WP5- Improving bio-based industry in the pulp and paper sector

D5.2 "Report for Stakeholders: Pulp and paper sector-wide recommendations"

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1 Executive Summary

The European pulp and paper sector is undergoing a strategic transformation, shifting from traditional paper production to integrated biorefineries that generate a diverse array of bio-based products. This evolution is driven by declining demand for graphic paper, increasing interest in sustainable packaging, and the sector's ambition to contribute more significantly to the bioeconomy.

Emerging bio-based products already account for approximately 3% of the sector's turnover, with expectations for substantial growth. This report, developed under the Horizon Europe-funded ALIGNED project, presents sector-wide recommendations to improve sustainability assessment practices. It draws on stakeholder consultations and sectoral analysis.

Despite the sector's innovation, several environmental and methodological challenges persist. The pulp and paper industry is energy-intensive, contributing significantly to carbon emissions and water pollution. Stakeholders recognize Life Cycle Assessment (LCA) as a valuable tool for environmental evaluation but face barriers including data limitations, lack of harmonization, and methodological complexity. Similar challenges were highlighted in an exemplary case study on a novel biorefining technology. Specific concerns include difficulties in applying consequential LCA, handling multifunctionality, assessing biogenic carbon, and managing uncertainty in emerging technologies.

To address these challenges, the report offers four key recommendations:

- **Enhance Data Collection and Sharing:** Sector-specific frameworks and metadata templates are proposed to improve data quality and accessibility.
- **Anticipate Future Performance:** Adoption of consequential and prospective LCA approaches is recommended to reflect evolving technologies and market dynamics.
- **Apply Scenario and Sensitivity Analysis:** Modelling multiple functional units and testing economic allocation assumptions can improve robustness.
- **Conduct Uncertainty Analysis:** Evaluating variability in early-stage technologies and modelling assumptions supports informed decision-making.

By implementing these recommendations, the pulp and paper sector can strengthen the credibility of its environmental assessments, support sustainable innovation, and align more effectively with European climate and bioeconomy goals.

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1. Overview of the sector

Europe is the world's second-largest producer of pulp and paper, manufacturing 37 million tonnes of pulp and 100 million tonnes of paper (Cepi, 2021). However, the consumption of graphic paper products (i.e. printer paper, newspapers and books) is decreasing in Europe due to digitalization. While there is an increase in demand for paper-based packaging material the current level of profits for the pulp and paper sector is relatively low (Toppinen, Patari, Tuppura, & Jantunen, 2017). Thus, traditional pulp and paper manufacturing units are transforming towards multi-output biorefineries. These biorefineries produce bio-based products such as cellulose, biodiesel, bio-naphtha, lignosulphonate and tall oil products. The production of these bio-based products led to an additional turnover of almost 2.7 billion euros, which is almost 3% of the EU pulp and paper sector's turnover (Cepi, 2021). Through R&D programs and investment plans, this share of emerging bio-based products as a part of the EU's pulp and paper sector's turnover is expected to be substantially larger in the future.
The main source of feedstock for pulp and paper products are forestry products, mainly logs from trees, also known as roundwood. The roundwood consists of bark, cellulose, hemicellulose, lignin and extractives. The bark protects the fibres of the log, which are held together by the lignin. The pulping process aims at extracting these fibres by removing the lignin. Paper with a high lignin content has lower strength, worse performance, and the lignin can be attributed to the yellowing of the paper over time. Therefore, the main purpose of chemical pulping is the separation of as much lignin as possible. Chemical/kraft pulp production can remove 85 – 93 % of lignin from wood. The lignin extracted from this process is a low value black liquor used for combustion or power generation. However, lignin has a range of potential applications such as in adhesives, surfactants used as additives in concrete, textile dyes, batteries etc., or to reinforce bioplastics (Jung, 2022). Lignin, however, is not produced at industrial scale due to its unique non-uniform structure and the presence of organic and inorganic impurities that contribute to its complex chemical reactivity (Shasha Zheng, 2025).

Given the emerging need for diversification and valorisation of pulp production, the case study used in the ALIGNED project draws upon the novel technology developed by Bloom Biorenewables Ltd. Bloom has developed a "lignin first" biorefinery concept, where they focus on extraction, de-polymerization and valorisation of lignin. Lignin is valorised using Aldehyde Assisted Fraction (AAF) technique to produce lignin with well-defined properties and stabilized chemical structure. The technology is equally useful to extract stabilized structures of cellulose, hemi-cellulose and other lignocellulosic sugars (such as dimethyl glyoxylate xylose DMGX). Stabilized structures of lignin and hemicellulose are then valorised to be used for diverse end uses, such as cosmetics, textiles, bioplastics, food additives, biofuels, etc.

2. Identified sustainability assessment challenges

In this chapter, the main sustainability assessment challenges will be elaborated. The section describes which environmental and assessment challenges identified during the ALIGNED project with inputs from the sector overview, stakeholder workshops and project partners from the case study.

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2.1 Main environmental challenges associated with the sector

The key environmental challenges identified within the sector are typically related to resource consumption – particularly related to energy and water consumption.

Production of pulp and paper is an energy-intensive process. In Europe, this sector is the fourth largest industrial consumer of energy. The sector's energy intensity significantly contributes to the carbon emissions. The EU pulp and paper sector directly emitted 29 Mt of CO_2 in 2020, which is about 15% of global pulp and paper emissions (Cepi, 2021). In addition, the sector indirectly caused 8.77 Mt of CO_2 emissions through its bought electricity. This amounts to an additional CO_2 eq. emissions per tonne of paper produced (Cepi, 2021).

Water is a key element of the pulp and paper production. Many mills reuse 90% of their water consumption (Cepi, 2021). However, pulp production is also a chemically intensive process. During pulp bleaching, chlorinated and organic compounds and nutrients are released into wastewater. Wastewater from pulp and paper mills can cause serious threats to both aquatic and human health, as it pollutes surface water and underground water.

2.2 Assessment challenges identified by stakeholders within the sector

In the ALIGNED project, stakeholders indicated that impact of climate change, followed by increasing demands from customers and government policies were driving the push for environmental sustainability in the pulp and paper sector. Stakeholders supported the use of LCA as a tool for sustainability assessment as it is **holistic and data-driven with a scope beyond GHG emissions**.

LCAs are also considered as **time-consuming**, **complex, expensive, subjected to data limitations and not harmonized**.

However, stakeholders indicated that the verification of LCA results is largely hindered by data reliability, data availability as well as unclear definitions. They mentioned difficulties in performing internal LCAs, where data would have to be gathered from the suppliers, who often use different scopes and criteria.

The lack of data was particularly highlighted in relation to the use of consequential LCA methodology. Stakeholders indicated the challenges of using consequential LCAs were lack of market data, lack of renewable feedstock data, lack of expertise and incompatibility with existing standards.

Additional challenges related to LCA are related to the calculation of biogenic carbon, and the application of allocation to different co-products. Given the steady transformation of the pulp production to biorefining of novel materials, stakeholders indicate a strong interest in applying the prospective LCA but lack the framework or guidelines to do so.

2.3 Assessment challenges identified in the case study that are applicable to the pulp and paper sector

In the initial application of LCA, the case study on the biorefining process Bloom Biorenewables identified the following challenges in their assessment. This includes the reason what types of problems can occur in similar case studies.

- **Carbon neutrality principle for biomass** – This assumption potentially oversimplifies the actual carbon dynamics
- **System Boundaries** – Conducting cradle to grave assessments are challenging as most products produced are platform chemicals that can be used in several products which makes the identification of end of life difficult.

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- **Handling multifunctionality of co-products** – The biorefining produces multiple products. It is still unclear which markets the novel biomaterials will target and which functionally equivalent products will be substituted.
  Handling multifunctionality using allocation requires subjective decisions. Economic allocation depends on market prices which are currently not determined for novel products and are likely to fluctuate with time and market demand. This leads to inconsistencies and uncertainty in the results.
- **Upscaling and prospective assessment** – In general, there is uncertainty regarding the functioning of the technology at a potential industrial scale.

3. Recommendations

While LCA is considered a useful tool for a holistic environmental assessment, there are challenges related to lack of data and harmonization of methods. This section provides recommendations in relation to the challenges identified by stakeholders.

3.1 Improve sector specific data collection and sharing

Given that a key challenge in the implementation of LCA is lack of data, efforts need to be made to collect and share data.
The ALIGNED project provides some specific frameworks and templates that can be useful to build sector specific foreground systems (Pizzol, Ghose, & Lancz, ALIGNED D1.2 Description of scientific methods (Task 1.2 Framework for foreground life cycle inventory of bio-based sectors - LCI data template), 2024). This framework also provides a template to add relevant metadata associated with the data that can support findability and re-usability of the data.

3.2 Anticipate future performance

The pulp and paper sector is a key bio-based sector that is rapidly transforming. Given the transition in technologies and production of novel biomaterials and increasing competition for bio-based feedstock, the environmental assessment needs to anticipate its future development. This can be done by:

1) Application of consequential LCA – which considers market constraints and demand. ALIGNED provides a clear framework that can be used to identify resource constraints and marginal supply of bio-based feedstock in Europe (Pizzol M. , Ghose, Bollesen, & Nørgaard, 2024).
2) Application of prospective LCA – the ALIGNED project provides a framework to perform the LCA using prospective background databases (Cherubini & Wanatabe, 2024). This is particularly useful for the pulp and paper sector as the technologies and novel materials upcoming in this sector are likely to be used in future scenarios where the energy and resource use and availability are also likely to change.

3.3 Adopt scenario and sensitivity analysis

There is no clear market trend for demand and use of novel biomaterials. This creates several challenges related choice of functional unit, addressing multi-functionality and the choice of system boundaries. Using insights from the case study for this sector, the ALIGNED project recommends:

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1) In case of multi-functionality and unclear markets for the different co-products, analyse the system using multiple functional units. i.e., create different models that consider the demand for one product, while all other co-products substitute functionally equivalent product. For example, the case study analysed in ALIGNED three models were developed using three different functional units (e.g. 1 kg of cellulose, 1 kg of Lignin and 1 kg DMGX). To identify mechanisms to include substitution of functionally equivalent products the ALIGNED project provides specific guidelines in WP1 (Pizzol, Ghose, & Nørgaard Bollesen, 2024).
2) If the multifunctionality is handled using economic allocation, then the results should test the sensitivity of the results in relation to fluctuations in market prices.
3) Use of end-of-life scenarios can also support the challenges with assessing biogenic carbon. The system boundaries for assessment of biorefinery products are usually cradle-to-use as their final use can vary. ALIGNED recommends using the -1/+1 method in a cradle to grave analysis particularly to provide meaningful carbon balance. Using short-term and long-term end-of-life scenarios can be used to provide meaningful carbon balances.

3.4 Identify and perform uncertainty analysis

Uncertainty can arise from several factors. It is recommended to perform an uncertainty analysis. Identifying and performing an uncertainty analysis can support the reliability of the LCA model. ALIGNED provides a framework for interpreting uncertainty (Pizzol, Watanabe, Tschulkow, & Javourez, 2024).

- Early-stage technologies may perform differently under varying conditions (e.g., scale-up, geographic location, operational parameters). Uncertainty analysis captures this variability and helps assess the robustness of LCA results.
- Modelling assumptions such as system boundaries or allocation methods can contribute to uncertainty. Uncertainty analysis helps identify which choices most influence outcomes.
- Policy makers, investors, and stakeholders need to make decisions on novel technologies even when data is incomplete. Uncertainty analysis provides confidence intervals or probabilistic outcomes, supporting more informed decisions.

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4. Conclusions

The European pulp and paper sector is undergoing a significant transformation—from traditional paper production to integrated biorefineries producing a diverse range of bio-based materials. This presents both opportunities and challenges for sustainability assessment. While LCA is widely recognized as a valuable tool for evaluating environmental performance, its effective application in this sector is hindered by data limitations, methodological inconsistencies, and the complexity of emerging technologies. Stakeholders have expressed strong interest in using LCA to guide sustainable innovation, but face barriers related to data availability, harmonization, and the lack of sector-specific guidance.

To address these issues, the ALIGNED project offers a suite of actionable recommendations: improving sector-specific data collection and sharing, applying consequential and prospective LCA approaches, adopting scenario and sensitivity analyses, and conducting robust uncertainty assessments. These strategies are essential for capturing the dynamic nature of the sector and ensuring that sustainability assessments remain credible and forward-looking. By implementing these recommendations, the pulp and paper sector can enhance the transparency and robustness of its environmental evaluations, support the development of novel bio-based products, and contribute meaningfully to broader climate goals.

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