Nordic Energy Research

Sustainable use of biomass for heating and transport fuel

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February 2020

Acknowledgements
***Sustainable use of biomass for heating and transport fuel* is a report made by Analysys Mason for Nordic Energy Research.** The work has been supervised by a steering group composed of Nordic Energy Research, Nordic Forest Research (SNS) and Nordic Joint Committee for Agricultural and Food Research (NKJ).

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Nordic Energy Research
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Foreword

This publication is the result of work undertaken by Analysys Mason in close cooperation with Nordic Energy Research (NER), the platform for cooperative energy research and knowledge development that is used for policy development under the auspices of the Nordic Council of Ministers. The work has been supervised by a steering group composed of Nordic Energy Research, Nordic Forest Research (SNS) and Nordic Joint Committee for Agricultural and Food Research (NKJ).

The vision of the Nordic Council of Ministers is that the Nordic region will become the most sustainable and integrated region in the world. The energy sector has an important role in this transition.

In the last ten years, the share of renewables in the total primary energy demand of the Nordic region has increased sharply. The growth is mainly due to an increased use of bioenergy. It is widely believed that, in order to reach carbon neutrality, the use of bioenergy should continue to grow.

For many years, however, the sustainability of harvesting and using biomass for energy purposes has been intensely debated. The core issue is whether and under which conditions an increased use of biomass is compatible with other societal goals, relating for example to food supply, wood products, biodiversity, land use and other environmental goals.

Against this backdrop, the Nordic Council of Ministers assigned Nordic Energy Research the task of assessing the potential for sustainable use of biomass in the Nordic countries in relation to transport and heating. Based on this assignment, NER has produced a number of leaflets, organized four expert seminars and ordered this policy brief. *Sustainable use of biomass for heating and transport fuel* provides an orientation on the topic of sustainable biomass and highlights a number of important issues. Furthermore, it outlines a number of policy recommendations.

Hopefully this policy brief will contribute to the current debate by shedding additional light on the important but complicated issue of sustainable use of biomass.

Klaus Skytte

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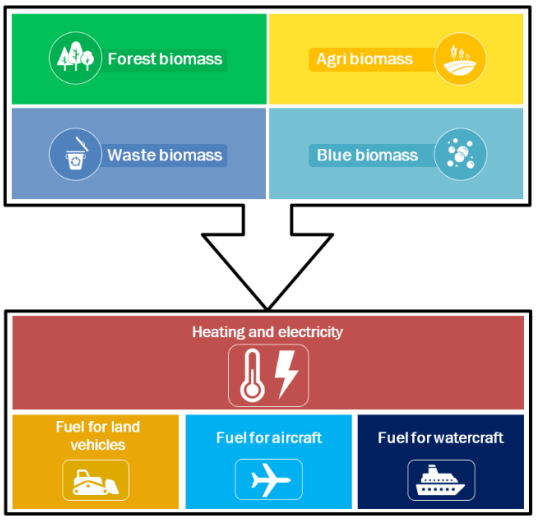
Executive summary

To meet climate policies in the Nordic region it is increasingly clear that the burning of non-renewable fuels must be reduced. While developing long-term technology and infrastructure to allow this systemic readjustment, immediate short-term changes are critical if the commitments already made are to be met. Substituting fossil fuels with renewable biofuels is key to bridge the gap to a low-carbon future.

Bioenergy is an important topic in the Nordic countries but the sustainability of biomass for energy is being debated and the issue is complex. Some analysts expect biomass to provide large amounts of clean energy at acceptable environmental costs and with net positive socioeconomic effects; others project limited potential and large adverse effects such as increased hunger, biodiversity loss, and substantial GHG emissions.



To provide guidance on this matter, Nordic Energy Research, Nordic Forest Research, and Nordic Joint Committee for Agricultural and Food Research have produced this policy brief. Focus throughout the brief is biomass from forestry, agriculture, waste, and the marine environment as a source of energy for heating and transportation fuels.

Similarities in structures (e.g. economic and ecological) and political ambition provide **fruitful ground for joint Nordic efforts in further developing sustainable biomass**. In addition, a unified Nordic voice with regards to bioenergy increases the countries' collective weight in international forums. To move forward, **policy recommendations are presented aiming to:**

- Increasing the level of sustainability in Nordic bioenergy
- Increasing production and usage of sustainable bioenergy in the Nordics
- Increasing collaboration with regions outside the Nordic countries

Calculating an exact value for sustainable biomass in the Nordics in TWh, along with a clear recommendation of how to reach this volume and how to ensure compliance with the sustainability criteria will, however, require further elaboration. The differing perspectives on what defines 'sustainable biomass' make it difficult to make definitive judgments on compliance, even if adopting the formalised sustainability criteria outlined in the RED II, which are still under discussion as well as complicated. Nevertheless, **five important points can be made:**

- Joint Nordic efforts play an important role in increasing the use of sustainable bioenergy
- Sustainability is included in existing legislation encompassing Nordic biomass providers
- The sustainability of Nordic biomass for heating and transport can be further improved
- Measures need to be taken to support the development of sustainable bioenergy in the Nordics
- In order to mitigate climate change, Nordic efforts need to be exported to the rest of the world

1 Sustainable bioenergy and transition to a greener economy

Bioenergy is important in the transition to a greener economy, but its overall sustainability is a subject of debate. In theory, the use of plant-based products leads to no non-renewable carbon emissions being added to the atmosphere. Examples include district heating fuelled by wood instead of coal or vehicles running on biofuels instead of petroleum products.[1] In practice, a more detailed examination of the sustainability of biomass use shows that the issue is much more complicated – it depends on the time frame considered, the source of the feedstock etc. Opinions remain divided and several questions related to sustainable bioenergy on a systems level have yet to reach an unambiguous conclusion.

1.1 Climate policy and the role of bioenergy

All Nordic countries have ambitious goals to reduce emission of 'greenhouse gases' (GHG) and together the Nordics have signed the Declaration on Nordic Carbon Neutrality.

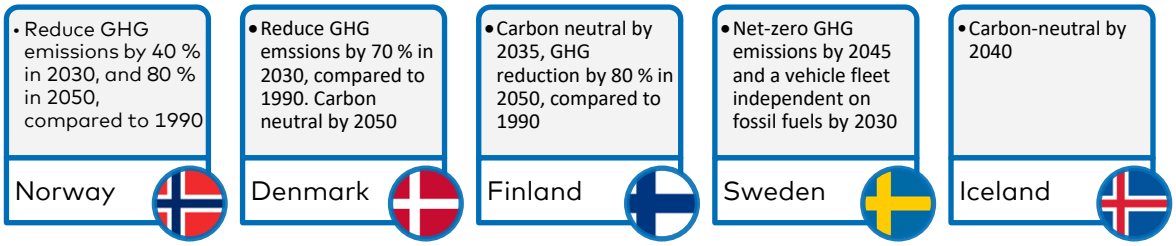


Figure 1: GHG emissions targets in the Nordic countries. Sources: Norway[2], Denmark[3], Finland[4,5], Sweden[6,7], Iceland[8]

Meeting these targets, and the carbon-neutrality goals in particular, will require rapid and concerted actions, and is likely to be dependent on strong growth in the use of biomass for energy purposes. In addition to short-term actions, the Nordics need to consider more long-term strategies in terms of transitioning into a greener economy.[9]

A strong growth of biomass use **(~50 % up to 2050)** is needed to reach the Carbon Neutral Scenario

The share of renewables in the region's total primary energy demand has been growing steadily over the last decade, from 29 % in 2006 to 39 % in 2016. This growth is mainly due to an increased use of bioenergy. In addition, biomass, together with hydropower, constitute the main sources of renewable energy in the Nordic region.[10]

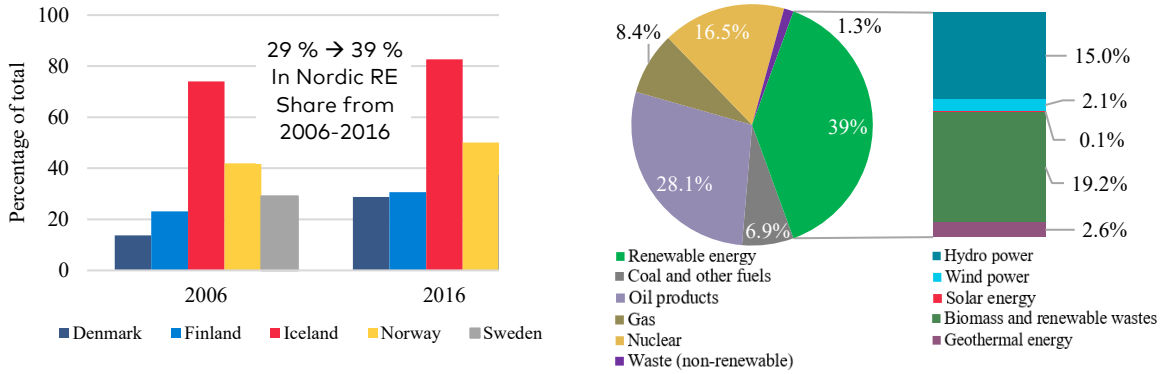


Figure 2: Left: Share of Renewable Energy (RE) in total primary energy demand. Right: Percentage total primary energy demand by energy source (2016)[11]

1.2 The assignment – sustainability of bioenergy in the Nordics

Given the Nordic countries' biomass resources, and the sustainability commitments made, bioenergy is an important topic in the region. The sustainability of biomass for energy is discussed intensively. To gain guidance in this context, the Nordic Council of Ministers assigned Nordic Energy Research to address the topic. More specifically, the Nordic Council of Ministers requested an analysis of the potential for sustainable use of biomass in the Nordic countries in relation to transport and heating, and called for a unified Nordic effort to illustrate how it can be ensured that the biomass and biofuel used are sustainable. Based on this request, Nordic Energy Research produced:

Table 1: Deliverables from Nordic Energy Research

Leaflets	Seminars	Policy brief
• Bioenergy in the Nordics • Food waste to biofuels • Sustainable jet fuel	• Biofuel strategy for the coming decade - The Nordic region at the forefront of technology and sustainability! *Gothenburg 6 Nov 2019* • Sustainable biomass in the Nordics - How should we farm the ocean? *Oslo 14 Nov 2019* • Biomass in the heating sector - how, how much and how long? *Copenhagen 21 Nov 2019* • Bioenergy Sustainability: A view from Finland towards Nordic Policy Makers *Helsinki 22 Nov 2019*	• Sustainable use of biomass for heating and transport fuel

This policy brief which you now hold in your hand provides an orientation on the topic and highlights important issues in relation to the sustainable use of bioenergy. In addition, a series of policy recommendations are outlined. The information in this document is based on research, reports, policy documents, and input from the four seminars presented above.

1.3 Defining core terms

Biomass: 2018/2001/EU: "the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin"[12]

Biomass fuels: Gaseous and solid fuels produced from biomass[13]

Bioenergy: Energy that is derived from biological matter (i.e. from plants and animals) but which has not undergone a geological process (cf. fossil fuels)[14]

Biofuels: Liquid fuel for transport produced from biomass[15]

Bioliquids: Liquid fuel for energy purposes other than for transport, produced from biomass[16]

Blue biomass: Biomass material from the marine environment with special focus on seaweed and kelp

Food waste: Waste and residues produced along the food value chain: from production to consumer[17]

Sustainability: There is no universally accepted definition of sustainable biomass. However, the revised renewable energy directive 2018/2001/EU (commonly known as RED II) establishes several criteria relevant for the assessment of biomass sustainability. The criteria state what properties biomass must fulfil to contribute towards the Union target of a 32 % share of energy coming from renewable sources by 2030, and other issues.[18] The directive differentiates between sustainability criteria and GHG emissions savings criteria for new plants, both of which are needed for energy to be considered 'renewable'. These are applicable no matter where the biomass originates geographically.[19]

There are also competing definitions of what is required for biomass to be considered sustainable.[20] For example, the ISO 13065:2015 sustainability criteria for bioenergy includes economic, social and long-term values in its definition.[21] The international Global Bioenergy Partnership has identified 24 sustainability criteria for bioenergy.[22] There are also sector-specific sustainability certifications available, for example, Forest Stewardship Council (FSC) and the industry-developed Programme for the Endorsement of Forest Certification (PEFC) in forestry.[23]

1.3.1 Sustainability criteria for biomass production according to RED II

Below are the sustainability criteria from directive 2018/2001/EU (RED II) for the three main sources for biomass. If they are not fulfilled for a biomass producer, the use of the biomass cannot contribute towards the target of a 32 % share of energy coming from renewable sources by 2030.[24]

Table 2: Criteria for main biomass feedstocks to be considered sustainable, according to RED II

Forest biomass[25]	Agro biomass[26]	Waste biomass[27]
• legality of harvesting operations • regeneration of harvested areas • areas designated by law for nature protection purposes are protected • minimise the negative impact of harvesting on soil quality and biodiversity • long-term production capacity of the forest is maintained or improved • biomass meets the LULUCF criteria, meaning that the country or region of origin of the biomass: - is a Party to the Paris Agreement - has submitted a Nationally Determined Contribution to the UNFCCC, or has national or subnational laws in place, in accordance with Article 5 of the Paris agreement The criteria must be enforced at national, or forest sourcing level	• Operator or national authority must have monitoring, or management plans for soil quality and carbon • Raw material cannot be obtained from land: - with a high biodiversity value - with a high-carbon stock - that was peatland in January 2008	• If the biofuels, -liquid, or -mass is produced from waste and residues not originating from agriculture, aquaculture, fisheries, or forestry, they only need to fulfil the GHG emissions savings criteria

1.3.2 GHG emissions savings criteria according to RED II

To decide whether the use of biomass for energy or transportation purposes are to be considered 'renewable' the EU has also defined criteria on GHG emissions savings. The criteria are different if the biomass is to be used in transportation, or if it is to be used for heat or energy; and in the latter case, the criteria also differs depending on the effect of the plant. Low-effect plants are not included.[28] The greenhouse gas savings that arise from using biomass for energy or transportation purposes are calculated though one of four methods, ranging from using a default value, an actual value, or one of two formulas described in annexes to the directive.[29]

Heat and electricity plants using biomass can contribute to the EU goal of renewable energy if, by using biofuels, bioliquids or biomass, they save at least 70 % of greenhouse gases for plants starting operation from 2021 to 2025; for plants starting from 2026 and on, the savings must be 80 %. New electricity-only plants must meet more detailed criteria (for example they cannot use fossil fuels as a main fuel).[30]

Calculated greenhouse gas savings from using biomass for energy purposes in the transportation sector must be at least 50 % for biofuels, biogas and bioliquids produced in facilities in operation on or before 5 October 2015. For production in facilities put in operation between 6 October 2015 and 31 December 2020, at least 60 % must be saved; and at least 65 % reduction is required if the facility starts operating in 2021 or thereafter.[31]

2 Current and future supply of biomass

The main sources of biomass in the Nordics include forest, agriculture (agro) and waste. In addition, aquatic (blue) biomass is under development and is briefly covered (although not included in the calculations due to lack of quantitative estimations). Peat is not included in this policy brief.

The current potential for bioenergy in the Nordic countries amount to approximately 480 TWh, while the future potential is estimated to approximately 640 TWh.[32] Potential is in this chapter defined as the "overall maximum amount of biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits".[33] This can be compared to the 290 TWh consumption of primary solid biomass fuels, biogases and renewable municipal waste in the Nordic countries in 2017.[34]

2.1 Forest biomass – the largest biomass supply in the Nordics

Forest biomass accounts for around 70 % of the total biomass supply in the Nordics. Sweden and Finland have the largest supply, Norway accounts for about 10 % of the total, while Denmark and Iceland have limited forest assets.[35] The current estimated potential is approximately 350 TWh.[36] Commercial forests in the Nordics are harvested primarily to generate wood sales for material use as this generates higher returns for forest owners.[37] Wood-based bioenergy is generally created as a by-product. In its wider sense, forest biomass suitable as energy sources therefore includes black liquor, chips, bark, sawdust, harvesting residues, stumps, and small-diameter wood.[38]

Overall, the Nordic supply of forest biomass is expected to increase. Due to continuous improvements in forest management, the yield is steadily increasing, implying that more can be harvested from a given area.[39] Evidence show that the production of wood and woody biomass could increase by 50–100 % if management is optimised by introducing fast-growing conifer species, poplar and hybrid aspen stands.[40] Theoretical potential is expected to increase, especially in Sweden and Finland where the potential is notably higher than in other Nordic countries.[41]

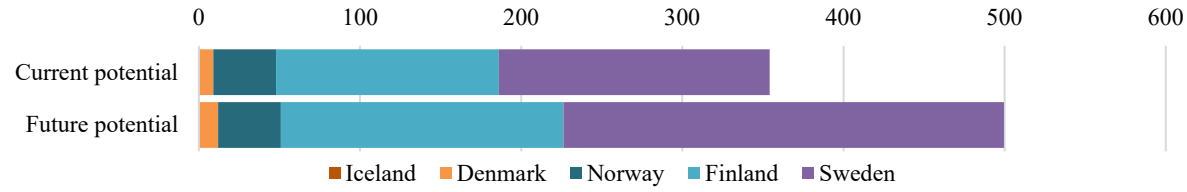


Figure 3: Biomass potential in the Nordic forestry sector [TWh][42]

In Finland and Sweden, most of the large-scale biomass use consists of industry residues, while in Denmark, pellets are the main type of forest biomass used for energy production.[43]

2.2 Agro biomass - accounts for 20 % of the total biomass supply in the Nordics

Agro biomass suitable as energy sources consists of energy crops, straw, husk, grasses, and manure.[44] It accounts for around 20 % of the total biomass supply in the Nordics.[45] The potential supply is highest in Sweden and Denmark, followed by Finland and Norway, while the supply in Iceland is less than 1 % of the total Nordic potential. In Finland and Denmark, the potential is anticipated to increase while in Norway and Iceland the expectation is it will stay the same. In Sweden the potential is predicted to decrease due to a declining straw and husk production.[46]

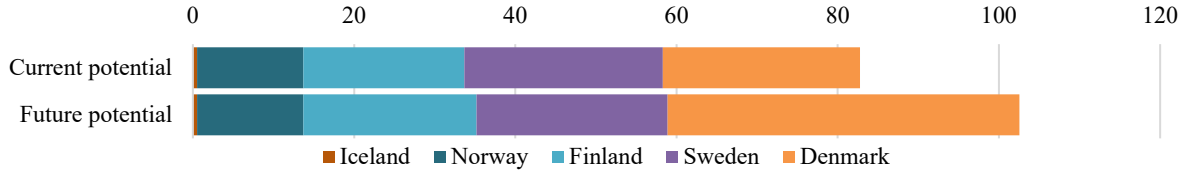


Figure 4: Biomass potential in the Nordic agriculture sector [TWh][47]

2.3 Waste biomass - expected to increase due to population and economic growth

Waste biomass suitable for energy purposes includes biological material from consumers (such as municipal solid waste), waste water sludge, cooking oil, and waste from fisheries and slaughter. The potential is expected to increase in all countries due to population and economic growth. In most of the Nordic countries, there is a policy pressure to reduce and separate biowaste, which will influence the future potential of waste biomass as an energy source.[48]

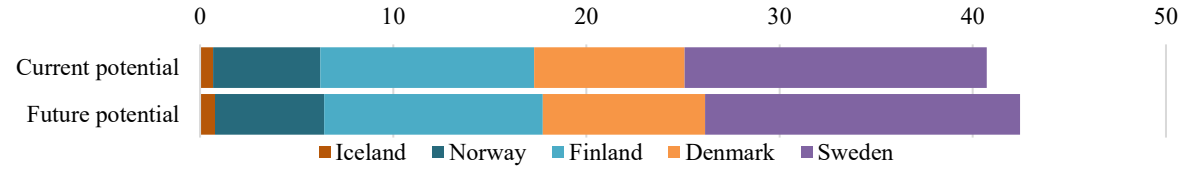


Figure 5: Biomass potential in Nordic waste [TWh][49]

2.4 Blue biomass - production is small but under development

Blue biomass consists of material from marine environments with special focus on seaweed and kelp. Using blue biomass to produce bioenergy is under development and further studies on the topics are requested.[50] Norwegian stakeholders are actively contributing to this development and the country has a large potential in kelp production.[51] An experimental site in Norway is currently producing 40 tons of seaweed per year, but the business behind the site expects a future potential close to 50 000 tons.[52] As with other biomass production, marine biomass has several use cases including producing food, medicine, high-value chemicals and industrial commodities such as biofuels, bioliquids, and biomass fuels.[53]

Using marine biomass to produce bioenergy has several challenges. For example, the components of biomass can differ depending on when it is harvested, which means it is hard to optimise the refining processes.[54] Today, the main challenges are to attain high yields, produce high-quality biomass and maintain stable production.[55] It has also proved hard to handle the water content in the production process.[56]

3 Areas of application

A total of 290 TWh of biomass energy was consumed in the Nordic countries in 2017, of which 89 % is primary biomass fuels, 8 % is municipal waste, and 3 % is biogas.[57]

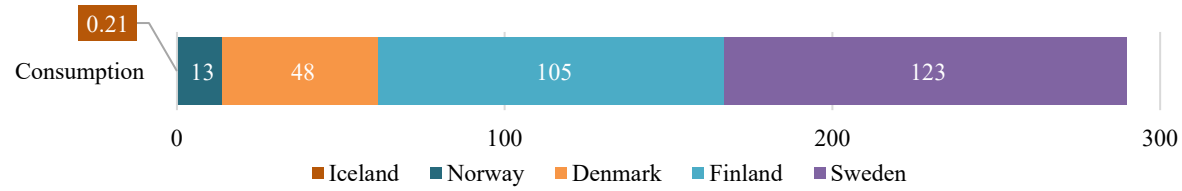


Figure 6: Biomass usage for energy in the Nordic region [TWh][58]

3.1 Biomass for heating and electricity

Biomass is widely used for heating and energy purposes in the Nordic region, especially when compared to the EU average. Biomass is used extensively for district heating production in all countries except Iceland, which has vast geothermal resources. Nordic countries have a high share of district heating, demonstrating the important role municipalities have played in enabling the development of district heating. Renewable energy used in the district heating production is largely based on biomass. In Denmark (unlike Sweden and Finland), a large share of biomass is imported and almost all waste (if not recycled) is used for energy production. Consequently, waste-to-energy is an important part of the Danish waste management system.[59]

Many district heating producers are part of the European Emissions Trading System (EU ETS), and if using fossil fuels for the production, are affected by CO_2 prices. However, according to the free-allocation provision, district heating companies receive free emission allowances based on benchmarks, allowing them to even receive income from selling the allowances.[60]

3.2 Biomass for transportation fuel

The transportation sector is still dependent on fossil fuels, and strategies to increase alternative fuels should account for the unique needs of transportation means. Biofuels are generally regarded best suited as a replacement for liquid fossil fuels in long-distance, heavy-duty road, and marine freight and aviation; where electrification is seen as unfeasible in the near future.[61]

Biomass can be converted into several types of biofuels, depending on feedstock and required use case. The two most common biofuels used in transport are bioethanol, which is used as a petrol substitute, and biodiesel which is used as a diesel substitute. *Biogas* is sourced from organic/animal wastes, sewage, and grasses and is transformed via digestion processes. *Ethanol* is sourced from sugar- or starch-containing crops (e.g. sugar cane, corn, grain, and sugar beets) and is transformed via fermentation processes. *Synthetic fuels* are sourced from cellulosic materials and are transformed via gasification processes.[62]

The share of biofuels and biomass fuels in the transportation sector differs between the Nordic countries, where Sweden has the largest share (16.1 %),[63] and Denmark has the lowest share (5.7 %)[64] (2016). The Nordic countries have committed to the Renewable

Energy Directive (RED) and national goals on emission reduction, creating a motive for increased use of bioenergy in transportation.[65]

Land vehicles' use of renewable energy has grown substantially, primarily biofuels mixed into gasoline and diesel (blend-in fuels), but also through alternative fuels like biodiesel, biogas et cetera. Pure biodiesel has increased in recent years, primarily for buses and heavy goods vehicles.[66] Overall, increasing CO_2 pricing has made biomass and other renewable energy sources more competitive.[67] Machinery in agriculture, forestry, and construction can potentially use alcohol derived from biomass where significant power is needed.[68] In urban, light- and mid-duty freight, and in short-distance passenger trips, electric or hydrogen vehicles are viewed as the best suited to replace fossil fuels.[69] However, as most current engines can tolerate blend-ins of 10-20 % biofuels, and many modern cars can tolerate much higher shares, the biofuels share can potentially increase further, when vehicles evolve.[70]

Aviation traffic is responsible for 2 % of the global anthropogenic CO_2 emissions. The International Civil Aviation Organization (ICAO) forecasts that by 2050, emissions could grow three- to seven-fold.[71] Sustainable jet fuel has been recognised as a key measure for reducing climate impact emissions,[72] and an increasing number of flights now operate on a blend of commissioned biomass fuels.[73]

The potential to use biomass to fuel aviation has yet to be fully explored, as a wide range of factors affects the outcome of estimates. The world has yet to see a fully functioning commercial supply chain for sustainable jet fuel. The aviation industry's main target is to get access to a reliable supply of high-performance biomass fuel at reasonable price. Currently, some companies are working on validation and demonstration of a sustainable value chain from forest waste feedstock to jet fuel.[74] Analysis of the business impact shows that transition to sustainable jet fuel is likely to create jobs for feedstock processing and production in the agriculture and forestry sectors corresponding to between 6 000 and 10 000 new jobs.[75]

The maritime sector is working on reducing GHG emissions, under the leadership of the International Maritime Organization (IMO) strategy to reduce annual emissions from international shipping by at least 50 % by 2050, compared to 2008.[76] One aspect of this related to minimising requirements for fuel, which also means lower-cost transport. The sector has a lot of possibilities due to how the vessels' motors are built, and some existing fuels can be used blended into the tank. Electric vessels are available and viable for shorter distances, but battery technology does not yet allow sufficient power to be stored to fuel transoceanic freight. Biomethane, ammonia, and alcohol have been identified as the most promising short- to medium-term fuels in the marine sector. To use alcohol would require new engines and fueling infrastructure. Gas should, in theory, be cheap but would need larger fuel tanks, which means that less cargo can be transported on the ship.[77]

Marine shipping accounts for 93 % of total freight in the Nordics, and the sector is auditing whether biofuels (primarily methanol) can provide a sustainable alternative to fossil fuels.[78] Methanol has the advantage of being compatible with existing infrastructure and can replace methanol produced from fossil fuel.[79] In the short term, low blends of biogas or HVO can be easier to implement than renewable methanol since it requires fewer changes.[80] Even if biofuels are not yet abundantly used, marine biofuels can be designed to be technically compatible with marine engines and could hence be used as drop-in fuels in the short term.[81] A more common use of marine biofuels is likely to be implemented where air quality is sensitive, and ship operators are required to comply with regulations to use cleaner fuels.[82]

4 Sustainable bioenergy – a complex matter

In its essence, replacing fossil-based fuels with sustainably produced biomass from forestry, agriculture, biological waste, and marine environments will decrease GHG emission. Through the use of sustainable bioenergy, the combustion of biomass replaces part of the natural degradation, which means that the balance in coal storage can be maintained, or even decreased. This is significantly different from combustion of fossil fuels, where new coal from stable geological layers is transferred to the atmosphere. This core message is important to keep in mind when delving into the details and nuances of sustainable biomass, which indeed is more complex.

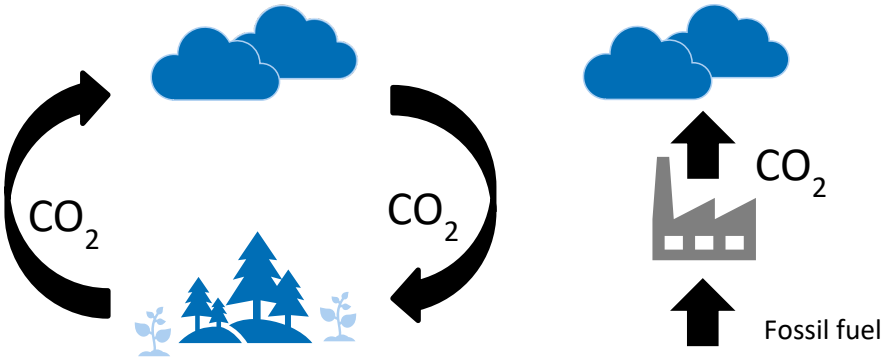


Figure 7: Carbon flowchart for bioenergy from forestry and agriculture (left) and fossil fuels (right)

The complexity with regards to sustainable bioenergy primarily derives from existing tensions between various goals within the overall objective of environmental sustainability (including carbon management and climate change, water management, soil productivity, biodiversity, landscape structure), competing political objectives (such as food security, rural development, economic and social impact), as well as diverging logic and perspectives among different stakeholders. In addition, if adopting a wider understanding of sustainability (in line with the three aspects of sustainable development: environmental, social, and economic) also the financial aspects and profitability of actors engaged in the production and use of bioenergy becomes important.

The sustainability of Nordic biomass production is regulated through a range of national policies and legislation and covered by EU regulation through, for example, RED II. In addition, it is subject to different voluntary sustainability standards and certifications.

4.1 A reflection on sustainable biomass in relation to RED II

In addition to national regulations, several criteria for sustainable forestry are found in the recast RED II (as mentioned in section 1.3.1). In a recent report [83], Nordic Energy Research assess Nordic forestry's potential compliance risks with the RED II. The main identified risks relate to differences in definitions between the directive and local legislation, in particular regarding harvesting permits and forest regeneration. The report did not assess the criteria on protection areas, impacts on soil quality, biodiversity or long-term production capacity, due to difficulties in the interpretation of these concepts.

Table 3: Country level compliance with the criteria for primary forest biomass[84]

	Norway	Denmark	Finland	Sweden	Iceland
Sustainability of harvesting criteria	Uncertainties e.g. related to harvesting permit definition	Uncertainties e.g. related to harvesting permit and forest regeneration definition	Uncertainties e.g. related to harvesting permit definition	Uncertainties e.g. related to harvesting permit definition	Not mentioned

Biomass from agriculture is, besides national legislation, regulated by the Common Agricultural Policy (CAP), where sustainability is one of the main objectives. Environmental measures relate to biodiversity and ecosystem services in the agricultural landscape. In addition to general provisions for the conservation of natural values in the agricultural landscape, there are specific sustainability criteria in RED II that apply to the production of agricultural crops to be used for bioenergy.[85]

Waste biomass is not included in the sustainability criteria in RED II, but is affected by the GHG emissions savings criteria.[86] EU countries should also handle waste in accordance with the waste hierarchy, which states that energy recovery is not the most desirable way to handle waste, as prevention, re-use and recycling are more desirable.[87]

Regarding blue biomass, the production is still small and it is not covered by the sustainability criteria in RED II.

4.2 The complexity of sustainable bioenergy - exemplifying cases

Goal conflicts

- Increased production of biofuels, bioliquids, and biomass fuels can support goals on reducing CO_2 emissions and play a central role in moving our society towards a 'bioeconomy' that is less dependent on fossil-based products. But if the biofuels are derived from natural forest, there is a risk to biodiversity and ecosystem services in forests,[88] and harm to forest wildlife and local livelihoods. The problems of declining biodiversity have been widely reported by environmental NGOs and the UN.[89] Extracting and transporting the source materials can sometimes require significant energy and cost, undermining that apparent gain.

- In the case of a major increase in the volume of production of biofuels, bioliquids, and biomass fuels, sustainability criteria might be hard to fulfil beyond 2030. This conclusion reflects competition between bioenergy and food production (which might increase food prices), disruption of ecosystems (if monocultures are expanded), and effects on water and soil.[90] These issues are however expected to be manageable from a sustainability perspective in the short term (2025-2030).[91]

The time aspect

- The sustainability of fuel that is composed of or includes biomass is typically predicated on a short carbon cycle, where carbon is absorbed in biomass, and re-released into the atmosphere when the biomass is used for energy purposes. There is however some critique against the assumption that biomass production is part of a short carbon cycle. Looking at the largest pool of biomass in the Nordics – forests – the re-sequestration of carbon can take from a few decades up to

centuries to show a net positive effect. This means that the burning of forest biomass is not necessary carbon neutral within the timeframe of the Paris Agreement.[92]

- Recent research suggest that a managed forest has a steadily increasing positive effect compared to a preserved forest. However, some uncertainties on climate benefits remain. In the short run, a preserved forest is expected to have the most positive effect, but this wears off as the trees mature. If a previously managed forest is preserved, it will initially have a more positive effect than if it had been managed, mainly due to fewer emissions from harvesting and production. However, after the initial growth, a saturation phase is reached, when carbon uptake and release balance each other out. The forest will then become a static carbon store. Hence, in a longer perspective, managed forests have steadily increasing positive climate effects.[93]

- The Paris Agreement produces a need for negative emissions by the middle of the 21st century. Forests are one of the lowest-cost and most effective climate solutions with the potential to provide considerable negative emissions.[94] However, simulations imply that the effect might decrease. By 2030 the carbon sink in managed forests is expected to decline by 32 %, and the trend is expected to continue until 2050. This is due to EU forests becoming older (which decreases the CO_2 uptake) and because forest harvest removals are expected to increase over time. The effect is partially compensated by a rising carbon sink from afforestation and decreasing emissions from deforestation.[95]

Technology development

- UNCDD has identified Bio-Energy with Carbon Capture Storage (BECCS), as a way to create 'negative' GHG emissions. Carbon is assumed to be absorbed when biomass grows and then captured before or after combustion for indefinite underground storage.[96] However, how to do this at scale and at a viable cost remains largely unproven.[97]

5 Vital issues and related policy recommendations

All Nordic countries have ambitious GHG emission targets and share a genuine interest in collaboration on climate policy, showcased through joint policy work such as the Declaration on Nordic Carbon Neutrality.[98] The Nordic countries also share an interest in the use of bioenergy as a replacement for fossil-based alternatives and are engaged in ongoing dialogue regarding bioenergy. Several inter-Nordic research collaborations are in progress[99] such as the SPIRETH project which has demonstrated that Nordic funding can open opportunities for companies to embark on more sustainable paths.[100] The similarities in structures (e.g. economic and ecological) and ambition offer further opportunities to increase Nordic collaboration. The seminars held within the scope of this project clearly showed a strong demand for increased knowledge and technology transfer (of both successes and failures) within the Nordics. In addition to the gains in knowledge and technology development, a unified Nordic voice with regards to bioenergy increases the countries' collective weight in international forums.[101] This context creates a fruitful ground for joint effort in terms of sustainable biomass for heating and transportation, and in what follows we present important questions moving forward on this topic and related policy recommendations.

5.1 Increasing the level of sustainability in Nordic bioenergy

In order to increase the level of sustainability in Nordic bioenergy, the complexities associated with goal conflicts, competing political objectives, and diverging logics and perspectives needs to be managed. One way to do that is through increased systems thinking.

To make sense of a complex system of interrelated and changing factors, researchers and policy makers often focus on one perspective at a time and on a few metrics important to that specific perspective. This approach is often a necessary strategy to derive reliable results, but at the same time it obstructs a complete and systemic view. For example, compliance with certain sustainability criteria, such as requirements for protection areas, and impacts on soil quality and biodiversity, are difficult to assess resulting in their exclusion in analyses and compilations.[102] By developing a more complete, holistic view of sustainable bioenergy, suboptimal partial solutions can be avoided. A holistic view should also mitigate the potential goal conflicts among the various perspectives that may be hindering the development of bioenergy in the Nordic region. Facilitating a more effective, systemic view on sustainable bioenergy requires significant resources and expertise from different areas, both within and outside of academia. Given the many similarities among the Nordic countries (in terms of climate policy and ambition but also with regards to natural resources and technological and economic development), Nordic collaboration should be an efficient and fruitful way to tackle the challenge of more systemic thinking.

The process of negotiating and agreeing upon sustainability criteria exemplifies the complexity associated with sustainable bioenergy. The recast Renewable Energy Directive for 2021-2030 (RED II) tackles some of these challenges by identifying a set of criteria for sustainability and for GHG emission saving. These criteria, the interpretation of the criteria, and the possibility to comply with them and indeed assess compliance, are however under discussion. In order to increase the level of sustainability in Nordic bioenergy these sustainability criteria, and indeed other measures of sustainability, need to be further developed. Necessary development includes both the wider issue of what aspects to include

in the criteria (relating to an increased system thinking), and the more tangible issue of interpretation and compliance of set criteria.

Policy recommendations aimed at increasing the level of sustainability in Nordic bioenergy:

- *Enhancing Nordic collaboration across sustainability perspectives and sectors (forestry, agriculture, waste, fisheries, energy etc.).* Solutions include enhanced systems thinking within policymaking, research, and industry, and finding synergies across perspective and sectors.[103,104]
- *Promoting a variety of solutions for sustainable bioenergy in the Nordics.* Due to the many uncertainties within the system it is not possible to identify one perfect solution, set of technologies or production systems, for sustainable bioenergy. Therefore, it is important to use the Nordic arena to develop and test a wide range of solutions.[105]
- *Joint Nordic research collaborations to bridge current knowledge gaps* such as how to handle conflicts between different objectives, how best to utilise biomass to balance the whole renewable energy system, how to prepare for the effects of climate change, how to internalise environmental effects of agriculture in the economy, and how to increase supply chain efficiency and technological development.[106]
- *Further develop and refine sustainability criteria,* for example enhancing the possibility to measure and ensure compliance with the sustainability criteria in RED II, develop accounting methodologies and policy framework for BECCS, and develop methods to ensure that imported biomass is produced in accordance with relevant sustainability criteria.[107]

5.2 Increasing production and usage of sustainable bioenergy in the Nordics

Many Nordic actors show great engagement in the sustainable production and use of biomass for energy purposes, and ongoing work in this field is likely to further increase the amount of sustainable biomass used. On this backdrop, establishing precisely how to realise the full potential for sustainable biomass becomes a key question. This section explores some of the related uncertainties and contradictions, and offers policy recommendations.

How much biomass fuels do the Nordic countries need? Do the Nordic countries have enough biomass to meet those needs? What biomass can we use, and how can we use it efficiently? And what should the biomass actually be used for? These are all central questions when discussing bioenergy but to find the right solution requires careful navigation of the various fluctuating and interdependent factors. In addition, the questions are not purely scientific but associated with a range of normative decisions opening up for different answers depending on the logic or incentive driving the enquirer.

For future bioenergy business models to become fully sustainable the raw material needs to be used as efficiently as possible.[108] Biomass in its raw format has many potential outlets, and to maximize value production these outlets need careful analysis. As an example, when oil is recovered from beneath the ground, it is separated into its various component fractions in such a way as to allow each substance to be used for the most economically valuable purpose. Thus, each constituent hydrocarbon is used to create plastics, fuel cars, or simply surface roads according to their characteristics, and in some cases can be processed to create a higher-value product. A similar approach needs to be established for biomass, as many of the raw materials have the potential to be used for any of a range of competing purposes. Burning biomass for electricity or heating, or using it to produce fuel creates a relatively low economic return for the raw material compared to more refined products such as paper, pulp, and timber.

Industry actors also argue that the bioenergy sector lacks long-term policy frameworks (such as fuel quality standards).[109] This is creating challenging uncertainties for the businesses ranging from complex risk management to lack of interest from investors.[110] This in turn results in challenges with financing and scaling up bioenergy production plants.[111,112,113] Unless efficient policies and regulations are introduced and maintained (e.g. carbon taxes, emission trading, subsidies) bioenergy companies will struggle to create the economy of scale necessary to compete with fossil fuels.[114,115,116] Finally, intellectual property rights and patent 'trolling' are (according to industry representatives) undermining the bioenergy sector.[117,118]

Recognising this complexity, a range of policy recommendations have been identified aiming to support the development of bioenergy in the Nordic region.

Policy recommendations aimed at increasing the production and usage of sustainable bioenergy in the Nordics:

- *Enhancing knowledge and technology transfer within the Nordic countries* in order to support the development of relevant technological innovations and implementations. Solutions include increased collaboration between Nordic researchers, policymakers, and industry actors through joint projects and networks.[119]
- *Develop joint Nordic policies and regulations to promote investment in the green transition.* In order to ensure investments in, and create a reasonable risk management for, bioenergy enterprises, the industry requests long-term, clear, and stable policy and regulations.[120]
- *Ensure incentives are technology-neutral.* The transition towards increased bioenergy in the Nordic region will require the development of new technologies. This process needs to happen rapidly, and in order to ensure technological developments are not hampered by the slower pace of policy development, incentives need to be technology-neutral, also in relation to other non-bioenergy renewable energy sources.[121,122,123,124]
- *Consider import of biomass from outside of the Nordic region.* A larger share of the Nordic biomass might be needed to produce high-value products,[125] increasing the need for import of biomass for heat, electricity and biomass fuels. Banning biomass imports could hamper the development of bioenergy; allowing imports of biomass could provide an opportunity to transfer Nordic knowledge on sustainable production of biomass and in bioenergy as such (potentially motivating other nations to use bioenergy).[126] There are however challenges with importing biomass which need to be handled, such as ensuring a sustainable production of the biomass if produced in other parts of the world.[127] The questions related to import of biomass from outside of the Nordics hence needs further investigation.[128]
- *Facilitate transportation of biomass.* Transport distances are likely to increase, as biomass in less accessible areas will be more profitable than today. Solutions includes building better roads, creating more effective online data for road conditions, digitalising and optimising the transport system, and increasing the transport loads.[129]
- *Decrease the costs of harvesting biomass.* The average cost of harvesting is likely to increase when new, previously inaccessible areas are developed, where the terrain might be challenging. Solutions include increased collaboration between forest owners through digitalisation, development of harvesters and education for forest owners.[130]
- *Consider easing EU regulations' restriction on energy crops.* Solutions include discussing the possibility to add environmental and climate benefits into the EU Common Agricultural Policy (CAP).[131]
- *Increase the value of straw.* Solutions include making biochar, using straw for higher-value products and biofuel, biogas, combustion and CO_2 capture.[132]
- *Develop regulation for waste-water sludge.* Solutions include increased knowledge and improved data management on water sludge utilisation.[133]

- *Improve source separation of biomass.* Solutions include source separation incentives such as lower fees if separating, development of credible systems, and education and information to the public on the value of separation.[134]
- *Support research on blue biomass,* including process design and biochemical development.[135,136]
- *Manage the identified market barriers hampering the development of sustainable jet fuel,* including the price structure, the feedstock supply, the technology development and the financial availability, as well as the very definition of what constitutes sustainable alternatives for aviation fuels.[137]
- *Enact policy initiatives and instruments supporting the introduction of renewable marine fuel,* both in the short and long term. To be effective, such support should influence performance of renewable options to meet the relevant criteria. Possible support mechanisms include CO_2 taxes on marine fuels, quota systems promoting a specific level of renewable marine fuels, and subsidies for investments in renewable marine fuels (for retrofits and new construction). A better understanding of stakeholder preferences may improve the design and implementation of policies.[138]
- *Support bioenergy from food waste* through coordination of biofuels policy priorities between countries, harmonisation of practices and regulations related to food waste and bioenergy, and Nordic research and development programmes to promote new technologies matched to the Nordic conditions. As part of this, test labs can be a tool to share findings and innovations.[139]

5.3 Making an impact - the importance of knowledge and technology transfer

Regardless of how advanced the Nordic region becomes in terms of bioenergy, the potential to make a significant contribution to averting climate change will be unrealised unless the knowledge and technology is transferred to other parts of the world. The Nordic countries are collaborating to showcase solutions that achieve emissions savings and can be scaled up internationally; for example, the Nordic Energy Solutions projects administered by Nordic Energy Research.[140] Biomass is one focus as biofuels, bioliquids, and biomass fuels feedstock is globally available and often at relatively low cost.[141] As the field of bioenergy evolves in the Nordic region there is a need to also step up in terms of transferring the knowledge and technology outside of the Nordic region.

Policy recommendations with regards to collaboration with regions outside the Nordic countries:

- *Enhancing knowledge exchange and technology transfer between the Nordic region and other parts of the world.* Solutions include increased collaboration between researchers, policymakers, and industry actors from the Nordic region and other parts of the world. e.g. through joint projects and networks.[142]

6 Concluding remarks

The purpose of this policy brief to is to provide an analysis of the potential for sustainable use of biomass in the Nordic countries in relation to transport and heating, and to illustrate how the Nordic countries jointly can work to ensure that the biomass and biofuel used are sustainable.

Calculating an exact value for sustainable biomass in the Nordics in TWh, along with a clear recommendation of how to reach this volume and how to ensure compliance with the sustainability criteria will, however, require some further elaboration. The differing perspectives on what defines 'sustainable biomass' make it difficult to make definitive judgments on compliance, even if adopting the sustainability criteria outlined in the RED II, which are still under discussion as well as complicated. Nevertheless, five important points can be made:

1. **Joint Nordic efforts play an important role in increasing the use of sustainable bioenergy**
   Similarities in political ambition, ecological setting, economic and social structures offer a valuable context to increase Nordic collaboration on sustainable bioenergy. In addition to the gains in knowledge and technology development, a unified Nordic voice with regards to bioenergy increases the countries' collective weight in international forums.
2. **Sustainability is included in existing legislation encompassing Nordic biomass providers**
   Although under both discussion and development, sustainability measures are included in existing regulations on biomass production and constitutes an integrated part of the sector.
3. **The sustainability of Nordic biomass for heating and transport can be further improved**
   Sustainable bioenergy is a complex issue due to a range of goal conflicts and the challenges in defining and measuring sustainability. Increased system thinking could mitigate some goal conflicts and further work on how to develop, interpret, comply, and assess compliance with existing sustainability criteria could improve the sustainability of Nordic bioenergy.
4. **Measures need to be taken to support the development of sustainable bioenergy in the Nordics**
   Considering both the current engagement with sustainability which Nordic biomass providers show, and that ongoing work within this field likely will result in increased levels of sustainable biomass, it becomes interesting to discuss how to increase the levels of biomass in the Nordics in general.
5. **In order to mitigate climate change, Nordic efforts need to be exported to the rest of the world.**
   Regardless of how advanced the Nordic region becomes in terms of bioenergy, the potential to make a significant contribution to averting climate change will be unrealised unless the knowledge and technology is transferred to other parts of the world.

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