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DBFZ

DISCUSSION PAPER

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Contact persons:

Dr Harry Schindler
Tel.: +49 (0)341 2434-557
E-mail: harry.schindler@dbfz.de
Dr Volker Lenz
Tel.: +49 (0)341 2434-450
E-mail: volker.lenz@dbfz.de

DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Torgauer Straße 116
04347 Leipzig
Tel.: +49 (0)341 2434-112
E-mail: info@dbfz.de
Web: www.dbfz.de

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Content

List of abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
BECCU	Bioenergy with Carbon Capture and Utilization
BEG	*Bundesförderung für effiziente Gebäude* (Federal funding for efficient buildings)
BEW	*Bundesförderung für effiziente Wärmenetze* (Federal funding for efficient heating grids)
EEG	*Erneuerbare-Energien-Gesetz* (German Renewable Energy Sources Act)
ESR	EU Effort Sharing Regulation (EU Reg. 2018/842)
ETS	EU Emissions Trading System (EU Reg. 2003/87 EG)
GEG	*Gebäudeenergiegesetz* (German Building Energy Act)
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
RED	EU Renewable Energy Directive (EU Dir. 2018/2001)
SDG	UN Sustainable Development Goal(s)

Summary

- Wood is not only required for producing furniture, paper and construction materials. Forest biomass also represents an important renewable resource for energy supply, nature conservation and the chemical industry. **Regarding the manifold demands and its limited availability, wood uses have to be balanced carefully.**

- **Climate effects of forest bioenergy are complex and context specific.** General statements proclaiming climate neutrality of wood fuels or that using these fuels results in larger emissions than fossil energy sources do not sufficiently reflect this complexity.

- Next to climate effects, the use of wood for energy also affects other ecologic, economic and social sustainability goals. Therefore, **assessing sustainability** of forest bioenergy **has to move beyond the mere analysis of greenhouse gas balances.**

- One way of securing the ecological, economic and social sustainability of forest bioenergy is to **align all wood uses according to the criterion of 'qualified climate protection efficiency'.** According to this criterion, wood is allocated, within ecological and social boundaries, between forests, material wood products and forest bioenergy in a way that minimises the costs of climate policy across all sectors. From this perspective, an efficient contribution from forests and the land use sector LULUCF to comprehensive climate targets is a key criterion for the sustainable scope of forest bioenergy.

- Long-lasting wood products and the multiple use of wood in cascades can contribute to climate mitigation and resource protection. However, whether current energy policies ensure sustainable wood cascades with forest bioenergy as the last stage is questionable. **The EU RED's utilisation hierarchy and the exclusions of specific forest biomasses do not reflect the complex and dynamic reality of forestry and timber markets.** Implementing and further expanding such requirements pose substantial risks of overburdening state and wood users alike with increasing monitoring and certification processes.

- Instead addressing symptoms of distorted timber markets with the help of RED sustainability criteria, eliminating the causes of inefficient allocations of timber resources may provide a more suitable strategy for creating sustainable wood cascades. This does not require energy policies, but a climate policy approach. Such a strategy includes a **CO_2 price on biogenic carbon emissions from wood as well as subsidies for carbon storage.** This policy mix can ensure climate-friendly forest bioenergy without having to determine the complex greenhouse gas effects of individual wood fuels.

- **General financial support for forest bioenergy, e.g., via subsidies for heating systems or for electricity generation from forest biomass is an obstacle for sustainable wood use.** Such subsidies are economically inefficient and undermine existing targets to expand the LULUCF carbon sink. Accelerating the heat transition by such means also risks a shortage of wood for the material bioeconomy. An exception to this rule are subsidies for innovative energy technologies, such as hybrid heating systems. The necessary socio-political cushioning of the heat transition should be designed as incentive-neutral as possible, for example via lump-sum transfers.

- Reducing energy subsidies and including emissions from wood into CO_2 pricing will not be the end of forest bioenergy. Rather, these steps initiate the **necessary transformation towards a multifunctional role for wood-based energy carriers.** In future, these must provide renewable carbon in addition to heat, electricity or fuels and, in conjunction with CCS, contribute to offsetting residual emissions or enable negative emissions.

1 Introduction

In Germany, around half of the available wood is used for energy, in 2020 approximately 60 million cubic metres. Around a quarter of this is roundwood of various qualities, which is mostly burnt as firewood in private fireplaces or tiled stoves. Commercial uses, for example wood-fired (heating) power stations, mainly rely on waste wood, residues from wood harvesting or wood processing, low-quality industrial wood or other wood, for example from landscape conservation.[1]

Energy generation from wood has long been the subject of controversial debates. On the one hand, wood is an important option for reducing fossil fuels in the heating sector – around two thirds of renewable heat in Germany are currently generated from this energy source.[2] Relevant demand for Wood also comes from the power and transport sectors: among other things, there are increasing efforts – both abroad and in Germany – to switch power generation in coal-fired power plants to biomass, especially wood, in the future. In the transport sector, projections by the European Commission see a high demand for wood-based fuels in the future in order to replace fossil fuels in shipping and aviation.[3]

On the other hand, there are concerns that the energy sectors' demand for wood will reduce forests' contributions to overarching climate targets in the medium to long term.[4] The carbon sink of forests and harvested wood products is to be significantly increased by 2030, not least in order to compensate for 'residual emissions' that are technically difficult to abate.[5] In the future, more wood will also be needed for material uses, as the construction sector, among others, is expected to use more wood-based building materials to reduce its greenhouse gas emissions.[6]

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1 Umweltbundesamt [Federal Environmental Agency] (Ed.) (2022): Aktuelle Nutzung und Förderung der Holzenergie, Teilbericht zu den Projekten BioSINK und BioWISE, https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2023-01-05_cc_12-2022_aktuelle_nutzung_und_foerderung_der_holzenergie.pdf.

2 Umweltbundesamt [Federal Environmental Agency] (2023): Renewable energies in figures, https://www.umweltbundesamt.de/en/topics/climate-energy/renewable-energies/renewable-energies-in-figures.

3 EU COM (2021): COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Accompanying the Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, SWD(2021) 635 final, p. 57f.

4 E.g., Searchinger, T. D. et al. (2018): Europe's renewable energy directive poised to harm global forests. In: Nature Communications 9 (1), S. 3741, https://www.nature.com/articles/s41467-018-06175-4.

5 Art. 4 Sect. 2 of Directive (EU) 2018/841, amended by Directive (EU) 2023/839 of 19/04/2023, https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:02018R0841-20230511.

6 BMWSB and BMEL (2023): Handreichung Holzbauinitiative. Strategie der Bundesregierung zur Stärkung des Holzbaus als ein wichtiger Beitrag für ein klimagerechtes und ressourceneffizientes Bauen, https://www.bmwsb.bund.de/SharedDocs/downloads/Webs/BMWSB/DE/veroeffentlichungen/bauen/holzbauinitiative.html.

The competing demands for wood and its complex climate effects make it difficult to identify the extent to which forest bioenergy is sustainable. This paper aims to contribute to a better understanding of this challenge and possible solutions. To this end, first, the greenhouse gas effects of forest bioenergy are introduced (Section 2). In a second step, an integrated sustainability concept is outlined that considers economic, social and ecological sustainability aspects in addition to climate effects (Section 3). On this basis, third, a systematic policy approach for sustainable forest bioenergy is presented (Section 4).

2 Climate effects of forest bioenergy

Analyses studying the potential climate effects of forest bioenergy have come to a variety of conclusions. These range from the position that forest bioenergy is fundamentally climate-neutral to the view that it causes higher greenhouse gas emissions than fossil fuels. In reality, the climate effects of forest bioenergy depend heavily on the spatial and temporal context, such as how biomass growth dynamics in a particular forest or land use context change as a result of energy demand. Upstream emissions associated with processing, transport and other activities related to the production and use of forest bioenergy sources can also play an important role.

This results in a complex overall picture that can be broken down into different assessment levels. Among other things, the following climate-relevant effects should be considered:

1. Combustion emissions: When wood is burned, the carbon stored in the biomass is released. In addition, incomplete combustion can release greenhouse air pollutants such as methane or black carbon. The capture and storage of combustion emissions (CCS) can delay their release over relevant periods of time.

2. Upstream emissions: Forestry, wood transport and the further processing of wood into fuels such as pellets can cause additional fossil greenhouse gas emissions. These are constantly changing in the course of the energy transition.

3. Abated emissions: Forest bioenergy can replace fossil fuels and avoid the associated greenhouse gas emissions.

4. Carbon sequestration in forests and wood products as well as emissions from land use change: Logging ends growth and thus the further process of carbon sequestration in the harvested biomass. Regrowing wood binds carbon from the atmosphere again. If wood is used materially instead of for energy, it stores carbon in comparison to the energy-related release. If forest areas are expanded at the expense of other land uses, additional climate impacts can occur.

This diversity of climate effects of forest bioenergy illustrates that assessing its climate policy impact is challenging and may require the use of elaborate models. Regardless of the method used, it is important to capture effects at the level of forests and land use as well as at the level of wood and energy products (see Figure 1).

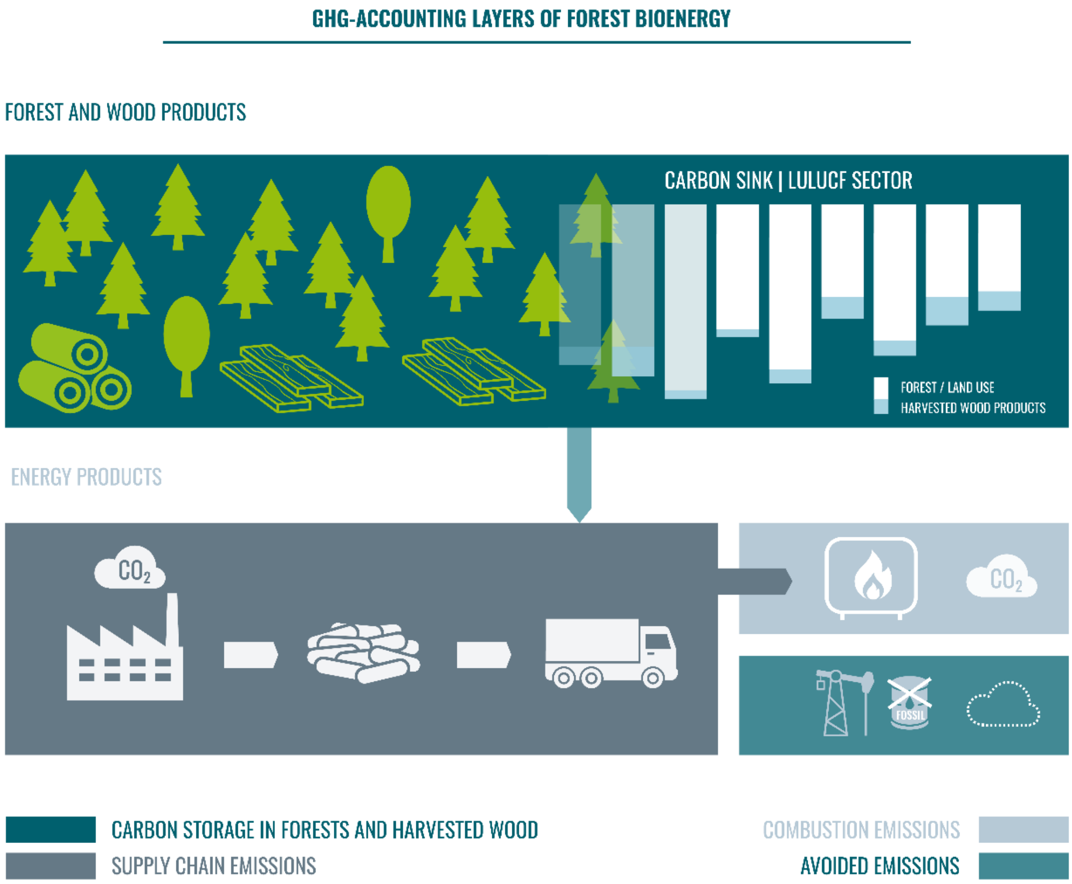

Figure 1: Levels of the greenhouse gas balance of forest bioenergy (simplified illustration)

The complexity arising from these different assessment levels and the different ways of dealing with them is one of the main reasons for the contradictory assessments regarding climate effects of forest bioenergy. In addition to the particularities of the respective forest ecosystems analysed in each case, the choice of different spatial and temporal system boundaries for the analysis, particularly at the level of wood provision, often leads to significantly different results.

For example, results regarding the climate effects of forest bioenergy will differ depending on whether climate effects are considered with regard to an individual tree or at the level of larger areas (overall balance of biomass growth and extraction over a selected forest area and a defined period of time). Estimating effects after 10, 50 or 100 years will also lead to different results.

The great importance of the forest carbon sink for a greenhouse gas balance of forest bioenergy suggests an analysis for larger territorial units or even for entire countries in order to derive more general statements and trends for the evaluation of forest bioenergy. However, such analyses require suitable databases (e.g., national forest inventory and corresponding market data) that allow the carbon balance of the respective area to be linked with the greenhouse gas balance of wood products. Accordingly, this type of analysis requires more effort and is significantly more complex than the simplified analysis at the individual tree level.

Greenhouse gas balances at regional level can represent a compromise between highly complex and oversimplified approaches to assessing the climate impact of forest bioenergy.

As a compromise between the two poles of a comprehensive, model-based and correspondingly complex analysis on the one hand and overly simplified approaches such as the isolated comparison of combustion emissions on the other, it is increasingly common to carry out life cycle analyses at regional level. This considers the respective area where forestry decisions are made that affect the harvesting of the biomass.[7] Such an analysis allows for more specific, region-based statements on the climate effects of biomass utilisation on certain areas.

Even if, as described above, it is difficult to make generalised statements about the climate effects of forest bioenergy, the following points can be concluded:

- The development of a forest's carbon sink is a key indicator for the contribution of forest areas and forest bioenergy to climate change mitigation. The management of forest areas influences this indicator positively or negatively, depending on the condition of the forest area. The development of the forest's carbon balance is also an important indicator of the long-term sustainable availability of wood as a raw material for material and energy utilisation. To put it simply, if a sharp increase in demand for wood for energy were to lead to an extraction of wood higher than its growth, this would have a negative impact on the forest's carbon balance. This would be an important indicator of a negative carbon footprint of the corresponding forest bioenergy pathways. In regions where the extraction of wood for material and energy applications is in line with a stable or positive development of forest biomass, wood harvests can be utilised without impairing the forest’s greenhouse gas balance. The development of the sink performance over time is also important

[7] See the proposal by Cowie, A. L. et al. (2021): Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy. GCB Bioenergy, 13:8, 1210-1231. https://doi.org/10.1111/gcbb.12844.

for the assessment, especially with regard to the forestry sector's overarching contributions to climate change mitigation. A key follow-up question would then be at which point in the utilisation cascade energy use should occur. In order to remove the carbon bound in wood from the atmosphere as long as possible, wood should be utilised materially as long as possible. The energetic use of wood is an option when a higher-value material utilisation is no longer viable (see Section **Fehler! Verweisquelle konnte nicht gefunden werden.**).

- Further factors influencing the greenhouse gas balance of forest bioenergy arise via the direct process chain for the provision of heat, electricity or fuels from wood biomass (at the end of an utilisation cascade). The provision of energy should be as efficient as possible in order to achieve a favourable greenhouse gas balance. The following aspects are relevant here, among others: the energy sources and auxiliary materials used and their upstream chain emissions, the efficiency of energy provision from wood as well as the areas of application of forest bioenergy and the associated substitution of other energy sources, combustion effectiveness and any positive substitution effects of the conversion residues (e.g. ashes in concrete). These emissions can be measured and balanced along the process chain and further reduced through alternative input materials and energy sources, as well as by the use of technical options (e.g. CO_2 capture).

To summarise, climate effects of forest bioenergy are complex and require careful consideration of the respective context. Generalised statements about wood fuels being climate-neutral or more harmful to the climate than fossil fuels do not reflect the multi-layered reality of climate effects. With the help of greenhouse gas balances, which record both the effects of forest bioenergy on forests and at product level, the climate impact can be illustrated. In practice, a middle ground must be sought between the most comprehensive possible representation of all climate effects and the associated data collection and, if necessary, modelling effort. Balancing approaches at regional level can represent such a compromise.

3 Sustainability of forest bioenergy

Climate effects are an important element in assessing whether forest bioenergy is sustainable. However, considering greenhouse gas effects alone is not sufficient. Such an assessment also requires to consider whether alternative (material) uses of wood or other available energy options are more beneficial for climate change mitigation. In addition to climate protection, other sustainability dimensions must be considered as well. For example, wood utilisation (or the underlying wood production) has an impact on food security (agriculture is not possible where forests grow), biodiversity, jobs, economic growth, etc. The complexity of sustainability assessments is further increased with the frequent trade-offs between different sustainability dimensions, for example when more jobs and value creation through forest bioenergy come along with negative impacts on climate. Furthermore, a sustainability concept for forest bioenergy should integrate ecological boundaries such as the 1.5-2-degree target of climate protection.[8] In other words, missing such boundaries cannot be offset by economic benefits (growth, jobs), for example. The same applies to unacceptable losses of biodiversity.

In addition to emission effects, other sustainability dimensions and the relevant ecological limits must be considered.

The complexity of the sustainability effects of biomass energy utilisation has given rise to elaborate evaluation studies in the past.[9] Often, the contributions of bioenergy to the UN Sustainable Development Goals (SDGs) are assessed here. Although such analyses provide many important insights, key questions remain unanswered. For example, it remains unclear how sustainability effects of a certain fuel change with increasing or decreasing demand. In other words, it remains unclear which *total amount* of bioenergy is sustainable or compatible with ecological limits. It is also often not evident whether forest bioenergy performs better or worse compared to energy options. Assessing individual sustainability effects also raises the question of how to rate bioenergy options that positively influence some SDGs but a negative impact on others (dealing with *trade-offs,* see Figure 2).

8 https://www.stockholmresilience.org/research/planetary-boundaries.html.

9 E.g., Blair, M. J. et al. (2021): Contribution of Biomass Supply Chains for Bioenergy to Sustainable Development Goals, Land 2021, 10, 181. https://doi.org/10.3390/land10020181; Welfle, A. J. et al. (2023): Sustainability of bioenergy – Mapping the risks & benefits to inform future bioenergy systems, Biomass and Bioenergy 177 (2023) 106919, https://doi.org/10.1016/j.biombioe.2023.106919.

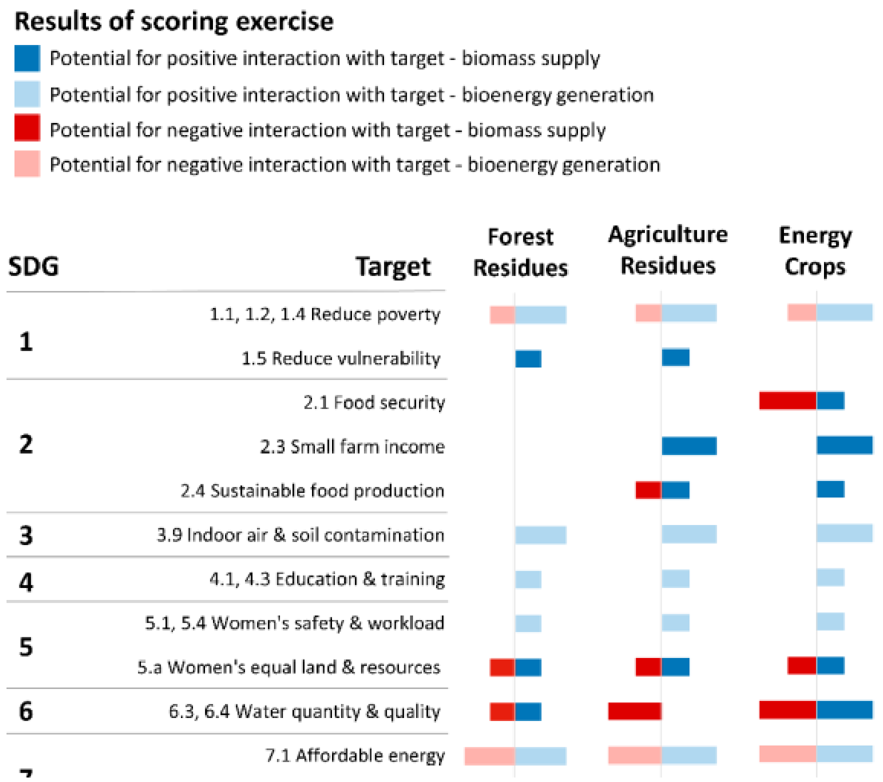

Figure 2: Effects of different biogenic energy sources on UN sustainability goals (SDGs) (detail). Source: Blair, M. J. et al. (2021): Contribution of Biomass Supply Chains for Bioenergy to Sustainable Development Goals, Land 2021, 10, 181. https://doi.org/10.3390/land10020181.

These trade-offs show that a definite answer to the question of the sustainability of forest bioenergy is rarely possible. Whether progress on one SDG outweighs setbacks on another SDG, and whether the contradictory overall picture is more sustainable than the contradictory picture of alternative energy options, must ultimately be decided by politics within the scope of ecological boundaries.

The European Union's climate policy already includes a specific sustainability compass for forest bioenergy.

This does not imply, however, that assessing the sustainability of forest bioenergy is arbitrary. In the following, we argue that a plausible sustainability framework for forest bioenergy has already been established in the European Union's climate policy. It provides guidance for considering forest bioenergy in public policies such as Germany's subsidies for using renewable energy in buildings (BEG) or for renewable electricity (REA).[10] This framework considers both the complex greenhouse gas effects of forest bioenergy as well

[10] BEG: Federal Funding for Efficient Buildings, REA: Renewable Energy Act (see List of abbreviations).

as its impact on SDGs and relevant ecological (planetary) boundaries. Being embedded in key EU legislation, it can also claim a high level of political legitimacy. The following deliberations therefore refer to the EU policy level, but the main conclusions can also be applied to the national level.

The EU's approach to sustainable forest bioenergy is labelled here as 'qualified climate protection efficiency'. The core of this sustainability approach is the EU's ambition not to *maximise* the contributions of forests, harvested wood products or forest bioenergy to climate targets, but to bring these contributions into balance with each other and other climate change mitigation options. In terms of European climate policy, this means striking a balance between the climate change mitigation contributions of the LULUCF sector (forests, wood products, peatlands, grassland, etc.), the EU ETS sectors (energy and industry) and the Effort sharing sectors (buildings, transport, etc.). This ‘division of labour' in terms of climate policy is intended to help achieve climate neutrality in an efficient manner, whereby efficiency here means minimising the overall costs of climate protection.[11]

Applying the efficiency principle means saving resources that can be used for other sustainability goals.

Reducing costs through efficient climate protection is not only important in order to increase acceptance for the transformation to climate neutrality. Applying the efficiency principle also means saving resources that can be used for contributions to other ecological, social or economic sustainability targets. In this way, compliance with the planetary boundary in climate protection (1.5-to-2-degree target) can be combined with maximum contributions to economic, social and ecological sustainability goals.

[11] See Recital 4 of the European Climate Law. Recitals 2 and 6 of the EU LULUCF Regulation also refer to the fact that "the reduction of greenhouse gas emissions... shall be achieved in the most cost-effective manner" and that the sector's contribution to climate protection "shall be optimised". The flexibility rules of the EU LULUCF Regulation (Article 12) and the EU Effort Sharing Regulation (Article 7) also refer to the goal of cost-effective climate protection. This enables climate protection efforts to be shifted to the other sector, allowing them to take place where the lowest costs are incurred.

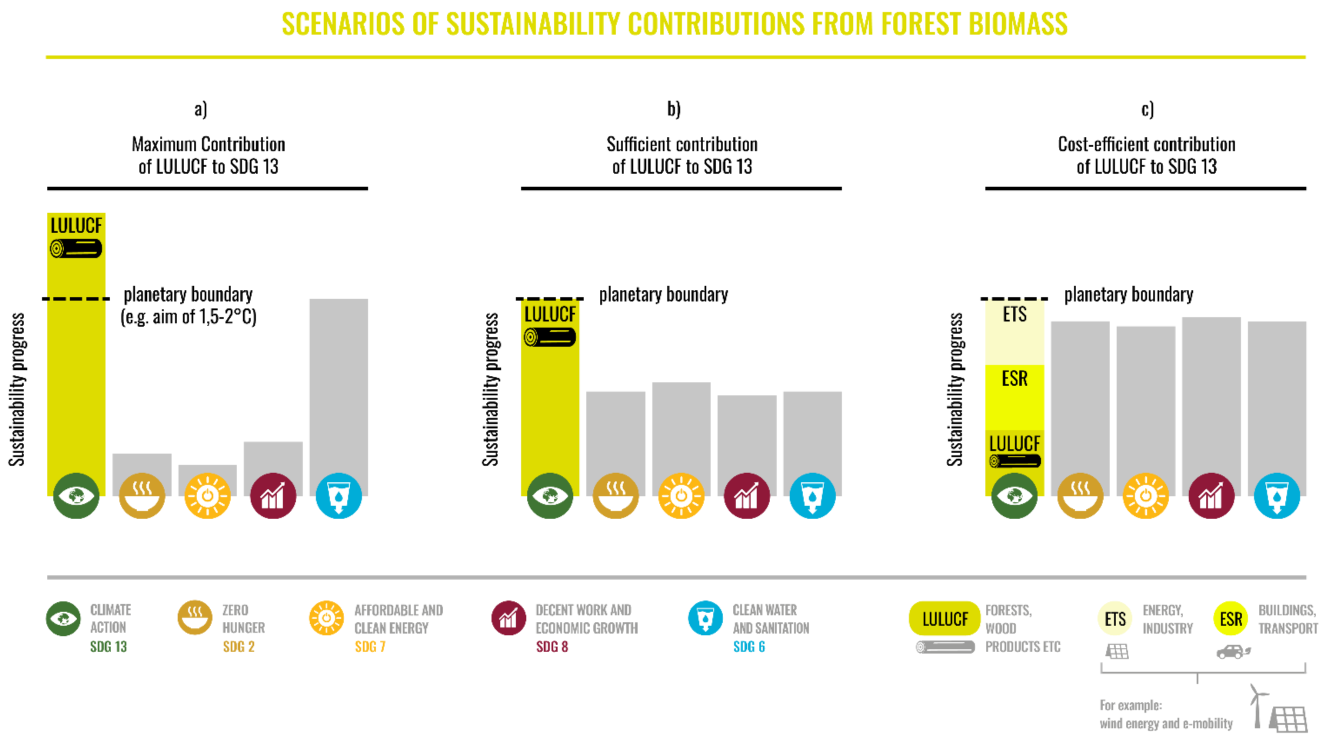

Figure 3: Sustainability effects of different LULUCF sinks

Figure 3 illustrates this integrated sustainability approach with a focus on the contribution of forests, harvested wood products and forest bioenergy (LULUCF sector):[12] Figure 3a depicts a hypothetical extreme scenario for illustrative purposes. In this scenario, all land areas in the EU are converted to forests in order to *maximise* their contribution to the overarching climate target (maximum target contribution to SDG 13). This would exceed the EU's required contribution to meeting the planetary boundary in terms of climate: Not only would the sink performance of the LULUCF sector be greatly increased. There would also be no land available anymore for emission sources from agriculture, industry, transport, buildings, etc. It is obvious that such a scenario without sufficient food, jobs, mobility options or housing can hardly be called sustainable (low achievements, e.g., regarding SDGs 2, 7 and 8).

In contrast, Figure 3b depicts a scenario where contributions of forests and harvested wood products to the overarching climate target are limited to a level that is just about *sufficient* to maintain the planetary boundary of the climate. This unleashes resources especially in

12 In regard to forest bioenergy, emissions from combustion are reported in the LULUCF sector (negative contribution to its climate target) while accelerated biomass growth related to the demand for forest bioenergy is reported here as well (positive contribution to climate target).

terms of land that can be used to produce food (SDG 2) or for industrial activities with corresponding jobs (SDGs 7 and 8).

However, sustainability contributions to these and other SDGs can be increased even further without violating the climate related planetary boundary by distributing the necessary climate protection efforts *across all sectors in a cost-minimising manner* (Figure 3c). Here, in addition to the carbon sink provided by forests and harvested wood products, the ETS and Effort sharing sectors also contribute to climate protection, for example through renewable energies from biomass, wind and solar power plants or through energy efficiency measures. All resources saved by minimising the overall economic costs of achieving climate neutrality by 2050 can be 'invested' in other sustainability dimensions, for example in the production of additional food, in environmental protection measures or in social policy initiatives. In this way, climate protection can be optimally combined with other ecological, economic and social sustainability goals.

As long as the climate target of the LULUCF sector is not met, the extent of forest bioenergy should be scrutinised.

The main conclusion of this approach to sustainable forest bioenergy is that forests, harvested wood products and forest bioenergy should make an *efficient (cost-effective) contribution to the overall climate target*. One advantage of this approach is that in this context the efficiency principle provides clear contours to the often vague concept of sustainability. Specific conclusions for the evaluation and political management of forest bioenergy can now be derived (see also Section **Fehler! Verweisquelle konnte nicht gefunden werden.**). In particular, an efficient contribution of the LULUCF sector to the 1.5-2-degree target appears as a key benchmark for the sustainability of forest bioenergy utilisations. As long as this sector target is not met, the extent of the utilisation of forest bioenergy should therefore be scrutinised, insofar as this sector target represents an efficient climate protection contribution of the sector.[13] Missing the target means that protecting the climate with the help of forests and wood products costs less than protecting the climate with forest bioenergy. This applies at least if there are no other, more cost-

[13] The European Commission's working documents reveal that the cost-effectiveness criterion played a key role in deriving the new LULUCF target for 2030 of -310 million tonnes of CO_2 (see EU COM (2021): SWD(2021) 609 final, Section 4.2.1 and Annex 4). Due to the uncertain effects of climate change on the stability of carbon storage in forests, such a sector target can only ever represent a rough approximation. Ultimately, this target must be set *politically* within the scientific uncertainty range, similar to the overarching temperature target of the Paris Climate Agreement. Also due to the uncertainties associated with target setting, the LULUCF Regulation and the Effort Sharing Regulation provide for flexibility rules that enable the transfer of emission allowances between sectors. This enables subsequent adjustments to the climate policy ambition level in these sectors. For example, more or less climate protection can be realised in the LULUCF sector by 2030, depending on whether this sector also enables stable, efficient carbon storage as climate change progresses. However, any substantial deviations from the targets must at least be substantiated.

effective and easily implementable mitigation measures available within the LULUCF sector (e.g., additional renaturation of peatlands, expansion of grassland, etc.).

"Sustainable forestry" is not enough to ensure the sustainability of forest bioenergy.

In addition to the guidance provide by the LULUCF climate target, from the perspective of climate efficiency it becomes also clear that 'sustainable forest management' – often understood as limiting timber harvest to timber growth – is not always sufficient to ensure the sustainability of forest bioenergy. If the contribution of forests to climate protection is below its climate-efficient level, carbon storage in existing forests or the overall forest area should be increased (timber harvest below timber growth). However, if the existing forests contribute more than necessary to the climate protection portfolio of a state or the EU, a temporary reduction in carbon stocks due to forest bioenergy can also be sustainable (timber harvest exceeding timber growth). In other words, the criterion of 'sustainable forest management' neglects the question of whether the existing forests are sustainable in their current *extent* (extent of forest areas) and in relation to their current *age structure*.

Thirdly, the principle of cost-effective climate protection means that the contributions within the LULUCF sector to the overall climate target should also be efficiently structured. For example, forest areas and/or carbon stocks in forests should be expanded as long as these measures have lower costs than the renaturation of peatlands or carbon farming in agriculture. As long as this is not the case, it is possible to achieve the sector target with a lower use of resources. Wasted resources reduce possibilities for further improvements in other sustainability dimensions.

Within environmental and socio-political guard rails, forest bioenergy can compete for the most efficient climate protection measures.

Finally, the criterion of climate protection efficiency must be expanded ("qualified") to include the protection of biodiversity and other environmental resources (soil, water, air). In addition, socio-political standards and goals have to be considered. The efficiency principle can constitute an important starting point for comprehensive sustainability. On its own, however, it does not guarantee that other planetary (and local) boundaries or minimum social standards are met. For this reason, effective environmental and socio-political guard rails must be created, such as emissions standards for fine particulate matter or biodiversity-related protected areas. Within these guard rails, forest bioenergy can compete for the most efficient climate protection measures. Hence, for forest bioenergy to be fully sustainable, specific measures ensuring the efficiency of wood uses (see next section) must be combined with a general environmental and social policy framework.

Box 1 | Pellet boiler or heat pump?

If sustainability is approached from the perspective of cost-effective climate protection, a frequent blind spot becomes apparent in the debate on forest bioenergy: It is often argued that fossil greenhouse gas emissions can be better reduced using alternative renewable energies - in the heating sector, for example, with heat pumps based on wind or solar power. After all, these technologies often have lower greenhouse gas emissions during their life cycle than wood fuels. While heat pumps may indeed be better options for protecting the climate in many cases, such arguments ignore the fact that greenhouse gas balances of energy options should not be the only decisive factor in choosing the best climate mitigation option. As explained above, it is reasonable to select these options according to whether they contribute to a cost-minimised climate mitigation portfolio. In other words, the decisive factor is not the *amount of emissions reduced*, but the *costs of emissions reduction* (per tonne of CO_2 avoided).

This means that a pellet boiler can be a more sustainable climate protection option even in the case of a less favourable greenhouse gas balance, if purchasing and operating a heat pump entails significantly higher costs. The additional costs associated with the heat pump would reduce the availability of resources in other places, e.g. for further climate change mitigation measures or other sustainability contributions. These undesirable effects can offset or even outweigh the benefits of the greenhouse gas balance of heat pumps.[14]

However, a simple comparison of the purchase and operating costs of pellet boilers versus heat pumps is not sufficient. Instead, the heat pump related costs must be compared with the pellet boiler costs plus the costs of those climate protection measures in the LULUCF sector that may be required to offset the emissions from wood combustion.[15] In other words, forest bioenergy can be a more sustainable climate protection option if energy generation from wood in

[14] For the same reason, the ongoing debate about the supposed inefficiency of biofuels often falls short of the mark. Wind power and PV systems may have significantly higher *energy yields* per hectare. However, the *value* of the energy generated is often significantly lower than that of biofuels. Finally, unlike biofuels, electricity cannot be used directly in areas that are difficult to electrify, such as air and sea transport. It must first be converted into electricity-based fuels. At least with regard to such applications, the land use efficiency of biofuels would therefore have to be compared with that of electricity-based fuels (PtX). Due to high conversion losses, the "kilometres travelled per hectare" of the latter can also be expected to be rather moderate.

[15] Strictly speaking, upstream emissions from both energy options must also be considered here, including the sector-specific costs of mitigating these upstream emissions.

combination with LULUCF measures such as afforestation or peatland restoration is more cost-effective than the use of alternative renewable energies.

Of course, this presupposes that the carbon sink performance in the LULUCF sector develops in line with the target and that additional climate protection measures in this sector are available. If this is not the case, this can be seen as an important indication that using alternative renewable energies is more sustainable than forest bioenergy, or that the expansion of alternative renewables is easier to implement than additional climate protection measures in the LULUCF sector. When considering nature-based versus (energy) technology-based climate protection measures, it should also be borne in mind that nature-based carbon stocks can be reduced as a result of forest fires, for example. Cost estimates of mitigation measures in the LULUCF sector must therefore be weighted with the corresponding non-permanence risk.

The following conclusions can be drawn from these considerations:

- Even if the various climate effects of forest bioenergy are ignored, the question of sustainability remains complex. An answer cannot be provided solely in terms of greenhouse gas effects. Instead, comparative cost assessments of climate protection measures in the energy and LULUCF sectors are required.
- Forest bioenergy is more likely to be sustainable if favourable and sufficient greenhouse gas abatement options are available and ready to be implemented in the LULUCF sector.
- Forest bioenergy is more likely to be sustainable if it is used to close 'gaps in the energy system' - for example in peak-load boilers that supplement heat pumps in times of high electricity prices (hybrid heating solutions). During these periods, the greenhouse gas abatement costs of electricity-based energy options rise, which means that forest bioenergy can temporarily become a more cost-effective climate protection option.

4 Rethinking forest bioenergy policy

Based on the premise that efficiency in climate protection constitutes an important basis for sustainable wood utilisations, two conclusions can be drawn: Firstly, it is not straightforward for consumers to determine whether certain wood fuels are sustainable based on their individual characteristics – such as whether or not they originate from their region. Rather, 'systemic criteria' are decisive, in particular the total amount of wood consumption in a region or the development of the sink performance of forests relative to their efficient contribution to climate protection. This is only one of several reasons why policymakers and not consumers are responsible to ensure the sustainability of forest bioenergy.

The second conclusion concerns the possibilities for fulfilling this task, i.e. the design of the political framework for forest bioenergy. The approach of efficient climate protection opens up an alternative to the elaborate command and control approach in the forest bioenergy sector, as it is currently being pursued with the help of the EU's Renewable Energy Directive (see box 2).

Box 2 | Regulation of forest bioenergy by the EU-RED

The EU's Renewable Energy Directive (RED) sets out numerous sustainability criteria for forest bioenergy, compliance with which must be ensured through certification and additional governmental controls. However, for various reasons, the associated high level of bureaucracy only covers economic or social sustainability aspects to a very limited extent. Furthermore, the effects of forest bioenergy on the LULUCF sector have not yet been considered in the greenhouse gas reduction requirements of the RED.

The latest revision of the directive (RED III) recognises these shortcomings, among other things by referring to the LULUCF climate target. However, it does not provide the member states with any effective instruments to correct them. It merely specifies a utilisation hierarchy for wood, according to which forest bioenergy should only be eligible for public support when harvested wood products can no longer be reused or recycled. The hierarchy is motivated by the hope of wood being increasingly used for material purposes, thus leading to additional carbon storage in wood products. It remains unclear, however, *to what extent* material uses should replace uses for energy. After all, repair or recycling processes can be expanded almost indefinitely – if unlimited amounts of labour, energy and other resources are employed.[16]

In this case, not only could forest bioenergy be reduced to a level below its sustainable level. Excessive recycling can also become a sustainability problem itself as a result of excessive resource consumption and emissions related to the recycling process.[17] If, in view of such ambiguities, the EU Member States decide to pursue the reuse and recycling of wood only to the extent that these processes are currently competitive, the utilisation hierarchy could remain largely ineffective.[18]

The additional RED III provision of selecting wood uses according to the highest economic and ecological value is also hardly useful in differentiating between material and energy utilisations. With wood markets being distorted by numerous market failures and policy instruments, current market prices do not provide sufficient indication of the social value of wood products or forest bioenergy (see below). Trying to account for this challenge by applying a product-related economic-ecological assessment according to the current approach of the RED is anything but promising considering the large variety of wood products.

In other words, the 'termination criterion' of the RED remains elusive when it comes to determining at what stage material uses of wood are no longer sustainable and energy uses should be preferred. The usual approach to limit bioenergy to 'biogenic residues and wastes' is also inadequate here, as these resources are intended to be increasingly reused – materially – in a future circular bioeconomy.

If efficient climate protection is the starting point for ensuring sustainable forest bioenergy, the political framework for forest bioenergy no longer has to be designed under the opaque objective of *'sustainable wood utilisation'*. Instead, the far more specific task of ensuring

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16 It is becoming increasingly possible to process wood products that are contaminated with chemicals, e.g. Besserer, A. et al. (2021): Cascading Recycling of Wood Waste: A Review, Polymers 2021, 13, 1752, https://doi.org/10.3390/polym13111752.

17 See for example the controversial discussions on the chemical recycling of plastics. A fundamental discussion of this challenge can be found in Baumol, W. J. (1977): On recycling as a moot environmental issue, Journal of Environmental Economics and Management, 4-1, S. 83-87, https://www.sciencedirect.com/science/article/pii/0095069677900171 and Sorensen, P. B. (2017): The Basic Environmental Economics of The Circular Economy, EPRU Working Paper Series 2017-04, https://www.econstor.eu/bitstream/10419/202436/1/1006747559.pdf.

18 The approach of the German Closed Substance Cycle and Waste Management Act (*Kreislaufwirtschaftsgesetz*, KrWG) of only authorising energy recovery when recycling etc. is no longer "technically possible" or "economically reasonable" (Section 6 (2) KrWG) may be an option here. However, the associated case-by-case reviews examinations increase the complexity of regulating forest bioenergy. It is also doubtful whether the criterion of technical feasibility is helpful in such a technologically dynamic environment as the material bioeconomy.

climate-efficient biomass allocation arises. Correcting market failures, for example with the help of tradable emissions certificates, can be a suitable policy strategy for this. This approach has already been applied in practice with the existing emissions trading systems, which internalise the external climate effects of fossil fuels. In such corrected markets, market participants can apply 'ecologically true' prices to select the products that generate the greatest benefit and are also compatible with climate protection targets. Using the exemplary comparison of pellet boilers and heat pumps above, this means that the price for the pellet boiler solution should reflect the costs of additional climate protection measures in the LULUCF sector.

Correcting market failures eliminates the root causes of unsustainable timber utilisation, instead of addressing the symptoms of distorted markets, as it is currently the case.

Addressing market failures would mean eliminating the *causes* of unsustainable timber utilisation instead of limiting the manifold symptoms of distorted markets by applying RED criteria. Such a market-based approach would rely on the following instruments:[19]

- **CO_2 price on emissions from wood:** Forest economic analyses have long pointed out that a CO_2 price on biogenic emissions is a key policy measure for efficient climate protection contributions from forests, wood products and forest bioenergy.[20] A price has to be put on fossil upstream emissions related to forest bioenergy as well, which is already implemented by the existing emissions trading systems in the EU and Germany.[21] The fact that wood, unlike fossil fuels, is a renewable resource should not be addressed at the level of CO_2 pricing, but through other policy instruments (see next point).

[19] In addition, there are emissions trading systems for reducing fossil emissions, which are already established and are therefore not listed separately here.

[20] Van Kooten, G. C. et al. (1995): Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services, American Journal of Agricultural Economics 77-2, 365-374, https://www.jstor.org/stable/1243546; Lintunen, J. et al. (2016a): On the economics of forests and climate change: Deriving optimal policies, Journal of Forest Economics 24-1, 130-156, https://www.nowpublishers.com/article/Details/JFE-0315.

[21] In principle, the proposal for a CO_2 price on biogenic emissions can also be applied to biofuels from 'energy crops', see Lundgren, T. et al. (2008): The Economics of Biofuels, International Review of Environmental and Resource Economics, 2, 237–280, https://www.nowpublishers.com/article/Details/IRERE-0017). Unlike forest biomass, however, emissions from land use changes are more relevant here than combustion emissions. The latter usually have no significant climate impact due to the rapid regrowth of non-perennial biomass, which is why their harvest is are not reported under the international IPCC Convention on Greenhouse Gas Accounting. However, pricing emissions, particularly from indirect land use changes, is likely to be very challenging in practice, as this ultimately requires a global solution (e.g. Merfort, L. et al. (2023): Bioenergy-induced land-use-change emissions with sectorally fragmented policies, nature climate change 13, pages 685–692, https://www.nature.com/articles/s41558-023-01697-2). Regulating the greenhouse gas emissions of biofuels – for example with the help of the current RED limits for the eligibility of such fuels with a high risk of land-use change – is therefore likely to be more suitable than price-based control for the time being.

- **Subsidy for carbon storage:** The CO_2 price has to be supplemented by systematic subsidies for carbon storage in forests and possibly in harvested wood products and geological reservoirs.[22] In combination, both instruments maximise the joint climate protection contribution of wood in the LULUCF sector and in the energy sector. Rewarding the carbon storage in wood is also a key to sustainable wood cascades, as this provides climate-friendly uses of wood with a competitive advantage. Market prices corrected in this way also reveal the threshold where further wood recycling is no longer sustainable (corrected prices as a 'termination criterion' for material utilisations).

- **Subsidies for innovative forest bioenergy:** A general promotion of forest bioenergy in the heat or electricity sector is not necessary from the perspective of climate-efficient wood utilisation. On the contrary, it contributes to the depletion of wood resources and should therefore be reconsidered.[23] Subsidies are required only where markets do not ensure fair competition even after climate and other environmental externalities have been corrected. This applies above all to innovative forest bioenergy solutions, as markets usually do not provide sufficient incentives for innovations for various reasons.[24] Support should therefore continue for options such as hybrid heating systems or lignocellulosic fuels. Lock-in effects can also justify subsidies, for example if new forest bioenergy technologies have high marginal costs due to low production volumes (lack of economies of scale), or where infrastructures tailored to fossil fuels hinder the market access of renewable energies.

- **Effective protection of biodiversity and the environment:** Effective environmental protection measures, including precautions to protect biodiversity, must provide a sustainable operating space for the utilisation of wood for both energy and material purposes. Shortcomings in environmental policy should not be mended retrospectively by excluding certain utilisations of wood via means of energy policy (e.g., by creating 'no-go areas' for fuelwood extraction[25]). Instead, an effective environmental policy must ensure that no wood resources reach markets in the

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22 Ibid.

23 Regarding quotas such as Germany's Building Energy Act (BEG) or the greenhouse gas reduction quota, the eligibility of forest bioenergy could be reasonable. The prerequisite is that these quotas do not favour forest bioenergy over other renewable energies. As other renewable options are also subsidised in the BEG, an exclusion of subsidies for forest bioenergy could mean unequal treatment. However, this can be justified in view of the threat of missing the target in the LULUCF sector.

24 E.g., Jaffe, A. B. et al. (2004): A tale of two market failures: Technology and environmental policy, Ecological Economics 54-2–3, 164-174, https://doi.org/10.1016/j.ecolecon.2004.12.027.

25 Article 29 of the EU Renewable Energy Directive stipulates that bioenergy cannot be counted towards the Directive's renewable energy target if the fuels originate from areas with high carbon storage or high biodiversity.

first place, if their extraction is associated with unacceptable biodiversity or environmental effects.

Figure 4 shows an overview of relevant market failures in connection with forest bioenergy[26] as well as possible policy responses. The external effects of fossil fuels, which represent a further cause of inefficient wood utilisation, were added here. Overall, a complex picture of five different market distortions relevant for forest bioenergy emerges. These market failures have opposing effects and sometimes lead to insufficient demand for forest bioenergy, sometimes to excessive demand (blue and red arrows). A policy strategy addressing the causes of inefficient wood utilisation may therefore require a paradox mix of instruments consisting of pricing and support measures (green arrows).

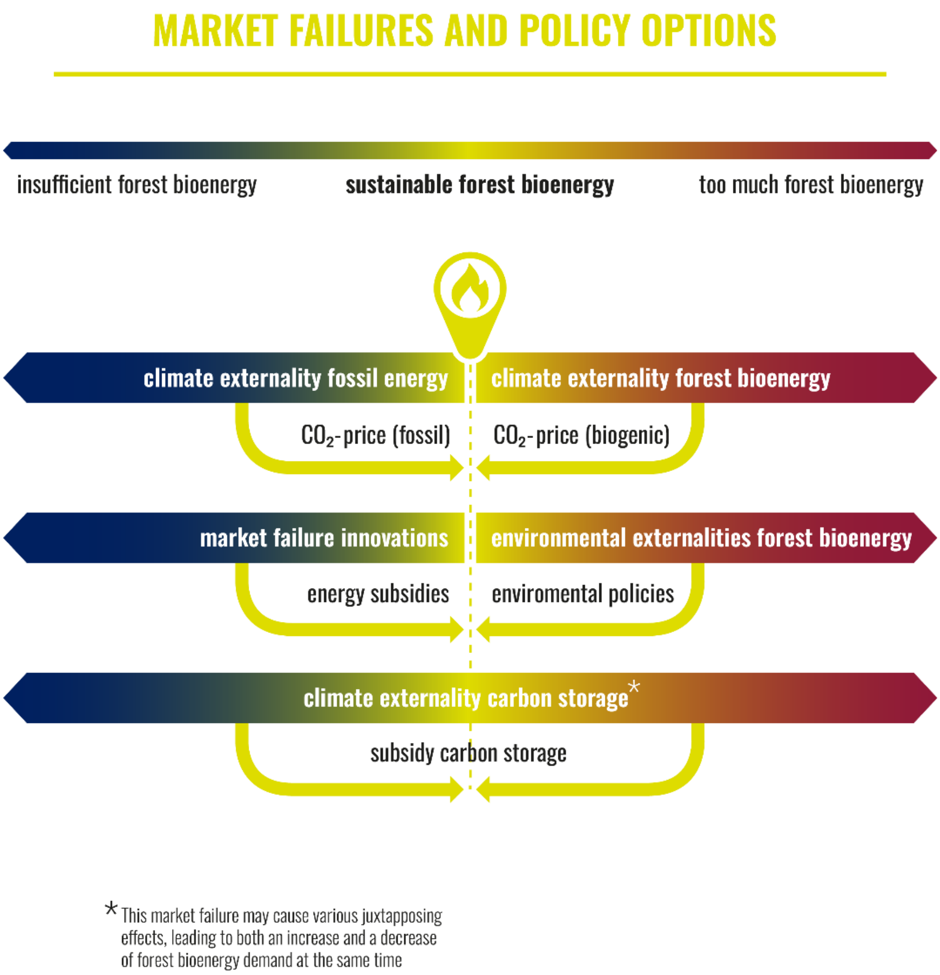

Figure 4: Market failure in connection with forest bioenergy and political options for action

26 These market failures are also the reason why the frequent argument of wood emissions being part of the 'natural carbon cycle' – and therefore irrelevant – is not convincing. As a result of distorted markets, among other things, this natural cycle process has been massively interfered with for centuries. In view of the overexploitation of the earth's forests in the 'Anthropocene', it should be obvious that the notion of a 'natural' cycle is far from being plausible nowadays.

CO_2 pricing and subsidies for carbon storage are at the centre of the policy mix. It addresses the desirable and undesirable effects of forest bioenergy separately. While the CO_2 price limits the climate externality of wood, the subsidy promotes carbon

Ensuring sustainable forest bioenergy is possible without assessing the complex climate effects of individual wood fuels.

storage in wood resources prior to their use for energy.[27] As a result of this separation, it is possible and climate-efficient to apply uniform CO_2 pricing to all wood fuels based on their combustion emissions, regardless of their individual life-cycle emissions. Fossil upstream chain emissions are already covered by national and EU emissions trading, while the effects of forest bioenergy demand on biomass growth in forests are addressed by promoting carbon storages. Hence, the government can ensure sustainable forest bioenergy without having to assess the complex climate effects of wood fuels or allocate them individually to these products.

By means of CO_2 pricing and subsidizing carbon storages, sustainable wood cascades can be implemented without having to design complicated rules for cascade use.

The policy mix reveals that forest bioenergy should not be favoured over fossil fuels by classifying its emissions as *climate-neutral*, as is currently the case in the EU and German emissions trading systems. Instead, the renewability of wood should be reflected in the form of *corrected fuel costs*. Although wood fuels are not directly subsidised under this policy approach, the storage of carbon in forests and possibly also in wood products used as materials is.[28] When this subsidisation reduces the overall production costs for wood, forest bioenergy can ultimately also benefit from this.[29]

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27 More precisely, this subsidy internalises the positive climate externality of carbon storages, mirroring the internalisation of negative externalities of emissions through emissions trading systems, for example. It is therefore an essential component of efficient and therefore sustainable wood utilisation.

28 See the notes on implementing the instrument mix below.

29 E.g., Lintunen, J. et al. (2016a): On the economics of forests and climate change: Deriving optimal policies, Journal of Forest Economics 24-1, 130-156. However, depending on the initial level of wood utilisation, it is conceivable that the price-reducing effect of the subsidy will be more than offset by the price-driving effect of a simultaneous (possibly temporary) shortage in the supply of wood. Even in this case - with rising wood fuel costs - the resulting volume of forest bioenergy is climate-efficient.

It is essential that the wood use policies no longer focus on the end of the bioenergy value chain (emissions pricing and, if necessary, supplementary sustainability criteria for energy), but also at the beginning (promotion of carbon storage). Not only will this strengthen forest bioenergy compared to fossil fuels. At the same time, it also increases the competitiveness of climate-efficient forests and material wood uses over forest bioenergy in line with the RED's wood use hierarchy. In addition, high-quality and long-lasting material uses of wood become more attractive compared to low-quality wood products, as the CO_2 price incentivises waste generation, which is then used for energy, to be delayed for as long as possible. In this way, sustainable wood cascades can be realised without having to design and enforce complicated rules for cascade use.

The fact that the policy mix starts at the beginning of the value chain also shows that it is insufficient to simply introduce CO_2 pricing for biogenic emissions to ensure the sustainability of forest bioenergy. This isolated approach is likely to result in insufficient quantities of both natural carbon sinks and forest bioenergy. Instead, an additional promotion of carbon storages is required in order to provide a sustainable volume of forests and wood products, which in turn forms the starting point for sustainable forest bioenergy. In the long term, an increased wood supply could even result in rising potential for forest bioenergy, with simultaneously increased carbon sinks in forests and harvested wood products.[30]

CO_2 pricing of biogenic emissions can be applied to combustion or to the harvesting of wood. In the latter case, additional subsidies for wood products are required.

There are various options for implementing a market-based policy mix:[31] CO_2 pricing could either be applied to combustion emissions or to forest owners at the time of harvesting. In the latter case – similar to the *accounting* of carbon emissions from wood according to the current IPCC methodology for national greenhouse gas inventories[32] – the removal of wood from forests would be classified as an emission also at the *policy level*. Wood fuels could then continue to be treated as emission-free.[33] In this case, not energy plants but forest owners would participate in emissions trading. This decision also determines whether wood products should also be subsidised in addition to forests. Another option for a market-based policy design is whether forest owners also receive support for *existing* carbon stocks or only for *growth*. As the way in which the instrument mix is implemented has various

30 See ibid.
31 Lintunen, J. et al. (2016b): How should a forest carbon rent policy be implemented?, Forest Policy and Economics 69 (2016) 31–39.
32 IPCC (2019): 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1, Chapter 1, Section 1.1.
33 At least in terms of CO_2 emissions.

effects, for example on existing emissions trading systems (quantity of certificates available), public budgets (scope and administrative burden of support) and acceptance on the part of the forestry sector (ratio of support to certificate costs), it should be prepared carefully, taking the aforementioned aspects into account. As with other political measures, a compromise between a theoretically optimal and a practicable as well as acceptable implementation has to be found.

For an effective CO_2 pricing the RED and emissions trading systems have to be decoupled.

In order for the CO_2 price to be effective as a guiding instrument for sustainable forest bioenergy, the RED and existing emissions trading systems have to be separated clearly. This means that all biogenic emissions from wood, including emissions from fuels compliant to RED criteria, should be subject to the CO_2-price. To avoid shocks in the energy sector, a gradual introduction of CO_2 pricing for emissions from wood could be considered. The time needed to specify the pricing details can also be used to reduce existing direct energy subsidies for wood in the heat and electricity sectors, etc., contributing to a gradual adjustment of the market situation.

This reduction in subsidies prior to the introduction of CO_2 pricing can help to finance the carbon storage subsidy. If the zero rating for emissions from forest bioenergy is subsequently revised in emissions trading systems, additional revenue will be available from these instruments.[34] Ideally, these processes should be accompanied by close monitoring of timber and energy markets, so that adjustments can be made if necessary.

The RED would still retain an important role under a market-based policy approach. Its role should be to specifically promote innovative technologies that are obstructed by additional market failures (see above).[35] Together with CO_2 pricing, this would result in the paradox but logical situation that innovative forest bioenergy solutions are priced and subsidised at the same time.[36] Reducing the CO_2 price may be a pragmatic alternative in this case.

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[34] Regardless of the details of financing a carbon storage subsidy, it is important to recognise that contributions from forests and wood products to climate change mitigation are a public good. Its provision is the responsibility not only of wood users but of the general public, as it enjoys the benefits from climate protection as a whole. Therefore, it can be argued, that subsidizing carbon storage is not a new task for public finances, but that this task has always existed but has not been sufficiently recognized yet.

[35] With regard to the function of the RED and support for renewable energy, it could also be argued that support for forest bioenergy is necessary to compensate for competitive disadvantages resulting from the various subsidies for fossil fuels. However, it would be shortsighted to offset the effect of distorting subsidies (for fossil fuels) by implementing other distorting subsidies (for forest bioenergy). Forests and material uses of wood will fall victim to this subsidy race. If any, this provides another argument for reducing fossil subsidies. The goal of sustainable wood cascades thus represents a further justification for this urgent task.

[36] There is no actual contradiction, as pricing is based on emissions, but the subsidy would not reward high emissions. Instead, it should compensate for innovation costs.

By contrast, protecting the environment, for example in the area of biodiversity or soils (e.g. "no-go areas"), should not be the task of energy policy (RED). Current sustainability criteria constitute retrospective repairs of environmental policy shortcomings. Instead, biodiversity and soils should be effectively protected through environmental law. It should not matter whether environmental damages arise from demand for energy or for material uses.[37]

Environmental protection should be the task of environmental policy, not energy policy.

In the past, environmental protection criteria embedded in energy policy may have been a shortcut to stricter environmental protection, that was not politically feasible or obvious for all wood uses and therefore restricted to supposedly inferior energy uses. However, since the recent adoption of the EU Nature Restoration Law it has become clear that environmental protection requires to curb all demands, including from material uses. Figure 5 illustrates the structure of the proposed instrument mix compared to the current regulatory approach based on the RED.

If environmental protection is relocated back from energy law to environmental law, it is necessary to examine how the environmental sustainability of timber imports can be guaranteed that are not covered by EU environmental regulations or international agreements (e.g. by means of trade policy instruments). Supplementary measures may also be necessary in view of the lack of coverage of fossil upstream chain emissions from wood imports by the EU's emissions trading systems. However, as the CO_2 price for biogenic emissions from forest bioenergy would also apply to imported wood, the EU markets are likely to become less attractive for global trade in wood fuels such as wood pellets.

In order to improve the social balance and acceptance of market-based bioenergy policy, it is important to limit the burden on low-income households, not least in the heat transition. In the long term, climate-efficient wood utilisation increases the possibilities for financing distributional policies by saving resources. In order not to reduce these possibilities,

[37] This applies at least where the protection of global or local load limits is concerned. Where there is room for manoeuvre in setting environmental protection levels, for example because even lower levels of protection do not yet mean unacceptable risks for people or irreversible damage to the environment, it may make sense to differentiate the level of protection by type of use. After all, environmental standards in such cases generally represent a trade-off with utilisation claims. A lower level of environmental protection can therefore be derived from higher-value utilisation claims. In the practice of forest bioenergy, however, such a differentiation of environmental protection requirements according to supposedly higher-value material or lower-value energy utilisation is likely to encounter the challenge that wood harvesting is rarely carried out exclusively for one or the other purpose.

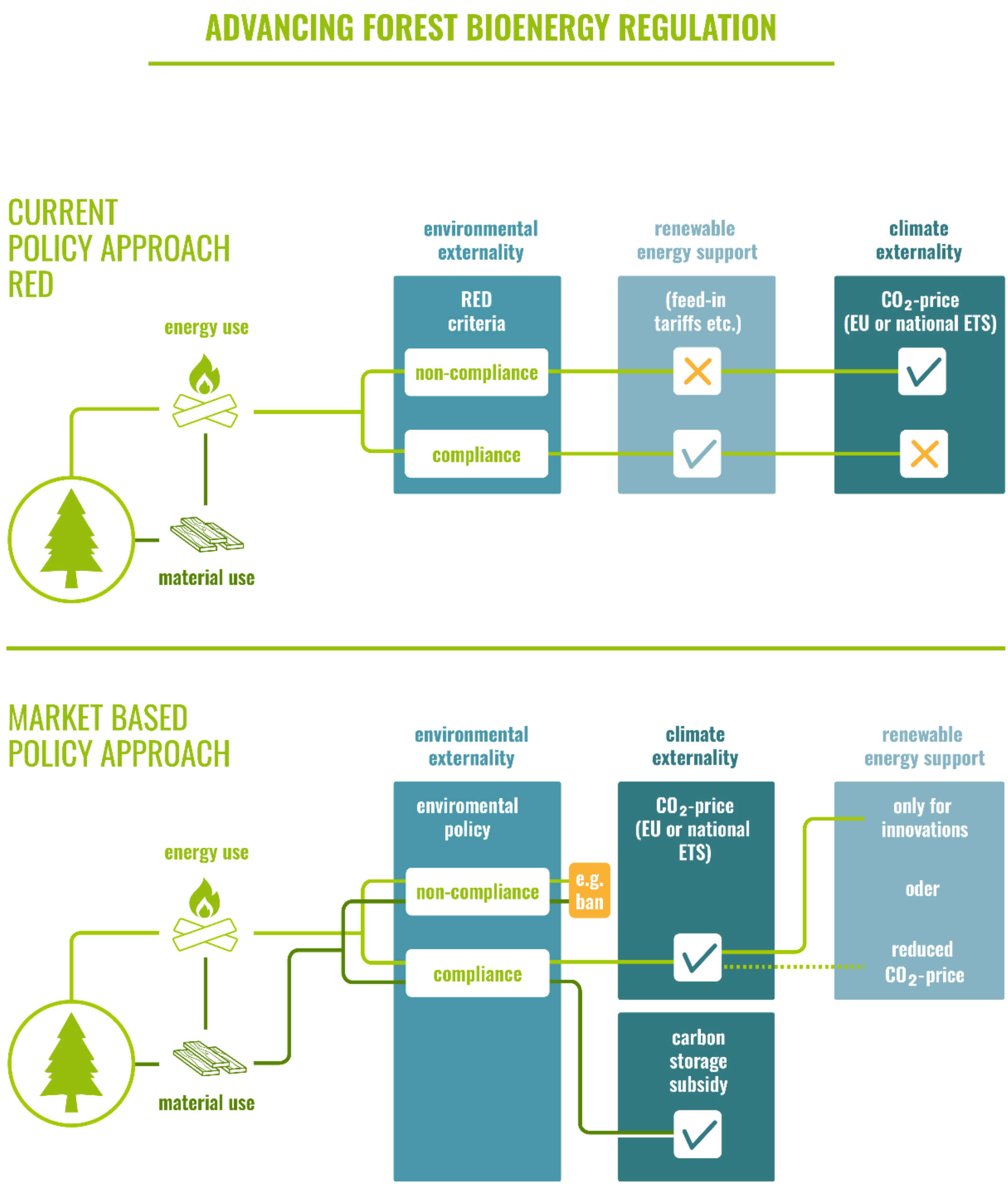

Figure 5: Overview of the various control approaches

the cushioning of social hardship should not undermine the efficient allocation of wood. For this reason, it is advisable to support households rather via incentive-neutral lump-sum transfers than with climate-damaging subsidies for monovalent wood heating systems or wood fuels. Supporting low-income households via subsidies for biomass heating systems as it is done with the BEG can also be deceptive in the context of forest bioenergy. In the end, the additional costs for climate protection caused by such subsidies must be financed by higher taxes or cuts of other distributional policies. If tax increases lack political consensus and welfare state policies are cut instead, this will affect especially low-income households.

A CO_2 price on greenhouse gas emissions from wood will not put an end to forest bioenergy. Instead, this instrument can contribute to the recovery and strengthening of climate-efficient forests, enabling higher harvest volumes in the long term and thus also a relevant level of wood utilisations for energy purposes.[38] In addition, a CO_2 price incentivises the creation of sustainable business models with forest bioenergy that offer additional value for climate protection through the capture and storage or use of biogenic carbon (BECCS/BECCU[39]). While the storage option can be used to avoid the CO_2 price, high-quality

A CO_2 price is not the end of forest bioenergy, but the beginning of multifunctional wood utilisations in the energy sector.

utilisation of biogenic carbon enables additional revenues that can ensure competitive forest bioenergy even if the CO_2 price applies. The policy mix thus paves the way for efficient contributions from wood fuels to a net-neutral economy that reach beyond energy benefits.[40] Current studies indicate that providing negative emissions and renewable carbon for electricity-based fuels, for example, could even be more important in the long term than the energy generated upstream.[41] Curtailing energy subsidies and including forest biomass into emissions trading systems will therefore not close the case of forest bioenergy but introduce a multifunctional role for future uses of wood-based energy carriers.

38 Van Kooten, G. C. et al. (1995): Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services, American Journal of Agricultural Economics 77-2, 365-374, https://www.jstor.org/stable/1243546; Lintunen, J.; Uusivuori, J. (2016a): On the economics of forests and climate change: Deriving optimal policies, Journal of Forest Economics 24, 130-156.

39 Bioenergy with Carbon Capture and Storage, Bioenergy with Carbon Capture and Utilization.

40 On the different phases of bioenergy in the course of the energy transition, see acatech (2019): Biomass: striking a balance between energy and climate policies. Strategies for sustainable bioenergy use. Position paper February 2019, https://www.acatech.de/publikation/biomasse-im-spannungsfeld-zwischen-energie-und-klimapolitik-strategien-fuer-eine-nachhaltige-bioenergienutzung/download-pdf?lang=en

41 Millinger, M. et al. (2024): Diversity of biomass usage pathways to achieve emissions targets in the European energy system, preprint, https://www.researchsquare.com/article/rs-3097648/v1.

5 Conclusion

Consistent climate policy must systematically take the greenhouse gas effects of forest bioenergy into account. In addition to climate policy reasons, the future bioeconomy imposes an urgency to limit forest bioenergy to a sustainable level. To this end, complex climate impacts as well as economic, social and other ecological goals must be considered. In this discussion paper, it was argued that a climate-efficient use of wood resources can be an important guiding principle for sustainable forest bioenergy. This means allocating wood resources among forests, harvested wood products and forest bioenergy in a way that minimizes overall costs of climate change mitigation. This endeavour must be embedded within effective environmental and socio-political guard rails.

Whether sustainable forest bioenergy can be guaranteed with the help of the EU RED should be scrutinised more closely in view of the complexity of this challenge. By ignoring market failures in the LULUCF sector, the directive's utilisation hierarchy for wood implies a permanent struggle against the centrifugal forces of distorted markets. The energy sector's structurally excessive demand for wood constantly incentivises undermining the hierarchy through the creative search for legal loopholes or illegal practices.

Even if existing energy subsidies are dismantled under the pressure of the new use hierarchy, incentives for forest bioenergy will continue to increase along with the rising prices in the emissions trading systems, as long as a zero rating applies to emissions from RED-compliant forest bioenergy. The numerous endeavours to convert coal-fired power plants to biomass already illustrate this development.

A market-based regulatory approach with the help of CO_2 pricing and the promotion of carbon storage is challenging as well, and will not always lead to optimal wood cascades. Among other things, the necessary quantification of carbon storage in wood poses a challenge, especially if an implementation option is chosen in which carbon storage in harvested wood products has to be considered. Here, too, pragmatic solutions are needed, such as restricting subsidies to selected product areas, as is already the case with initiatives in Germany supporting timber construction, for example.

However, correcting market failures may nevertheless be more promising in realising sustainable wood cascades. The implementation costs are likely to be significantly lower than with a state-administered implementation of utilisation hierarchies, if only because there would be no more need to calculate lifecycle greenhouse gas balances for each wood fuel. Above all, even an imperfect market-based solution reduces the current centrifugal forces in the timber markets by shifting the incentives in favour of sustainable timber cascades.

It may appear attractive to use forest bioenergy to achieve rapid progress in the heating transition or in the defossilisation of aviation and shipping. However, such progress undermines the goal of strengthening the LULUCF sink. It also risks higher costs of climate policy as well as a lack of domestic wood resources for the material bioeconomy. Supporting private households by means of energy policy – for example through subsidising monovalent wood heating systems via the BEG – may therefore be offset by higher prices for climate-friendly products in the future that could be based on biogenic residues and waste materials. In addition, a shortage of financial resources in Germany's Climate and Transformation Fund (KTF) as the key fund for financing national climate policies is foreseeable, as an increasing need for climate protection measures in the LULUCF sector must be financed. This would result in reduced climate protection in other places, tax increases or cuts in welfare services.

If current energy subsidies continue, we can also expect an increase in imports of wood and forest bioenergy sources. Biomass imports certainly do not contradict sustainability goals per se. They can rather support these goals, for example if they contribute to creating jobs and higher incomes in countries with sufficient LULUCF sinks and more favourable options for climate change mitigation. Currently, however, timber imports are often associated with substantial environmental and social sustainability risks.[42] These should not be ignored lightly. Furthermore, increasing the resource base through imports merely conceals the inefficient utilisation of wood as a resource instead of eliminating the causes and consequences of misallocations – such as increased costs of climate protection.

By contrast, the shift towards a market-based regulation of forest bioenergy can create an important dynamic for the next phase of climate policy, where ‚unavoidable residual emissions' are to be compensated for by expanding carbon sinks and generating negative emissions. This will also pave the way for a sustainable development of the bioeconomy. As the climate neutrality target is only a few decades away and investments in forests and energy infrastructures often involve long-term processes, revising forest bioenergy policy should begin as soon as possible.

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[42] E.g., Egenolf, V. et al (2023): The impact of the German timber footprint on potential species loss in supply regions, Science of The Total Environment Volume 901, 25 November 2023, 165897, https://doi.org/10.1016/j.scitotenv.2023.165897; Wang, S. et al (2023): The booming non-food bioeconomy drives large share of global land-use emissions, Global Environmental Change, 83, 102760, https://doi.org/10.1016/j.gloenvcha.2023.102760.

DBFZ Deutsches Biomasseforschungs-zentrum gemeinnützige GmbH
Torgauer Str. 116
D - 04347 Leipzig
Phone: +49 (0)341 2434-112
www.dbfz.de/en/statements