as **Finland** and **Denmark** where it contributes more than 10% of the total electrical production. However, the most extensively used renewable source for electricity in Denmark is wind. In Mediterranean areas, such as **Spain**, biomass demand for energy is often much lower for electricity generation but remains important for heat. In **Finland**, primary solid biomass holds the largest share of renewable energy sources (after hydro power) with a production increase by 39% between 2000-2018. The use of other bioenergy sources, such as biogas and renewable waste have further increased significantly from 137 GWh in 2000 to 1,089 GWh in 2018. Solid biomass is the main source of Finland's heating production and expected to continue to lead the consumption and production of energy for heating and cooling reaching 97 TWh in 2030. In terms of biomass supply, wood residues and forest chips are expected to see the biggest increase in the next decade (41-50 TWh between 2020-3030), black liquor will increase by 5 TWh (from 44-49 TWh between 2020-2030 (Smith et al., 2021), while a slight increase is expected for wood pellets. The use of forest waste will remain stable. The growth in biomass demand for energy is in part supported by the Finnish NECP, which sees a number of policy measures in place to promote the use of biomass including promoting forest chips and other wood-based fuels, promoting biogas in electricity and heat production, as well as promoting biomass transport (Smith et al., 2021; Ministry of Economic Affairs and Employment, 2019).

In **Denmark**, solid biomass and biogas are dominating the heating sector with an increasing trend while heat pumps are expected to increase significantly by 2030. Denmark is one of the leading users of straw for energy production via district heating schemes, industrial processing, and domestic heating. Further technology development is being conducted to enhance the efficiency, optimisation, sustainability, and profitability of the utilisation of agricultural residual biomass – especially straw for biofuel gasification (Smith et al, 2021)[11]. Projections show that electricity will continue to depend mainly on other renewables, such as wind, while bioenergy and solar PV complement the renewable energy mix. Wood biomass constitutes more than half of the total national bioenergy consumption with wood pellets mainly imported, while the majority of other bioenergy forms are produced domestically. Forest biomass is expected to decrease slightly in Denmark in the coming years due to an increasing focus on sustainable forest biomass and the implementation of national forest regulations and agreements (Smith et al, 2021).,[12]

In **Spain**, bioenergy plays a marginal role in the total energy mix. The major sources for electricity generation are hydro energy and wind energy, with recent development in solar PV production. Solid biomass is the main source of Spain's heating production, yet with a considerable increase in heat pumps since 2014. An increase in the renewable electricity production is expected up to 2025 but expected to decrease from 2030. The main source of biomass production is the forestry sector, where the largest developments are expected to occur in response to demands from the heating and electricity sectors. To meet the increasing demand for biomass, Spain is encouraging the use of woody pruning waste as a feedstock to complement more traditional sources and is promoting the

[11] DTU (2019) Denmark should focus on converting straw to biofuel. Access date: 11/11/2021. Available at : https://www.dtu.dk/english/news/2019/06/denmark-should-focus-on-converting-straw-to-biofuel??id=4ef702ec-09cf-41df-abc7-46e8517ee6be

[12] DTU (2019) Denmark should focus on converting straw to biofuel. Access date: 11/11/2021. Available at : https://www.dtu.dk/english/news/2019/06/denmark-should-focus-on-converting-straw-to-biofuel??id=4ef702ec-09cf-41df-abc7-46e8517ee6be

use of residual forest biomass[13]. Agricultural residues are an important source of biomass feedstock in Spain, with potential increases from sources such as residues from olive and fruit trees, or from[14,](Smith et a., 2021). Dedicated energy crops are also foreseen as a potential source, grown on some of Spain's abandoned land areas.

Box 6: Coverage of bioenergy and biomass in the EU MSs Recovery and Resilience Plans (RRPs) to achieve key strategic objectives - the case of Germany and France

As a response to the COVID-19 crisis, the European Commission (EC) established a recovery package, including a green recovery fund (Recovery and Resilience Facility),[15] addressing social and economic impacts, whilst transforming into more digital, sustainable and resilience societies in alignment with the European Green Deal objectives. To receive funding from EU recovery fund, countries must fulfil funding criteria set by the EC. These include a minimum expenditure benchmark of 37% devoted to EU climate objectives, with the goal of carbon neutrality by 2050, and 20% to the digitalisation of the economy.

The RRFs include opportunities to invest in long-term, cost-effective, and sustainable uses of biomass and a sustainable circular bioeconomy. However, several recovery plans are not explicit on bioenergy and only includes limited investment components directly related to biomass supply and use. Instead, recovery plans are channelling green recovery money to biomass use in some others forms. For example, the Germany recovery includes very limited information on funds for bioenergy, biomass, and bioenergy, and it rather limited in scope, with specific and concrete measures focusing primarily on renewable (green) hydrogen and digitalization. However, some funds promote the use of biomass through

[13] Through the Spanish Strategy for the Development of Energy Use from Forest biomass

[14] FuturEnviro (2021) Biomass could satisfy total energy demand in Spain for 28 days per annum. Accessed on 11/11/21. Available at: https://futurenviro.es/en/biomass-could-satisfy-total-energy-demand-in-spain-for-28-days-per-annum/

[15] European Council (2021) A recovery plan for Europe. Accessed on 11/11/21/ Available at: https://www.consilium.europa.eu/en/policies/eu-recovery-plan/

sustainable forest management (EUR 680m), 'building with wood (EUR 20m), and through measures to endure climate-friendly timber constructions. The focus on green hydrogen, and the expansion of wind power and solar PV could potentially reduce demand on biomass for bioenergy purposes[16].

The French RRP has allocated 50% of its economic recovery budget towards the ecological transition and the EU emissions reduction. France requires new public buildings to contains at least 50% wood in construction, promotes the use of materials for insultation with low environmental footprints e.g. bio-sources materials, as well as promotes the use of biomass boilers aiming e.g. to decarbonise the industry. These measures can lead to an increase demand of biomass resources. Further, one of key strategies to facilitate the financing of measures promoting innovation for the ecological transition is the bio-sources products, biotechnology, and sustainable fuels strategy. This strategy is expected to provide significant climate benefits and contribute to climate objectives. Additionally, the French PPR includes measures to ensure biodiversity and resilience (total of EUR 550m), as well use of environmental footprint of bio-sources materials – focusing on waste projects (NRRP, 2021)[17].

3.3 Supply versus demand

The demand for EU biomass is predicated on meeting material and energy needs – which themselves could be tempered through reduced consumption and increased resource efficiency. There are alternatives to biomass for many such needs, with some being more environmentally sustainable (such as wind power in the electricity generation sector), and others (such as fossil-based plastics in packaging) being less sustainable. The supply to meet these demands then varies considerably depending on the conditions of that supply, including type of biomass, suitability for the end use, and sustainability and economic

[16] Bundesministerium der Finanzen (2021). Deutscher Aufbau- und Resilienzplan (the German recovery and resilience plan). Accessed on 12/11/21. Available at: https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Europa/DARP/deutscher-aufbau-und-resilienzplan.htmlile&v=

[17] Gouvernment (2021) Presentation of the National Recovery and Resilience Plan. Accessed on: 11/11/21. Available at: https://www.aft.gouv.fr/en/french-recovery-plan

considerations. The range of supply potentials is confusing, as it masks the assumptions which underpin those figures.

Demand scenarios are envisioning a near-doubling to a tripling in bioenergy by 2050 and a 50% increase in material consumption. A recently published report (Material Economics, 2021) found that the demand for biomass would be up to 19 EJ by 2050. This level is within the range of the estimated theoretical and technical availability of biomass up to 30 EJ by 2050 via intensive extraction of bioresources. However, considering the ecological limits of biomass supply (see section 2.2) the sustainable potential supply is much lower. The realistic and sustainable scenarios for supply consistent with EU environmental and climate goals ranges between 9-17.2 EJ/yr (191-409 Mtoe) by 2030 and between 9-22 EJ/yr (215-478 Mtoe) by 2050, with an average biomass supply of 14.2 EJ/yr (340.2 Mtoe) in 2050. A narrower range of range between 11-13 EJ/yr is seen when considering EU sustainability criteria and economic considerations to provide a more realistic estimate (Material Economics, 2021). Using this estimate, a gap of 6-8 EJ/yr (143.4-191.2 Mtoe) emerges from the expected demand. This is corroborated from several other literature sources, leaving a gap of around 6 EJ/yr (143.4 Mtoe) between the hoped-for levels of EU biomass in current climate mitigation scenarios, and the availability of sustainable sources. Regarding forest biomass, the average sustainable forest supply is 170 Mtoe (7.1 EJ/yr) in 2030 (range from 74-264 Mtoe (3.1-11 EJ/yr)), while the average sustainable forest supply in 2050 is 163 Mtoe (6.8 EJ/yr)(ranges from 67-291(2.8-12.2 EJ/yr)). The average current total forest supply is 189.7 Mtoe (7.9 EJ/yr), indicating that we are already past the average limit for sustainable forest biomass supply (see **Error! Reference source not found.**).

However, understanding the impact of supply versus demand, is complex. Supply figures vary considerably as do those in the demand/use sectors. The accuracy of the underlying data and clarity on the assumptions and caveats around supply and demand estimates is therefore critical. Yet, there continues to be an issue of data availability and comparability when making assessments, and there needs to be a much clearer outlining of the assumptions and scope that underpin the data in all cases so that they can be compared easily. The European Commission's JRC recent (2021) assessment of the wood resource balance in the EU concluded that the forest management intensity, in terms of harvest to increment ratio is underestimated, and that the amount of uncategorized woody biomass for energy generation has been growing steadily, with the reasonable assumption that part of this is made up of removals form EU forests (Jonsson et al., 2021). The analysis suggests that removals and fellings in official statistics are under reported and thus that forest harvesting intensity is also underestimated. This is a cause for concern when woody biomass use is expected to grow, whilst forest biodiversity risks decline along with the forest carbon stock.

4. DEALING WITH THE UNCERTAINTY OF BIOMASS AVAILBAILITY AND WORKING WITHIN ECOLOGICAL BOUNDARIES

There is a genuine and robust reason to transition the economy away from fossil, metal, and mineral resources towards those which are bio-based and renewable. Yet the principal challenge is that at present there isn't the possibility to replace on a 1:1 basis the fossil and mineral demands from society with those from bio-resources, even with significant increase in supply or reduction in demands. In the short to medium term (i.e. until 2050), the potential additional benefits from harvested wood products and materials substitution are unlikely to compensate for the reduction of the net forest sink associated with the increased harvesting. Therefore importantly, is it not solely the demand for biomass that needs to reduce, rather the demand for material and energy use in general – so that all sustainable supply streams (bio-based or otherwise) can play a role in a more sustainable economy. This is coupled to an ever pressing need to allow natural and semi-natural ecosystems to restore and thrive, growing natural carbon sinks, and reducing GHG emissions.

Within the debate on the use of biomass for energy and material purposes there is a spectrum of views on how sustainable the use of biomass is. These range from a fundamental belief that biomass should be used and exploited as a green and renewable resource as it can be regrown and comes from natural systems, to one that sees biomass as much more valuable and important to societal goals if it is left in-situ and protected. In practice these views extend to advocated positions of increasing biomass harvesting and production, to avoiding its use entirely. **Based on the review undertaken in this report, the current utilisation of biomass and biomass types exceeds what can be produced sustainably, and therefore there needs to be a limit to biomass exploitation.** What this limit should be and how it is implemented, is a more difficult question to resolve, with significant uncertainty in the amount and type of biomass that can be harvested and used without impacting carbon balances and ecosystem function. Existing sustainability criteria alone cannot address the cumulative impacts associated with biomass harvesting and utilisation at scale, with supply-side limitations being a necessary addition. Demand-side measures (such as removing policy incentives to utilise biomass for energy or improving the way carbon is accounted from biomass use in the economy) will be important in driving down the scale of demand for resource use, and thus allowing sustainability criteria to be more effective.

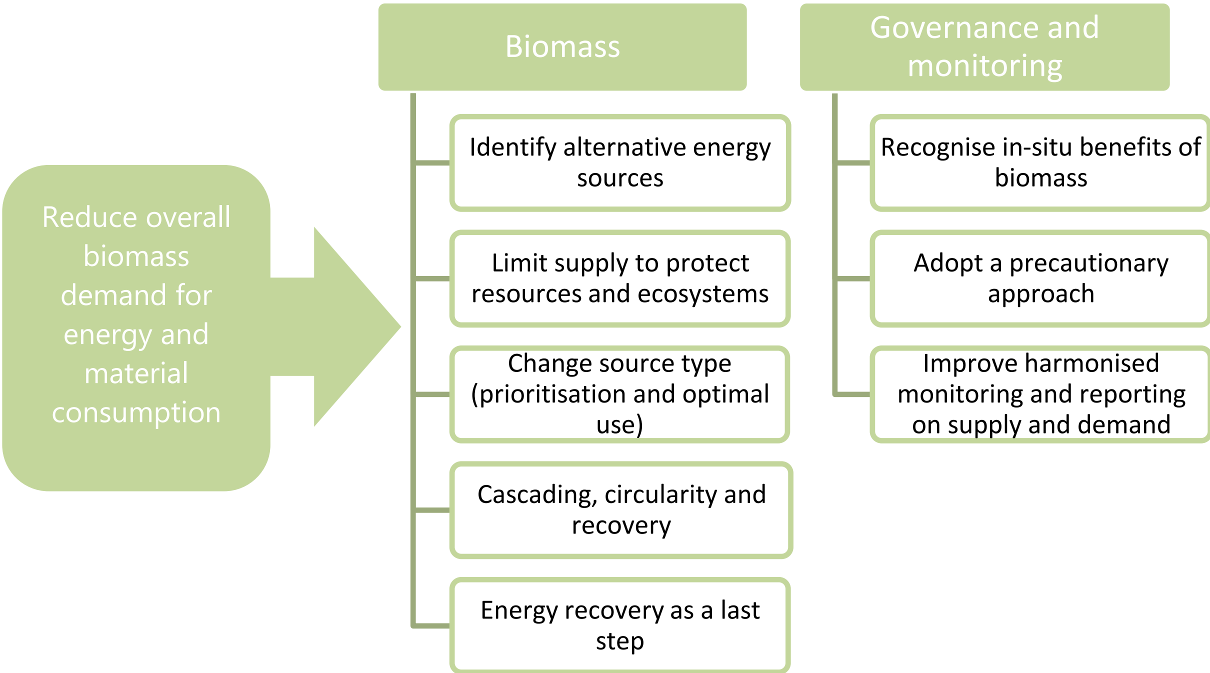
Further, the type of biomass that is utilised has an impact on sustainability limits as much as the amount of biomass. This is evident in the assessment of supply potentials earlier in this report, where sustainable supplies can appear to be similar to current levels of use. That is not to say that current use is sustainable, the evidence here is clear, rather than the volume of use 'could' be sustainable, but that there would need to be a fundamental shift away from utilising primary biomass (harvested biomass from land) towards utilising wastes and end-of-life biomass after it has passed through various use-phases before energy recover. Flanking measures (other policies and incentives) will be needed to ensure circularity and cascading use to maximise resource efficiency. This would serve to prioritise genuine wastes and residual streams over primary biomass that affects land use and ecosystem function directly. When uncertainty exists in both sustainable limits and biomass types, it is appropriate that a precautionary approach is taken so as not to jeopardise the role of biomass use in the economy, where it can genuinely add value and contribute to EU climate and environmental goals. For example, if we consider the point in the lifecycle of a piece of biomass and its role in energy generation, it is feasible that higher economic value application of timber, can, after its functional lifetime in a material form (through cascaded use), be reutilised and eventually captured for energy. The challenge in incentivising this approach is that the forest sector (which currently command the market for wood products) would have no immediate (financial) reward for that reuse, as they sell the timber fibre only once. This has and continues to be a challenge of implementing the circular economy in general. In this case, however, the potential for remuneration or recognition of the value of the un-harvested forest and biomass resources becomes increasingly relevant.

If not well-governed, the increasing demand for biomass for a variety of end-uses is and will continue to lead to pressure on natural resources and create competition within the biomass supply chains. Setting priorities for one biomass use over another depends on the different perspectives, interests, and policies in place, and a prioritisation or hierarchy of uses based on their environmental performance and/or alternatives. Therefore, **there is an urgent need to take more integrated and systematic approaches to the multiple uses and demands of bioresources to better understanding competing uses, implications on GHG emissions and the environment and to stay within planetary boundaries**. A more integrated understanding of sectoral demands could further support the cross-sectoral use of biomass to go beyond sectoral decarbonisation to ensure carbon removals. This would require an improved monitoring framework assessing both sustainable biomass supply with existing and future demands, not only in the energy sector, but also the wider bioeconomy.

4.1 Actions on the biomass supply chain

Addressing the increasing demands and risks of 'unsustainable' biomass supply will require both action on the supply- and demand-side. The demand for biomass will need to reduce and the supply of biomass will necessarily need to be limited whilst diversifying across a wider range of biomass types and sources. **Error! Reference source not found.** illustrates a structured approach to valorising biomass in the EU's green deal objectives whilst ensuring its sustainable use.

Figure 4: Structured approach to valorising biomass in the EU's Green Deal objective whilst ensuring its sustainable use



In general, **demand for materials and energy will need to reduce to take pressure off all resource streams and any substitution needs for biomass**. Reduction of the EU's material footprint is fast becoming an EU priority goal. The European Parliament's amendments to the 8th Environmental Action Programme draft text includes the requirement to "*significantly decreasing the Union's material and consumption footprints to bring them into planetary boundaries as soon as possible, including through the introduction of binding Union targets for significantly reducing the Union's material and consumption footprints as well as binding mid-term and long-term targets for the reduction in the use of primary raw materials*". Simply put, with less demand for materials and energy in general, the implementation of circular economy actions (including cascading) and a diversification of biomass resource streams with a focus on waste and residues, the pressure on primary raw materials will reduce. Following the schematic illustration above, the sections below propose actions on how to valorise biomass in the EU's Green Deal objective whilst ensuring its sustainable use within ecological boundaries.

4.1.1 Biomass actions

Identify alternatives where they exist

One action towards reducing demand on biomass and individual biomass streams is to identify and prioritise alternatives to biomass for energy. This would aim to ensure that where sectors compete for the same limited sustainable biomass resources, priority is given to uses which have limited or no existing sustainable alternatives. Such prioritisation should be based on several considerations including availability of alternatives, and where biomass provides the most added value to climate and environmental objectives as well as to society (such as retention of carbon in its material form for as long as possible). In some cases, more sustainable alternatives that do not require biomass are readily available, particularly for energy generation, such as wind, solar, green hydrogen, and heat pumps – which are foreseen to increase over the medium to long-term (Material Economics, 2021). Further, there are other biomass uses where the alternatives are more limited, such as in material substitution to reduce the dependency on fossil and mineral resources. These are expected to grow through the development and promotion of the circular-bioeconomy. Therefore, there **is a need to promote, develop and scale-up alternative sustainable and renewable energy sources, deploying those first before turning to biomass as a source of energy**.

One specific challenge is identifying where, if and how, biomass can provide a meaningful climate benefit when used for energy recovery as opposed to other material uses or remaining in situ. Whilst biomass is seen as part of the transition away from fossil fuels, the use for energy can impact on the wider economic transition away from fossil and mineral resource use in the wider economy and the degradation of natural resources in ecosystems. Only the incentive structure and the carbon accounting mechanism allow biomass to be seen differently to fossil fuels themselves. At a fundamental level the debate here is **whether it is appropriate that the EU has a continuing reliance on carbon-based fuel sources of any kind (living carbon in the form of biomass or fossil carbon in the form of coal, gas, and oil), or that the transition away from carbon energy sources is the important step in favour of genuine renewables (solar, wind, hydro).**

Governments and stakeholders responsible for the ownership or management op bio-resources will play a critical role here in steering and prioritising the use of biomass (including biomaterials) and other renewable energy sources by **removing subsidies that allow for the burning of biomass**, and instead direct the financial benefit and incentives towards other renewable and sustainable energy alternatives, or towards more efficient use of biomass considering circularity and cascading. Taking away the economic advantage to regulate the biomass use will most likely lead to a reduced demand on bioresources for bioenergy as it is unlikely to be economically viable in the long-term with emerging energy technologies (Material Economics, 2021). **Recognising the in-situ benefits of growing carbon sinks in forests and their ecosystem and environmental implications, could provide an additional revenue stream** for the forest industries and owners of those systems, as providing benefits to society.

Be cautious with supply to protect resources

Based on the review of sustainable biomass supply undertaken in this report, the current utilisation of biomass exceeds what can be produced sustainability – undermining the ability of ecosystem systems to act as carbon sink. Further, a discussion with several stakeholders (see Box 3) showed agreement that biomass should only be used where sustainable and that this may mean limiting certain biomass streams. As such, **there is agreement on the need to limit biomass exploitation to protect ecosystems and the services they provide**. However, setting a limit – or a cap – on biomass supply or use is a more difficult question to resolve due to significant uncertainty in the amount and type of biomass that can be harvested and used without negatively impacting carbon and ecosystem balance. Further, large disagreements between different stakeholders on what constitutes "sustainable" biomass, the different types of biomass, and the role of biomass going forward makes it difficult to set an agreed limit on supply or use in general. However, even if a limit to biomass exploitation is difficult to define and imperfect, putting a cap on biomass use in the bioenergy market is sending a signal that there is an upper limit to its use, which is currently not communicated anywhere.

There are current limits to certain biomass types for use in renewable energy generation (food and feed-based biofuels, for example), through exclusion or caps on the use of certain feedstocks in the RED. This is based on the need to ensure that the resulting renewable energy delivers on the carbon benefits associated with renewables (a limit on certain feedstocks), whilst not causing adverse impacts on the environment (exclusion criteria on the source of feedstocks). Limiting feedstock volume in general is a blunt tool to ensure sustainability and climate mitigation benefits. There are some forms of biomass, such as genuine wastes and some residues that cannot be functionally used in a material or chemical form and where energy recovery is a last step in the value chain of those fibres. Any limit should not preclude this use of waste.

Restricting the supply of biomass for energy from primary sources does however have value as part of a set of responses. Coupled with cascading use, where biomass is kept in its material form for as long as possible, a cap on primary sourced biomass for energy should lead to a transition and focus on the use of waste biomass at the end of the value chain rather than at the beginning. As recovery techniques and technologies improve, this supply may reduce over time naturally.

Change biomass source type – prioritisation and optimal biomass sources

The *type* of biomass that is utilised has an impact on sustainability limits as much as the *amount* of biomass. **Diversification of bioresources** could lessen the pressure on any one stream or natural resource such as woody biomass, increasing the potential resource base and reducing dependency on single supply streams[18]. Increased heterogeneity of bioresources streams should therefore focus on bioresources with better carbon performance and lower environmental impacts, which should focus on end-of-life biomass and waste streams, rather than primary forms. If done correctly, diversification of bioresources streams could reduce the pressure on primary biomass resources, land, and ecosystems, whilst making biomass supply chains more resilient to future shocks. Regardless of the diversification, **the type of biomass used needs to change and be accompanied by flanking measures to ensure circularity and cascading to maximise resource efficiency**.

Advancement in energy and bio-resource production techniques and technologies

***Advancement in energy and bio-resource production techniques* and technologies** could further support the diversification of bioresources and energy sources. For example, accelerating the development of non-bio, low-emissions resource alternatives to reduce demand for biomass in key applications. Estimates that *"by 2050 a sufficient quantity of renewable hydrogen will be available to be used in advanced biofuel thermochemical conversion technologies"* Panoutsou & Maniatis (2021) suggest that biomass fuels will also be

[18] Which is particularly relevant as climate change events have already disrupted some biomass supply streams, as well as food and fodder harvests.

able to be substituted with more sustainable alternatives. Supporting critical innovation of biomass types, such as algae to explore their supply potential, suitability, sustainability, and scale of implementation is another developing area, although the same sustainability considerations should apply as to all biomass, and the question of carbon-based fuel sources remains. Where biomass is used, priority should be given to the more efficient energy conversion technologies to improve resource efficiency and reduce biomass demand. However, technological developments are only part of the overall package of approaches to improve the sustainability of biomass use in energy and should not be used to justify the current or further extraction of biomass beyond sustainability limits.

Cascading, circularity and recovery

In addition to diversification and advancement of grown bioresources, **there is a need to make more efficient use of biomaterials that are already in use, through greater circularity (recovery and re-use) and cascading (sequential use phases)**. Keeping biomass in use and utilising the same biomass for multiple sequential applications can be an effective means of both reducing the demand on newly harvested resources and extending the lifetime of already sequestered carbon. Such approaches are already evident in EU policy frameworks[19] including the European Bioeconomy Strategy promoting the sustainable use of biological resources through a circular cross-sectoral approach and the EU Circular Economy Action Plan aiming to increase the proportion of renewable or recycled resources, reduce consumption of raw materials, whilst ensuring environmental protection.

Box 7: Understanding cascading use

Cascading use is described as a complex interaction of materials flows and their utilisation in different sectors and products and used as a way to increase resource efficiency – for example through the *value pyramid* (Vis et al., 2016). The cascading use principle gives priority to higher value uses that allow the reuse and recycling of products and raw materials, and promotes energy use only when other options are running out. In a biomass context it builds material uses of biomass into the supply chain for energy generation so that multiple demands (material and energy uses) can be met with the same biomass, over time. Thus, it consequently

[19] However, there is a need to ensure more efficient, coherent, and scaled up policy frameworks and actions promoting circularity (incl. recovery and recycling) and cascading use of biomass to make biomass supply, use and demands sustainable in practice.

prioritises material use of biomass before biomass for energy purposes due to the end-life of biomass when burned as bioenergy.

One of the main aims and benefits of **circular biomass use** is that it keeps biomass in its material form for as long as possible. From a climate perspective this means the carbon in that biomass is retained (sequestered) for longer, and from a resource perspective reduces the demand for new or primary biomass. The challenge with energy recovery is that it is typically the last phase of the cascading chain beyond which it is only really feasible to recover minerals from combusted materials, or digestates and some fibre from anaerobic digestion.

Existing biomass waste streams, industrial by-and co-products are slowly being realised as a resource stream, with growth in some areas more than others. For example, paper and cardboard where the recycling rates are already relatively high. For example, between 2010-2015, the amount of biological waste that was not recovered (via recycling or energy recovery) was reduced by as much as 45%[20]. However, in most biomass categories, recycling and circularity is currently less limited, providing untapped potentials. The expanding growth of demand from both energy and material uses will, to some extent, be mitigated with an increasing move toward a circular bioeconomy and cascading use. **Further increases in biomass circularity and in the valorisation of waste and residual streams therefore offer a key potential of additional biomass supply, whilst creating less pressure on the natural environment than other primary streams.** This can be particularly important in balancing the retention of carbon in forests whilst utilising wastes for the generation of energy where other more sustainable alternatives (such as wind or solar) are not available.

Energy recovery as a last step

Energy recovery enables there to be a functional use of biomass for energy whilst also recognising the in-situ benefits of biomass, as well as the material and chemical economic (and substitutional) benefits of biomass – further valorising an individual biomass stream. The challenge with energy recovery is that it is typically the last phase of the cascading chain beyond which it is only really feasible to recover minerals from combusted materials, or digestates and some

[20] SU Science Hub (2019) Food, feed, fibres, fuels. Enough biomass for a sustainable bioeconomy? Accessed on: 11/11/21. Available at: https://ec.europa.eu/jrc/en/news/food-feed-fibres-fuels-enough-biomass-sustainable-bioeconomy

fibre from anaerobic digestion. The energy recovery as a last step in the biomass chain and the biomass *"material first"* logic with higher value use of biomass is already widely applied in much of the forest-based industry. The approach is based on the fact the end-biomass has no commercial value and therefore could be used for energy generation. There remains a question on the carbon implications of still combusting biomass to produce energy and the resulting CO2 emissions that result. Any energy recovery approach at end of life would necessarily need to consider carbon capture techniques to lessen the impact of the re-release of carbon into the atmosphere, even from wastes or end-of-life biomass.

4.1.2 Governance and monitoring actions

If the biomass supply chain is not well-governed, the increasing demand for biomass for a variety of end-uses is and will continue to lead to pressure on natural resources and create competition within the biomass supply chain.

Recognise and valorise in-situ benefits of biomass

Whether or not there is agreement between stakeholders that subsidies or policy incentives drive biomass use for energy, **there are limited to no incentives to retain biomass in its living form – other than through broader strategy goals** (such as the EU Biodiversity strategy or Forest Strategy). Retaining living biomass, in the form of forests and ecosystems provides a much wider range of environment and social benefits than the extraction of biomass for material or energy use alone. However, the market systems to reward those who own or manage these resources does not exist. Even carbon pricing mechanisms are relatively nascent in this area of avoided carbon emissions as opposed to pricing the carbon that is used or intended to be used. **The current market therefore lacks incentives to keep biomass in situ to counter those which look at the 'use' of biomass, in energy, or the wider bioeconomy**. Work in this area is much needed, and particularly involving those stakeholders who own, manage and process biomass at present. Discussion in the stakeholder workshop illustrated that forest owners and managers see their role as both managing the forest for future generations, and actively contributing to the extraction of material resources. It is highly unlikely that in the near-term we will see forests going entirely untouched and being remunerated to not extract or use biomass runs counter to common perception in these groups.

Adopt a precautionary approach

As seen from this report, uncertainty and significant divergence of opinion between stakeholders exists in both sustainable limits and biomass types, and further at which point ecological boundaries and tipping points will be breached, or where carbon impacts undermine the expected GHG savings when full carbon accounting takes place. Yet, **sustainable bioenergy and wider bioeconomy transition must recognise and take responsibility for its reliance on natural capital and prioritise management options that maintain or enhance ecosystem condition and the delivery of ecosystem services.** The most obvious of routes to address the impact of over-exploitation of biomass for energy production is to take **a precautionary approach** so as not to jeopardise the role of biomass use in the economy, where it can genuinely add value and contribute to EU climate and environmental goals.

In addition to the various measures already outlined, a precautionary approach would be one in which the use of biomass is only favoured where there is certainty on the sustainability of that biomass and where other alternatives for energy generation do not or could not exist. This means that despite the relative ease and compatibility with current energy systems, biomass use for energy should not be a default option.

Improved harmonised monitoring and reporting on supply and demand

There is a lack of consistency and accuracy in supply and demand figures, as such, **there is a need to improve harmonised monitoring and reporting on supply and demand so that they can be compared consistently and accurately for policy development** – this is partly taking place through JRC and EEA monitoring, but the interpretation of the data based on sustainability constraints varies considerably and would need further harmonisation. In doing so, transparency on the assumptions underpinning biomass supply estimates should be enhanced. Further, to ensure a more integrated understanding of multiple uses of biomass and sectoral demands and support the cross-sectoral use of biomass to go beyond sectoral decarbonisation to ensure carbon removals, would require improve monitoring framework that assess both the sustainable biomass supply with existing and future demands.

Included in the harmonised monitoring and reporting should be the clear definitions of sustainability for biomass, that would allow greater comparability or interrogation of existing reports that are not produced through EU institutions. This may necessitate further research to identify pathways that minimise trade-offs and maximise synergies between climate mitigation and biodiversity conservation, as part of the sustainability definition. Such research could be undertaken through the Horizon Europe mechanism.

A consistent approach in policy

Currently there are a range of competing policy demands and drivers for the use of biomass, which run in some ways counter to the strategic objectives of the Green Deal and existing strategy targets (e.g. Forest and Biodiversity) to protect ecosystems and (re) build carbon stocks in their natural form. This is understandable as policies have evolved at different speeds and for different reasons, but with the real impact on ecosystems and the urgency to restrict further release of carbon into the atmosphere, the policies that implicate the use of biomass need to be both revised and harmonised. This will involve scrutiny in a wide range of policy areas, including energy policy, bioeconomy and circular economy policies, carbon accounting mechanism, conservation policy, land use and industry policies. It is the package of these policies that will help to steer and address the use of biomass in the economy providing it with a place in the sustainability transition rather than running counter to it. This should include the restructuring of policies to:

- **provide** a clear future trajectory for those sectors that currently manage and use biomass.
- **prevent** system lock-in that would prolong the use of unsustainable biomass streams.
- **ensure** that anything that releases carbon into the atmosphere and contributes to climate impacts is disincentivised.
- **promote** only the ecological high value use of biomass, including the value of biomass in its living and natural form.
- **re-establish** the economic, environment and social value of natural ecosystems and their protection.
- **ensure** that trade and import policies are aligned with the EU's internal goals based on the above, and thus avoiding the export of environmental and social impacts beyond the EU's borders.

5. KEY POLICY RECOMMENDATIONS

This section provides key policy recommendations intended to support the sustainable development of the EU bioenergy (and bioeconomy) whilst respecting ecological boundaries.

- There is a significant divergence of opinion between stakeholders on how to treat biomass within EU policy, and it is important to recognise those who will be impacted by future policy changes. Yet, **sustainable bioenergy and wider bioeconomy transition must recognise and take responsibility for its reliance on natural capital and prioritise management options that maintain or enhance ecosystem condition and the delivery of ecosystem services.**
- The most obvious of routes to address the impact of over-exploitation of biomass for energy production is to **take a precautionary approach and limit its use whilst focusing more on genuine and renewable alternatives which are already common but relatively under-utilised in the EU's energy mix**. Setting a clear and long-term trajectory for the use of biomass and its role in the EU's Green Deal will help all stakeholders to recognise the opportunities, plan, invest and benefit.
- **The current deployment of nearly 60% of renewable energy from biomass is not in line with the goals of the EU Green Deal – particularly when considering future demand scenarios.** For biomass to continue to have a role in the EU's sustainability transition its use will need to be limited, and that this limited sustainable resource to be targeted towards high-environmental-value applications in those areas where there are no suitable or more sustainable alternatives. Wind and solar power are good examples of alternatives that have minimal impact on the environment whilst providing genuinely renewable sources of energy without impacting natural carbon sinks or necessitating a recovery period, to capture emissions. As such, there **is a need to promote, develop and scale-up alternative sustainable and renewable energy sources, deploying those first before turning to biomass as a source of energy**.
- **Policy scenarios need to include a robust counterfactual assessment of the ecosystem and carbon benefits of not using the biomass and the land associated with its production for energy purposes.** This would serve to identify **(the counterfactual)** and what contribution such biomass and land would make towards the EU's climate goals through its sequestration and sink potential, as well as through avoided emissions (from harvesting and combustion), whilst other sources of renewables are scaled up.
- Stakeholders who are responsible for the ownership or management of bio-resources and the ecosystems from which they arise, such as forests, will need

support in this transition. This can in-part be achieved by **recognising and incentivising the value of the in-situ benefits of biomass to the climate (retaining carbon in its living form) and the environment, rewarding those who protect and enhance the resource over those who extract and exploit it.** This could be achieved, for example by paying directly for the carbon value of forests, avoided emissions or carbon sequestered (akin to emerging carbon farming initiatives promoted in the EU's Farm to Fork strategy); or through other income mechanisms for forests associated with tourism. The full modalities of such an approach would need to be researched and developed.

- The prioritisation of biomass towards where it provides the most added value to climate and environmental objectives (even if this means that it remains *in situ*), will **require the introduction of complementary policy measures of circularity (recovery and re-use) and cascading (sequential use phases) to maximise resource efficiency, with energy recovery only as a final step**.
- Focussing on alternatives and prioritising biomass use touches on a wide range of different and existing policies. **The addition of an overarching biomass (and bioeconomy) governance mechanism within the EU policy framework would help to guide biomass use in a consistent and coherent way towards the EU's climate and environmental goals**. This should include the restructuring of policies to focus on the contribution to achieving the EU's 2030 and 2050 biodiversity and climate objectives as set out in the EU Forest Strategy. Specifically, the overarching biomass framework should:
    - **provide** a clear future trajectory for those sectors that currently manage and use biomass
    - **prevent** system lock-in that would prolong the use of unsustainable biomass streams
    - **ensure** that anything that releases carbon into the atmosphere and contributes to climate impacts is disincentivised
    - **promote** only the ecological high value use of biomass, including the value of biomass in its living and natural form
    - **re-establish** the economic, environment and social value of natural ecosystems and their protection
    - **ensure** that trade and import policies are aligned with the EU's internal goals based on the above, and thus avoiding the export of environmental and social impacts beyond the EU's borders.

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Annex 1 Key studies for the EU biomass supply review

The table below provides an overview of key literature and data reviewed to perform the assessment of biomass availability and supply in the EU.

Reference	Study title	Objective	Spatial coverage	Timeframe	Method	Type of potential
Bentsen, N., Felby, C. (2012)	Biomass for energy in the European Union – a review of bioenergy resource assessment	Biomass for energy in the European Union	EU-27	2030	Review of resource assessments	Theoretical, technical, sustainable
Böttcher et al. (2012)	Biomass availability and supply analysis.	Estimation of biomass potentials for bioenergy and demonstration of harmonised approaches developed within BEE	EU-27	2010, 2020, 2030	Statistical, spatially explicit, integrated modelling	Theoretical, technical, economic, sustainable implementation
De Wit & Faaij (2010)	European biomass resource potential and costs	Assessment of the European cost and supply potential for biomass resources	EU+UA	2030	Resource focused – spatially explicit	Technical, economic

EC (2017)	Sustainable and optimal use of biomass for energy in the EU beyond 2020	Biomass supply potentials for the EU and biomass demand from the material sector by 2030	U-28 (+ biomass imports)	2012, 2020, 2030	Integrated modelling (model Green-X)	Restricted (stronger utilisation restrictions); Reference (EU wood availability given under today's circumstances); Resource (maximum possible utilisation in the EU under long-term sustainable conditions)
Elbersen et al. (2013)	Assessing the effect of stricter sustainability criteria on EU biomass crop potential	Quantification of technically constrained biomass potentials or different scenarios assumptions	EU-27	2020, 2030	Integrated model	Ecologically sustainable
Faaij (2018)	Securing sustainable resource availability of biomass for energy applications in	Sustainable resource availability of biomass for energy applications in Europe	Europe	Current, 2020, 2030	Literature review	Theoretical, economic, implementation, ecologically potential

Kluts et al. (2017)	Sustainability constraints / Europe; a review of recent literature in determining European bioenergy potential: A review of existing studies and steps forward	Review of European Land and bioenergy potential studies to (i) identify shortcomings of how they account for agricultural intensification and sustainability constraints; and (ii) provide suggestions to how to overcome shortcoming and improve future assessments.	EU	2020, 2030	Review	Ecological sustainability, technical potential
Material Economics (2021)	EU biomass use in a net-zero economy – a course corrections for EU biomass	EU biomass supply and prioritise EU biomass resources in a low-carbon transition	EU	Current, (2030), 2050	Modelling	Sustainable potential
Panoutsou, C., & Maniatis, D., (2021). Imperial College London	Sustainable biomass availability in the EU, to 2050. Ref: REDII Anne IX A/B	The report provides an estimates of the sustainable biomass potential availability in the EU and the UK by 2030 and 2050 and to provides	EU and the UK	2030, 2050	Scenario development	Sustainable potential, includes only feedstock included in the Annex IX of REDII (part A and B)

		and evaluation of the advanced biofuel potential.				
Ruiz et al. (2015)	The JRC-EU-TIMES model: Bioenergy potentials for EU and neighbouring countries	Quantification of current and future biomass potentials for energy	EU and neighbouring countries	2020, 2050	Modelling	Bioenergy potentials: Three scenarios (low, reference high)

Annex 2 Summary table of ranges of EU biomass supply in Mteo (EJ/yr) based on review of recent sources

A) All potentials, but the ecological (environmentally sustainable) potential.
B) Total agricultural production without considering what is used for feed and fodder.

Types of biomass	Current biomass supply in Mtoe/yr (EJ/yr)a	Potential biomass supply 2030 Mtoe/yr (EJ/yr)a	Potential biomass supply 2050 Mtoe/yr (EJ/yr)a	Sustainable biomass supply 2030 Mtoe/yr (EJ/yr)a	Sustainable biomass supply 2050 Mtoe/yr (EJ/yr)a
Total of EU biomass supply	148-434.4 Mtoe (6.2-18.2 EJ/yr) Average: 277.3 Mtoe	391-448 Mtoe (16,4-18,7 EJ/yr) Average: 419.5 Mtoe	143-737 Mtoe (6-30 EJ/yr) Average: 461 Mtoe	191-409 Mtoe (8-17.1 EJ/yr) Average: 295 Mtoe	206-533 Mtoe (8,6-22,3 EJ/yr) Average: 323.8 Mtoe
Forest					
Total forest	131.5-265.3 Mtoe (5.5-11.1 EJ/yr) Average: 189.7 Mtoe	74-260.5 Mtoe (3.1-10.9 EJ/yr) Average: 139.4 Mtoe	67-263 Mtoe (2.8-11 EJ/yr) Average: 168.7 Mtoe	74-264 Mtoe (3.1-11 EJ/yr) Average: 170 Mtoe	67-291 Mtoe (2.8-12.2 EJ/yr) Average: 163.5 Mtoe
Primary forests	90.8-184 Mtoe (3.8-7.7 EJ/yr)	NA	110 Mtoe (4.6 EJ/yr)	129.5 Mtoe (5.4 EJ/yr)	114.7-133.8 Mtoe (4.8-5.6 EJ/yr)
Forest residues	14.3-124.3 Mtoe (0.6-5.2 EJ/yr)	3.5-8.6 Mtoe (0.1-0.4 EJ/yr)	6.4-57.9 Mtoe (0.3-2.4 EJ/yr)	NA	9.6-19-1 Mteo (0.4-0.8 EJ/yr)
Industrial by-products	43 Mtoe (1.8 EJ/yr)	NA	NA	NA	38.2-40.6 Mtoe (1.6-1.7 EJ/yr)
Agriculture					
Total agriculture	35.9-346.6 Mtoe (1.5-14.5 EJ/yr) Average: 155.1 Mtoe	60-192 Mtoe (2.5-8 EJ/yr) Average: 115 Mtoe	88-230 Mtoe (3.7-9.6 EJ/yr) Average: 155.7 Mtoe	124-181 Mtoe (5.2-7.9 EJ/yr) Average: 152.5 Mtoe	23.9-207-9 Mtoe (1-8.7 EJ/yr) Average 120.2 Mtoe

Dedicated energy crops	12-351 Mtoe (0.5-14.7 EJ/yr)	48-439 Mtoe (2-18.4 EJ/yr)	NA	36-64 Mtoe (1.5-2.7 EJ/yr)	4.8-133-8 Mtoe (0.2-5.6 EJ/yr)
Agriculture residues	16.7 Mtoe (0.7 EJ/yr)	21.5-74.1 Mtoe (0.9-3.1 EJ/yr)	14.3-342.7 Mtoe (1.9-5 EJ/yr)	36-98 Mtoe (1.54.1 EJ/yr)	19.1-74.1 Mtoe (0.8-3.1 EJ/yr)
Waste					
Total waste	11.3-33.5 Mtoe (0.5-1.4 EJ/yr) Average: 24.8 Mtoe	13-41 Mtoe (0.54-1.7 EJ/yr) Average: 27.5 Mtoe	12-119 Mtoe (0.5-5 EJ/yr) Average: 49.9 Mtoe	44-53 Mtoe (1.8-2.2 EJ/yr) Average 48.5 Mtoe	11.8-64.5 Mtoe 0.5-2.7 EJ/yr) Average: 40 Mtoe
Paper and cardboard waste	5-15 Mtoe (0.2-0.6 EJ/yr)	NA	NA	NA	12-23.9 Mtoe (0.5-1 EJ/yr)
Wood waste	5-15 Mtoe (0.2-0-6 EJ/yr)	10 Mtoe) (0.4 EJ/yr)	NA	NA	7.2-12 Mtoe (0.3-0.5 EJ/yr)
Other waste (e.g. sewage sludges, animal and mixed food waste, vegetal waste, dredging spoils)	0.5-2.8 (11.3-66.9 Mtoe)	NA	10.5-51.1 Mtoe (0.4-2.1 EJ/yr)	NA	12-28.7 Mtoe (0.5–1.2 EJ/yr)

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