Task 2.3 Regional Biomass and Nutrient Availabilities in North Sweden

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Magnus Matisons and Eva Fridman BioFuel Regio

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1 Regional biomass and nutrient availabilities in BioFuel Region

1.1 Introduction

1.1.1 Background

A short introduction of the region and possible bio-based solutions.

The total land area for BioFuel Region is 221 800 km^2 of which 67 % is forest land (148 920 km^2). The total growing forest stock is 1 314 million m^3 and the annual growth is 45 million m^3. The protected forest area amounts to 42 990 km^2 or approx. 20 % of the productive forest land. Additional to this there are voluntarily set aside areas made by private forest owners.

The quantity of woody biomass supplied to the market depends on decisions of individual forest owners whether to perform harvesting operations or not. The main market driver for the forest owners when to deliver to market is the timber prices. Price for wood energy has no or little influence. The annual harvest in the region is on average 31 million m^3. In addition to domestic wood, imported round wood can also contribute to the regional market.

Sawn timber products and pulp and paper products have dominated the use over a long time but the use of forest biomass for energy purposes has grown rapidly over the past decades. In the near future, the use of forest biomass in biorefineries is expected to increase rapidly. Forestry is a co-production system, i.e. several products are produced simultaneously, such as saw logs, pulpwood and logging residues (branches and tops left in the forest after harvest operations). Therefore, the potential amounts of the different assortments are not independent. As a result of forest industry activities large amounts of by-products (in this case we focus on sawdust and bark) are available. These by-products are today used mainly for the generation of power and heat in CHPs (Combined Heat and Power plants). As a result of harvesting operations, large volumes of logging residues (LR) are available in the region. Most of this potential is not used today because of the higher costs of harvesting, transport and storing compared to the marked price for sawdust and bark. What is used, is mainly used for combustion. The illustration below shows the present flows of woody biomass from the forest and between different industry segments.

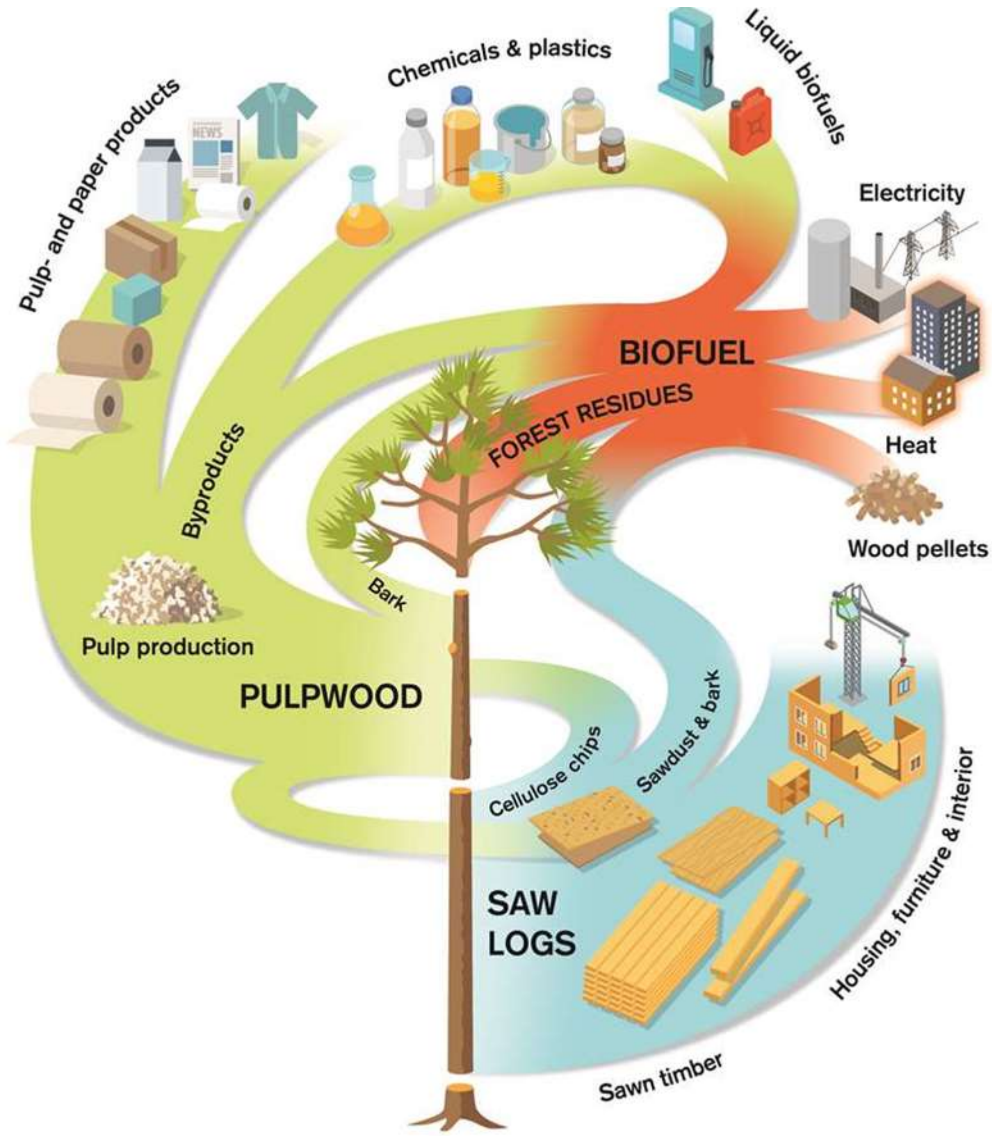

Figure 1. The value chain of the forest biomass showing the flows of woody biomass from the forest and between different industry segments (own image).

1.1.2 Scope

To describe a value chain from forest industry by-products and forestry by-products to a biobased end product is not straight forward. Many biorefining technologies will depend on input of several different woody biomass assortments and have an output of several end products. Assortments or by products not suitable for biorefining, or side streams after a biorefinery process, will be available for the energy market. The quality of biomass assortments can be improved with different methods of pre-treatment e.g., comminution, drying, fractioning, sorting and compaction etc.

<u>Forest industry by products</u>

In this report, five different forest industry by product assortments are included; sawdust, bark, cellulose chips (c-chips), dry chips, and shavings (see Figure 2). Dry chips and shavings represent rather small volumes and c-chips are exclusively used by pulp and paper industries and are not considered as an available biomass assortment. As data has been collected from many different sources presented with different units, it has been important to determine the conversion rates between ton, m3sub, MWh for the different assortments (Table 1).

Figure 2. Picture of assortments, A = Bark, B = C-Chips, C = Sawdust and D = Shavings (*Persson, L* [1])

Table 1: Conversion rates between ton, m³sub (solid volume under bark), MWh for the assortments sawdust, bark, c-chips, dry chips, and shavings with the assumed moisture content in precent. Nd stands for no data. (*Persson, L* [1])

Assortment	**Raw ton**	**m³sub**	**MWh**	**Moisture content (%)**
Sawdust	1	1.2	2.3	50%
Bark	1	1.3	2.0	55%
C-Chips	1	1.1	2.2	50%
Dry Chips	1	2.0	4.3	17%
Shavings	1	Nd	4.2	Nd

Compared to many other forest industry by-products, sawdust has unique qualities that makes it desirable for energy production, fibre board production as well as for emerging biorefining technologies. Sawdust has a well-defined and homogeneous quality, low ash content and few elements that can have a negative impact on biorefining process parameters. Particle size distribution is small with many small particles of similar size. Sawdust already exists in large quantities at the sawmills and the infrastructure for procurement is already available.

Bark

[1] Persson, L. Mapping the market of unrefined forest industry by-products in northern Sweden. Rapport från Institutionen för skogens biomaterial och teknologi, 2021:10 Umeå, 2021 (https://stud.epsilon.slu.se/17846/3/persson-l-20220623.pdf)

Before processing of round wood in sawmills and pulp mills, logs are debarked resulting in huge amounts of bark available near the big industries. Of the round wood input approx. 10% will end up as bark. The heterogeneous nature of bark with high ash content and big particle size distribution makes it problematic for many biorefining technologies but pre-treatment and mixing with other assortments can make some bark acceptable. Bark is today used together with other wood fuels for generation of heat and green electricity in CHPs near big cities.

Logging residues (LR)

LR have a bulky, heterogenes and troublesome nature with a mix of stem wood, bark and foliage. After crushing/chipping, particle size distribution is normally high with high proportions of fine particles, and not seldom, a varying proportion of non-organic materials originating from collection. Altogether this makes LR the most challenging biomass resource to mobilize, handle and to refine. Pre-treatment and mixing with other assortments can make some LR acceptable.

1.2 Biomass Availability

1.2.1 Biomass availability feedstock 1

As by-products come from a main process such as sawing wood at a sawmills or pulp-and paper mills, the potential volume available of these by-product assortments is connected to the volumes processed. About half of the annual harvested roundwood (37 m^3 sub timber) in Sweden 2017 is fed into 104 bigger sawmills all over Sweden. 28 of those sawmills are together with 8 pulp mills located in Northern Sweden. Pulpwood is debarked before processing. About 10% of the processed logs will result in bark. About half of the timber being fed into a sawmill ends up as sawn goods. From roundwood volume, around 50% becomes sawn wood products, 20% sawdust, 10% bark, 20% chips and shavings. These are average figures and quite a large variation can be observed between individual sawmills. However, these variations are not considered in this report. Some of the by-products can be used internally by the sawmills, mainly for drying of the sawn goods. Woodchips are today used by the pulp and paper industry while sawdust and bark are mainly used by pellet industries or for combustion in CHPs.

	Production 1000 m3 sawn wood/year	**Sawdust (dry ton)**	**Bark (dry ton)**	**Pulp chips (dry ton)**	**Wood chips (dry ton)**	**Shavings (raw ton)**	**Total volume by-products (dry ton)**
Sawmills (28)	4 792	396 902	175 747	1 031 369	42 348	27 463	1 673 829
Pulp/paper mills (8)		2 551	55 073				57 624
Total	**4 792**	**399 453**	**230 820**	1 031 369	42 348	27 463	**1 731 453**

Table 2.Amounts of by-products in the sawmills and pulp- and paper industries in the region (Persson, L[2]).

[2] Persson, L. Mapping the market of unrefined forest industry by-products in northern Sweden. Rapport från Institutionen för skogens biomaterial och teknologi, 2021:10 Umeå, 2021 (https://stud.epsilon.slu.se/17846/3/persson-l-20220623.pdf)

1.2.2 Biomass availability feedstock 2

Logging residues

As a result of harvesting operations, large volumes of logging residues (LR) are available in the region. These LR's are hardly utilized at all since LR have a low commercial value due to their location far away from most existing end consumers and the costs of harvesting, transport and storing is too high compared to the price of forest industry by products. If we don't extract the logging residues from the forest, they will decompose within 5-10 years in the forest releasing CO2 to atmosphere anyway. Environmental impact of LR extraction is small and well-known and regulated by the national forestry act. What is used, is mainly used for combustion.

In previous projects (forest refine), several studies on the procurement of LR have been carried out. In these studies, we have found that LR is a potential feedstock to produce high value compounds. LR and especially needles, contain high amounts of valuable compounds that can be used to produce a range of added value-products, for example, pharmaceuticals or cosmetic ingredients, platform and specialty chemicals, dietary supplements, biopolymers, bioplastics, foams/emulsions, and coatings. These nature-derived ingredients open possibilities for substituting fossil-based products. LR has complex and varied nature and the needles are rich in chemicals that many biorefining processes cannot handle. Needles and bark can be problematic for many biorefining processes and separation of the needles and/or bark for the extraction of high-value chemicals can improve the quality of the remaining fraction that can be used by other biorefining processes (bio coal, biofuels, etc.).

1.3 Nutrient Availability

1.3.1 Nutrient availability

Agricultural land is harvested once or several times annually, continuously removing organic matter and nutrients from the soils. To compensate for these losses and nutrient leakage, mostly fossil-based fertilizers must be used. In tropical forests most of the nutrients are found in the living biomass while in boreal forests most of the nutrients are found in the forest soils. Harvesting of tropical forests and removing the trees makes it almost impossible to re-establish the forest eco system due to nutrient deficiency. This is why further deforestation in the tropics must be halted. Tropical forests have millions of years of continuity and are rich in biodiversity with many endemic species while boreal forests are young (a few thousand years) poor in biodiversity with few endemic spices. Species in boreal forests have adopted to disturbance e.g., forest fires and can adopt to changes and spread into new niches.

Forest soils in the northern Sweden region are mostly till soils, poor in plant available nutrients thus the trees grow very slowly. Nitrogen is the most limiting nutrient for growth of the trees. If we add nitrogen fertilizers, trees will respond with increased growth. Forest management practices are regulated by the Swedish forestry act to prevent long-term impaired growth potentials and nutrient leakage from forest soils to water recipients. During a rotation period, thinning operations are carried out once or twice and final felling is carried out after approximately 100 years, removing most of the valuable stem wood. During these 100 years' time, nutrients are recycled when needles and twigs continuously litter from the trees. Litter is decomposed and nutrient is reused by the trees. After harvest, forest soils are scarified to make more nutrients available for the planted seedlings. For every tree that is removed, at least two new trees are planted. This practice has resulted in that we today have twice as much forest, in cubic meters, as we had 100 years ago. Increased forest growth together with increasing temperatures increases the rate of weathering and makes more nutrients available for the trees.

Removal of stem wood does not pose a threat to long-term productivity of forests but removal of LR can be problematic on poor soil as most of the nitrogen is found in the needles. LR is removed only from relatively fertile spruce-dominated forests and is not recommended in pine-dominated forests on poor forest land. To prevent the negative impact of LR removal, it is recommended to leave LR in the forest for one season to dry and to drop as much as possible of the needles. It is also recommended to return the ashes after combustion, to forest soils where LR has been removed. However, nitrogen will be lost in the flue gases during combustion, so this recommendation seldom affects the growth of the new stand. However, if we add biomass ashes to peat soils, it has been shown to have a positive effect on tree growth as peat soils are poor in potassium that still is available in the ashes. However, due to concerns about the negative impact on peat ecosystems, this is not recommended. Trials have been made in the region to fertilize forest soils with municipal sewage sludge. Neither this is recommended, as sewage sludge can contaminate forest soils with heavy metals.

1.4 Discussion of the Results

The costs of harvesting, transporting, storing, and handling of the biomass are prime determinants of overall biorefining costs. Thus, it is vitally important to develop local forest biomass supply systems that can efficiently supply biorefineries with sufficient raw material that meets their specific quality and seasonal demands. Biomass resources not fulfilling economical or quality requirements from end users cannot be mobilized.

Low hanging fruits are forest industry by products as they are available in large amounts in one place. To maximize possible synergies, refineries can preferably be integrated just next to existing forest industries. However, most of the forest industry by-products are already used, either internally, or by pellet producers or CHP plants. In the near future, new processes are likely to be developed to upgrade by-products, like sawdust, both into high-value products and to different types of biofuels. It is likely that competition for the forest industry by-products, especially those with a well-defined quality, like sawdust will soon increase.

The tree stem, excluding bark, is a relatively homogeneous material and its chemical and physical properties are well known, while bark and crown components have a much more heterogeneous chemical composition. Thus, for many biorefining processes stem wood (eg. sawdust and shavings) is arguably the most straightforward production material. Specific quality demands of each biorefining process will determine what biomass assortments are possible to use.

CHPs can compensate for the future shortage of sawdust by burning LR (Logging residues) that today are not fully utilized or other more complex fuels not suitable for upgrading. CHP technology is robust and designed to handle more complex fuels.

Wood fuels often have a wet and bulky nature making road transport over long distances not feasible. Wood fuels are typically sourced within a 100 km radius from the end consumer. Another thing to consider is the biomass suppliers' willingness to sell. In northern Sweden, a few big forest companies have a dominating market position. Business relations and trust has developed between sellers and buyers of wood fuels for several decades. Therefore, it is not realistic to assume that a new facility demanding biomass will be able to source all available biomass. To conclude, biomass availability is highly case-specific and should answer the following question: What biomass assortments of a good enough quality can for several decades be sourced at an affordable price within a 100 km radius from the biorefinery? A potential limiting factor for biomass availability can also be EU policies aiming to regulate forest management practices and determining what assortments can be used for different purposes. In previous studies, we have assumed that 50% of forest industry by-products will be available and based on this assumption calculated marginal cost curves for biomass acquisition.

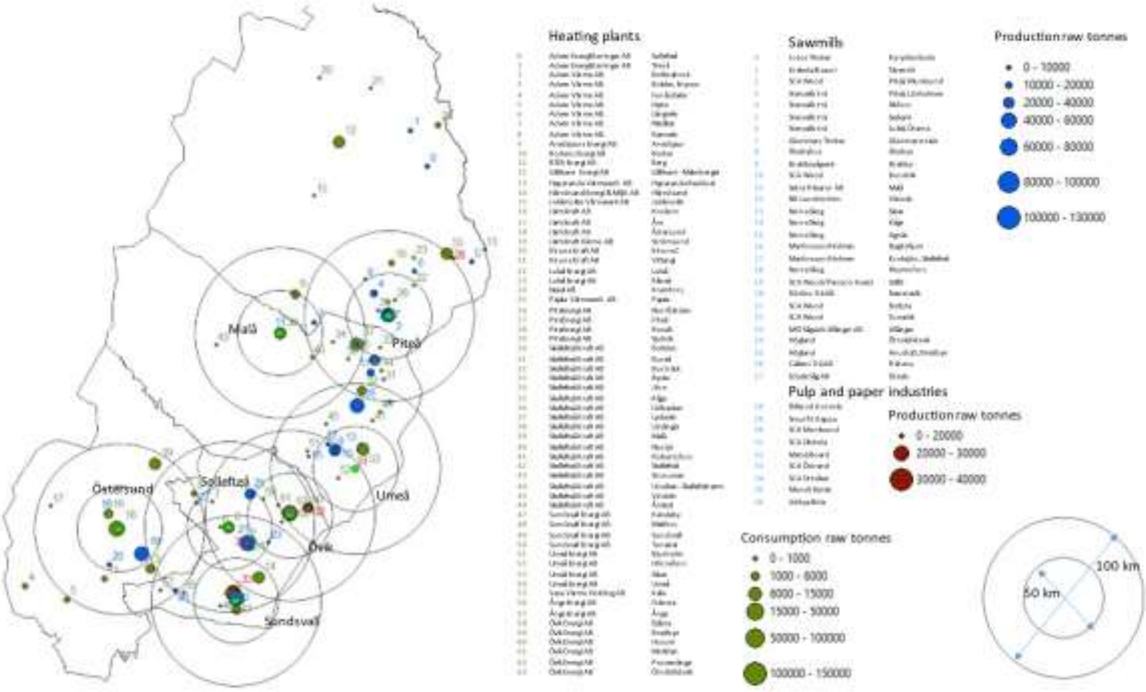

Figure 3. Map of northern Sweden with major industries producing and consuming sawdust and bark. Raw material supply areas for potential biorefineries. (Athanassiadis, D. Analyses from Swedish University of Agricultural Sciences, Forest Biomaterials and Technology)

The use of forestry by-products will lead to the following changes in the market. Heating oil was commonly used for heating in Sweden before the 1980s, but today biomass has a dominant position in the Swedish heat market as a fuel for CHP for district heating. Very little fossil fuels are today used for heating. Biomass is also the main energy source for energy intense forest industries. Today, most of the forest industry by-products are already used, either internally, or by pellet producers or by combined heat and power (CHP) plants. Only outputs with high water content like fibre sludge and green liquor etc. are difficult to use. In northern Sweden, several investments are planned for the production of biocarbon, biofuels and biochemicals based on forest industry by-products (sawdust and bark). These investments are on higher levels in the biomass value pyramid than energy generation. Upgrading is likely to have the following effects.

- Upgrading creates added value to sawdust. This in line with the cascading principle.
- New production creates synergies with the existing forest industries and raises the overall efficiency of both processes. It also reduces energy needed for transports of bulky sawdust as the productions will take place integrated or close to the sawmill. New end users are aiming to find most suitable places that can maximise these synergies.
- When you create added value to a by-product it becomes more economical for forest industries to supply more by products to the market and use less internally. This promotes investments in in energy efficient technology. We have seen several examples of this during the past decades.
- Biofuels used for transports today can in the future be upgraded to biobased materials and biochemicals can stay and circulate in the society for a longer time and in the end of the life cycle can be used for energy generations.
- CHP plants can compensate for the shortage of sawdust by burning logging residues (branches and tops) that today are not fully utilized or other more complex fuels not suitable for upgrading. CHP technology is robust and designed to handle more complex fuels. If we don't extract the logging residues from the forest they will decompose (5-10 years) in the forest releasing CO2 to atmosphere anyway.

Environmental impact of LR extraction is small and well known and regulated by the national forestry act.

1.5 Conclusions and Recommendations

1.5.1 Conclusions

Forestry is a co-production system, i.e. several products are produced simultaneously, such as saw logs, pulp-wood, sawdust, bark and logging residues. Therefore, the potential amounts of the different assortments are not independent.

The estimation of current residues is given below. The data for sawdust, bark, chips and savings are actual figures. Potential may be higher. The logging residues are a rough estimate of what could be collected on basis of a medium mobilisation scenario within sound ecological boundaries.

Table 3, Estimations on biomass potential and applications (Persson, L[3])

Biomass stream	By-products (annual production, dry)	Current application	Possible application
sawdust	300 kt	wood pulp (paper & textiles), wood panels, energy production	high value products, biofuels
bark	230 kt		
pulp chips	1 Mt		
wood chips	40 kt		
shavings	30 kt		
logging residues	2-4 Mt	largely not extracted, combustion	high value compounds

Logistics: Biorefinery plants need huge amounts of biomass at an affordable price. Efficient biomass logistics is very important for increased availability at an affordable price. The costs of harvesting, transporting, storing and handling of the biomass are prime determinants of overall biorefining costs. Wood fuels often have a wet and bulky nature making road transport over long distances not feasible. Wood fuels are typically sourced within a 100 km radius from the end consumer. Solutions for improved biomass logistics are available here (https://biofuelregion.se/projekt/forest-refine/).

Costs allocation: Calculating production costs for one product in a co-production system is not straightforward. Generally, there is no unambiguous way to allocate costs between the different products in an operation. The forest-based industries and the energy production sector are intricately interlinked, displaying synergies as well as competition. Sawmilling by-products are used for wood pulp (for paper as well as textile fibres) and wood-based panels manufacturing as well as for energy production, while side-streams from chemical pulping are used in the chemical industry as well as for energy production.

[3] Persson, L. Mapping the market of unrefined forest industry by-products in northern Sweden. Rapport från Institutionen för skogens biomaterial och teknologi, 2021:10 Umeå, 2021 (https://stud.epsilon.slu.se/17846/3/persson-l-20220623.pdf)

Dynamics in supply and demand: The demand, and thus price, for sawlogs is one of the most determinant factors for the supply of primary woody biomass, including woody biomass for energy. The supply of primary woody biomass might also be affected by external factors, such as natural disturbances. Energy and material use (mainly wood-based panels but also wood pulp manufacturing) also compete for primary sources of woody biomass. This means that developments in wood-based markets are instrumental to the supply of woody biomass for biorefining purposes, and thus an assessment of sources and uses of woody biomass needs to consider existing forest-based industries. Increased competition for sawdust and bark today used for combustion will make CHP plants look for alternative wood fuels. Logging residues represent a huge, underutilized biomass resource. To mobilize this resource, several actors must make strategic decisions.

Forest resources and climate: Forest resources within the EU are on the increase. Between 1990 and 2020, forest area increased by 9% and the volume of wood in European forests rose by 50%. Over the last 100 years the standing volume in Swedish forests has almost doubled and carbon stocks in forests and forest soil have quadrupled. At the same time, more than 4 billion cubic meters of timber have been felled and delivered to the society. Sustainable forest management has a positive impact on climate change mitigation. If we don't extract biomass from regions with positive forest trends, we face the risk of importing biomass from countries where we can observe a negative trend of deforestation.

Recommendations

For the SCALE-UP regional platform:

- To share information and to promote joint activities to boost the bioeconomy in northern Sweden. One example is the ongoing support to mobilize more logging residues in the region.
- To mobilize actors within the whole value chain and to communicate and exchange best practices for cost-effective deliveries of logging residues with high quality. A wood fuel network including buyers and sellers of wood fuels in northern Sweden should be mobilized in this task.
- To identify challenges and solutions in the logging residue value chain with a web survey. To identify important areas where best practices can be shared and developed. To design workshops and training sessions together with heating plant, entrepreneurs, and suppliers of wood fuels.

For research:

- To make more biomass economically available over vast geographical areas, it is important to develop more efficient forest machinery and transports on road and railway.

Policy:

- All policy measures aiming to hamper active forest management will decrease the availability of all woody biomass assortments.
- An increase in the use of woody biomass to reduce carbon emissions should be promoted through active and sustainable forest management across the EU and should not be hampered by policy constraints.