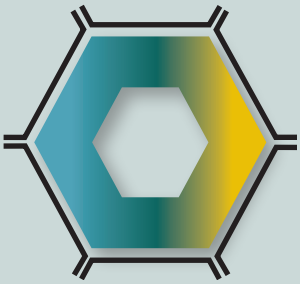
BIO ECONOMY PROGRAM

BIOENERGY

Knowledge transfer in the Nordic-Baltic region for increased uptake of sustainable bioenergy

This scoping paper is commissioned by the Nordic Council of Ministers and funded through the Bioeconomy Program.

SNS NK Nordic Energy Research



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Executive summary

The Nordic-Baltic region faces urgent challenges in reducing CO_2 emissions, requiring a joint effort towards sustainable energy solutions. Leveraging bioenergy solutions emerges as a key strategy to meet emission goals. It offers the potential to diminish reliance on fossil fuels across various sectors including heating, electricity generation, and transportation.

Commissioned by the Nordic Council of Ministers and supported through the Bioeconomy programme, this scoping paper delves into the intricate landscape of bioenergy innovations within the region. Employing a mixed-method approach combining desktop research and interviews, the study identifies opportunities for further knowledge transfer activities in the Nordic-Baltic region.

A technology neutral approach is vital for knowledge exchange activities as highlighted by experts included in the study. The interviews moreover led to the following observations:

- ✓ Current biomass challenges are directly linked to geopolitical conflicts
- ✓ Bioenergy has to rely on by-products, low value biomass, and waste
- ✓ Bioenergy innovations are required to be flexible
- ✓ Regional areas of excellence provide opportunity for knowledge sharing
- ✓ Nordic-Baltic strongholds lie in integrated systems of bioenergy solutions
- ✓ Nordic-Baltic experts would benefit from a cooperation platform and regional funding
- ✓ Universities are a useful meeting place for experts to build solutions for local contexts

The Nordic-Baltic region gathers a wealth of expertise and industry interest in biomass use for energy production. Additionally, the region showcases various integrated system solutions for bioenergy—knowledge that could be applicable to other areas lacking such comprehensive approaches. This context provides a fertile foundation for fostering regional knowledge exchange and facilitating the adoption of innovative practices. Yet, amidst geopolitical uncertainties and fluctuating markets, the need for adaptability and flexibility in bioenergy strategies becomes apparent. In response to these findings, a series of recommendations are proposed for further knowledge sharing activities:

- ✓ Facilitating industry and academy interactions via a Nordic-Baltic cooperation platform
- ✓ Supporting existing Networks active in the region
- ✓ Creating a Nordic- Baltic call to promote regional cooperation
- ✓ Identifying successful integrated local solutions for knowledge sharing
- ✓ Involving tomorrow's talents: Organisation of Nordic-Baltic hackathons

1 Reaching carbon neutrality in the Nordic-Baltic region

The Nordic-Baltic region has ambitious CO_2 emission reduction goals

The Nordic Vision 2030 reflects the Nordic objective of becoming the most sustainable and integrated region in the world by 2030. To achieve this target, three strategic areas have been prioritised; a green Nordic Region, a competitive Nordic Region, and a socially sustainable Nordic Region (see Figure 1).[1] The objective is further institutionalised by several important agreements and milestones. For instance, the Nordic countries adopted the Helsingfors declaration in 2019, concretising the goal of reducing greenhouse gas emissions (GHG)[2].

In the Baltic-Nordic roadmap for Co-operation on Clean Energy Technologies decarbonisation of industry is places as a main goal for the period 2030-2050[3]. Furthermore, in the Nordic Energy Ministers' Declaration of October 2023, the importance of freeing the region from its dependence on fossil fuels was stressed against the backdrop of the simultaneous climate- and geopolitical crises and their impact on energy imports and prices[4].

Figure 1 Our Vision 2030

The Nordic region will become the most sustainable and integrated region in the world

A competitive Nordic region
Together, we will promote green growth in the Nordic regionbased on knowledge, innovation, mobility and digital integration.

A green Nordic region
Together, we will promote a green transition of our societies and work towards carbon neutrality and a sustainable circular and bio-based economy.

A socially sustainable Nordic region
Together, we will promote an inclusive, equal and interconnected region with shared values and strengthened cultural exchange and welfare.

Source: Nordic Council of Ministers, 2021[5]

To reduce emissions regional cooperation is key

To reach the region's ambitious goal of reduced GHG emissions, cooperation is identified as a key element.

The Baltic-Nordic Roadmap for Co-operation on Clean Energy Technologies (CETs) highlights the importance of strengthening existing collaborative efforts.

It also recommends initiating new areas of collaboration and exploring the future potential of CETs in the regional context[6].

In addition, decision makers attending the Nordic Council of Ministers' High-Level Inspiration Conference on 28 September 2023 reiterated the key role of co-operation to reach the Nordic Vision 2030 goals[7].

Bioenergy for fuel and heating can support emission reductions

A potential area for collaboration to reduce GHG emissions in the Nordic-Baltic region is the production and usage of sustainable bioenergy for fuel and district heating. In the policy brief by Nordic Energy Research "Sustainable use of biomass for heating and transport fuel" published in 2020, several recommendations are presented to decrease the use of fossil fuels in favour of biofuels. Amongst others, it was recommended to deepen current efforts on knowledge and technology transfer between researchers, policymakers, and industry actors within the region[8].

The sustainability of bioenergy is a debated area

Bioenergy is an important topic in the Nordic-Baltic region due to its potential in reducing in GHG emissions by replacing fossil fuels. The sustainability of bioenergy use remains however a debated area and potential negative impacts need to be addressed. The use of biomass for energy production can put a strain on other sectors also requiring biomass. An increase in demand for biomass for bioenergy production might create market instabilities and momentarily increase prices or induce shortages. These disturbances can negatively impact biomass reliant sectors such as the agricultural sector, food industry and construction sector. Moreover, biomass extraction might have a detrimental impact on local ecosystems and their biodiversity. Finally, some biomass sources such as crops residues and branches from harvested wood are playing a crucial role in maintaining soil quality, their harvesting can consequently have a negative impact on soils. Biomass extraction therefore requires adequate control measures to prevent reduced soil quality and threats to biodiversity[9] [10].

The EU Taxonomy perspective on bioenergy

The EU taxonomy provides companies, investors and policymakers with definitions for which economic activities can be considered sustainable. The taxonomy has six environmental objectives with specific technical screening criteria (TSC). Climate change mitigation and climate change adaption are the only two TSC that have been implemented to date. An activity needs to fulfil a defined set of sub-criteria ("substantial contribution criteria") for each TSC to be aligned with the taxonomy. A substantial contribution criterion determines whether the activity has a positive impact on climate change mitigation/adaptation[11].

Bioenergy is covered by the taxonomy through five different activities; Electricity generation from bioenergy, Cogeneration of heat/cool and power from bioenergy, Production of heat/cool from bioenergy, Manufacture of biogas and biofuels for use in transport and of bioliquids, and District heating/cooling distribution.

The substantial contribution criterions related to climate mitigation for all five activities except district heating/cooling distribution include:

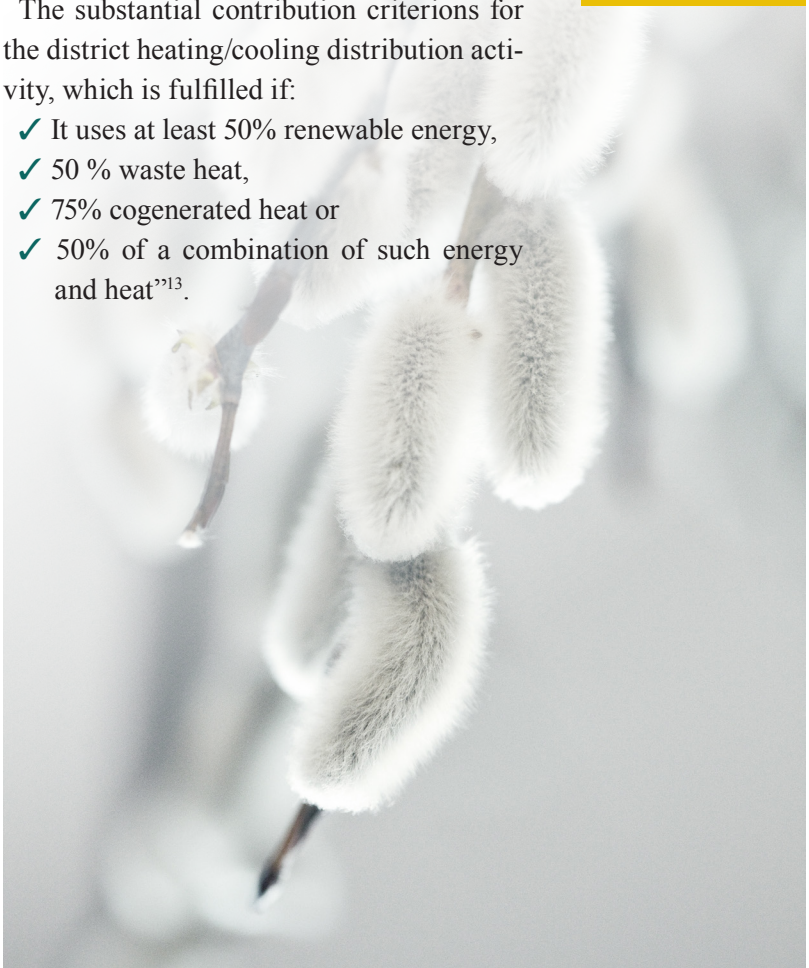
- ✓ Using agricultural and/or forest biomass,
- ✓ GHG emission savings of 80% compared to a fossil fuel alternative
- ✓ Efficiency requirements on production of anaerobic digestion of organic materials and thermal input[12].

The substantial contribution criterions for the district heating/cooling distribution activity, which is fulfilled if:

- ✓ It uses at least 50% renewable energy,
- ✓ 50 % waste heat,
- ✓ 75% cogenerated heat or
- ✓ 50% of a combination of such energy and heat"[13].

Summary

The Nordic-Baltic region has ambitious CO_2 emission reduction goals. To reach these goals, increased regional cooperation is necessary and bioenergy for fuel and heating may play a vital role due to its potential to reduce reliance on fossil fuels and hence curb overall GHG emissions.



2 Biomass for energy production

Biomass has multiple use cases for heating and electricity generation

The use of biomass for energy production and heating purposes is widely spread across the Nordic-Baltic countries, which makes the region a front runner in bioenergy use in the EU. Municipalities play an important role for the region's energy production and consumption, with developed systems for district heating in which biomass is commonly used. Sweden and Finland primarily use biomass produced in their respective territories, while Denmark imports a large share of its biomass and utilises almost all domestic non-recycled waste for energy production. Differentiating itself from other Nordic countries, Iceland mainly relies on its considerable geothermal resources[14] [15].

In the Baltic countries biomass plays a major role in the energy production and its contribution to the overall energy mix is growing. In Latvia a steady growth rate of biomass and renewables-based energy production helped significantly reduce its dependency on imported energy resources from 64% in 2005 to 36% in 2022[16] [17]. In Estonia 50% of the countries heat production is created from biomass and more than 20% of the country's energy production is based on biomass[18]. In Lithuania biomass contributes to a total of 75% of the country's heat production and around two-thirds of its domestic energy production.[19]

Biomass offers different solutions for transport fuel

The transportation sector can benefit from using biomass to reduce its carbon footprint. Today, transportation remains heavily reliant on fossil fuels and was responsible for

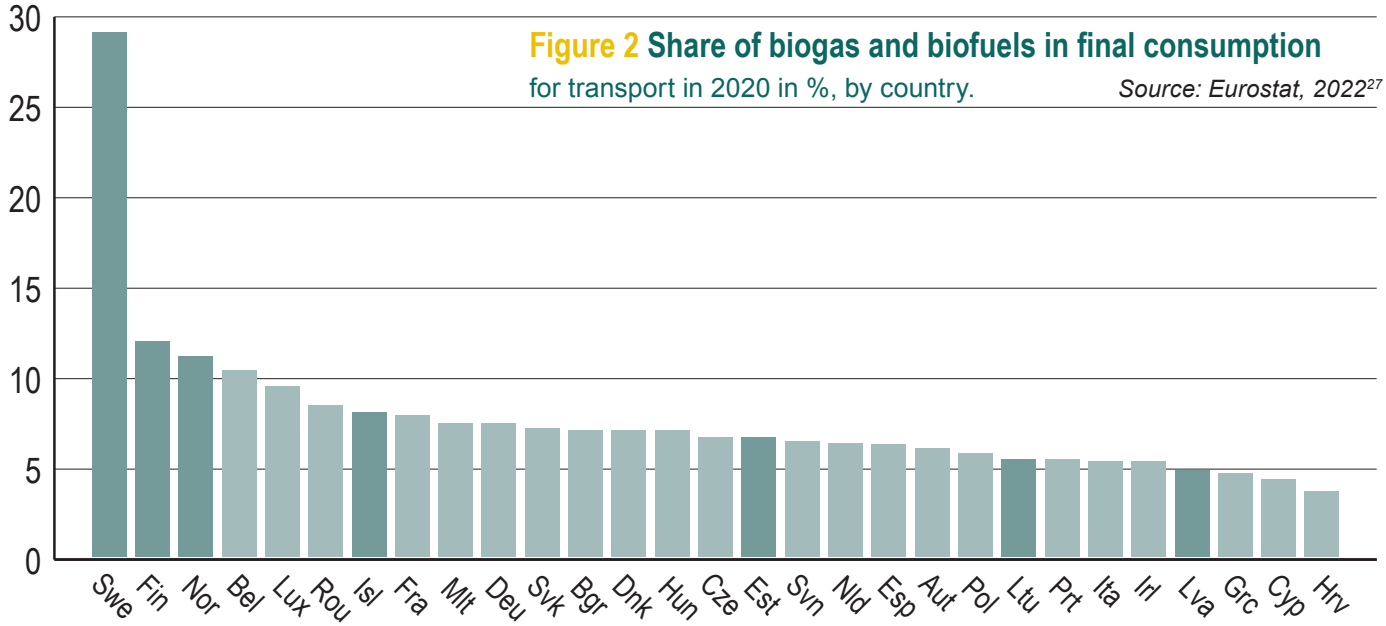


Figure 2 Share of biogas and biofuels in final consumption
for transport in 2020 in %, by country. *Source: Eurostat, 2022*[27]

Biofuels and their production processes

Four main types of biofuels are currently available as alternatives to fossil fuels: biodiesel, biogas, ethanol, and synthetic fuels. Liquid biofuels aren't feedstock agnostic, meaning that different types of biofuels can be created, depending on the type of biomass used as input. They are produced with the following processes[25] [26]:

✓ Biodiesel: created from oils and fats from animal or vegetal sources such as vegetable oil, it is transformed via various chemical transformation processes.

✓ Biogas: created from wastes of organic or animal sources such as sewage sludge, household waste or agricultural waste, it is transformed via digestion processes.

✓ Ethanol: created from crops with high starch or sugar content such as grains, corn, sugar beets, it is transformed via fermentation processes.

✓ Synthetic fuels: created from cellulosic materials deriving from wood and plants, it is transformed via gasification processes.

22% of total CO_2 global emissions in 2022[20]. While CO_2 emissions reduced significantly in 2020 due to the COVID-19 pandemic, the return to normalised transport activities in 2021 resulted in a continuation of the growth trend of CO_2 emissions[21] [22]. Alternative fuel solutions are required and must be adapted to the unique needs of the different types of transport they target. For instance, heavy land vehicles, light land vehicles and aircrafts require different solutions tailored to their technical specificities. Biofuels are considered a prime substitute for fossil fuel, especially for aviation, marine freight, and heavy-duty road transports for which electrification solutions are not yet fully developed[23] [24]. For example, bioethanol and biodiesel, replacing petrol and diesel respectively, are the two most common biofuels in the transportation sector.

The share of biofuels in the transportation sector differs between the Nordic countries (Figure 2).

Sweden has the largest share of biofuels used as fuel source for transportation in the EU (29%), followed by Finland (11,9%) and Nor-

way (11,1%). Iceland (8,0%), Denmark (7,0%), and the Baltics with Estonia (6,6%), Lithuania (5,4%) and Latvia (4,8%) are behind their Nordic partners Sweden, Norway and Finland in terms of biomass fuels in transportation.

Various biomass options are available for land vehicles

Road transports are currently responsible for 15% of total CO_2 global emissions[28]. The transport sector's demand for renewable energy has increased considerably and the main solution adopted is blend-in fuels (biofuels mixed into gasoline or diesel).

Alternative options such as biodiesel and biogas are also increasingly gaining importance. For instance, biodiesel has recently grown in use for heavier land vehicles such as buses and goods vehicles. Alternatives for other land vehicles requiring significant power, such as machinery used in forestry, construction, and agriculture also include alcohol derived from biomass. For lighter land vehicles, such as light and mid-duty goods vehicles and short distance passenger vehicles, electricity and hydrogen solutions are considered the most suitable for replacing fossil fuels.

Biomass offers multiple solutions for aviation traffic

The aviation sector accounts for 2,5% of total CO_2 global emissions[29]. It is one of the fastest growing transportation sectors and if not addressed its emissions are expected to grow and account for 22% of total CO_2 global emissions by 2050. Sustainable Aviation Fuels (SAFs) are considered the main mitigation solution to the growing CO_2 emissions of the sector as electrification of planes is not a foreseeable solution on the short or medium term[30].

Despite their recognised importance, SAFs currently represent only 0,1% of the sector's fuel demand. Amongst others, SAFs prices are a deterrent for the demand, as they tend to be 2 to 5 times more costly than traditional jet fuels[31].

Biomass fuels' potential must be further investigated, and many hurdles have yet to be cleared, for a wider adoption to occur. Commercial supply chains must be implemented for SAFs to allow a reliable flow of high-performance fuel supply. Policy incentives could also be a solution to support financing and adoption of SAFs[32 33].

The maritime sector can adopt different biomass solutions

The maritime sector constitutes the backbone of goods transportation. Every year, up to 70% of the global trade in terms of value is shipped through maritime transports and the sector accounts for 3% of total CO_2 global emissions. The International Maritime Organization (IMO) is actively addressing the sector's emissions and has pledged to reduce them by 50% from their 2008 levels for the year 2050[34]. The maritime sector is flexible and can adopt various solutions due to the technical characteristics of vessels' engines, for instance, existing biofuels can already be blended and used in traditional vessels' tanks. Electrification is already available for shorter distance; however, the current battery technology and storage capacity is not suited for longer transoceanic maritime freight.

Summary

Heating, electricity generation, and transports are responsible for considerable GHG emissions, in particular the transport sector which is accountable for 22% of total CO_2 global emissions in 2022. Biomass for heating and transport fuel represents a solution to decrease these emissions. Different bioenergy solutions are however necessary depending on the sector and use case.

3 Knowledge sharing for increased uptake of bioenergy

Over the years, the Nordic Council of Ministers have issued several activities related to bioenergy. Nordic Energy Research, Nordic Forest Research and Nordic Agri Research have produced several reports and leaflets on the topic and have also been engaged in Nordic seminars discussing how to define and ensure a sustainable production of bioenergy (Table 1).

This scoping paper was commissioned by the Nordic Council of Ministers and funded through the Bioeconomy programme. The aim with the paper is to act upon one of the recommendations presented in the report ”Sustainable use of biomass for heating and transport fuel” from 2020, namely:

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[36].

Consequently, the aim of this project is to identify bioenergy bioenergy innovations relevant for further knowledge transfer efforts within the Nordic-Baltic region. In addition, this scoping paper include recommendations on knowledge sharing activities in the Nordic-Baltic region to support the development of relevant innovations and implementations.

Table 1: Selections of Nordic deliverables on Bioenergy

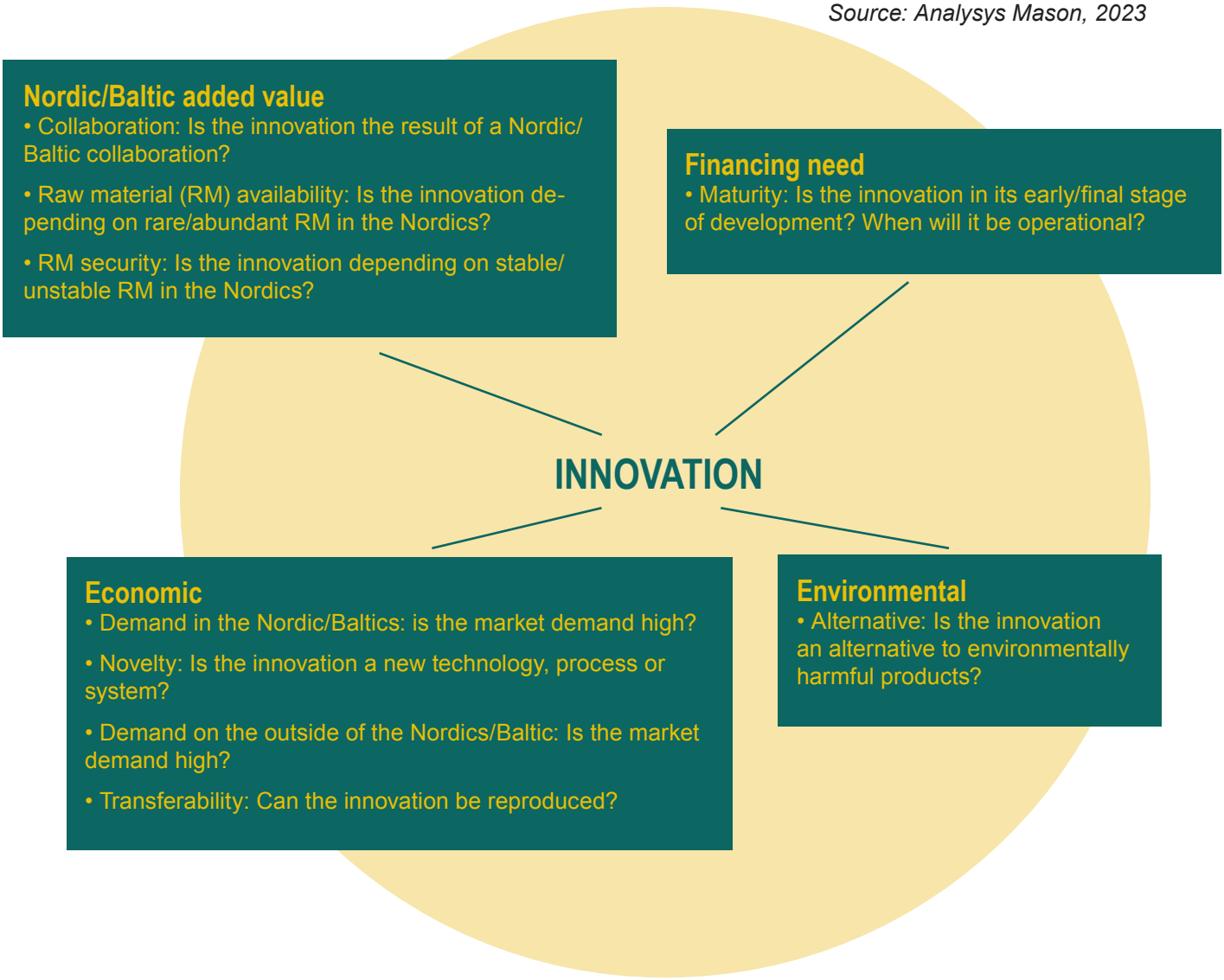
Leaflets	Seminars	Reports
• Bioenergy in the Nordics • Food waste to biofuels • Sustainable jet fuel	•Biofuel strategy for the coming decade – The Nordic region at the forefront of technology and sustainability *Gothemburg 6 nov 2019* • Sistanable biomass in the Nordics – How should we farm the ocean? *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 2 Nov 2019*	• Sustainable use of biomass for heating and transport fuel

3.2. Multi method approach for data analysis

To manage the wide range of countries and biomass sources covered by the scope of this assignment, a multi-method approach was used. It included a systematic desktop research and document analysis, enabling an overview of the topic, as well as semi-structured interviews with bioenergy experts to identify and prioritise areas relevant to focus on in the Nordic-Baltic context. The multi-method approach resulted in a mapping of bioenergy related innovations, a set of criteria to prioritise among the identified innovations, a list of organisations and experts relevant to invite to knowledge sharing activities, and finally a set of recommendations for further knowledge sharing in the Nordic-Baltic region.

Figure 3: Multiple Criteria Analysis framework

Source: Analysys Mason, 2023



3.2.1 Desktop research for the mapping of bioenergy innovations

The initial mapping of relevant innovations was based on a systematic desktop research carried out in September 2023. The search was made via the Google search engine and covered the Nordic-Baltic region for the period 2020-2023. The timespan was chosen to focus on innovations implemented since the publication of NEF's report "Sustainable use of biomass for heating and transport fuel" in 2020. The keywords used were derived from the previous report to cover the subject area and include all the areas of interest (biomass for heating and electricity, biofuel for watercrafts, aircraft, and land vehicles). The search included eight countries and was made in Danish, Estonian, Finnish, Icelandic, Latvian, Lithuanian, Norwegian, and Swedish. An additional snowball research was conducted as a complement to the systematic research. It started from local institutions' – and universities' webpages and databases, exploring various project pages

to identify additional relevant innovations. To ensure consistency, the snowball research followed the same set of screening criteria as the systematic research. Although extensive, the mapping should not be seen as all encompassing, but rather providing an overview of innovations of relevance for future knowledge sharing activities.

3.2.2 Criteria for prioritising bioenergy innovations

At the outset of the project the ambition was to prioritise among innovations identified in the desktop research and focus knowledge sharing activities on prioritised innovations. To enable this prioritisation, a set of criteria was developed. The criteria were informed by the multiple criteria analysis (MCA) framework developed by UNEP Copenhagen Climate Centre. In addition to this framework, inspiration was taken from previous work assessing technologies for climate change adaptation[37]. The set of criteria covered items such as economic value, environmental value, institutional/implementation barrier, financing needs, and Nordic-Baltic added value (Figure 3).

3.2.3 Semi-structured interviews with bioenergy experts

A total of 19 respondents representing private companies, research institutions, interest organisations and universities in the Nordic-Baltic region were interviewed (Table 2). A total of 19 respondents representing private companies, research institutions, interest organisations and universities in the Nordic-Baltic region were interviewed. The interviews served to validate and extend the list of innovations derived from the desktop research. In addition, local strongholds with regards to bioenergy were discussed and with regards to bioenergy were discussed and the respondents provided useful input on essential aspects of bioenergy development and insights on useful knowledge sharing activities for experts in the field. The interviews were of a semi-structured format with a set of predefined questions in combination with the possibility for the respondent to elaborate on topics adjacent to the questions.

Table 2: Organisations interviewed per country

Source: Analysys Mason, 2023

	Aarhus University, Organic Fuel Technology A/S
	The Faroese Environment Agency
	VTT Technical Research Centre of Finland, Bioenergy Association of Finland, Lapperenranta -Lahti University of Technology (LUT)
	Icelandic Centre for Research (RANNIS)*
	Estonian Biomass Association
	Latvian Biomass Association (LATbio)
	Centre for Physical Science and Technology, Lithuanian Energy Institute*, Litbioma
	Ergon Nordic, The Norwegian Institute of Bioeconomy Research (NIBIO)
	Chalmers University of Technology, Phoenix BioPower, SveBio, Bioenergy Innovation

Summary

This scoping paper was commissioned by the Nordic Council of Ministers and funded through the Bioeconomy programme. The aim of the project is to identify bioenergy innovations relevant for further knowledge transfer efforts within the Nordic- Baltic region and suggest activities enabling increased knowledge sharing. In addition, this scoping paper include recommendations. A mixed method approach was adopted combining desktop research with, a multiple criteria analysis, and interviews.

4. Bioenergy innovations in the Nordic-Baltic region

4.1 High-level overview of bioenergy innovations in the region

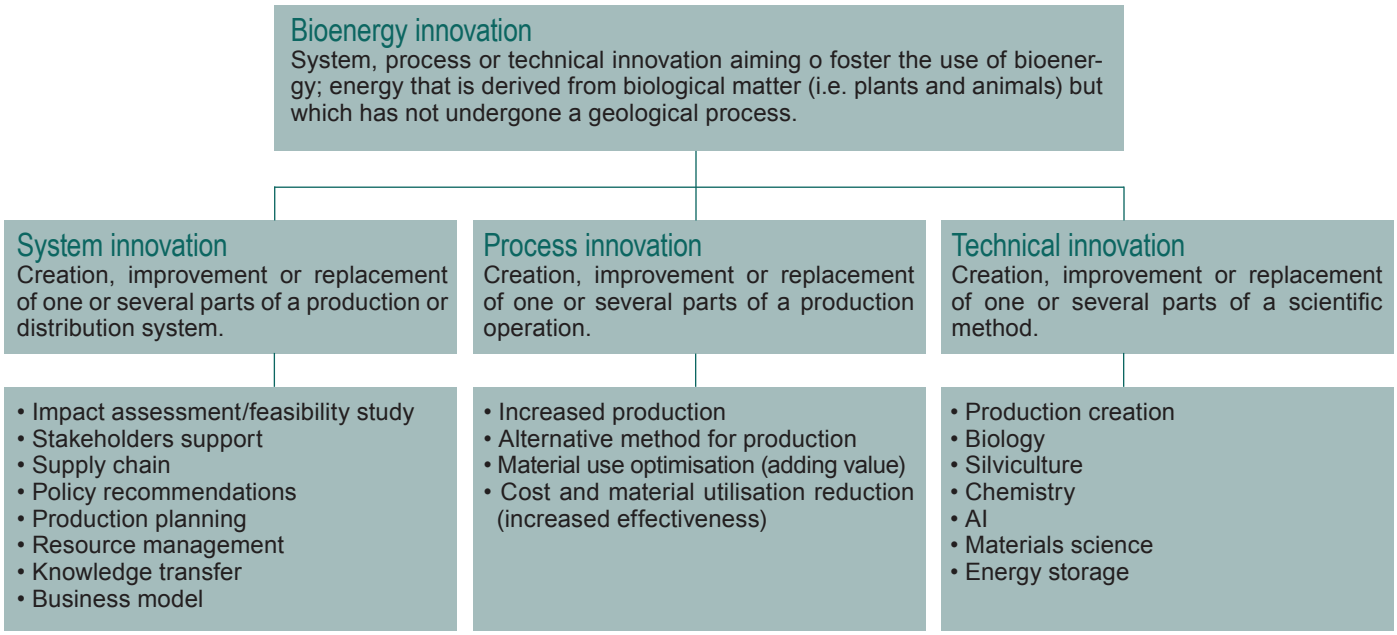
The desktop research conducted in September 2023 resulted in a list of 53 innovations. These innovations range from production planning models to material development (see a full list in annex) and encompass different types of innovations.

While the list is not comprehensive it provides an overview of most of the relevant current bioenergy innovations in the Nordic-Baltic region. In this paper inspiration is taken from innovation theories providing a framework for categorising the innovation types (Figure 4)[38]. The framework distinguishes between system innovations as innovations focused on distribution systems, process innovations as innovation focused on production operations, and technical innovations as innovations focused on scientific method.

The innovations are split between the Nordics and Baltics countries (Figure 5). The list however gathers more examples from Sweden and Denmark with 25 and 15 innovations respectively. This gap might be explained by the availability of biomass in these countries alongside the lack of fossil fuel resources and lesser imports of biogas.

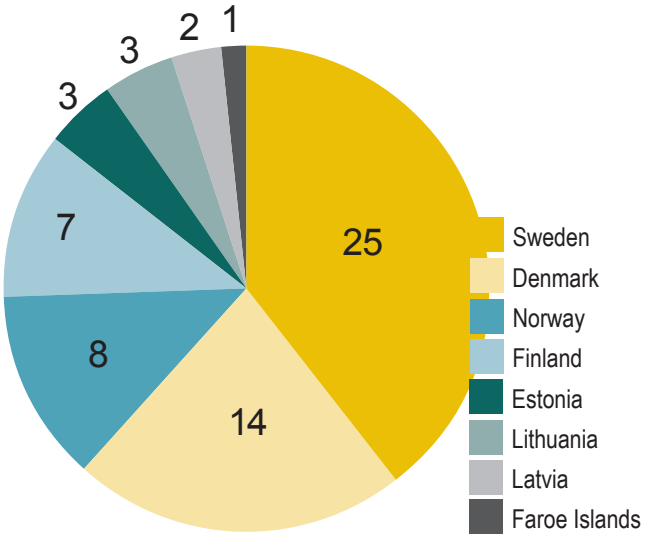
The type of biomass used for the different innovations varies (Figure 6). Most common is biomass from forestry with 15 innovations, waste is specified in 12 of the innovations,

Figure 4: Framework categorising the innovation types



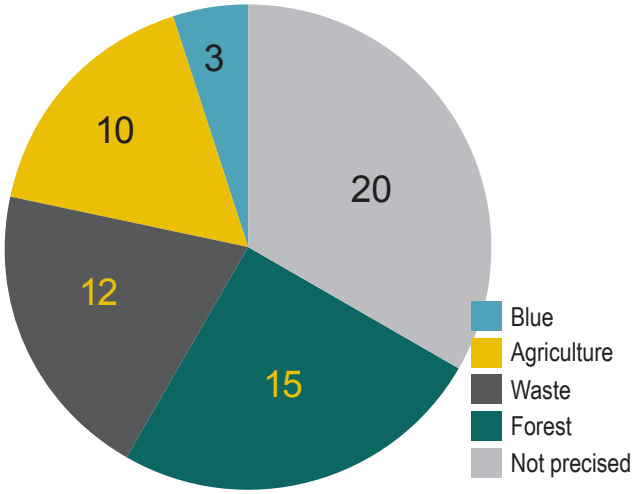
Source: Analysys Mason, 2023

Figure 5: Number of projects by country*



Source: Analysys Mason, 2023
Note: One project can involve several countries.

Figure 6: Source of biomass*



Source: Analysys Mason, 2023
*Note: One project can involve several sources of biomass.

agricultural biomass for ten innovations and blue biomass in three. For a majority of the innovations however, the source of biomass was not specified.

The majority of innovations listed (23) are targeting biomass fuels, it is followed by 15 innovations not targeting a specific area of application and a minority in the sample is divided between projects working with bioliquids for heating and/ or electricity, biofuels for aircraft, watercraft, or land vehicles (Figure 7).

4.2 Expert input on bioenergy innovations in the region

Interviews were held from September to December 2023. The following sections details results of the conversations led with respondents.

4.2.1 Challenges affecting the Nordic-Baltic bioenergy sector

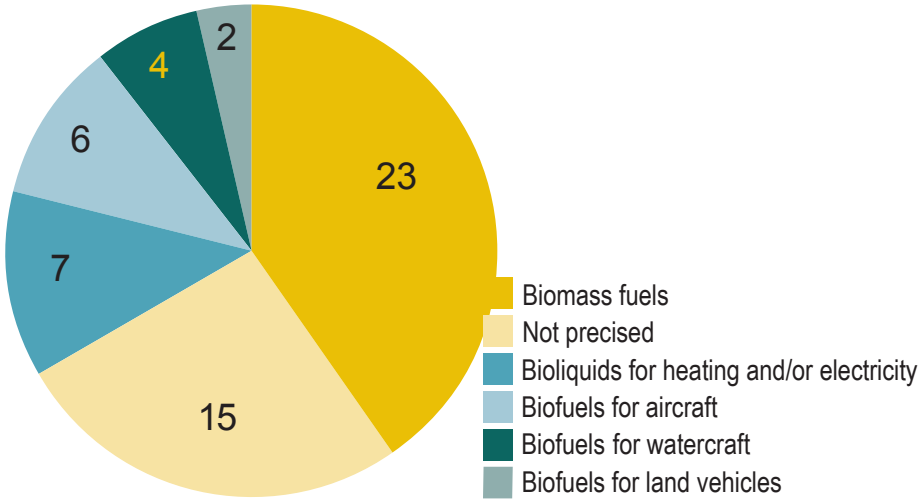
Current biomass challenges are directly linked to geopolitical conflicts

The development of biofuels is heavily impacted by the current geopolitical climate in Europe.

Respondents emphasized the effects of Russia's invasion of Ukraine on security of supply, through both the supply of imported energy and the supply of imported biomass. The war has impacted stock levels, prices of energy and raw material.

This constrain on biomass availability creates competition between different biomass-dependent sectors. Affordability and access to bioenergy for individual consumers and companies is therefore currently a challenge.

Figure 7: Area of application



Source: Analysys Mason, 2023
*Note: One project can involve several areas of application.

Bioenergy has to rely on by-products, low value biomass, and waste

Improved energy efficiency, coupled by flexible production and consumption, will be necessary to support a secure and well-functioning energy market. In this context, an increased focus on only using by-products and waste for bioenergy is of the utmost importance as it will avoid unnecessary competition between sectors. Respondents stressed the importance of targeting the use of lower value biomass products such as waste from biomass-based industries and raw material of low economic value to avoid competition with other uses of biomass such as food items, building materials, furniture items.

Bioenergy innovations are required to be flexible

Biological diversity within the biomass field poses a challenge to the production of sustainable bioenergy. When discussing biomass for bioenergy with respondents, a key term guided all conversations, namely flexibility. Biomass as energy source entails a considerable challenge since the feedstock evolves constantly as seasons go by. For instance, wood harvested in the same area will have different humidity properties if harvested with or without leaves, and after heavy rains or a period of drought. In practice it means that innovations have to be flexible with regards to the biomass sources they target. Preferably, flexibility should also apply to the outputs produced and their specific use cases. To reach higher adoption levels for biofuels, it is necessary to allow users to gradually switch between fossil fuels and their bio alternatives. Moreover, in case of shortage or distribution disruptions, it is beneficial if users can switch between biofuels and traditional fuels.

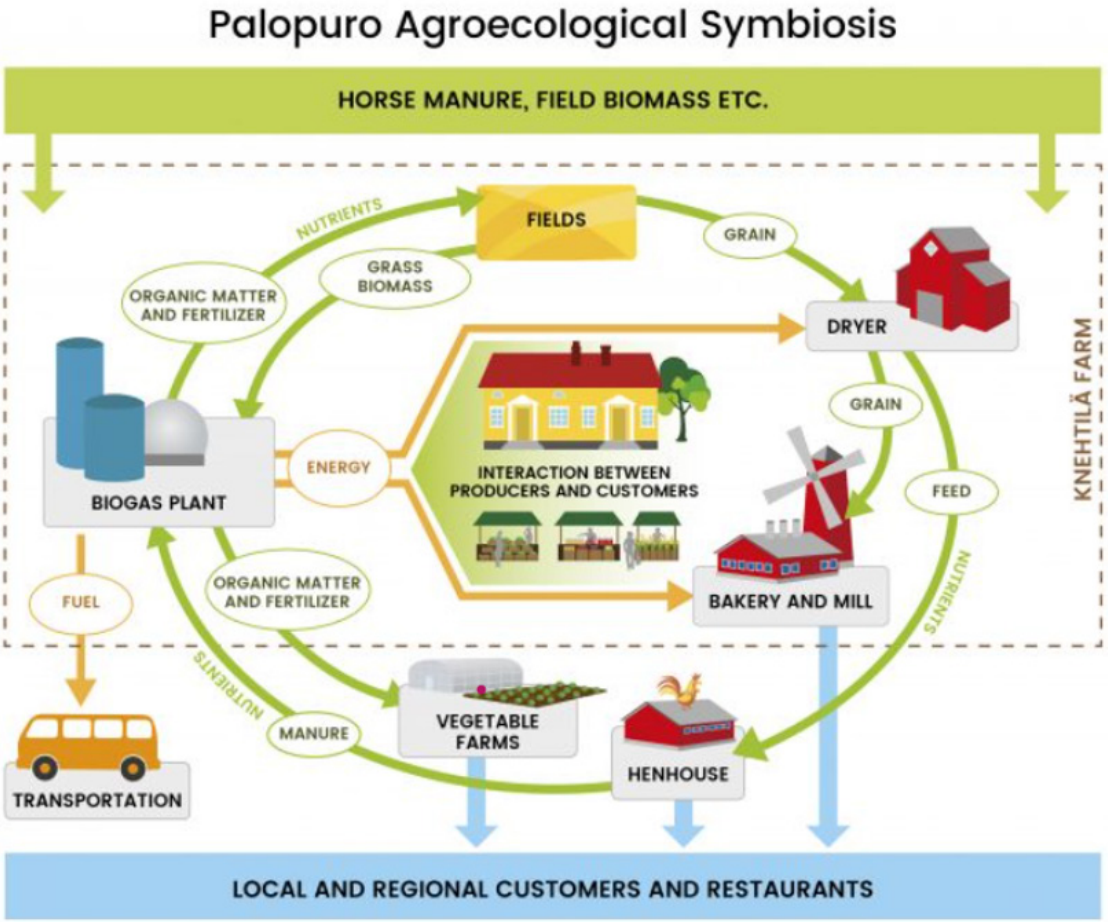
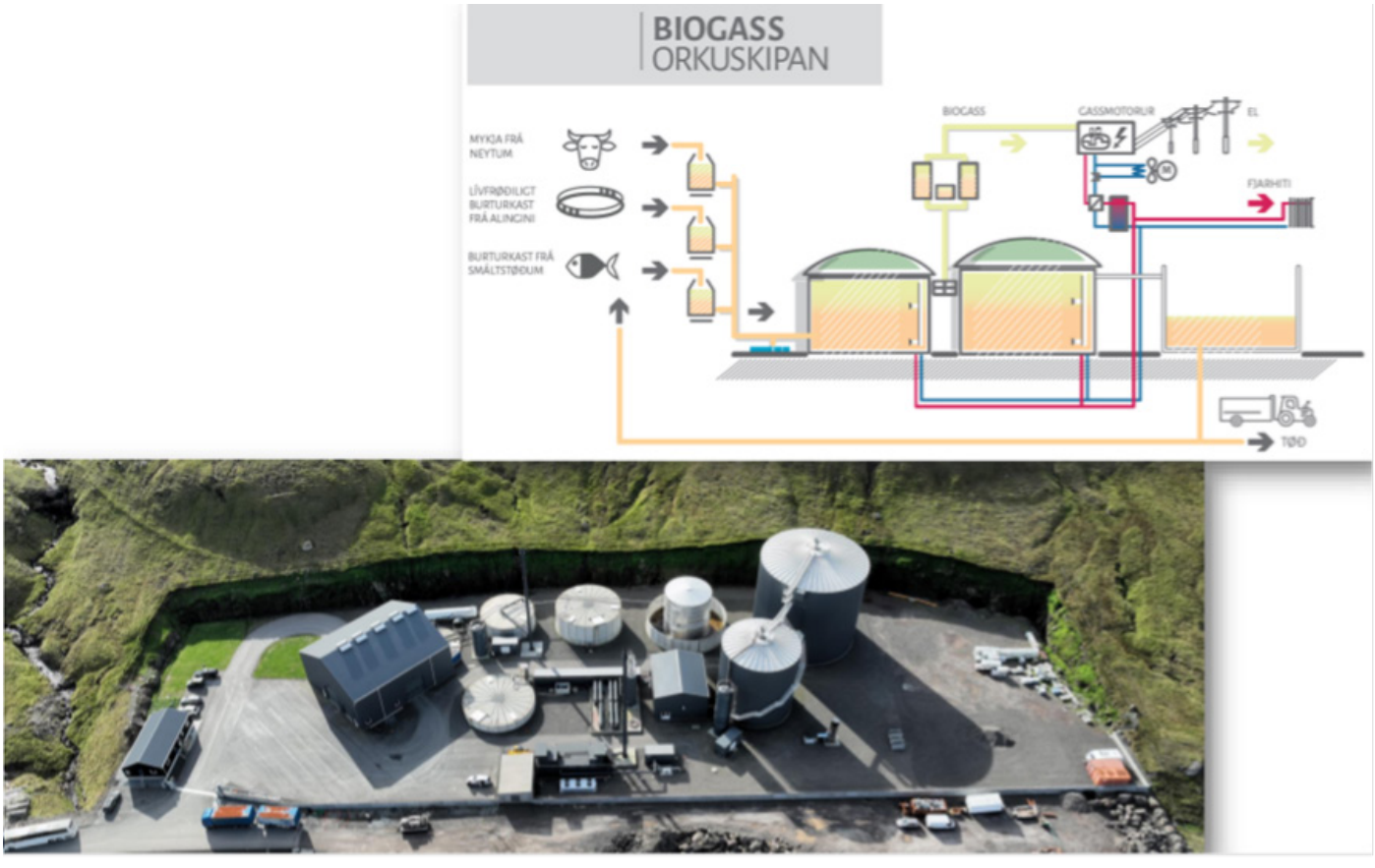


Figure 8: Examples of integrated solutions for Bioenergy in the Nordic-Baltic region

Source: Analysys Mason, 2023



Integrated solutions examples from Top to bottom: Palopuro Agroecological Symbiosis in Finland[39], Bakkafrost Førka refinery in the Faroe Islands[40], Liquid Wind FlagshipONE in Sweden[41].

4.2.2 Local strongholds can support the creation of solutions tailored to local contexts

Regional areas of excellence provide opportunity for knowledge sharing

Throughout the interviews, many respondents addressed the importance of identifying local strongholds in the Nordic-Baltic countries. The region gathers a considerable concentration of knowledge and cutting-edge research. For instance, pyrolysis was identified as an area of excellence in countries with a long forestry history, while the use of agricultural biomass has developed further in countries with a smaller forestry sector, such as Denmark and the Faroe Islands. Creating synergies between various existing areas of expertise is considered an efficient way to continue creating Nordic added value.

Nordic-Baltic strongholds lie in integrated systems of bioenergy solutions

The societal development towards a local circular economy with integrated solutions appeared as a central element when identifying strengths in the region. Respondents

observed a Nordic-Baltic stronghold with regards to integrated energy system developments. Various examples of powerplants integrating biomass byproducts, using excess heat for district heating, and producing additional outputs such as fertilisers provided a clear message: the region has an advantage when developing locally integrated solutions. The region gathers important sources of knowledge and skills when it comes to locally integrated solutions (see Figure 8). Many refineries and biorefineries could however be improved through the addition of locally sourced inputs and through finding use cases for the outputs and by-products created. Sharing information on types of integrated solutions for powerplants and refineries, as well as emerging technical solutions for integration of additional input/output flows would therefore be highly relevant.

4.2.3 Establishing fruitful cooperation within the bioenergy field

Nordic-Baltic experts would benefit from a cooperation platform and regional funding.

Researchers and industry experts expressed interest in participating in knowledge sharing activities. Respondents mentioned the importance of embracing a holistic Nordic-Baltic approach to knowledge sharing activities. A platform allowing Nordic-Baltic research and industry to meet would be beneficial to create a broad vision of the regional bioenergy development. It would also foster discussions and workshops on more targeted bioenergy challenges. For instance, such platform could be developed following the model of Trees For Me[42], a centre of excellence dedicated to knowledge exchange and development on fast-growing broadleaf trees for sustainable forestry, materials and energy in Sweden. It was highlighted that a structure organising meetings and documenting discussion would contribute greatly to federalising currently fragmented conversations. Additionally, it would help addressing the challenge of limited time resources allocated to knowledge sharing.

Respondents also manifested a need for Nordic and Baltic dedicated funding. Grounded in regional similarities and the desire to increase collaboration, a regional and reoccurring bioenergy call would support the development of common projects and activities.

Universities are a useful meeting place for experts to build solutions for local contexts

Bioenergy solutions involve many stakeholders from different sectors and industries. The solutions are complex and highly dependent on the local contexts in which they evolve. For instance, utility companies generating bioenergy often operate on a local, municipal, or at the most regional level. This is largely because the biomass required to

generate bioenergy or heat is often sourced from local waste, agricultural production, or forestry sector.

Interviewees emphasized the importance of integrating the contributions of various local entities in bioenergy solutions. These include local government institutions, which oversee and establish regulatory frameworks; utility companies responsible for maintaining the local network infrastructure for district heating and (bio-)gas; and industry experts and researchers, bringing expertise and knowledge from industry and academy. The diversity of these different input sources is deemed essential to guarantee the incorporation of all local nuances and resources into the innovation process.

Universities were suggested as an ideal meeting space for industry, public stakeholders, and local expert knowledge to collaboratively foster the bioenergy innovation. Among other activities, events organized by universities similar in format to hackathons, were viewed as potential opportunities for such collaborations. Moreover, they were deemed an efficient media to involve local students to participate in the development of innovative solutions.

Summary

Bioenergy entails a broad set of innovations evolving in a tumultuous geopolitical context with volatile and discontinued markets. The Nordic Baltic region gathers high levels of skills and expertise as well as significant industry interest in the use of biomass for energy production. Moreover, various examples of integrated system solutions for bioenergy are identified throughout the region, a knowledge which could be transferable to areas lacking integrated solutions. This context creates a fruitful base to build further regional knowledge exchange and expand the uptake of innovations.

5. Concluding remarks

Bioenergy can help reduce emissions, it however requires to be flexible and adaptative

The Nordic-Baltic countries have ambitious goals regarding carbon neutrality. Increasing the use of bioenergy for transportation and heating is one solution to decrease the reliance on fossil fuels and hence GHG emissions. The development of bioenergy in the Nordic-Baltic region is however considerably influenced by the current geopolitical issues in Europe. Amongst others, present challenges regard resource security, halt on imports of raw material from Russia, and price fluctuations. In this context an increased focus on flexibility and adaptability becomes necessary.

A technology neutral approach is recommended for knowledge exchange activities on bioenergy

Respondents who participated in this projects' interviews emphasised technology neutrality as a core element of further knowledge sharing efforts in the region. For this reason, it is recommended to halt the innovation ranking through Multiple Criteria Analysis presented in the section 3.2.2 and instead adopt a technology neutral approach for recommendations on knowledge sharing activities.

Bioenergy relies on a complex human and technological ecosystem. Multiple actors are involved in the process of using biomass for fuel and electricity. These actors include district heating providers, private and public transportation, individual consumers, municipalities, and companies. Moreover, the different subfields within the bioenergy sphere require specific technologies sometimes not applicable to other fields. For instance, technologies crucial for liquid biofuels for aircrafts might not be applicable to excess heat conversion in district heating systems. Well-functioning systems adapted to different technologies are of great importance. They allow flexibility and adaptivity while preventing power disruptions. Various technologies are essential to different areas of the value chain, it is therefore recommended to embrace technology neutrality for knowledge exchange activities in the Nordic-Baltic region.

Liquid biofuels and bio-oils are identified as a fragmented area within bioenergy research

In general, choosing one technology to focus on at the detriment of others could have negative effects on the development and use of bioenergy. Still, some areas are more critical and in greater need of targeted efforts than others. A pattern emerged regarding certain technologies which could benefit from an increased degree of research harmonisation and collaboration in their development, namely liquid biofuels. The field of liquid biofuels and bio-oils is more fragmented than other biomass-related innovations. Considerable challenges must be tackled to allow a wider adoption of these solutions. Amongst others, the last steps of bio-oil production require further improvements. The conversion of bio crude-oil into biofuel with quality standards suitable for aviation and road transport is a specific topic which could benefit from heightened cooperation.

5.1 Recommendations for future knowledge sharing activities

Based on the findings presented in this scoping paper five recommendations for future knowledge sharing activities are put forward.

5.1.1 Facilitating industry and academy interactions via a Nordic-Baltic cooperation platform

Future efforts to develop and share knowledge need to embrace a holistic Nordic-Baltic approach, making sure to involve stakeholders throughout the region. Experts from the region would benefit from a platform to meet, gain access to a wide insight the bioenergy field, and cooperate.

Recommendation: Create a Nordic-Baltic cooperation platform on bioenergy

This cooperation platform could for example entail:

- ✓ Organisation of a general yearly meeting to share knowledge
- ✓ Organisation of targeted workshops based on yearly meeting discussions
- ✓ Redaction and dissemination of workshops and meetings results

5.1.2 Supporting existing Networks active in the region

Each country of the Nordic-Baltic region has a bioenergy association with a bespoke network and sets of yearly meetings. Moreover, existing networks and yearly conference already gather experts to share knowledge on certain aspects of bioenergy. For instance, the Nordic Biochar Network[43] gathers members from the Nordic countries, organises and promotes events related to biochar. Similarly, from 2016 to 2022 the Nordic Baltic Energy Conference[44] provided energy experts with a forum to meet and exchange knowledge. Identifying these initiatives and supporting them through the suggested Nordic Baltic cooperation platform would support knowledge exchange and federalisation of research and innovation in the region.

Recommendation: Identification of existing regional networks and initiatives

This could include the following activities:

- ✓ Support provided through the Nordic Baltic platform by dissemination of information
- ✓ Inclusion of existing networks and entities in the platform's workshops and meetings

5.1.3 Creating a Nordic- Baltic call to promote regional cooperation

The countries of the Nordic-Baltic region share various similar features and aim to address the same carbon challenges. In recent years, Nordforsk has opened various calls on bioenergy related topics. The increase of such calls and the creation of a Nordic-Baltic programme for bioenergy research and funding would benefit the regional research environment through encouraging collaboration tailored to the Nordic-Baltic context.

Recommendation: Creation of a Nordic-Baltic research program on bioenergy

This could include the following activities:

- ✓ Design of a regional research program
- ✓ Creation of calls on topics via the cooperation platform
- ✓ Presentation of research results via the cooperation platform

5.1.4 Identifying successful integrated local solutions for knowledge sharing

There are already several examples of integrated systems of bioenergy solutions in the Nordic-Baltic region. Knowledge throughout the region of these integrated local bioenergy systems is however limited, which creates an opportunity for increased and structured knowledge sharing.

Recommendation: Identification of existing integrated local solutions in the Nordic-Baltic region

This could include the following activities:

- ✓ Creation of a media to share the knowledge gathered
- ✓ Presentation of the solutions via the cooperation platform

5.1.5 Involving tomorrow's talents: Organisation of Nordic-Baltic hackathons

Universities are a crucial element of local ecosystems, they gather knowledge and expertise and have the potential to gather local decision-makers, industry experts, and students. These fora can be crucial environments to develop innovative solution to the energy systems of the area the host universities are located in. A suggested activity to reap the benefits of universities fora are hackathons. They give the opportunity to develop solutions in a shorter time frame and allow to involve students.

Recommendation: Organisation of a Nordic-Baltic hackathon roadshow

This could include the following activities:

- ✓ Communication with universities and regions interested in participating in hackathons
- ✓ Presentation of examples of existing integrated bioenergy solutions
- ✓ Selection of local sites to use as development subjects for each hackathon
- ✓ Organisation of local hackathons

Defining core terms

Biomass source

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”[45] [46].

Waste biomass: organic residual products coming from the materials used for food transformation and production, wastewater sludge from treated industrial or human waste, and waste from gardens and parks maintenance. Waste can also contain other elements such as manure or forestry residue in minor quantities[47] [48].

Forest biomass: raw material coming from the forestry industry such as wood, harvest residues (sawdust, stumps, bark), and sludge from pulp and paper industry[49].

Agriculture biomass: raw material coming from the agriculture industry such as energy crops, grass, manure, and straw and husk[50].

Blue biomass: material from the living organisms found in marine environments, especially seaweed and kelp[51].

Area of application

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)[52] [53].

Biofuels: Liquid fuel produced from biomass for transport[54] [55].

Bioliquids: Liquid fuel produced from biomass for energy purposes other than for transport[56] [57].

Biomass fuels: gaseous and solid fuels produced from biomass[58] [59].

Bioliquids for heating and/or electricity: Liquid fuels produced from biomass to supply heating and/or electricity[60] [61].

List of innovations identified

Id-nr	Title	Country	Link
1	Production of hydrogen and biochar from woody biomass via steam iron process utilizing iron ore concentrate	Sweden	bioplusportalen.se/en/project/production-of-hydrogen-and-biochar-from-woody-biomass-via-steam-iron-process-utilizing-iron-ore-concentrate/
2	Biorefining of bark in biochemical conversion and in forest-industrial processes	Sweden	bioplusportalen.se/en/project/biorefining-of-bark-in-biochemical-conversion-and-in-forest-industrial-processes/
3	Systems analysis of biomass and carbon capture across energy sectors	Sweden	bioplusportalen.se/en/project/systems-analysis-of-biomass-and-carbon-capture-across-energy-sectors/
4	Sustainable and cost-effective production of biobased fuels and chemicals via slurry hydroprocessing of forest residues	Sweden	bioplusportalen.se/en/project/sustainable-and-cost-effective-production-of-biobased-fuels-and-chemicals-via-slurry-hydroprocessing-of-forest-residues/
5	Next generation surveillance of biogas plants using AI – for improved efficiency and resource utlisation	Sweden	bioplusportalen.se/en/project/next-generation-surveillance-of-biogas-plants-using-ai-for-improved-efficiency-and-resource-utlisation/
6	The role of bioenergy to achieve energy and climate goals – an assessment of a changeable function in a dynamic energy system	Sweden	bioplusportalen.se/en/project/the-role-of-bioenergy-to-achieve-energy-and-climate-goals-an-assessment-of-a-changeable-function-in-a-dynamic-energy-system/
7	Biogas Scenarios	Sweden	bioplusportalen.se/en/project/biogas-scenarios/
8	Prestudy for commercial plants for OFS sustainable biofuels	Sweden	bioplusportalen.se/en/project/prestudy-for-commercial-plants-for-ofs-sustainable-biofuels/
9	Sustainable aviation fuel from thermocatalytic refining of lignin and lignin-derivatives: development of biorefinery catalysts and reaction systems	Sweden, Finland	bioplusportalen.se/en/project/sustainable-aviation-fuel-from-thermocatalytic-refining-of-lignin-and-lignin-derivatives-development-of-biorefinery-catalysts-and-reaction-systems/
10	Efficient biofuel production and logistics at terminals and industry	Sweden	bioplusportalen.se/en/project/efficient-biofuel-production-and-logistics-at-terminals-and-industry/
11	Reserve power service based on biogas	Sweden	bioplusportalen.se/en/project/reserve-power-service-based-on-biogas/

12	Biogas and biofertilizer production in Mellanbygden, Västerbotten	Sweden	bioplusportalen.se/en/project/biogas-and-biofertilizer-production-in-mellanbygden-vasterbotten/
13	Grey alder as a potential for increased energy-oriented production in Sweden – Evaluation of progeny experiments and their transformation to long-term silvicultural experiments	Sweden	bioplusportalen.se/en/project/grey-alder-as-a-potential-for-increased-energy-oriented-production-in-sweden-evaluation-of-progeny-experiments-and-their-transformation-to-long-term-silvicultural-experiments/
14	ECO-FORCE FUELS: ECO-eFficient biORefinery for Competitive production of grEen renewable shipping FUELS	Sweden	bioplusportalen.se/en/project/eco-force-fuels-eco-efficient-biorefinery-for-competitive-production-of-green-renewable-shipping-fuels/
15	BioPower 2023	Sweden	bioplusportalen.se/en/project/biopower-2023/
16	Efficient syngas fermentation of gasified woody biomass	Finland, Sweden, Norway	bioplusportalen.se/en/project/efficient-syngas-fermentation-of-gasified-woody-biomass/
17	Development of Cost-Effective Process for Phyco-Remediation of Dairy Wastewater and Valorization of Algal Biomass for Production of Biofuel and Biochemical: A Sustainable Approach towards Bio-Refinery	Norway	AlgalBB | NMBU https://prosjektbanken.forskningsradet.no/project/EU/101064183?Kilde=EU&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=0&Ar=2023&Ar=2022&Ar=2021&Ar=2020&TemaEmne.1=Bioteknologi
18	UNPRECEDENTED	Norway	UNPRECEDENTED | NMBU
19	Biofuel production from fish waste using data mining and data modeling for optimal catalyst selection	Norway	Biofuel production through big data | NMBU
20	HyProFuel	Denmark	HyProFuel Hydroprocessing Sustainable Fuels for Aviation and Heavy Transport | Energiteknologi (energiforskning.dk)
21	WaveFuel	Denmark	WaveFuels | Energiteknologi (energiforskning.dk)

22	SkyClean	Denmark	SkyClean | Energiteknologi (energiforskning.dk)
23	Straw-Fueil-Oil	Denmark	Straw-Fuel-Oil: A sustainable drop-in biofuel for the decarbonization of the marine trans-portation sector | Energiteknologi (energiforskning.dk)
24	Sustainability of Vehicle Fuel Biomethane Prouced From Silage in Finland	Finland	(PDF) Sustainability of Vehicle Fuel Biomethane Produced from Grass Silage in Finland (researchgate.net)
25	Improving bio aviation fuel yield from biogenic carbon sources through electrolysis assisted chemical looping gasification	Sweden	Improving bio aviation fuel yield from biogenic carbon sources through electrolysis assisted chemical looping gasification (chalmers.se)
26	Bioenergy Retrofit of Facilitites for Heat and Power Production	Sweden, Lithuania	Bioenergy retrofit of facilities for heat and power production (BIORET) – Lithuanian Energy Institute (lei.lt)
27	Multifunctional Biomass Energy Technologies (MultiBET)	Lithuania	Multifunctional Biomass Energy Technologies (MultiBET) – Lithuanian Energy Institute (lei.lt)
28	Carbon Negative Biofuels from Organic Waste	Norway, Sweden, Finland	Contact - CARBIOW https://cordis.europa.eu/project/id/101084443
29	BUTTERFLY: Biomass Utilized To The Extended portfolio of Renewable Fuels with Large Yields	Finland	Biomass Utilized To The Extended portfolio of Renewable Fuels with Large Yields | BUTTERFLY | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu) https://research.lut.fi/converis/portal/detail/Project/21676712
30	International cooperation for sustainable aviation biofuels	Norway	International cooperation for sustainable aviation biofuels | ICARUS | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)
31	From solar energy to fuel: A holistic artificial photosynthesis platform for the production of viable solar fuels	Norway	From solar energy to fuel: A holistic artificial photosynthesis platform for the production of viable solar fuels | REFINE | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)

32	Sustainable On-site and Innovative Technologies for Advanced Transport BioFuels from MıcroalGae	Finland	Sustainable On-site and Innovative Technologies for Advanced Transport BioFuels from MıcroalGae | FuelGae | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)
33	Refinery integration, scale-up and certification for aviation and marine biofuels production	Norway, Finland	REFOLUTION – Refinery integration, scale-up and certification for aviation and marine biofuels production https://cordis.europa.eu/project/id/101096780
34	ECOLOOP	Estonia	ECOLOOP | ECOLOOP | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)
35	Sustainable production of Cellulose-based products and additives to be used in SMEs and rural areas	Latvia	https://celise.unican.es/ Sustainable production of Cellulose-based products and additives to be used in SMEs and rural areas
36	Accelerating circular bio-based solutions integration in European rural areas	Denmark, Lithuania, Latvia	https://biorural.eu/success-stories/ https://cordis.europa.eu/project/id/101060166
37	Integrating torrefaction of pulp and paper industry sludge with microbial conversion: A new approach to produce bioenergy carriers and biochemicals in a view of bio and circular economy	Estonia	Integrating torrefaction of pulp and paper industry sludge with microbial conversion: A new approach to produce bioenergy carriers and biochemicals in a view of bio and circular economy. | TOPIS-BioCirc | Project | Fact sheet | H2020 | CORDIS | European Commission (europa.eu)
38	Evaluation of industrial symbiosis between fish farming and a hydrogen plant in Alby	Sweden	bioplusportalen.se/en/project/evaluation-of-industrial-symbiosis-between-fish-farming-and-a-hydrogen-plant-in-alby/
39	Exploring the circular bioeconomy potential in cities. Proactive instruments for implementation by policy makers and stakeholders	Estonia	https://cordis.europa.eu/project/id/101023516 https://biocircularcities.eu/

40	Participation in IEA Bioenergy Task 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy	Denmark	Participation in IEA Bioenergy Task 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy | EUDP
41	IEA technology network ”IEA Bioenergy Task 39 – Commercializing Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks”	Denmark	IEA technology network ”IEA Bioenergy Task 39 – Commercializing Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks” | EUDP
42	IEA Bioenergy Task 32 - Biomass combustion - Danish representation 2022-2024	Denmark	IEA Bioenergy Task 32 - Biomass combustion - Danish representation 2022-2024 | EUDP
43	EUDP 2020-II Sulfur Recirculation for higher green power production and lower dioxin for-mation	Denmark	EUDP 2020-II Sulfur Recirculation for higher green power production and lower dioxin for-mation | EUDP
44	Trees For Me - Work Package 5	Sweden	Research Projects - Trees For Me
45	Trees For Me - Work Package 4	Sweden	Research Projects - Trees For Me
46	Trees For Me - Work Package 3	Sweden	Research Projects - Trees For Me
47	Trees For Me - Work Packages 1 and 2	Sweden	Research Projects - Trees For Me
48	HalmEnsilage – ensilage as a combined pre-treatment and storage of straw for biogas production	Denmark	HalmEnsilage – ensilage as a combined pre-treatment and storage of straw for biogas production | EUDP
49	Optimized combination of heat pump and biomass system	Denmark	Optimized combination of heat pump and biomass plant | EUDP
50	Development and testing of a total concept for trimming and salvaging biomass from winter rapeseed in the autumn year of use for biogas production.	Denmark	Development and testing of a total concept for trimming and salvaging biomass from winter rapeseed in the autumn year of use for biogas production. | EUDP

51	Increased energy yield and new green products from biogas plants	Denmark	Increased energy yield and new green products from biogas plants | EUDP
52	Capture and utilisation of co2 through photobioreactors to drive the green transition (capco2)	Denmark	CAPTURE AND HARNESS CO2 THROUGH PHOTOBIOREACTORS TO DRIVE THE GREEN TRANSITION (CAPCO2) | EUDP
53	Bakkafrost og Förka (upgrading biogas to biomethane)	Faroe Islands, Sweden	https://www.bakkafrost.com/en/about-us/news/biogas-plant-foerka-starts-production-of-green-energy-from-bio-organic-waste-from-bakkafrost-hatcheries

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