

NOVEL INDUSTRIAL ECOSYSTEMS AND VALUE CHAINS TO UTILIZE SIDE - STREAMS OF WOOD PRODUCT INDUSTRIES - FINNISH APPROACH

Erkki VERKASALO

Natural Resources Institute Finland (Luke), Production Systems
Yliopistokatu 6, FI-80100 Joensuu, Finland, E-mail: erkki.verkasalo@luke.fi

Jarkko LEPPÄLÄ

Natural Resources Institute Finland (Luke), Production Systems
Maarintie 6, FI-02150 Espoo, Finland, E-mail: jarkko.leppala@luke.fi

Timo MUHONEN

Natural Resources Institute Finland (Luke), Production Systems
Yliopistokatu 6, FI-80100 Joensuu, Finland, E-mail: timo.muhonen@luke.fi

Risto KORPINEN

Natural Resources Institute Finland (Luke), Production Systems
Tietotie 2, FI-02150 Espoo, Finland, E-mail: risto.korpinen@luke.fi

Veikko MÖTTÖNEN

Natural Resources Institute Finland (Luke), Production Systems
Yliopistokatu 6, FI-80100 Joensuu, Finland, E-mail: veikko.mottonen@luke.fi

Sirpa KURPPA

Natural Resources Institute Finland (Luke), Production Systems
Tietotie 4, FI-31600 Jokioinen, Finland, E-mail: sirpa.kurppa@luke.fi

Abstract:

Side-streams of wood product industries such as wood chips, planer shavings, saw dust, sanding dust, off-cut pieces, bark and liquid and gaseous wastes considerably contribute to cascading, sustainability and carbon balance as well as profitability of saw mill, plywood and further processing industries in northern Europe. They are important raw materials for pulp and paper, wood panel and bioenergy industries, and provide much basis for novel value-added products. Industrial ecosystems based on side-streams may be integrated with pulp and paper mills, chipboard or fibreboard mills or heating and power plants, concentrated to SME industry parks or decentralized between feedstock terminals, wood processing mills and biorefinery plants of different size. Availability and flows of raw materials and semi-finished products, enterprise network and collaboration, storage and transportation logistics and scaling of production essentially affect the optimal build-up of industrial ecosystems and value-add. The objective of this paper is to summarize results from our recent state-of-art and future perspective studies in Finland regarding industrial ecosystems based on side-streams of wood product industries. We stress here value and supply chains, scaling production, business and ownership, and present examples on well-functioning industrial ecosystems and enterprise networks in Finland.

Key words: wood product industries; side-streams; added value; industrial ecosystem; value chain.

INTRODUCTION

Wood-based side-streams are an important part of business income of wood product industries in North-European countries. In Finland, they currently constitute 15% of the revenue of large and medium-sized saw mills, and 7-12% of the income of plywood industries (Varis 2017a,b). On average 30–55% of their roundwood ends up to side-streams depending on the final product (Hassan et al. 2018). Of the logs with bark, saw mills obtain, on average, 42-54% sawn timber, depending on species, log size, region, saw mill technology and sawing set-up, and their side-streams consist of fresh and dry wood chips (28-32%), saw dust (10-15%) and bark (10-12%) (Varis 2017a; Verkasalo et al. 2017). Side-streams have a smaller role among furniture, building joinery, component and element manufacturers (including CLT) and pre-fabricated house and log house industries, and their volumes and economic significance are less known through statistics and research (Hassan et al. 2018; Kunttu et al. 2019). Side-streams of further processing are typically made up of planer shavings, saw and sanding dust and different-sized off-cut pieces and trimming wastes. Plywood, veneer and LVL industries generate fresh side-streams in log debarking and trimming, bolt rounding and peeler cores and fresh-cutting of veneer sheets, and dry side-streams after veneer drying in final cutting, edge-trimming and sanding. Processing birch or spruce at plywood mills provides, on average, 58% or 65% veneer for plywood, 16% or 12% rounding waste, 10% or 7% peeler cores, 3% off-cuts and 13% bark and dust, respectively (Koponen 1995; Varis 2017b). Some wood-based side-streams include

adhesives, surface treatment substances and wood impregnation chemicals. All wood product industries generate also smaller amounts of wood ashes as well as waste liquids and condensed vapours in drying, modification and treatment processes, which include water and different chemical substances, their origin being at least partly in wood and/or bark (Hakkila and Verkasalo 2009).

The main factors found influencing the use of forest biomass and side-streams are international and national policies, resource availability, networking of different industries, competitiveness of fossil products and fuels, and consumer behaviour, but the optimal allocation of side-streams depends on the targets and country-specific circumstances (Kunttu et al. 2019, Verkasalo et al. 2019). Wood chips, sawdust, and bark are considered the most valuable side-streams because of their relatively high quality and solid form (Hassan et al., 2018), but to date they have been mostly used in energy generation and partly in pulp and wood-based panel production in Europe (Hassan et al. 2018; Mantau 2015).

In Finland, the industry structure is dominated by chemical pulping and energy generation, with 60% of the wood-based side-streams used for energy generation but less than 1% for chipboard and fibreboard production (Ylitalo 2019). However, a range of new potential uses should be available in the chemical, biofuel, modified wood and composite industries, in the context of the growing interest for side-stream utilization. Here, the main drivers were identified as shortage of roundwood resources in the future, availability of side-stream resources (also through energy efficiency improvements), emerging markets for wood-based products, savings in raw material costs, climate change mitigation, cascading use of biomass and circular economy, and, finally, the EU policies (Antikainen et al. 2017; Kunttu et al. 2019; see also: Panssar et al. 2016; European Commission 2018).

Novel products, markets and stakeholders involved inevitably imply new supply and value chains, enterprise networks and collaboration, raw material and process integration, storage and transportation logistics and scaling the production at different steps for optimal build-up of industrial ecosystems and value-add. Depending on the case, production plants and enterprises may form different value networks where the degree of integration, concentration and decentralization varies. Industrial ecosystems are still under development in side-stream utilization, however, well-functioning examples already exist both on concentrated, integrated and decentralized solutions in Finland.

OBJECTIVE

The objective of this paper is to summarize results from our recent state-of-art and future perspective studies in Finland regarding industrial ecosystems based on side-streams of wood product industries. We stress here value and supply chains, scaling production, business and ownership, and present examples on well-functioning industrial ecosystems and enterprise networks.

MATERIALS AND METHODS

This paper is based on the results from three different projects of Natural Resources Finland Luke: UBES 2016-17 (Verkasalo et al. 2019), Woodpolis Kuhmo 2016-17 (Verkasalo et al. 2017) and WoodCircus 2018-2021 (WoodCircus 2019).

In the UBES project, we made an explorative background study regarding new biorefinery ecosystems and their scaling, performed a short impact analysis, identified relevant research, development and innovation (RDI) projects and presented an estimate on the resources needed in them in the future. We outlined the approach and definitions of biorefinery concept to investigate benefits and drawbacks of production scales from the viewpoints of volume-based and specialized production, set-up of value network and collaboration, and location of production sites and material logistics. Wood product industry based, chemical forest industry based and agro-biomass industry based solutions as well as hybrid raw material solutions were included to the survey.

In the Woodpolis Kuhmo project of the local wood product industry park, we mapped the current and potential side-streams, identified relevant new business opportunities for the companies and the development actions needed to fully implement the wood-based side-streams and develop the value network and industrial ecosystem. We outlined alternative ways to own use or selling of side-streams to new customers and presented new company-specific and production-oriented solutions to the local industries and suppliers of machine and equipment for side-stream handling or processing.

In the on-going WoodCircus project, the main goal is to increase knowledge, raise awareness and improve conditions to uptake resource efficient processing and recycling and support side-stream utilization and waste management in wood construction driven value chains in Europe (wood product industries, green field construction, building demolition, recycling). First, state-of-art analysis, fact finding, good practice mapping and SWOT-analysis were done in four European regions, continuing with actions of stakeholder integration, dissemination and policy impacts in EU and the countries.

In each project, we collected the data through literature review and internet search as well as performing focused interviews of selected experts in Finland RDI organisations, wood product industries, forest-based, agro-based and hybrid biorefinery and recycling companies and public regional decision

makers. We used semi-structural interview forms their design being specific in each project, mailing the forms to the experts prior to the interviews. The forms are available as appendices in the before-mentioned reports of the projects UBES and Woodpolis Kuhmo, and from the WoodCircus project materials of Luke.

In the UBES project we used relevant research literature searched through appropriate key words and Google advanced internet search (488 hits). Interviews were done by telephone among stakeholders (20) and by webropol among researchers (37). Finnish stakeholder network register of biorefinery branch was used to identify relevant participants to the interviews (104 enterprises, organisations or persons). For the purpose of this paper, we identified, analysed and compiled the answers relevant to the side-streams of wood product industries. In the Woodpolis Kuhmo project we interviewed 15 representatives from the companies of the Kantola industry park and 9 experts among Finnish RDI organisations (6) and consulting companies (3). All answers were considered relevant for this paper. In the WoodCircus project, we made 15 interviews in Finland among wood product, building with wood and recycling companies and public regional development agencies, and complemented them with a workshop among the member companies of Finnish Sawmill Industries Association (14 participants).

For this paper, the data was compiled and analysed using qualitative methods, and the main conclusions were drawn as researchers' desk work. Both causal reasoning (managerial thinking) and effectual reasoning (entrepreneurial thinking) were applied in the analysis (Sarasvathy 2008). Causal reasoning is based on selecting between given means to achieve a pre-determined goal, whereas effectual reasoning applies imagining possible new ends using a given set of means. In causal approach, product or service targets are defined first, and raw materials and other resources are collected thereafter. In effectual approach, development actions start from existing resources and produce thereafter new useful products or service through an interactive process. Effectuality is said to be more efficient than causality in the scarcity of resources.

The analysis includes summarizing the definitions of industrial ecosystems, basic rules of scaling production in typical cases of raw material, product and logistics situations, considerations of value chains, enterprise networks and business collaboration to launch novel products that are based on side-streams of wood product industries. Finnish SWOT analysis is presented and examples of the industrial ecosystems and networks are drawn as good practices from the before-mentioned projects.

RESULTS

Side-stream supplies, markets and current products

Finnish forest industry generated a total of 27.7 million tons of side-streams in 2016, consisting of 49.2% black liquor from pulp mills, 28.5% solid wood-based wastes, 14.1% sludge, 4.4% ashes, and 3.8% others (Hassan et al. 2018). Volumetrically, wood product industries produced around 9.1 Mm³ of wood chips, 4.0 Mm³ of saw dust and other wood residues and 3.3 Mm³ of bark in 2018 (Ylitalo 2019). Of the total volume, 8.6 Mm³ was supplied to the raw materials of pulp and paper mills which comprised almost all green wood chips and a part of saw dust, and the rest to heat and power plants. In the study of Hassan et al. (2018), side-streams of saw mills comprised 48% of pulp chips, 43% of saw dust and bark for energy, and 8% of slabs, endings and dry wood residues for energy, whereas side-streams of plywood, veneer and LVL mills comprised 50% of pulp chips, 30% of fuel chips and 20% of bark, saw and sanding dust and other wood residues for energy. Finnish chipboard and fibreboard mills – which are only one of each in Finland – use saw dust and bark, and roundwood only in exceptional supply conditions (Kumar and Verkasalo 2018).

In Finland, the main products starting from saw mills and veneer chips are chemical, mechanical and semi-chemical pulps and the resultant versatility of paper and paperboard grades (Hakkila and Verkasalo 2009; Kunttu et al. 2019). The market of green chips is steady, albeit the considerable fluctuation in market prices, and the demand is growing further due to the announced and prospective investments in pulping (e.g., Kunttu et al. 2019; WoodCircus 2019).

The market of other side-streams, mainly saw dust, dry chips and bark is more problematic and dependent on the demand of and public subsidies to the bioenergy sector. There are three pulp mills that continuously use saw dust in the integrated production of different packaging papers and paperboards, and approximately 30 wood pellet factories throughout the country that use mainly saw dust and planer shavings as their raw material (Kunttu et al. 2019). Combined heat and power plants (CHP) of the municipal energy companies and forest industries are important users of wood residues and bark, and wood product industries are commonly co-owners of the plants. However, the utilization rate of CHP plants varies much according to the demand of heat and market price of electricity, strongly affecting the market price and demand of wood residues and bark. Other factors affecting negatively to the markets are public subsidies of alternative bioenergy sources, such as forest chips and logging residues, import of forest chips, wood residues and bark, long transportation distances and high transportation costs, and lack of alternative large-scale uses (Verkasalo et al. 2017, Kunttu et al. 2019). There is locally some demand of side-stream materials for green infrastructure building, landscape management, soil improvement, horse stables and other animal houses.

The newest biorefinery products from side-streams comprise mainly pyrolysis oil for replacing light heating oil in heating plants and industries, and liquid fuels from saw dust for vehicles (tall oil, bioethanol), their demand being based on the obligation to mix renewable fuels to petroleum and diesel in land vehicle traffic (E10, E15, biodiesel). There are only a few ready-to-market products that aim to Business-to-Business markets (BtoB). However, wood lignin based adhesives and paints were recently started to produce, replacing their phenolic components, and biodegradable packaging materials from wood fibres were launched for food, beverages and catering. In Business-to-Consumer market (BtoC), some wood fractions, such as extractives from knotwood and inner bark of spruce and pine are used in small amounts in nutritional, medical and skin care products and cosmetics.

Industrial ecosystems and value chains

Industrial symbiosis or ecosystem is a whole of several enterprises where companies complement and provide added value for each other by utilising effectively raw materials, technology, service and energy (e.g., Axtell et al. 2008). Side-stream or waste generated in the production of a company can be a raw material for another company, as a result, the material changing from a cost item to valuable factor of production. In the recent scientific literature, industrial ecosystems have been understood in a large context, not only as material circulation but also sharing knowledge and insight between the stakeholders to generate new ideas and innovations. Business ecosystems to be built around industrial symbioses provide more added value using less natural resources than in traditional industrial value chains, utilizing materials and waste flows more efficiently with less energy, water and amount of wastes. Business ecosystems are understood differently in various contexts, but finally the group of agents, i.e. members of ecosystem should share the business values and revenue logic.

According to our findings, the entire pathway of a new product or service idea to the customer market lasts typically 10-15 years in wood based industries, because of needs to develop manufacturing technology and knowledge, create product or service standards, verify matching to regulatory requirements and build the value network of actors (Kunttu et al. 2019). The pathway includes several stages of up-scaling where the steps from the results of research and laboratory testing to the level of proof-of-concept, industrial piloting or pre-manufacturing and test marketing are usually the most crucial to raise the interest and convince the industrial operators and investors (expected revenue, profitability, risk management). This has been valid also in side-stream business.

Scaling of production volume affects essentially the organisation of sourcing raw materials or semi-finished products, manufacturing, deliveries and logistics in biorefinery processes. In a large-volume production of bigger companies, the structure of actor network, needs of collaboration and optimal location of manufacturing and storage steps are different than in a specialized production of SMEs. Management of value network, ownership of the companies, collaboration models, and readiness to incentives, resources and commitments to investment and development actions vary between large and small companies, being often linked with the degree of integration and decentralization.

Basically, we identified five typical value chains in Finland representing different industrial ecosystems of side-stream utilization where wood product industries are strongly involved:

1. Value chain of biorefinery located on the site or in the vicinity of a large manufacturer of chemical forest products which receives side-streams from wood product industries and supplies further-processing industries with its basic products and all industries on the site with different infrastructure service. Example: UPM Pietarsaari; UPM saw mill delivers chips to UPM sulphate pulp mill, one part of saw dust to Billerud kraft and sack paper mill and bark and one part of saw dust Alholma Kraft CHP plant; UPM supplies Billerud with a part of kraft pulp; UPM provides total green water, waste water and sludge management, security service, wood yard operations, RDI platform, etc.
2. Value chain of biorefinery where several chemical industries of large corporation procure raw materials, including side-streams, with long-term contracts from a number of wood products industries in a larger area which belong to the company or are independent companies, and supply further processors with their basic products and side-streams. RDI platform is strong. Example: Metsä Group, Fig. 1.
3. Value chain of a large wood product company with both basic production, further processing and possibly an energy plant. The use of side-streams in own production and energy plants is maximized and only chips is supplied to chemical forest industries. RDI is managed by the company itself. Example: Koskisen Oy, Fig. 2.
4. Value chain of several wood product companies in an industry park where SME companies build a local mutual network based on the basic products, further processed products and bioenergy. Collaboration potential is then maximal. Triple Helix based RDI platform can be innovative and flexible. Example: Woodpolis Kuhmo, Fig. 3.
5. Value chain of an individual wood product industry with none of or limited further processing. Side-streams are sold after sorting or up-grading to other companies located outside the site. Resources for RDI are typically limited. Example: Virtual saw mill, Fig. 4.

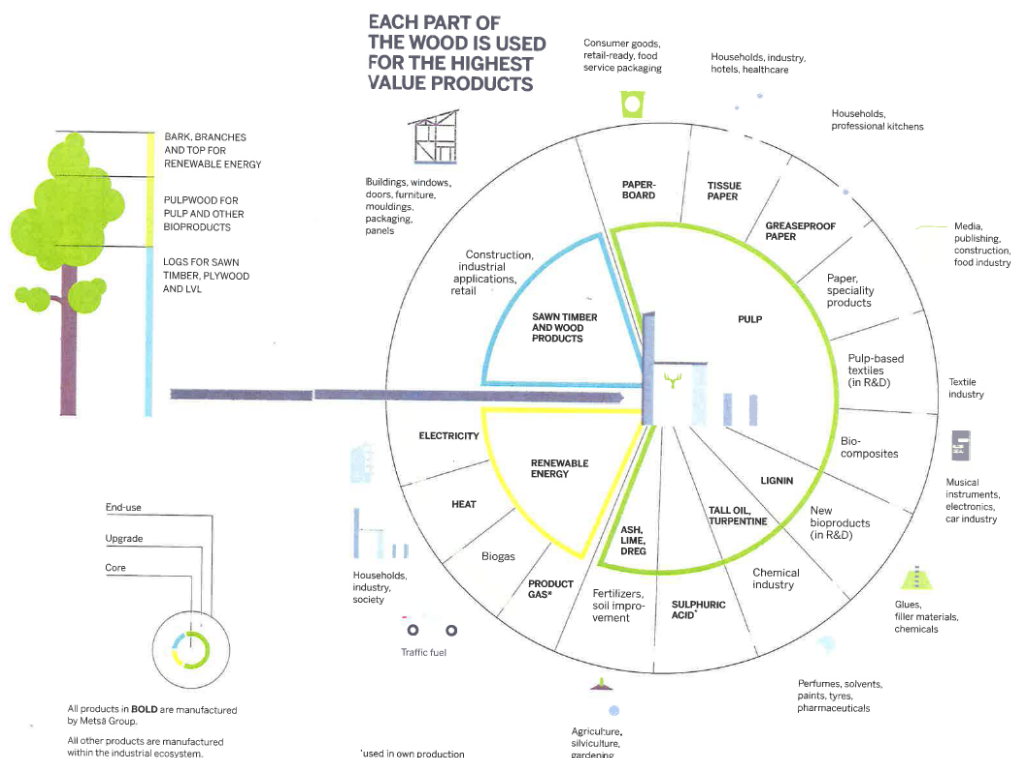


Fig. 1.

Value chain of integrated forest industry company (Source: Metsä Group).

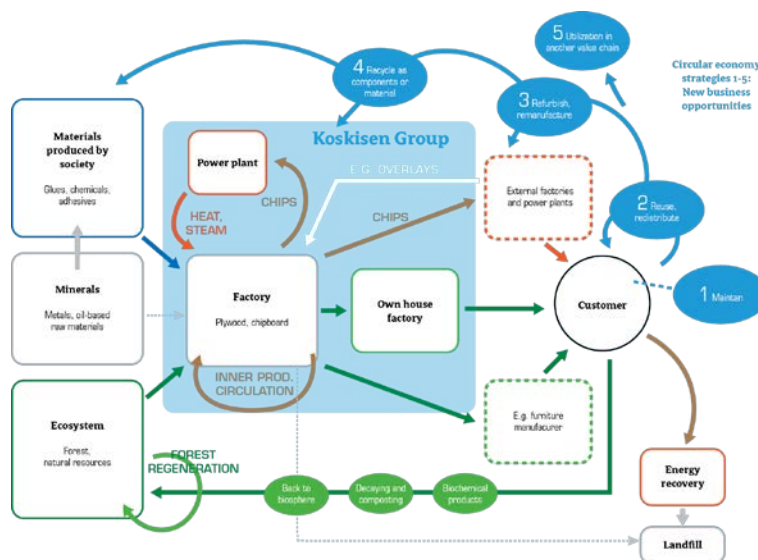


Fig. 2.

Value chain of wood products industry company (Source: Koskisen Group).

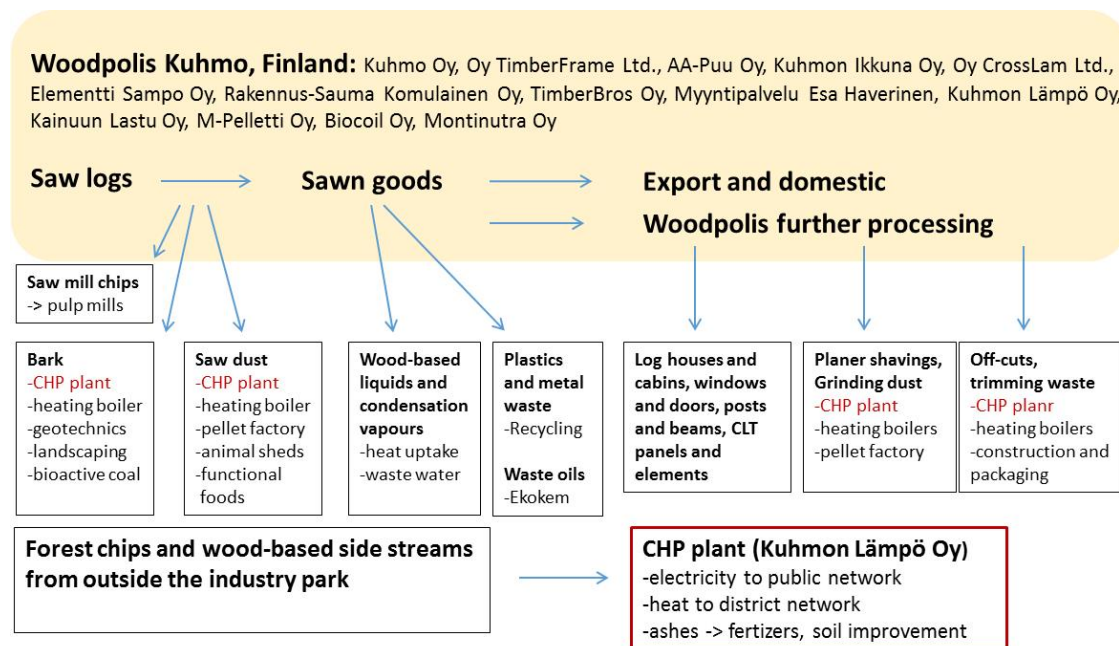


Fig. 3.

Value chain of industry-park based wood product industries (Verkasalo et al. 2019).

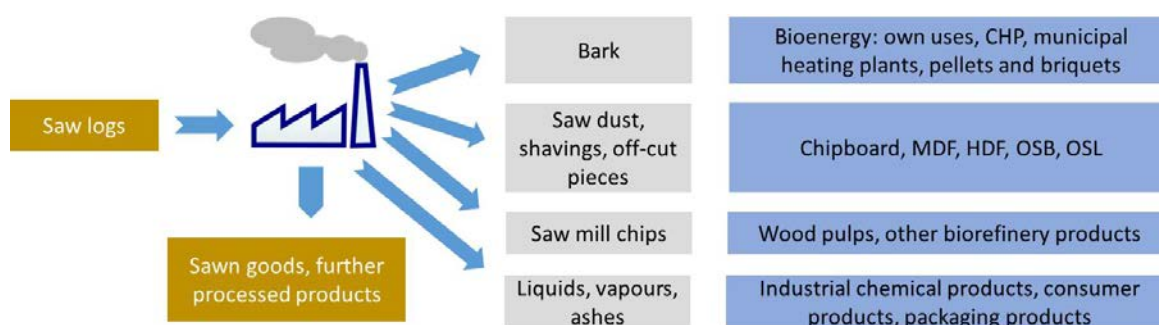


Fig. 4.

Value chain of individual sawmill (Verkasalo et al. 2019).

SWOT AND DEVELOPMENT OPTIONS

According to Thompson and Strickland (1999), a SWOT analysis enables an industry company to understand the dynamics of its business environment. Table 1 summarizes the current and potential strategic performance of side-stream utilization in Finland in the form of SWOT analysis, according to our studies. Likewise in Kunttu et al. (2019), the needs of industrial transformation towards ambitious circulation and smart regulation encouraging markets towards the targets are emphasized, but considering the current industry structure, prospective dynamics and RDI potential.

Table 1

SWOT analysis on the strategic performance of side-stream utilization of wood product industries in Finland

STRENGTHS Circular economy approach and sustainability Large total volumes of side-streams, renewable raw material and bioenergy sources (certificated) Shared procurement and delivery with other wood assortments, efficient comminution and bioenergy technology High resource efficiency and closed loops (+) Well-functioning value chain & market for chips (+) Efficient integrated forest products companies Versatile markets in energy sector Efficient regional solutions and public support in RDI, investments and regulatory work (Triple Helix) Dedicated and trustful companies of different sizes (in some regions) Future-oriented product development (+)	WEAKNESSES Varying profitability and lack of capital among wood product and bioenergy industries (RDI, investments) Unstable markets and low prices for most of the side-streams, except chips (for suppliers) High competition and costs of side-streams are critical in some regions (for users) Unprofitability of wood-based electricity generation Logistics costs and scattered sources of raw materials and semi-finished products Challenging landfill materials (most of wood ashes, painted, treated, glued) and hazardous wastes (contaminated) Weak durability of some side-stream based products Different interests and resources for incentives of integrated forest products companies and SMEs
OPPORTUNITIES Positive perspective for circular economy: aims and attitudes of society and decision makers Carbon sink approach and green policy incentives Positive and predictable regulation development Green deal agreements between private and public parties to achieve sustainable development goals Limited biomass resources call for more cascading New side-stream based products and users: value-added biorefineries, chemical and composite products (BtoB and BtoC), replacing coal and oil in energy generation with wood pellets and other wood-based products and renewable liquid fuels, overall replacing of plastics, biochar for soil amendment and water management, wood panels and other construction products, uses for off-cut pieces of building elements and furniture billets Trustful company relationships and collaboration Optimized integration: industry park approach, industrial ecosystems of large companies and SMEs Better classification, sorting and knowledge of side-streams & end-of-waste criteria (suppliers, users) Longer life-cycle, better durability, LCAs and EPDs for side-stream based products Markets & technology are developing in cascading Market & customer surveys, economic assessment of alternative products, proofs-of-concept Adoption of good practices (Europe, Eastern Asia, North America)	THREATS Slow reactions in company strategies and public policies to changing product and customer markets Slow and expensive development of new products and uses for side-streams Continuing low profitability and investment capacity of wood product and wood-based electricity industries Continuing scarce RDI resources and lack of proofs-of-concept, especially among SMEs of wood product and biorefinery industries Eventual lack of entrepreneurs and workers in the supply and manufacturing stages of the value chains (in some regions) Decreasing district heating outside urban districts Unpredictable regulation and subsidizing policies of bioenergy and waste management (EU, Finland) Lack of trust and collaboration between companies to build industrial ecosystems Disagreement of different producers and interest groups about the priority uses of side-streams and regulation and subsidizing policies (saw mills – bioenergy – wood panel industries) Omitting societal requirements, renewable raw material brand & carbon sink approach in strategic planning and dissemination to the different stakeholders and big audience

CONCLUSIONS

Finland is one of the most advanced industrial users of side-streams of wood product industries (saw mills, plywood, veneer and LVL mills, further processing industries), with a history of more than hundred years of manufacturing fibre-based, sugar-based and extractive products and derivatives of chemical components, or converting them to energy at the mills. Notably, wood residues have not been directly burned to the sky in the mills since 1950's. Wood pulp and bioenergy continue to be the most important primary addresses of the side-streams, but value-added chemical biorefinery products for a variety of BtoB and BtoB products have been started to rise during the 2000's, some of them being already in the market or under launching there. Unlike elsewhere in Europe, the few chipboard and fibreboard mills are currently minor users of side-streams; however, in the recent scientific discussion indicated a potential for re-invention of these industries. Access to and competitiveness in the product markets, relationships of product and raw material prices and level of knowledge and technology are important determinants for the Finnish production, and they have largely affected the success and failures of chipboard, fibreboard and different bioenergy industries.

Different products and raw materials lead to different supply and value chains and enterprise networks in the utilization of side-streams of wood product industries where the material and energy flows and set-up of companies, their responsibilities, ownerships and mill locations vary. The more advanced products are manufactured, the longer are the value chains and the more companies or other stakeholders are involved, the more important are the trustful industrial symbioses, or ecosystems, well-functioning collaboration and easy links between the participants and clear ownerships and responsibilities in the network. The degree of concentration, decentralization and integration should vary depending on the scale of production and volume of raw materials needed, orientation to basic, customized or specialized products, interactions between raw materials and products, logistical issues in transportation and storage, breakdown of value chain operations between the companies and needs of collaboration and responsibilities of the participants. Generally, the companies should benefit from integrated production systems to improve economic profitability, meet the future requirements of waste management and environmental control and achieve the most effective climate change mitigation impacts.

We identified five basic types of industrial ecosystems that are suitable for different kinds of side-stream utilization of wood product industries, examples of them being already present in the forest cluster. Some of them may be applied in hybrid cases where different renewable raw materials are used parallel to or combined with each other, for example, CHP plant generating heat and electricity using bark, saw dust, forest residues, peat and agro waste, LSL mill manufacturing laminated strand lumber (Scrimber) from cutting waste of wood veneers, bamboos and bagasse, or a mill manufacturing construction insulation materials using saw dust, natural hemp or willows.

Our selection of ecosystems is relevant also to the three scenarios of side-stream utilization by Kunttu et al. (2019): (I) Pulp and Bioenergy, (II) Versatile uses; (III) Long-lifetime products. Here, the first option is closest to the current structure and economic stability of the industries, the second option is dependent on global political actions emphasizing resource efficiency with large-scale circulation, substitution potential of non-renewable resources and economic risk diversification, and the third option highlights the carbon storage perspective. Notably, political tools such as regulations, standards and public support to RDI and investments are rated important to attract industries into resource- and energy efficient strategies with efficient material circulation of all side-streams, not only commercially viable by-products.

Regarding the research methodology, we could join the general opinion among the scientists of industrial ecosystems that effectual reasoning that aims to reflect entrepreneurial thinking is a suitable technique in this kind of set-up where several alternatives of product or service pathways are available to utilize existing or prospective resources which are labelled with scarcity. Causal reasoning can then help in selecting the choices. SWOT analysis is a necessary tool to understand the dynamics and impacts of the strategic and operative environment.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the projects UBES, New biorefinery ecosystems with benefits from scales (funding from Luke), Woodpolis Kuhmo, Investigation on side-streams of Kantola wood industry park (funding from Woodpolis Kuhmo) and WoodCircus, Underpinning the vital role of the forest-based sector in the circular bioeconomy (funding from EU H2020-CE-SC5, project 820892).

REFERENCES

Antikainen R, Dalhammar C, Hildén M, Judl J, Jääskeläinen T, Kautto P, Koskela S, Kuisma M, Lazarevic D, Mäenpää I, Ovaska JP, Peck P, Rodhe H, Temmes A, Thidell Å (2017) Renewal of forest based manufacturing towards a sustainable circular bioeconomy. Reports of the Finnish Environment Institute 13/2017.

- Axtell RL, Andrews CJ, Small MJ (2002) Agent-based modeling and industrial ecology. *Journal of Industrial Ecology* 5(4): 1-13. Online at: <https://doi.org/10.1162/10881980160084006>
- European Commission (2018) Updated Bioeconomy Strategy: A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment. Publications Office of the European Union, Brussels.
- Hakkila P, Verkasalo E (2009) Structure and properties of wood and woody biomass. In: Kellomäki, S. (ed.). *Forest Resources and Sustainable Management. Papermaking Science and Technology, Volume 2*, pp. 133-215. Paper Engineers' Association / Paperi ja Puu Oy. Gummerus Oy, Jyväskylä.
- Hassan MK., Villa A., Kuittinen S., Jänis J., Pappinen A (2018) An assessment of side-stream generation from Finnish forest industry. *Journal of Material Cycles and Waste Management*, pp. 1-16.
- Koponen H (1995) Wood panel production (in Finnish). Gummerus Oy, Saarijärvi. 212 p.
- Kumar A, Verkasalo E (2018) Current status and future implications of Finnish wood-based panel industries. *Proceedings of the 14th Annual Meeting of the Northern European Network for Wood Science and Engineering (SWE2018)* / Kallakas H. (ed.), pp. 12-126. Tallinn University of Technology, Estonia.
- Kunttu J, Hurmekoski E, Heräjärvi H, Hujala T, Leskinen P (2019) Preferable utilisation patterns of wood product industries' by-products in Finland. *Forest Policy and Economics* 2019-101946. Online at: <https://doi.org/10.1016/j.for.pol.2019.101946>
- Mantau U (2015) Wood flow analysis: quantification of resource potentials, cascades and carbon effects. *Biomass and Bioenergy*, 79 (2015), pp. 28-38.
- Pantsar M, Herlevi K, Järvinen L, Laita S (2016) Leading the cycle: Finnish road map to a circular economy 2016 – 2025. SITRA Studies 121. Online at: <https://media.sitra.fi/2017/02/28142644/Selvityksia121.pdf>
- Sarasvathy SD (2008) *Effectuation: Element of Entrepreneurial Expertise*. Edward Elgar Publishing, London, UK.
- Sathre R, Gustavsson L (2009) Process-based analysis of added value in forest product industries. *Forest policy and economics*, 11(1), pp. 65-75.
- Thompson AA, Strickland AJ (1999) *Strategic management: Cases and concepts*. Singapore: Irwin/McGraw-Hill.
- Varis R (Ed.) (2017a) *Sawmill Industry. The Association of Finnish Sawmillmen*. Saarijärven Offset, Saarijärvi, Finland. 285 p.
- Varis R (Ed.) (2017b) *Wood-Based Panel Industry*. Finnish Woodworking Engineers Association. Bookwell Oy, Porvoo, Finland. 276 p.
- Verkasalo E, Kurppa S, Korpinen R, Leppälä J, Muhonen T, Kurttila M, Katajajuuri JM (2019) UBES New biorefinery ecosystems with benefits from scales: results and recommendations of development project (In Finnish). *Natural Resources and Bioeconomy Studies*. Natural Resources Institute Finland (Luke). Manuscript.
- Verkasalo E, Möttönen V, Kilpeläinen H (2017) Investigation on side-streams of Kantola wood industry park, Woodpolis Kuhmo (In Finnish). 27 pp. + Appendices. *Natural Resources and Bioeconomy Studies*. Natural Resources Institute Finland (Luke).
- WoodCircus (2019) Underpinning the vital role of the forest-based sector in the Circular Bioeconomy. Online at: <https://woodcircus.eu/index.php/about/>
- Ylitalo E (2019) Official statistics of Finland: forest industry wood utilization, Natural Resources Institute (In Finnish). Online at: <http://stat.luke.fi/metsäteollisuuden-puunkäyttö/>