

Project title: Sustainable Supply Chain Design for Sawmills: A Novel Techno-Economic Analysis, Multi-Objective Optimization, and Industry 4.0-enabled Decision Support Tool

Industry partner(s): HAZI (in collaboration with the Basque Regional Government)

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Introduction & Background:

Forestry-based bioproducts continue to present strong economic potential by capturing value across the entire supply and production chain, with the lumber sector identified as the most profitable [1]. While wood processing yields both products and by-products, uncertainties in long-term supply and demand require a comprehensive Supply Chain (SC) analysis, covering everything from raw material sourcing to manufacturing and reuse. With transportation and logistics making up 45% of total industry costs, improving SC efficiency is critical for cost reduction and resilience [2]. The global lumber market is projected to reach \$174.3 billion in 2024, with sawmills and wood production contributing approximately \$50.8 billion (30%). The demand for lumber is driven by key purchasing industries, including paper products, millwork, wood pulp mills, logging, and lumber wholesalers. A significant portion of the market, \$11 billion in 2022, was allocated to international exports, emphasizing the importance of global trade for sawmill and wood-based industries gathered from Statistica data [3]. The sawmill industry in the Basque Country plays a pivotal role in the regional forestry supply chain, with diverse operations and innovative practices driving sustainability and economic growth. Given this projected growth, the Basque forestry sector has opportunities to strengthen its international market presence by expanding into emerging markets, optimizing supply chain efficiency, and diversifying value-added product offerings. Therefore, the objective of this project was to co-locate primary and secondary production facilities, for improved material utilization and value-adding potential through conducting two integrated phases. The first phase includes a detailed market assessment, supply-demand analysis, and a Techno-Economic Evaluation (TEA) focused on the viability of a sawmill using Radiata Pine in Murga, Spain, projected for 2050. This provides a structured investment framework for scaling up lumber and by-product commercialization. The second phase applies simulation modeling to optimize complex operations, reduce risk, and evaluate cost-effective scenarios.

Relevance to Circular Economy:

This research supports the development of circular supply chains in the Basque country by converting forestry waste, such as sawdust and bark, into high-value products like nanocellulose. The project integrates economic and simulation modeling tools to drive a shift toward a circular, resource-efficient forestry sector.

Methodology:

Lumber production starts with log arrival, cutting the logs, chipping and sawing, followed by drying and grading of final boards. Wood residues from sawing and trimming are repurposed for nanocellulose production. The methodology for scaling up both primary and secondary sawmill facility requires two main steps as shown in Figure 1: (1) development of economic feasibility based on TEA modeling using an Excel-based tool to estimate financial indicators such as Net Present Value (NPV) and Return on Investment (ROI) within 25 years planning horizon with an interest rate of 6%. For scaling up the sawmill facility, nanocellulose production feasibility depends on how sawdust and woodchips are allocated for converting to value-added product: 0% used in Case 1 (all sold), 50% in Case 2 (half for nanocellulose, half sold as pellets), and 100% in Case 3 (fully used for nanocellulose). Case 4 supplements 100% in-house use with additional external sawdust to boost yield. These scenarios highlight trade-offs in revenue and resource efficiency. (2) Optimization and simulation modelling are then developed to support strategic and tactical decisions for supplier selection and capacity planning. Simulation is conducted using the AnyLogic software [4] to evaluate system performance under various scenarios. A scenario analysis is conducted to examine the impact of different automation levels on production rate and prices.

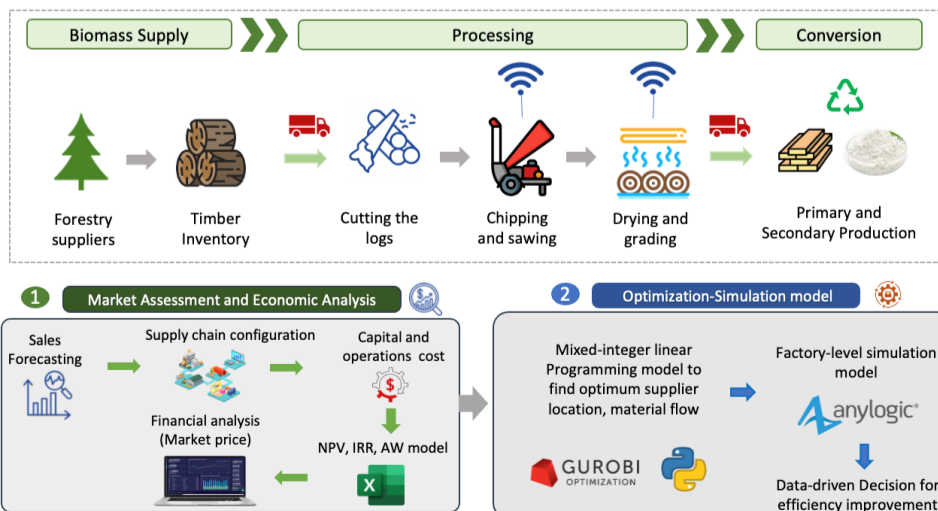


Figure 1: The proposed methodology framework for the feasibility study.

Results & Discussion:

Conducting market and demand analysis, the ranking of forestry-derived products highlights nanocellulose and biocomposites as having the highest opportunity, driven by their high market value (€3,000–9,000 per ton) and rapidly growing demand, particularly in automotive and packaging applications. The first phase results shown in Figure 2(a) indicate that both NPV and ROI increase significantly with the integration of secondary processing, reinforcing the economic benefits of expanding beyond primary lumber production. Case 1, which relies solely on lumber sales, has the lowest NPV and ROI, while Case 4, which maximizes secondary processing capacity, achieves the highest NPV (~\$1,332M) and ROI (~1000%). This trend demonstrates that scaling up secondary processing not only enhances total revenue but also accelerates investment returns and shortens the payback period. Also, Figure 2(b) shows that integrating secondary processing in Case 3 significantly increases Operating and Maintenance (O&M) costs compared to Case 1, which includes only primary processing. Specifically, Case 3 reaches a total O&M cost of \$13.8 million, up from \$9 million in Case 1. This rise is largely attributed to the additional energy, fuel, and maintenance demands of nanocellulose production. However, despite the higher operational costs, the enhanced revenue from secondary processing leads to greater overall profitability and a stronger ROI. In the second phase, the simulation results (Figure 3) indicate that while automation significantly increases upfront costs, it also boosts productivity and efficiency. As automation levels rise, the cost per unit output decreases, making High Automation the most cost-effective option in the long run for high-volume operations. This suggests that investing in automation can offer strong returns through higher throughput and reduced labor dependence.

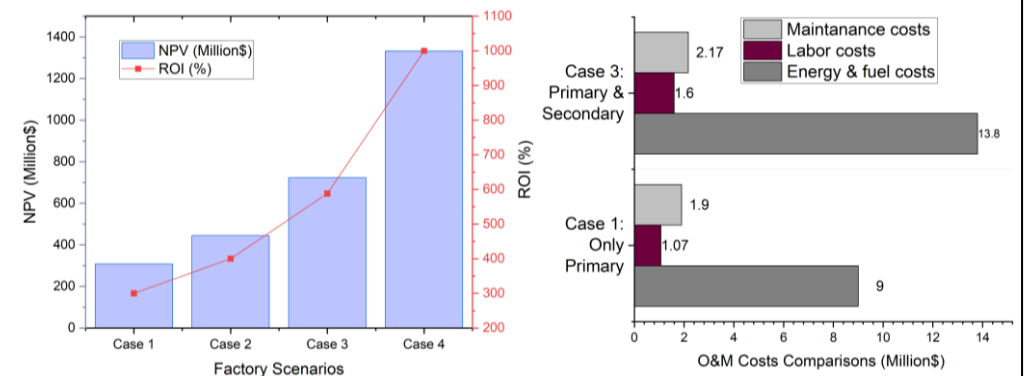


Figure 2: (left: a) NPV and annual ROI for the four cases. (right: b) Total costs breakdown for all cases (Operating & Maintenance costs).

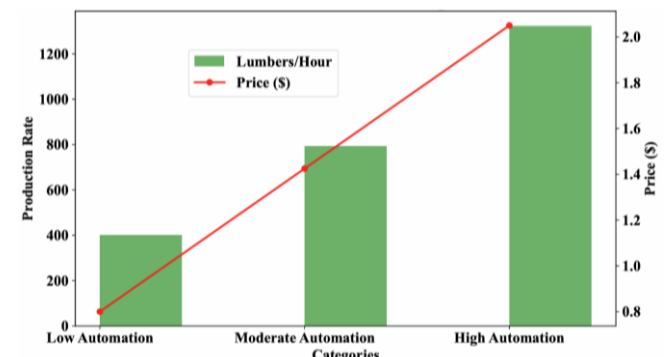


Figure 3: Impact of Automation Levels on Production Rate and Cost in Lumber Manufacturing.

Conclusion & Next Steps:

Integrating nanocellulose production into sawmill operations significantly boosts profitability by transforming low-value byproducts into high-demand, bio-based materials. Among the evaluated scenarios, Case 4, which utilizes all in-house sawdust and woodchips for nanocellulose and sources additional feedstock from local sawmills, achieves the highest Net Present Value (NPV) of \$1.3 billion with a rapid 2–3 year payback period, despite higher operational costs. Long-term competitiveness in the bioeconomy hinges on automation, securing stable market contracts, and adopting energy-efficient technologies. The company partner is currently developing the layout plan and preparing to implement a pilot plant at the targeted site in Murga, Spain.

References:

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