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CIRCULAR ECONOMY CEforestry

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Sustainable Utilization of Forestry Side Streams to Promote Circular Bioeconomy

FORESTRY INDUSTRY side streams from sawmills in the Baltic Sea region represent a vast, yet underutilized resource. Currently, many of these residues serve as low-value products, such as bioenergy. However, recent research under the CEForestry project demonstrates that these side streams such as bark and needles can be converted into high-value compounds, including tannins for industrial applications and antibacterial extracts for the cosmetics and food industries.

THIS BRIEF outlines policy recommendations to foster a circular bioeconomy by promoting the sustainable utilization of forestry side streams, while integrating best practices in sustainable forest management, business model innovation, and market-driven technological advancements.

Conclusions

1. Forest industry side streams from sawmills could be utilized in industrial scale high value-added products such as
   - Tannins as biocides for wastewater treatment and in pulp mills
   - Tannins for treatment of leather as tanning agents to replace imported vegetable tannins

2. Business potential has also been found in antibacterial extracts for cosmetics and food industry. These applications require more development to meet regulatory, safety and profitability needs.

The Baltic Sea region has a potential to become one of the leading regions in green growth and sustainable development

Circular bioeconomy in the Baltic Sea Region

THE EUROPEAN Bioeconomy Strategy and it`s Action Plan, adopted 2018, aims to promote the bio-based sector for investments and market development. It emphasizes replacing fossil-based materials with bio-based raw materials and products. The EU Bioeconomy Strategy has five key goals:

1. Ensure food and nutrition security
2. Manage natural resources sustainably
3. Reduce dependence on non-renewable and unsustainable resources
4. Limit and adapt to climate change
5. Strengthen European competitiveness and create jobs.

New EU bioeconomy strategy is being prepared and it should be finalized by the end of the year 2025. Bioeconomy is seen as one of the drivers for Europe's Green Growth. The new strategy will be designed to increase efficient and circular use of biological resources, scale up markets for bio-based products, materials and industries that substitute fossil-based inputs and ensure a sustainably-sourced and resilient biomass supply across sectors.

The EU Circular Economy Action Plan, adopted in 2015, aims to transition the European economy from a linear to a circular model. This plan includes 54 actions promoting circular economy practices. It encompasses initiatives along the entire life cycle of products, promotes circular economy processes, and fosters sustainable consumption. The goal is to ensure that resources are retained within the EU economy for as long as possible. Additionally, it focuses on sectors that use the most resources and have high potential for circularity. The circular economy action plan targets the entire life-cycle of products – the design, sustainable consumption and prevention of waste.

EU Member States have committed to making the EU the first climate-neutral continent by 2050. This requires reducing emissions by at least 55% by 2030 compared to 1990 levels.

As a prerequisite to reach the set climate neutrality goals the European Commission has adopted the circular economy action plan which contributes to the EU Green Deal by enabling the circular use of biomass and producing high value-added products from side and waste streams, such as bark residues and logging residue.

In 2023 the Monitoring framework was revised to support the circular economy and climate neutrality goals within the European Green Deal – the framework evaluates the progress and the direct and indirect benefits of its adoption thus allowing authorities and policy makers to identify optimal solutions.

Policy Area Bioeconomy is one of the fourteen policy areas related to the EU Strategy for the Baltic Sea Region. The Baltic Sea region has the potential to become a leading area in green growth and sustainable development. PA Bioeconomy includes actions related to forestry activities:

- Sustainable forestry and increased use of wood
- Sustainable food systems
- Bioeconomy trend analysis in the Baltic Sea region
- Promoting a more circular bioeconomy
- Multiple use of resources
- Sustainable bioeconomy and its contribution to climate change

The defined actions are set to decouple economic growth from the use of limited resources, instead the focus is on natural, bio-based and sustainable resources. Additionally, to the climate-neutrality goals, bioeconomy-based solutions are expected to create new business opportunities, local jobs and enable more resilient value chains that are self-sufficient.

Annual sawmill residues in the Baltic Sea region amount to over 1.48 million tonnes of dry bark and 2.25 million tonnes of sawdust—feedstocks sufficient to produce some 59 million kg of tannins (at a conservative 4% yield). By co-locating extraction facilities with large sawmills and leveraging existing transport corridors, Finland and Sweden can lead on raw-material supply. All Baltic Sea Region countries can develop innovative processing technologies to convert these raw materials into high-value products.

Available forestry side streams in the Baltic Sea Region

FORESTRY SIDE streams fall into two broad categories: forestry-derived residues (needles, bark, logging residues) generated during harvesting operations, and forest industry residues (sawdust, wood chips, bark) produced in sawmills. Coniferous species—spruce, pine—and broadleaved species—birch—differ both in chemical composition and volume. For example, spruce bark typically contains higher condensed-tannin content (up to 8–12 % by dry weight), whereas pine and birch residues yield different polyphenolic profiles suited for specialty applications such as antioxidants or UV-stabilizers. Separating these streams at source allows tailored extraction processes and maximizes value recovery.

The data on available forest industry side streams from sawmills not going to energy feed presented in Fig.2 and Table 1 have been collected from sawmills in Finland, Sweden, Latvia, Lithuania and Poland during 2023-2024 by the Swedish University of Agricultural Sciences (SLU). It has been estimated by SLU that dry bark available from sawmills for external use is close to 1500 million kilograms annually. In addition to sawmills the total generation of forestry side streams only in Finland was estimated to be almost 28 million tons in 2016. The share of solid wood-based residue was 28.5% reaching almost 8 million tons of wood-based side streams including bark (Hassan et.al. 2019).

Regionally, the Baltic Sea area exhibits significant variation in residue availability and processing capacity. Finland and Sweden together produce roughly 1 079 million kg of sawmill chips and 1 990 million kg of sawdust annually, whereas Poland, Latvia and Lithuania generate about 219 million kg of chips and 286 million kg of sawdust. This disparity reflects both the larger forest industry infrastructure in the Nordics and the emerging processing facilities in the Baltics.

The available volumes of wood chips, saw dust and bark from sawmills are high which create opportunities in addition to energy feed for utilizing bark also in high value-added industry chemicals such as bacteria treatment chemicals and leather treatment chemicals. Besides the volumes, the map gives a hint on where to locate a facility that will produce the above-mentioned chemicals. According to our experience from previous studies it is obvious that one of the best choices is to build the facility close to a bigger sawmill where a big number of by-products are produced. Another good choice is to integrate the new facility with a sawmill. In this case all transports by truck are almost eliminated.

Fig.1 Available forest industry side streams not going to energy feed from sawmills. https://interreg-baltic.eu/project/ceforestry/#output-0

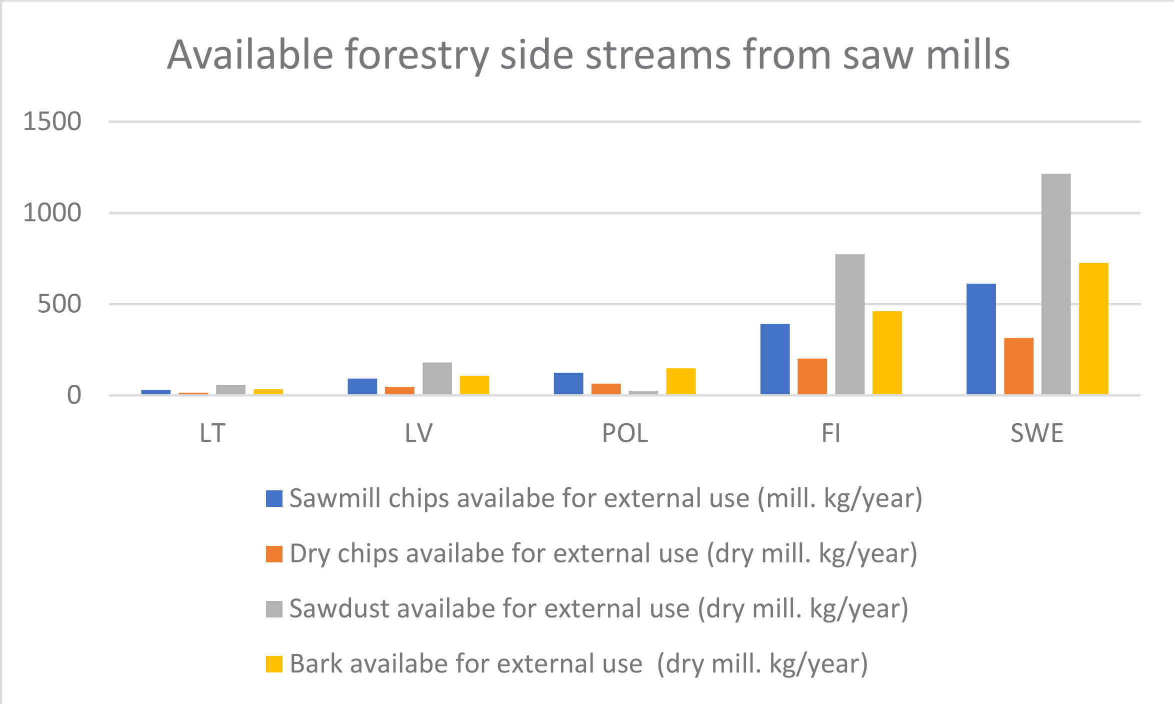


Fig.2 Available forest industry side streams from sawmills not going to energy feed in Lithuania, Latvia, Poland, Finland and Sweden. (Dimitris Athanassiadis, Leena Favén)

Table 1. Available forest industry side streams from sawmills for external use. (Dimitris Athanassiadis, Leena Favén)

	Sawmill chips available for external use (mill. kg/year)	Dry chips available for external use (dry mill. kg/year)	Sawdust available for external use (dry mill. kg/year)	Bark available for external use (dry mill. kg/year)
LT	29	15	58	35
LV	91	47	181	108
POL	125	65	25	148
FI	390	201	773	463
SWE	613	316	1214	727
Total	1249	644	2251	1480

Side-stream based products often undercut synthetic alternatives. Industrial tannins average USD 2–3 per kg, compared to petrochemical phenolics at USD 4–6 per kg. Leveraging free or low-cost feedstock - bark and needles typically sold at USD 10–20 per ton to energy users - can deliver extraction costs of USD 0.50–1.00 per kg of tannin, yielding gross margins above 50 % (Zhou et.al., 2020).

Tannins for industrial applications

Tannins: Sustainable and High-Value Industrial Raw Materials

Tannins, complex polyphenolic compounds naturally present in wood bark and other forestry side streams, have gained increasing attention as sustainable and high-value industrial raw materials. Their unique chemical structure enables them to act as natural crosslinkers, antioxidants, and biocides, making them attractive for several industrial uses.

Recent research has highlighted several promising applications:

- **ADHESIVES SECTOR:** Tannins extracted from European softwood bark have been shown to form robust, bio-based adhesives that can serve as alternatives to synthetic, petrochemical-derived binders. Zhou X and Du G (2020) demonstrated that these tannins, when combined with natural polymers, yield adhesives with improved mechanical performance and environmental compatibility.

- **WASTEWATER TREATMENT:** Tannin-based formulations have proven effective as natural biocides. Pagliaro et al. (2021) reported that tannins can inhibit microbial growth, which is critical for improving the efficiency of water treatment processes and reducing the chemical load from conventional biocides.

- **COSMETICS AND FOOD INDUSTRIES:** The antioxidant properties of tannins offer potential in the cosmetics and food industries, where they can replace synthetic antioxidants. Ojo (2022) reviewed the valorization of wood-derived tannins, emphasizing their role in enhancing product stability and shelf life in various formulations.

The global tannin market is estimated to exceed one million tons annually, with studies indicating that more than 60% of tannins are currently used for leather treatment. Research on natural tannins for leather applications shows that plant-derived tannins offer a sustainable alternative to conventional chemical tanning agents (Mustafa et al., 2024). The global tannin market is projected to grow at a 5,6% CAGR driven by rising demand from leather tanning, wine production, wood adhesives, and the shift toward natural antioxidants in food and cosmetics - to USD 3.6 billion by 2030 (Mordor Intelligence, 2025). At a conservative 4 % extraction yield from 1 480 million kg of dry bark, the Baltic Sea region could supply some 59 million kg of tannins annually—equivalent to nearly 5.9 % of the current global volume (1 000 000 tonnes).

Similarly, the antibacterial products market is forecast to increase from roughly USD 27.9 billion in 2024 to USD 40.1 billion by 2034, growing at a CAGR of 3.7% as healthcare, personal care, and food industries seek safer, bio-based biocides (Market.us., 2025). Embedding these figures highlights the lucrative opportunity of valorizing forestry residues into high-value tannins and natural antibacterial extracts.

In parallel, the valorization of forestry residues is gaining interest within the EU bioeconomy. A promising sustainable source of tannins is spruce bark, a major byproduct of sawmills. Recent work on green extraction methods has demonstrated that even with a conservative extraction yield of around 4%—to account for losses during storage and transportation—the annual tannin yield from sawmills could be approximately 59 million kilograms (Table 2). In a study by Das et al. (2020), subcritical water extraction was successfully applied to spruce bark, yielding high-purity tannins that are being evaluated for multiple industrial applications, including adhesives, biocides, and leather tanning. The storage drastically affects the chemical composition of bark. As a rule of thumb, the bark should be used as soon as possible after debarking, especially in summer. Additionally, drying of the fresh bark decreases its tannin content (Lappi et al. 2014, Jyske et al. 2020, Routa et al. 2020, Jylhä et al. 2021).

Table 2. Potential volumes of tannins from sawmills in Finland, Sweden, Latvia, Lithuania Poland. (Dimitris Athanassiadis, Leena Favén)

	Bark available for external use (dry mill. kg/year)	Tannins (4%) in bark mill. kg/year
LT	35	1
LV	108	4
POL	148	6
FI	463	19
SWE	727	29
Total	1480	59

Tannin extraction

Tannin extraction from softwood bark involves several key steps to isolate these valuable polyphenolic compounds. Initially, the bark is collected and ground into smaller particles to increase the surface area for extraction. Common extraction methods include hot water extraction, where ground bark is mixed with hot water and heated to a specific temperature, usually between 70°C and 90°C. After extraction, the tannin solution is purified to remove non-tannin compounds, often using techniques like ultrafiltration or adsorption. The purified tannin solution is then concentrated using methods like evaporation or spray-drying to obtain a tannin powder. Characterization techniques such as high-performance liquid chromatography (HPLC) and mass spectrometry (MS) are used to analyze the chemical composition and properties of the extracted tannins, ensuring their quality and suitability for various industrial applications.

Techno-economic feasibility of tannin production from forest industry side streams

According to the techno-economic feasibility study on tannins as biocides by Joonas Savelainen (2024) the tannin extraction process from spruce bark can be implemented to an industrial scale but the production capacity must be higher than the demand for only one pulp mill. The capital investment for a tannin manufacturing plant is close 2,2 million € and the operating costs have been estimated to be over 2 million €/year.

The utilization of tannins from bark in leather tanning has been evaluated to be technically and economically potential by Ilmari Niiranen (2025). Based on his techno-economic feasibility study the annual capacity of the tannin extraction plant is 4000 tons of tannin powder from 50 000 tons of spruce bark. The total capital investment is estimated to be 9,6 million euros. However, the profitability is sensitive to changes in total yield of tannins when scaling up and if prices for tannin vary.

CEBusiness model and market demand as a basis for policy recommendations

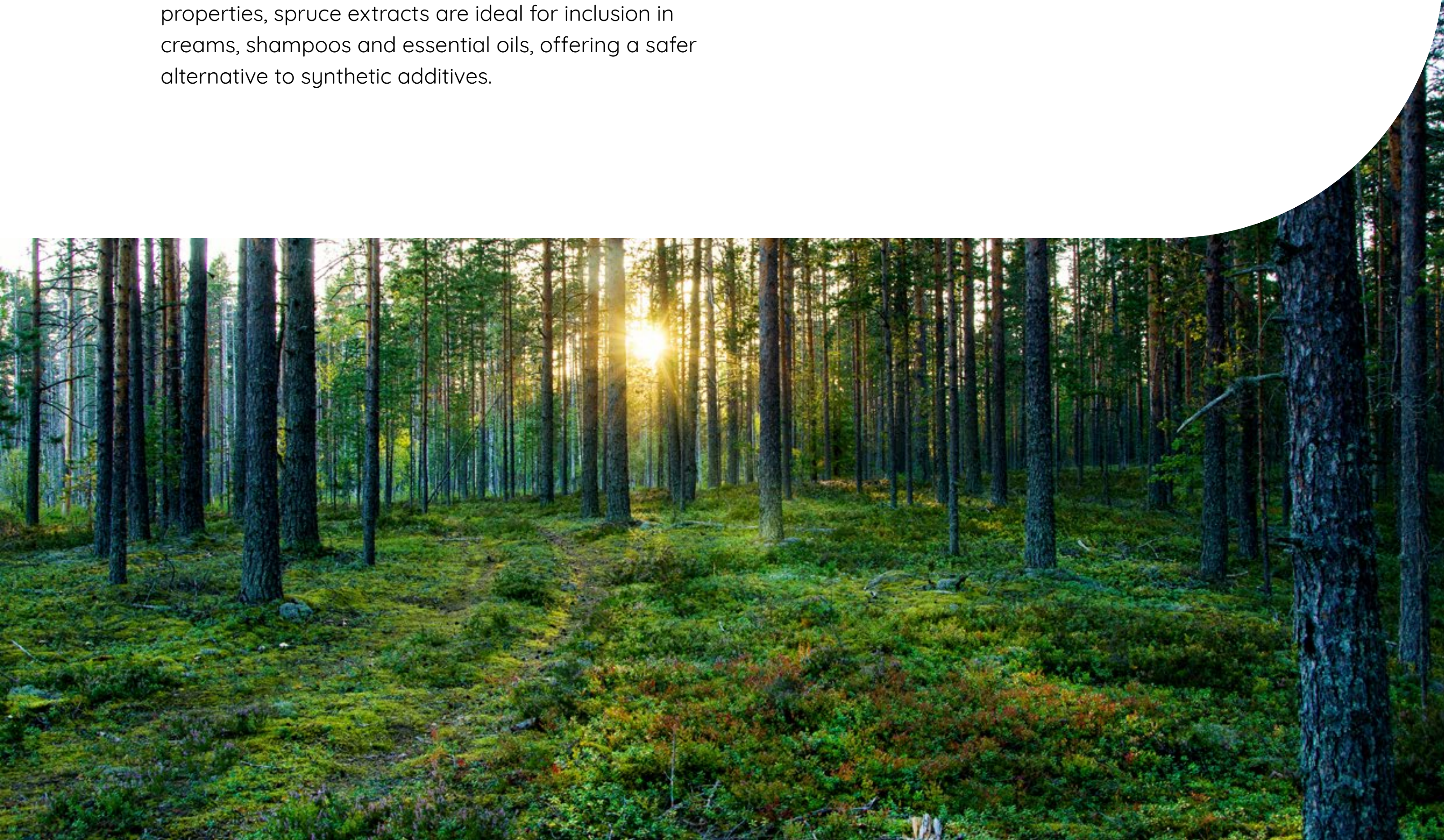
CEBusiness model

Circular economy business models that utilize forestry by-products, particularly spruce bark and spruce needles, offer promising avenues for innovation and sustainable regional development. These raw materials are widely available in the Baltic Sea region countries. They contain valuable bioactive compounds with antibacterial properties that are currently commercially underutilized. The extraction and transformation of such materials into natural-based products present viable alternatives to harmful chemical substances in various industries.

Extracts derived from spruce bark and needles can serve multiple sectors:

- Water and sewage management: they can function as natural biocides, helping maintain and protect water infrastructure by preventing microbial corrosion and biofilm formation.
- Paper manufacturing: in the pulp and paper industry, these extracts contribute to mitigating explosive hazards by reducing the generation of volatile gases during processing.
- Cosmetics: with their natural preservative and active properties, spruce extracts are ideal for inclusion in creams, shampoos and essential oils, offering a safer alternative to synthetic additives.
- Food preservation and functionalization: The antimicrobial and antioxidant properties of tannin-rich extracts present opportunities to extend food shelf life and reduce synthetic additive use, aligning with consumer preferences for clean-label products. However, scientific evidence indicates that tannins can also form complexes with dietary proteins and essential minerals, potentially lowering their bioavailability (Ojo, 2022). Therefore, their application in food systems requires careful dose control and regulatory assessment. Hydrothermal pre-treatments, such as soaking, boiling, or steaming, are known to significantly reduce the antinutritional impact of tannins while retaining their functional properties, thus offering a scientifically supported approach for safe utilization in food matrices.

In addition, innovative approaches to waste valorization allow forestry residues to be converted into high-quality fertilizers. By transforming post-production by-products into ash, which can then be reintroduced to the forest as a nutrient-rich amendment, these models support sustainable forest management and soil health (Pitman, 2006; Augusto et al., 2008).



Regional Economic Opportunities in the Baltic Sea Area

The Baltic Sea region presents a unique market opportunity. Northern countries like Finland and Sweden, endowed with extensive spruce forests, are well positioned to become leading suppliers of these valuable raw materials. All Baltic Sea Region countries can capitalize on emerging market opportunities by developing innovative processing technologies to convert these raw materials into high-value products. In addition, Poland, Lithuania and Latvia can serve as pivotal transit hubs due to their strategic geographic positioning and robust logistical networks. This capability facilitates the efficient distribution of these innovations across European and global markets, enhancing regional economic integration and competitiveness.

Benefits and Challenges for Policymakers

The primary benefits of these models include:

- Environmental sustainability and health implications: Replacing synthetic chemicals with natural tannin-rich extracts reduces environmental pollution and supports human health. Nonetheless, food-sector applications must also address the potential antinutritional effects of tannins, which can impair protein digestibility and mineral absorption if not appropriately processed (Ojo, 2022). This underlines the need for safety evaluations, particularly in foods intended for vulnerable populations such as children or the elderly.
- Economic growth: leveraging regional forestry by-products can spur job creation, innovation, and new revenue streams.
- Sustainable forest management: by recycling biomass as fertilizer, the models help maintain forest floor integrity, ensuring long-term forest health.

Several challenges need to be addressed:

- Regulatory hurdles: the introduction of these natural extracts as biocidal products faces strict legal requirements. Complex and prolonged procedures for market authorization may impede swift adoption.
- Product heterogeneity: the natural variability in spruce bark and needle extracts, due to differences in raw material quality and processing methods, complicates standardization and consistent product quality.
- Logistical considerations: ensuring the timely and proper handling of fresh biomass is crucial. Delays or improper storage can significantly degrade the raw material's quality, reducing its effectiveness.

In conclusion it can be stated that, the integrating these sustainable models into the Baltic Sea region's economic framework not only fosters environmental stewardship but also creates robust market opportunities.

> Policymakers are encouraged to support regulatory streamlining and investment in research and logistics infrastructure. This dual approach can unlock the full potential of spruce bark and needles, driving innovation, regional development, and global competitiveness in the sustainable production of natural extracts and fertilizers.

Market demand

The market for forest-based products is experiencing robust growth across key sectors such as cosmetics, pharmaceuticals, food, and nutraceuticals. In the Nordic and Baltic regions, consumer preferences are rapidly shifting toward natural, sustainable, and eco-friendly ingredients. This trend is supported by strong market forecasts for natural ingredients and bio-based chemicals, which are further reinforced by EU and regional sustainability directives. As such, the forest bioeconomy in these regions is well positioned to transition from traditional uses—primarily energy generation—to diversified, high-value product streams.

In an integrated biorefinery and value chain optimization approach, the development of an advanced biorefinery plays a central role. Such model proposes a sequential process whereby forestry side streams, such as bark and sawdust, are first utilized for the extraction of high-value compounds like tannins. The remaining biomass is subsequently processed into bioenergy or allocated for other low-value applications, thereby ensuring a zero-waste system. This comprehensive utilization not only enhances resource efficiency but also creates a cascading value chain that maximizes the overall yield from forestry residues.

Furthermore, strategic partnerships with local industries and research institutions are essential to foster innovation in processing technologies. This collaborative effort, bolstered by supportive EU policies promoting a circular bioeconomy, aims to secure investment and regulatory incentives. By integrating digital monitoring systems for quality assurance and supply chain transparency, this approach ensures that the production process remains responsive to evolving market demands while contributing to the sustainability goals of the EU forest bioeconomy.

A parallel strategy emphasizes the establishment of a circular business model with market diversification approach that leverages forestry side streams as the cornerstone for multiple, differentiated product lines. In this approach, the global shift toward a circular bioeconomy is harnessed to tap into emerging consumer segments that demand transparency and sustainability in the products they purchase. Market research suggests that the functional beverage and natural cosmetics sectors, along with nutraceutical and food supplement segments, are experiencing rapid growth, with some areas projecting annual growth rates exceeding 9%.

The proposed business model begins by positioning forestry side streams as the primary raw material for the development of high-quality, bio-based chemicals.

For instance, natural tannins and antibacterial extracts derived from these residues can be tailored for specific industrial applications, including but not limited to, eco-friendly leather tanning and the formulation of natural biocides. Simultaneously, another branch of the business focuses on converting these resources into consumer products, such as functional beverages and natural cosmetic ingredients. This dual-path strategy not only enhances resource utilization but also diversifies revenue streams, reducing reliance on any single market segment.

Central to this model is the emphasis on circularity, where the entire production process is designed to minimize waste and promote the recovery and valorization of by-products. Collaboration among forestry operators, processing firms, and end-product manufacturers is key to ensuring the seamless integration of value chains. Furthermore, transparent certification schemes and rigorous life-cycle assessments are employed to build consumer trust and meet stringent regulatory standards. By aligning the business model with both market trends and environmental imperatives, this approach supports the long-term viability and competitiveness of the EU forest bioeconomy. Both strategies - integrated biorefinery and circular business model diversification - are reinforced by supportive EU policies aimed at promoting a circular bioeconomy. In the Nordic and Baltic countries, these approaches can enhance regional competitiveness, foster innovation, and promote sustainable development across the entire forest value chain.

> Based on the market research and the emerging trends in the forest bioeconomy, the following recommendations are proposed for the Nordic and Baltic countries:

1. Support for Integrated Biorefinery Development

Governments should establish funding programs and innovation hubs that support the development of integrated biorefineries. These facilities should focus on maximizing the cascading use of forestry side streams - first extracting high-value compounds (e.g., tannins for industrial applications) and then utilizing residual biomass for bioenergy and other uses. Public-private partnerships and targeted R&D investments will be crucial for advancing processing technologies and ensuring economic viability.

2. Promotion of Circular Business Models

Policy frameworks should incentivize circular business models that encourage the valorization of forestry residues. This can be achieved through tax breaks, subsidies, or low-interest loans for companies that adopt practices to minimize waste and create diversified product lines. Certification schemes and standardized life-cycle assessments can further help build market trust and ensure compliance with sustainability standards.

3. Strengthening Regional Collaboration and Innovation Networks

Nordic and Baltic countries can benefit from enhanced cross-border collaboration in the forest bioeconomy sector. Establishing regional networks and innovation clusters that connect forestry operators, processing firms, research institutions, and end-product manufacturers can facilitate knowledge sharing, joint ventures, and technology transfer. Regional coordination should also align with EU policies on the circular economy and sustainable forestry management.

4. Enhancing Digitalization and Supply Chain Transparency

Investment in digital monitoring systems is essential for ensuring quality, traceability, and efficiency throughout the forestry value chain. Policies should promote the adoption of digital tools and data analytics to optimize resource management, track sustainability metrics, and improve supply chain transparency. Such measures will help regional industries adapt to changing market demands while maintaining high environmental standards.

5. Facilitating Market Access and International Trade

To support the growing demand for natural, sustainable products, governments should work to reduce trade barriers and streamline regulatory processes. This includes harmonizing standards across the Nordic and Baltic regions and ensuring that locally produced bio-based products meet international quality and safety standards. Enhanced market access initiatives can help regional industries expand their reach both within Europe and globally.

6. Fostering Research and Development in Bio-Based Innovations

Continuous investment in R&D is crucial for further improving extraction methods and developing new applications for forestry side streams. Governments should support research projects that focus on green extraction techniques, the valorization of bioactive compounds, and the development of novel bio-based products. This research should be disseminated widely to inform both industry practices and policy formulation.

- Increase Horizon Europe funding calls targeting green extraction techniques (e.g., subcritical water, ultrafiltration) to raise tannin yields from 4% toward 8–10%.
- Support pilot-scale demonstration plants within Innovation Hubs (e.g., Bioeconomy regions in Uusimaa and Pomorskie) to validate process economics.

This research should be disseminated widely to inform both industry practices and policy formulation. Open-access case studies on residue valorization are a good option to accelerate knowledge transfer across academia and industry.

7. Fostering Public - Private Partnerships

Cross-sector collaboration can bridge the gap from lab to market:

- Establishing regional clusters (e.g., Baltic Biorefineries Alliance) to unite sawmills, chemical SMEs, and research institutes under shared roadmaps.
- Incentivizing co-funding schemes to offer matching grants (e.g., 50:50 public-private) for joint R&D projects on forestry residue valorization.
- Development of blockchain-backed supply-chain platforms ensuring quality, traceability, and certification compliance, reducing transaction costs and building investor confidence

8. Certification of non-wood forest products including bark and needles in private forests for organic production

When using ingredients extracted from logging residues in consumer products (such as cosmetics or food products), the origin of the raw material can significantly impact the final product's price. For example, in cosmetics, the use of organic raw materials greatly increases the chances of obtaining a higher-than-usual price for the final product. However, certifying forests for organic production is a difficult and expensive process for private forest owners. For this reason, very few private forests in Finland, for example, have been certified for organic production. The situation is similar in many other EU countries. Additionally, organic certification practices can vary between different EU countries.

For the reasons mentioned above, the certification of non-wood forest products including bark and needles in private forests for organic production should be simplified and standardized across the EU, making it easy and profitable for forest owners to certify even small forest areas. This would also ensure the availability of logging residues for further processing based on organic production and for high value-added products. This process should begin with a comprehensive study on how to improve the availability and feasibility of organic certification for private forest owners.

9. Streamlined Regulatory Frameworks

Current EU biocide and food-additive regulations impose lengthy approval processes and varied national interpretations, slowing market entry for novel, bio-based extracts. Policymakers should:

- Harmonize safety-assessment requirements for tannin and antibacterial products under the EU Biocidal Products Regulation (BPR) and Novel Food Regulation.
- Introduce a "fast-track" for circular-bioeconomy feedstocks, drawing on the EU Green Deal's priorities to reduce assessment times by 25–30%.
- Standardize "regenerative forestry" certification across Member States—shifting from costly organic labels to biodiversity-focused credentials that ensure traceability and consumer trust.

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