WoodCircus

Underpinning the vital role of the forest-based sector in the Circular Bioeconomy

D2.2 Resource Efficiency, Side Streams and Value Chains Analysis – WP2 Final Report

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Executive summary

WoodCircus project belongs to the Horizon 2020 research and innovation programme under grant agreement No 820892. WoodCircus increases knowledge, raises awareness and improves conditions for an uptake of resource efficient processing and recycling in wood-based value chains, fostering increased competitiveness of the European woodworking sector.

WoodCircus is supported by 17 partners of whom five are industrial partners, three from federations and associations and seven from research organizations. The management structure is designed to fit the projects objective and the nature of a CSA project ensuring precise and timely information exchange among a high number of partners and stakeholders. The project management, quality assurance and risk management procedures of WoodCircus are designed to support the proper implementation of the project in a lean, open and supportive manner. The management, quality assurance and risk management procedures are taken into account in all tasks and activities of the project implementation, dissemination and overall communication activities by the coordinator and project partners.

WP2 Analysis of the state of art and fact finding data and compilation of good practices and further recommendations collected and analysed the existing knowledge and industry views, experience and know-how on utilization of side streams of wood product industries, wood construction and demolition as well as waste recycling and management, driven by wood construction value chain. Analysis of SWOT, good practices plus development potential and needs were performed on raw materials, products, markets, resource efficiency, classification systems, value chains and their stakeholders, processing technology and selected stakeholder collaboration including societal issues. The scope was in fact finding, update state of the art and review, from technical and regulatory point of view, about the recovery and recycling processes and organizations of value chains in four different regions of EU. Data collection included focused literature review and internet search, interviews or questionnaire surveys among 99 industry experts in 10 countries from four regions in Europe (southern, central, northern, eastern) and three special workshops (Warsaw for EU-13 countries, Helsinki for Finnish saw mill experts, Cologne for Central-European wood panel and bio-composite industry experts). WP2 consisted of the tasks: 2.1 Raw material categories and product potential, 2.2 Side stream processing and recycling techniques, 2.3 Resource efficiency in value chains. Good practices compiled in WP2 will be further analysed, screened and developed toward more detailed recommendations in the next stages of WoodCircus in WPs 4-5. Data collected on policy instruments and development incentives, funding programs and financing agencies will be compiled and analysed in WP6.

In EU-28 more than 70% of wood products are used in construction or furnishing. Of the log volume, about half ends up to side streams. The most usual way to treat waste wood is energy recovery or recycling (mostly wood panel industries), with large variation between countries. In 2016 recycling reached the first time higher value that energy recovery.

Construction, demolition and new bio-based products represent two of the five priority areas in the EU action plan for the circular economy. Circular economy is prevalent in practically all Europe, but significant differences between EU-28 member states are present in the status, performance and value chains of wood cascading and recycling. Regions and countries have

different opportunities and specific framework conditions which should be appreciated in policy actions and development priorities.

European companies know rather well the classification of wood side streams, but sorting and allocation to different uses should be improved. Companies are basically positive for harmonization of regulation and standards, but unpredictable and complex requirements are suspected. High resource efficiency and well-functioning value chains are strengths for industrial by-products and provide income for suppliers, whereas construction and especially demolition wastes cause costs. Value chains are different as viewed by suppliers and customers of different-level side streams and products.

New uses, markets and valorisation are needed and innovative products and advanced technology for by-products and recycle materials are under development. Competition of side streams between different uses is common, and market penetration with recycle products perceived of low quality and performance is difficult. Triple Helix collaboration works well in some regions, but not all over Europe due to regional specifics. Except big corporations of forest and energy sectors, companies lack either of know-how, incentives, resources and sometimes pressure for RTDI and investments (SMEs, secondary processing), or even all together.

Plentiful good practices regarding products and materials, technology and processes, management and efficiency, innovation and also construction and demolition have been identified in WoodCircus. Most of them are applicable and transferable to other European countries. Development needs were shown both in research, testing, piloting, proofs-of-concept and branding of side streams and their business and market potential, and regulation, standardization, communication, promotion, education, value chain management and stakeholder collaboration, four-angle sustainability and societal thinking. RTDI needs are in one hand common for all parts of side stream value chains, but on the other hand specific for different sub-sectors.

1 Introduction

WoodCircus project belongs to the Horizon 2020 research and innovation programme under grant agreement No 820892. WoodCircus increases knowledge, raises awareness and improves conditions for an uptake of resource efficient processing and recycling in wood-based value chains, and fosters increased competitiveness of the European woodworking sector. The project links the challenges and opportunities for resource efficiency and cascade use of wood and wood side streams with the aim to enhance the wood construction sector and improve environmental, economic, and social sustainability. The project identifies, evaluates and disseminates the outstanding good practices in process efficiency, wood waste collection, management and recycling in the woodworking value chains in Europe with a focus on wood construction. Achieving a thorough evaluation of the overall system's performance and a validation of the most relevant transferable solutions, the project produces sound, critical evidence and tangible decision support information for market actors, stakeholders and policymakers. To sustain the European exchange and market uptake of solutions, the project establishes a well-integrated network of the key existing stakeholders, notably between wood processing industries the waste management sector and the RDTI community.

2 WP2 – Analysis of the state of art and fact finding data and compilation of good practices and further recommendations

2.1 Objectives

The main objective of WP2 was to assemble the existing knowledge and good practices on wood processing technologies and value chains for the recovery (quantities and qualities) and product potential based on side streams of wood product industries (in the first hand) as well as know-how and experience on waste recycling and management within wood-based industrial sector and building with wood. The scope was to have an updated state of the art, from the technical and regulatory point of view, about the recovery and recycling processes and organization of value chains in the different regions EU and extra EU countries) based on fact finding and review on current practices.

Structured into three tasks, WP2 has been executed and interlinked in parallel with WP3 for mutual exchange of results on fact finding and current practices with criteria development and evaluation of good practices. COSMOB and LUKE are the responsible WP Leaders, with further contributions from Regional Lead Partners (RLP) and companies in the consortium. The working methods used include literature surveys, sub-regional expert interviews and webinars, SWOT analysis, visits to facilities, data and market assessments, review workshops (in close exchange with WP3, WP5 and WP6). The various collected data within these three tasks about good practices, supply chain initiatives and numerous company cases will be organized and delivered to the other WPs in the form of a database. Furthermore, selected datasets will be prepared and submitted to the EC Raw Material Scoreboard of RMIS system facilitated through direct exchange with the JRC at the end of WP2.

2.2 Task 2.1 Raw material categories and product potential

The objective is to identify and assess different types of wood-based raw materials, processed and recovered, in the project reference area and sub-regions for the basis of evaluating good practices and know-how for cross-border transfer of competence. Analysis and communication of key material and process factors determining the quantities and qualities and product

potential from side streams and recovered wood is performed, taking into account such factors as wood species, physico-mechanical characteristics, chemical characteristics and contamination, and needs of further processing technology and product requirements. In parallel, an analysis will focus on existing definitions and classifications on processed and recovered wood, according to international, national and regional regulations and standards, also related to wood waste disposal and management. This activity results in a catalogue of different raw material groups considering availability, capability and potential uses for primary products and side stream utilization among the reference industries, and represents a valid prerequisite for the determination of typologies and best practices on side streams and wastes.

2.3 Task 2.2 Side stream processing and recycling techniques

The main objective is to provide a detailed overview on available technologies and existing theoretical and practical knowledge on wood processing techniques, wood recovering and recycling, with the aim to identify the wide spectrum of good practices in terms of optimal technologies and uses of resources and process efficiency in woodworking, with a special focus on wood chains in construction. Sawmilling, wood-based panels, building, bioenergy and selected biorefinery industries are in the focus. An articulated list of relevant bibliographical references (scientific & grey literature) and industry cases is collected. Furthermore at least 10 visits to specialized industries in different sub-regions of the project are conducted with the aim to describe the existing and to identify promising technologies and good practices.

2.4 Task 2.3 Resource efficiency in value chains

The main objective is to review the know-how and practices on resource efficiency and its upgrade regarding yield, grade and relative value of main products and side streams among the reference industries, in order to assess their current status and innovation perspectives in the business and competitiveness development. The current and perspective value chains covering supply, production, marketing and distribution of side streams, recycled products and wood-based and hybrid wastes are mapped and analysed for each sub-region of the project. In addition to materials and products, the analysis covers industrial actors, enterprise networks and public stakeholders in order to provide full assessment of operational performance, economic viability, competition ability and cluster (triple helix) collaboration for the selection of development needs and good practices in innovating new products and services and optimal structure of value networks in the reference industrial sectors. For the background data, the current market situation is shortly explored for volumes and prices using international trade statistics and published market development estimates in relevant product groups and selected expert interviews.

3 Methodology

The first part in the fact finding process was the elaboration of a general analysis of the state of the art based on literature reviews, official sources such as reports, statistics and regulations. The objective of this phase was to provide a clear picture of what is the situation in different European regions involved to the project, regarding a) classification and definitions of processed and recovered wood based on national and regional regulations and standards, in relation to the disposal and management of wood waste, b) value chains, material flows and stakeholders. This process was then expanded by exploring c) raw materials, products and markets, d) processing and recycling technologies, e) resource efficiency and f) funding programmes and financing agencies.

The second part of the analysis was focused on the involvement of the stakeholders aiming at obtaining information on the quality and quantity and product potential (material recovery or energy generation) from lateral flows and recovered wood. In particular, two instruments were used: 1) organization of workshops that involved the participation of project representatives and stakeholders, 2) interviews with pre-mailed questionnaire forms addressed to the stakeholders involved in the wood-based side stream utilization and waste management chain.

In the last stages of the work, among the group of project partners a common SWOT analysis was compiled for Europe based on the fact finding process in different countries, and specifics for each region were pointed out to reveal their particular potentials and needs. Finally, good practices as well as development needs and recommendations were collected together from different regions, and potential for novel applications, cross-border transfer and policy recommendations were presented. Good practices compiled in WP2 will be further analysed, screened and developed toward more detailed recommendations in the next stages of WoodCircus in WPs 4-5. Policy instruments, development actions, funding programs and financing agencies will be compiled and analysed in WP6.

4 Analysis of the state of the art

4.1 Classification of side streams and wastes according to national and regional regulations

Italy

In February 1997 Italy adopted the National Framework Law (National Decree n° 22/1997) the so called «Ronchi Decree » aimed at the implementation of the European directives 91/156/EEC on waste, 91/689/EEC on hazardous waste and 94/62/EC on packaging and packaging waste, and oriented at reorganising the basic framework conditions and the strategic outlook for Municipal Solid Waste in the whole country.

The legislative Decree n. 22, which represents the standard reference framework for the classification and management of waste, introduces a **new system of classification** of wastes based on their:

- origin: distinguishing between **urban waste** and **special waste**, and
- hazards: distinguishing between **hazardous** and **non-hazardous** waste.

The Ronchi Decree identifies four priority objectives:

1. Reduction the quantity of goods (for example packaging) destined to become wastes at the production level
2. Encourage as much as possible the re-use and the recycling of the goods/raw materials with the waste differentiation process;
3. Waste-to-energy (energy production from waste) for unrecyclable waste;
4. Placing in a controlled landfill the waste which cannot be incinerated and/or the residues of that treatment process.

Legislative Decree 22/1997, with the later regulations that have modified and integrated it, constitutes the general discipline of the subject.

The current legislation (N° 152/2006) follows the Ronchi Decree waste classification. In particular[1]:

The urban waste (Par. 2 Article 184 of D. 156/06)

Urban waste is defined as waste that, even if cumbersome, comes from homes; moreover it includes waste of any kind or origin, lying on roads and public areas or on roads and private areas subject to public use or to maritime and lake beaches and on the banks of water courses; it includes vegetable waste from green areas, such as gardens, parks and area cemetery and waste from exhumations and extinctions, as well as other waste from cemetery activity.

Special waste (Par.3 Article 184 of D. 156/06)

The special waste includes:

a) Waste from agricultural and agro-industrial activities;
b) Waste deriving from demolition, construction, as well as hazardous waste deriving from excavation activities;
c) industrial waste, without prejudice to the provisions of article 185, paragraph 1, letter i);
d) Handicraft waste;
e) Waste from commercial activities;
f) Waste from service activities;
g) Waste deriving from the recovery and disposal of waste, sludge produced by water purification and other water treatments and from the purification of waste water and fume abatement;
h) Waste deriving from health activities;
i) Machinery for deteriorated and obsolete equipment;
j) Motor vehicles, trailers and the like out of use and their parts;
k) Fuel derived from waste;
l) Waste deriving from the mechanical selection of urban solid waste.

The refusal may cease to be considered as such when it has undergone a **recovery** operation, including **recycling** and preparation for **re-use**[2], i.e., when the substance or object is commonly used for specific purposes or there is a market or demand for that substance or object, the substance or object meets the technical requirements for specific purposes and respects the existing legislation and standards applicable to the products and when the use of the substance or object will not lead to overall negative impacts on the environment or human health

[1]Ecocerved, Camera di Commercio di Fermo. *Manuale per un comportamento corretto nella classificazione dei rifiuti speciali.* Ottobre 2012.

[2]Following the transposition of the directive 2008/98 about *recovery*, Italy differentiates the terms re-use and recycling. The term, *re-use* means all operations that allow the re-use (for the same purpose) of products that have not yet become waste; while the term *recycling* refers to recovery operations that allow the reprocessing of waste materials, so as to obtain new products, substances or materials to be used both for new purposes and for the same for which they were conceived.

Hazardous waste and the European Waste Catalogue (CER)

The various types of waste are coded according to the European list of waste -so-called CER[3] - referred to in Decision **2000/532/EC** and subsequent amendments.

"Hazardous substance" means any substance classified as dangerous according to Directive **67/548/EEC** and subsequent amendments: this classification is subject to updates, as research and knowledge in this field are constantly evolving. The classification of hazardous waste is based on the introduction of the decision 2000/532/ CE:

- On the origin

The waste is classified as dangerous because it is dangerous itself and in particular derives from its origin substantially attributable to the fact that these wastes have one or more of the hazard characteristics set out in Legislative Decree n. 152/06

- On the content of hazardous substances

- They are identified as dangerous with specific or generic reference to dangerous substances contained, only if the substances reach certain concentrations.

According to the D. 152/06 (article 184, paragraph 5), are **hazardous wastes** marked with a special asterisk in the list **CER2002**.

The types of waste in the wood sector

The typologies of wood waste include the wood shavings and wood scraps, packaging materials, sludge and painting water.

Some types of residues are present across the various production sectors in particular:

- wood scraps and untreated chips
- glues and adhesives (residues)
- paints (residues)
- sludge from painting booths
- slats of painting booths
- ashes, slag, combustion powders
- dirty sawdust of solvents and/or inks and/or paints
- containers dirty with solvents, inks, paints, glues

In addition, there are some sectors that are characterized by the presence of specific residues. In particular, the production of semi-finished products in wood (the plywood and particle board industries) is characterized by the presence of formaldehyde, glues and adhesives, acetone, organic sludge with metals, other organic sludge, diluents and or cleaning solvents, and to a lesser extent panel residues, thermoplastic resins etc. The production of wooden packaging is strongly characterized by the presence of fibre and wood pulp residues;

The furniture and wooden furniture industry is characterized above all by the prevalent presence of solvent residues, thinners and paint strippers used for the painting, polishing and cleaning of furniture: acetone, formaldehyde, xylenes, diluents and/or cleaning solvents paint strippers, and paint thinners.

[3] The ERC is the common reference nomenclature for the European Community, and aims to coordinate and improve all activities related to waste management.

Table 1 contains the list of typical waste typologies related to the wood sector.

Table 1 Wood waste classification according to CER

CER	DESCRIPTION
03	**Wastes from wood processing and panel production, furniture, pulp, paper and cardboard**
03 01	**waste from wood processing and panel and furniture production**
03 01 01	scraps of bark and cork
03 01 04*	sawdust, shavings, cutting residues, wood, particle board and veneers containing dangerous substances
03 01 05	sawdust, shavings, cutting residues, wood, particle board and veneers other than those mentioned in 03 01 04
03 01 99	waste not otherwise specified
03 02	**waste from wood preservation treatments**
03 02 01*	products for wood preservation treatments containing non-halogenated organic compounds
03 02 02*	products for wood preservation treatments containing chlorinated organic compounds
03 02 03*	products for wood preservation treatments containing organ metalling compounds
03 02 04*	products for wood preservation treatments containing inorganic compounds
03 02 05*	other products for conserving wood containing dangerous substances
03 02 99	products for conservative wood treatments not otherwise specified
03 03	**waste from the production and processing of pulp, paper and cardboard**
03 03 01	scraps of bark and wood
03 03 02	sludge recovery of maceration baths (green liquor)
03 03 05	sludge produced by the deinking process in paper recycling
03 03 07	mechanical separation waste in pulp from paper and cardboard waste
03 03 08	waste paper and cardboard selection destined to be recycled
03 03 09	waste sludge containing calcium carbonate
03 03 10	waste fibre and sludge containing fibres, fillers and coating products generated by the processes of mechanical separation
03 03 11	
03 03 99	sludge from on-site effluent treatment other than those mentioned in 03 03 10
	waste not otherwise specified
15	**Packaging waste, absorbents, rags, filtering materials and protective clothing**
15 01	**packaging (including urban packaging waste subject to separate collection)**
15 01 01	paper and cardboard packaging
15 01 03	wooden packaging
17	**Waste of construction and demolition operations**
17 02	**wood, glass and plastic**
17 02 01	wood
17 02 04*	glass, plastic and wood containing or contaminated by dangerous substances
19	**Waste from waste treatment plants, plants treatment of wastewater outside**
19 12	**wastes from mechanical waste treatment (e.g., sorting, shredding, compacting, reduction in pellets) not otherwise specified**
19 12 06*	wood containing dangerous substances
19 12 07	different wood than that mentioned in 19 12 06
20	**Urban waste (domestic and waste produced by activities Commercial and industrial and the institutions)**
20 01	**fractions subject to separate collection**
20 01 37*	wood containing dangerous substances
20 01 38	different wood than that mentioned in 20 01 37

Source: Our elaboration on CER catalogue[4].

Spain

According to the Law 22/2011[5] there are different classifications of wastes depending on the origin, composition, dangerous. Table 2 describes the different classification of wastes by categories.

Table 2 Waste classification in Spain

Composition	Origen	Danger

[4] CER catalogue available at http://www.ccrifiuti.it/doc/cer.pdf

[5] Ley 22/2011, de 28 de julio, de residuos y suelos contaminados. [Available at: http://smartleges.com/es/biblioteca-de-leyes/ley-22-2011-de-28-de-julio-de-residuos-y-suelos-contaminados/2014780]

Organic residue	Domestic waste	Inert waste
Inorganic waste	Commercial waste	Hazardous waste
Residue mix	Industrial waste	No hazardous waste
Hazardous waste	Bio-waste	
	Construction and demolition waste	
	Sanitary waste	
	Mining waste	
	Radioactive waste	
	Animal waste	

Source: Ley 22/2011, de 28 de julio, de residuos y suelos contaminados.

Focusing of wood waste, an important role is played by the Spanish Association of Wood Biomass Managers "ASERMA" (Asociación Española de Gestores de Biomasas de Madera) that is a reference within the sector and since 2007, thanks to its partners, can provide data on waste and other products they manage; In more detail, through a simple survey of associated companies, ASERM provides important annual information on the wood area.

Table 3 shows the classification of wood waste for Spain proposed by Ministry of Agriculture, Food and Environment[6] the that specify the typology of wood waste according to the origin and the destiny of wood waste.

Table 3 Wood waste classification in Spain

Category	Description	Origin	Destiny
1	Clean wood residue: wood residue in its natural state or from mechanical work (without chemical compounds)	Waste of packaging and scraps of manufacture that have not been painted or treated. Waste wood from felling and machining. Wood furniture in its natural state.	The recovery of the waste (recycling): board industry, horticulture
2	Wood waste treated with non-hazardous compounds. May contain non-halogenated organic compounds and does not contain preservatives	Waste, pallets, packaging, boards, furniture, doors and frames from the wood industry that do not contain hazardous pollutants	The material recovery (recycling) of the waste
3	Residue from wood that has been treated with halogenated organic compounds and does not contain preservatives	Pallets with composite materials, furniture with organic compounds halogenates, bulky waste (mixed)	Energy recovery (biomass) Incineration with energetic recovery Incineration without energy recovery
4	Residue of wood treated with preservatives as well as other wood residues that due to their contamination cannot be assimilated to any of the previous categories	Waste wood demolition and restoration as beams, windows, exterior doors, wood impregnated for extreme structures. Railway sleepers, telephony and light poles, fences. Impregnated garden furniture, Wood waste for industrial use	Energy recovery (biomass) Incineration with energetic recovery Incineration without energy recovery

Germany

[6]Ministerio de agricultura, alimentación y medio ambiente. (2012) DIseño metodologico para la clasificación de productos recuperables de los residuos de madera, orientado a potenciar enfoques de gestión, producción y consumo más sostenibile. Madrid. [Available at: https://www.miteco.gob.es/images/es/Informe%20residuos%20madera_29112010_para%20editar_tcm30-193004.pdf]

Waste management legislation is based on European law, German federal law, the regional laws of the federal states and the statutes of the local authority waste management services. The main pillar for the management of Wood Waste is the ordinance on the

The Ordinance laid down specific requirements for the recycling and energy recovery as well as for the disposal of waste wood on the basis of the Closed Substance Cycle and Waste Management Act[7]. These requirements provide a sustainable support for the environmentally sound recovery of waste wood and ensure that pollutants are eliminated from the economic cycle.

In the Ordinance, waste wood includes residues from the working and machining of wood and derived timber products as well as used products such as wood packaging, palettes, furniture and waste wood from demolition. The Ordinance covers all the common methods of waste wood management such as preparing waste wood for the production of derived timber products, the production of active carbon or industrial charcoal and synthesis gas and the energy recovery of waste wood as a substitute fuel. If waste wood cannot be recovered, it must be disposed of using thermal processes. Land filling is not permitted.

Table 4 Classification of recycled wood in Germany

Group	Classification	Examples	Treated	Contaminated	Hazardous
A I	Untreated recovered wood	Wooden packaging material e.g. palettes, wooden cases. Building and demolition wood. Wooden bulky rubbish of residential waste fraction	no	no	no
A II	Treated recovered wood	Building and demolition wood Wooden bulky rubbish of residential Doors, windows Residues from construction wood Wood from concrete casing	yes	no	no
A III	Contaminated recovered wood	Railway sleepers Transmission poles oil impregnated	yes	yes	no
A IV	Hazardous recovered wood	Piles and poles salt impregnated Chemical treated wood waste CCA and CCB	yes	yes	yes

[7]German Law Archive. https://germanlawarchive.iuscomp.org/?p=303

The Closed Substance Cycle and Waste Management Act (KrW-/AbfG) considerably extended the scope of waste law as compared to earlier legislation. Under the heading "closed substance cycle" the Act also includes all waste recovery measures relevant to the waste sector. The provisions in the Closed Substance Cycle and Waste Management Act[8] that in many cases had to be kept general need to be specified for individual waste flows by means of more detailed provisions in order to ensure legal and investment certainty in the enforcement of the law.

The Ordinance defines specific requirements for substance recycling and energy recovery and for the disposal of waste wood on the basis of the Closed Substance Cycle and Waste Management Act. At the same time, these requirements are harmonized with the requirements to be adhered for the management of waste wood pursuant to chemicals and hazardous substances law as well as the provisions governing the keeping of waste recovery and disposal records. The following regulations are particularly relevant:

- both residual woods from industry and wood products that have become waste are classified as waste wood in this Ordinance.
- The Ordinance identifies the current recovery procedures for waste wood, namely the processing of waste wood for the manufacture of derived timber products, the manufacture of active carbon/industrial charcoal, the production of synthetic gas as a chemical raw material and the energy recovery of waste wood. Other possible recovery paths are not regulated by the Ordinance but are also not excluded so that this does not stand in the way of incorporating new recovery paths and innovative recovery procedures for waste wood.
- The requirements in the Waste Wood Ordinance define high-quality substance recycling and energy recovery procedures.

Wood waste must be assigned to one of four waste wood categories depending on the level of pollution, from A I (waste wood in its natural state or only mechanically worked) to A IV (waste wood treated with wood preservatives, e.g. railway sleepers, hop poles, etc.) Instead of elaborate and uncertain sampling and analysis provisions, assignment to the respective category can occur on the basis of origin and in accordance with strict requirements for keeping waste wood separate and bans on mixing waste woods. To simplify assignment, the Ordinance contains a general rule to be assumed for the common types of waste wood. In the case of a mixture of different waste wood categories, the mixture must always be assigned to the category subject to the most stringent provisions.

In order to ensure safe recovery, the waste wood categories A I to A IV are then allocated to the individual substance recycling paths; energy recovery is governed by the provisions of the Federal Emission Control Act and the statutory ordinances issued on the basis thereof. Waste wood containing PCBs is classified as a "special category" if the PCB content is more than 50 mg/kg. Waste wood containing PCBs must be disposed of in accordance with the PCB/PCT Waste Ordinance – only thermal treatment procedures come into question.

The waste wood categories A I to A IV may be used for the manufacture of active carbon/industrial charcoal and the production of synthetic gas as well as in incineration and gasification plants that are licensed pursuant to the Fourth Ordinance on the Implementation

[8] Federal Ministry for the Environment, Natura Conservation and Nuclear Safety (2011). Closed-loop waste management.

of the Federal Emission Control Act and with regard to emissions are subject to the Seventeenth Ordinance on the Implementation of the Federal Emission Control Act. During these procedures, the organic pollutants contained in the waste wood are completely destroyed due to the high temperatures. Heavy metals are bound as solid in the residues or dispersed during waste gas purification.
Only certain pollution-free or low-pollution waste woods can be considered for use in manufacturing derived timber products. Compliance with this requirement is guaranteed by binding pollutant limit values, including relevant sampling and analysis provisions, for the wood chips produced for use as raw materials for the manufacture of derived timber products. Waste wood processed in this manner for the derived timber products industry ceases to be waste and can be processed there as a primary raw material. In the context of the energy recovery of waste wood, use of waste wood in installations where fodder is dried in direct contact with the installation's exhaust and flames is restricted to waste wood category A I. This ensures that fodder contamination is ruled out.

With regard to inspections and monitoring, the Waste Wood Ordinance is geared towards strengthening the personal responsibility of the installations, supplemented by moderate independent inspections and monitoring. The focus is on the operators of waste wood treatment installations that are obligated to allocate the waste wood to the given recovery paths. This allocation process is to be monitored regularly. This system of internal and independent monitoring is supported by documentation and reporting obligations. This provision produces a high level of precautionary environmental protection with the greatest possible personal responsibility while at the same time being enforcement-friendly.

France

In France, the *"Code de l'environnement"* defines the objectives and responsibilities of waste producers (articles L 541-2 et L 541-22).

The European Union Waste Directive was transcripted in French law by two texts from 201 and 2011 ("*Ordonnance n° 2010-1579 du 17 décembre 2010 portant diverses dispositions d'adaptation au droit de l'Union européenne dans le domaine des déchets"* and « *Décret du 11 juillet 2011 (no 2011-828)portant diverses dispositions relatives à la prévention et à la gestion des déchets*»).

The « Loi de transition énergétique pour une croissance verte[9] » from 2015 sets principles and objectives for waste management policy among which two are of upmost interest for wood waste :

- Development of recycling : 55 % in 2020 and 60 % in 2025 for non hazardous and non inert waste;

- Exclusion of wood from landfilling in 2025

This text also set the system of "Enlarged Responsibility of Producers" (Responsabilité Elargie du Producteur – REP)for furniture waste (Déchets d'Elements d'Ameublement – DEA). This

[9] LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte

system makes obligation to furniture marketers to fund the furniture waste recollection and management with high targets on recycling and energy recovery.

An objective of 70% recycling is also set for construction and demolition waste, and a REP system is foreseen for the near future in that sector too, as a new law on circular economy is being prepared by the government.

As for packaging, eco-design for recycling is already required, and a REP system for all packaging sectors including pallets is foreseen for 2024.

Energy recovery from wood waste falls under the ICPE regulation (Installations Classées pour la Protection de l'Environnement), in application of the IED Directive. In the simplest case and provided it complies with a limited contamination requirement, it can be used as fuel into combustion plants authorized under the 2910 status (from ICPE regulation nomenclature), which is a quite regular biomass boiler.

There are indeed two cases: the case of wood packaging waste which can be processed, under regulatory defined conditions to become a biofuel (following an "end-of-waste status process"): any kind of boiler (2910 A) can use that fuel. In the case of other wood waste, not contaminated with organohalogenated substances or heavy metals, and provided it complies with a limited contamination requirement, quite simple combustion equipments (2910 B) can use it. In case the requirement is not met, or if the waste is supposed to contain organohalogenated substances or heavy metals, energy recovery can only take place into waste incineration equipments, authorized for non hazardous or for hazardous waste depending on the regulatory status of the wood waste.

It is possible, at a quite expensive cost, to landfill wood waste, into non inert waste landfills.

The French regulation on classification of waste has no specificities and is the simple translation of the European classification of waste. Considering that sawmill by-products are not waste, there are only two regulatory classes : non hazardous and hazardous wood waste.

For material recycling, the only regulatory requirement is that waste wood is not classified as hazardous.

Apart from regulations, the French wood sector and waste actors have established a common classification of wood wastes in three main classes, A, B and C (with a subdivision of class A), see Table 5.

Two different systems have been adopted to publicly promote the development of energy recovery from waste:

- The renewable electricity rebuying obligation for EDF, the French National Electricity company, which, together with public investment support programmes, has allowed the development of a few large CHP plants using waste wood. The latest energy policy update nevertheless stops the investment support to this kind of equipments;
- The Heat Fund (Fond Chaleur), managed by ADEME (French agency for Environment and Energy Management) which supports investment for biomass fuelled heat boilers.

Table 5 Classification of recycled wood of French wood sector and waste actors

Wood waste	Recoverable wood waste from end-of-life products or industrial waste;
Class A1	Biomass in its natural state, neither impregnated nor coated with any substance; (uncoated, untreated wooden packaging waste)
Classe A2	Biomass in its natural state, neither impregnated nor coated with any substance (pieces of raw wood, bark, shredded wood, sawdust, sanding dust or scrap from the wood processing industry or its craft industry)
Class B	Non-hazardous wood waste containing a small amount of additives or other materials; glued wood, wood having received a surface treatment (preservation, finishing) or a coating (wallpaper, melamine, polypropylene, etc.);
Class C	Wood waste that may contain heavy metals or organohalogenated substances (within the meaning of the regulatory waste classification); example : creosote impregnated wood

UK

The Wood Recyclers Association has developed a grading structure for UK derived, non-virgin wood for recycling into products, feedstocks and fuels: the WRA grading structure (Table 6). The purpose of the grading structure is to provide a simple and common understanding as to what grade of material is suitable for each main market sector.

Table 6 UK wood waste classification and grades

Grade	Typical Markets	Typical Sources of Raw material	Typical Materials	Typical Non-Wood Content Prior to Processing
Grade A- "Clean" Recycled Wood	A feedstock for the manufacture of professional and consumer products such as animal bedding and horticultural mulches. May also be used as a fuel for renewable energy generation in non WID* installation, and for the manufacture of pellets and briquettes.	Distribution. Retailing. Packaging. Secondary Manufacture e.g. joinery. Pallet Reclamation.	Solid softwood and hardwood. Packaging waste, scrap pallets, packaging cases, and cable drums. Process off-cuts from manufacture of untreated products.	Nails and metal fixings. Minor amounts of paint, and surface coatings.

Grade B- Industrial Feedstock Grade	A feedstock for industrial wood processing operations such as the manufacture of panel products, including particle board and medium density fibreboard (MDF).	As Grade A, plus construction and demolition operations and transfer stations.	May contain up to 60% Grade A material as above, plus building and demolition materials and domestic furniture made from solid wood.	Nails and metal fixings. Some paints, plastics, glass, grit, coatings, binders and glues. Limits on treated or coated materials.
Grade C- Fuel Grade	Biomass fuel for use in the generation of electricity and/or heat in WID** compliant installations.	All above plus municipal collections, recycling centres, transfer stations and civic amenity recycling sites.	All of the above plus fencing products, flat pack furniture made from board products and DIY materials High content of panel products such as particle board, MDF, plywood, OSB and fibreboard.	Nails and metal fixings. Paints coatings and glues, paper, plastics and rubber, glass, grit. Coated and treated timber (non CCA or creosote).
Grade D- Hazardous Waste	Requires disposal at special facilities.	All of the above plus fencing, track work and transmission pole contractors.	Fencing Transmission Poles Railway sleepers Cooling towers.	Copper / Chrome / Arsenic preservation Treatments Creosote

Businesses are affected by a range of legislation relating to how they produce, handle and treat the waste created both directly by their employees and within their workplace in general. Key among these is the duty of care. This places a legal responsibility on businesses to ensure that they produce, store, transport and dispose of their business waste without harming the environment. The duty of care applies to all controlled waste, which includes both household and commercial & industrial, or C&I waste.

The requirements of the duty of care apply to the storage and transport of waste, including needing to check a business waste is being dealt with by an authorized waste carrier. Businesses must also complete waste transfer notes to document all waste they transfer from their site. Waste and recycling management services for businesses are offered by both waste management companies and local authorities. An increasing number of councils are providing business, or trade, waste collection services.

Businesses which are involved in waste management are also subject to the environmental permitting regime. In England this means they could have to apply for an environmental permit or, for some activities, an exemption from permitting. In Scotland and Northern Ireland, the system is managed by waste management licensing and pollution prevention and control permitting.

Several pieces of government and European legislation also place further responsibilities on businesses. These include producer responsibility legislation such as the Waste Electrical and Electronic Equipment (WEEE) Directive, the Packaging Waste Directive, the Batteries Directive and the End- of-Life Vehicle (ELV) Directive. As well as placing a financial responsibility on the manufacturers of new products to fund the collection, treatment and recycling of waste

materials, certain types of business often have a major role to play as a key avenue for the return of material. For example, retailers selling more than one pack of four AA portable batteries a day have a legal obligation to provide free in-store take-back of any waste portable batteries from end users.

However, businesses are largely unaffected directly by the major legislative drivers which aim to divert waste from landfill and recycle more such as the European Waste Framework Directive and the Landfill Directive. Instead, the main push for them to divert material from landfill comes from landfill tax, a levy which must be paid on every tons of waste sent to landfill.

Finland

In Finland, the European Union Waste Directive was implemented in 2012 by a reform of the Waste Act (646/2011). In addition to the Waste Act, separate regulations specifying the Waste Act have been published, the most important of which in the case of construction and demolition waste being the Government Decree on waste (179/2012) and the Landfill Regulation (331/2013). The aim of the comprehensive reform of waste legislation was to change Finnish legislation to better reflect current waste and environmental policy priorities and European Union legislation.

All activities must, wherever possible, be governed by the following order of priority: Reduce the amount and harmfulness of waste generated. However, if waste is generated, the waste holder must first prepare the waste for re-use or, in the alternative, recycle it. Where recycling is not possible, the holder of the waste shall recover the waste by other means, including energy recovery. If recovery is not possible, the waste must be disposed of.

In addition to increasing the recovery rate of construction wood waste the Finnish Waste Act 646/2011 defines the hierarchy of waste treatment on the basis of the EU Waste Framework Directive 2008/98/EC. The purpose of the waste hierarchy is to control waste treatment in the most efficient way possible. As a priority, waste production should be avoided. The 'polluter pays' principle ratified in the Waste Act, and extended producers' responsibilities are used as controls to avoid production. It means that the original producer must pay the costs of the waste treatment, or that the final disposal of the waste is to be done by the producers themselves. As a result of the Directive, the cost of disposing of each product at the end of its life is already paid at the time of purchase.

In Finland, VTT has compiled quality classification guidelines for decommissioned wood, especially for fuel use. Decommissioned wood, i.e. wood waste, is classified according to quality into four categories; A, B, C or D.

Category A and B wood waste is biofuel and is not subject to the Waste Act. They are covered by European standard EN 14961-1 for solid fuels. Category A contains pure, chemically untreated wood or wood product. Category B wood, on the other hand, is a chemically treated wood or wood product which, however, does not contain any halogenated organic compounds and heavy metals as a result of treatment with wood preservatives or coatings more than natural wood. Categories A and B therefore include natural wood, pallets and other packings of wood, miscellaneous wood waste and furniture.

Category C includes wood which may contain heavy metals and organic halogenated compounds such as fluorine, chlorine, bromine or iodine. This is treated as recycled fuel and is subject to the

provisions of the Government Decree on Waste Incineration. Category D wood is pressure impregnated wood material, and is classified as hazardous waste. Various compounds have been used for impregnation, which may contain, for example, copper, chromium or arsenic. Category D wood may only be disposed of in an environmentally hazardous landfill or in a plant specifically designed for incineration.

Impurities in decommissioned wood are divided into two categories, mechanical and chemical. The former includes soil, plastic, metal and concrete, and can generally be distinguished during the sorting or production process. Chemical contaminants are almost always an integral part of the wood material and thus separation and removal can be very difficult. Examples of chemical impurities are paints, coatings, wood preservatives and adhesives. Wood containing mechanical impurities shall be accepted for Category A of decommissioned wood, but not wood containing chemical contaminants. As regards wood waste, unpainted and nailed wood is included in category A. In general, wood waste from new construction is included in category B if its origin is known. Wood waste from demolition sites shall be classified as category C waste wood, unless it can be demonstrated through a quality system or through specific characteristics that the wood is not chemically treated. Wood waste from renovation can be comparable to wood from both new construction and demolition.

Decommissioned wood packaging consists mainly of untreated wood, but may contain pieces of compressed wood, nails and paint used for marking purposes as well as wood preservatives and adhesives. In addition to pallets, wood packaging includes various stands, racks and drawers, as well as cable reels, and barrels. When wood packaging is disposed of and thus ends up as waste, it will be classified as Category B waste wood, unless it is either pests treated or chemically contaminated during use. Wood packaging made entirely of untreated wood, usually disposable pallets, can be considered as Category A.

Challenges related to legislation

The EU Waste Directive and the Finnish Waste Decree require 70% of construction waste to be recovered as material by 2020 (excluding combustion). As Finland's building materials are made up of a relatively large proportion of wood, achieving this goal is challenging. Wood in construction and demolition waste is often dirty and otherwise unsuitable for recycling purposes. Construction-derived wood materials include, for example, surface treatment agents and metal fasteners, which make reuse and recycling difficult. Re-use and recycling into building materials are also limited by the quality requirements for building materials. In fact, the main method of recovering wood waste has been energy recovery. This has been seen as a viable option to promote the use of renewable energy sources and reduce the use of fossil fuels.

As a deviation from the Procurement Act, the Waste Act will also, from 2019, provide for a market-selling threshold for affiliated entities and contracting entities operating in the municipal waste management sector. Municipal-owned waste management companies are not subject to the EUR 500,000 limit for market-based activities at all. The waste company has a 10 percent sales limit until the end of 2029, after which it will drop to 5 percent. This restricts the sale of waste management services and products to municipal-owned companies. In addition, legislative changes are unpredictable and depend, among other things, on the composition of the government.

In Finland, missing overall organization of transportation systems of municipal, construction and mixed wastes is a drawback. Competition on transportation contracts organized by municipalities in their districts rather than individual contracts would provide more incentives to and improvements in site-by-site sorting in construction sites and economic advantages in waste transportation.

4.2 Value chains and stakeholders involved in different regions

General

The value chains of wood-based side streams and waste wood include different steps from production to valorisation, including sourcing, processing, transport, storage and distribution to the market. The term wood supply chain involves the logistics system from timber to final product that is delivered to a customer; the term means the deliveries and links between customers, suppliers and shippers in the forest business. In addition to the practitioners, the value chains are labelled by stakeholders such as machine, equipment and material suppliers, private and public financing bodies, decision makers in public administration, regulation and support to the economy and regional development, organizations and societies of research, development and innovation, etc. The construction sector is largely responsible for the resources used in Europe and is the dominant user of wood products, therefore value chains of buildings and their resource efficiency are at the core of side streams and waste approach.

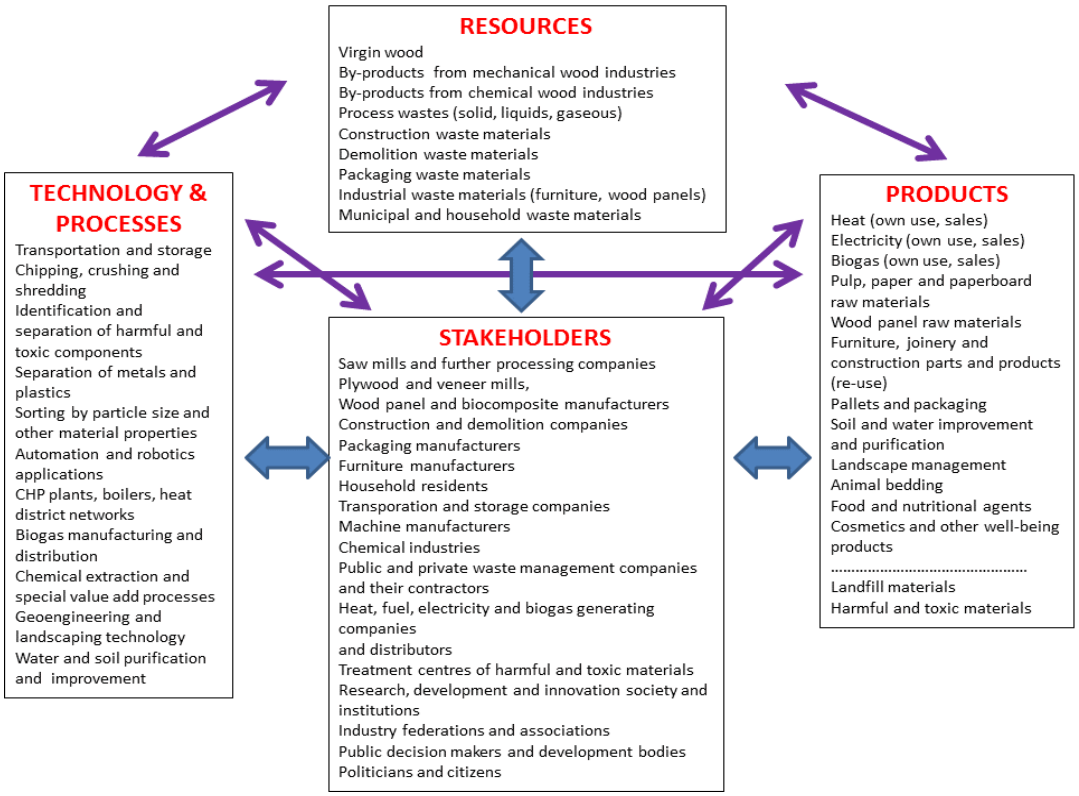
It is important to observe that value chains are not linear but dynamic as regards their composition and sequences in different regions in Europe. Physical material can be either raw material, intermediate product or in some cases end-product depending on the strategic business approach and operative practices as well as the organizational position of and competitive environment for individual companies in the value chain. This can be seen as different material flows and organization structures among the business.

Accordingly, interests and incentives to technology, processes, marketing and overall development differ between countries of various industrial traditions and supply-demand conditions of raw materials and products. The practitioners, other partners and operative responsibilities in the value chain also vary, both regarding the overall leadership of value chains, governance of its parts and collaboration between companies.

Figure 1 shows the sources of dynamics for the value chains of wood-based side streams, covering both commercial by-products and industrial wastes, which may be applied in different ways in European regions and countries. Depending on stakeholders, the materials of interest can be resources or products, various processes and levels of technology may be applied to achieve the desired products from the resources, and participation and integration of practitioners and stakeholders can be organised in different ways.

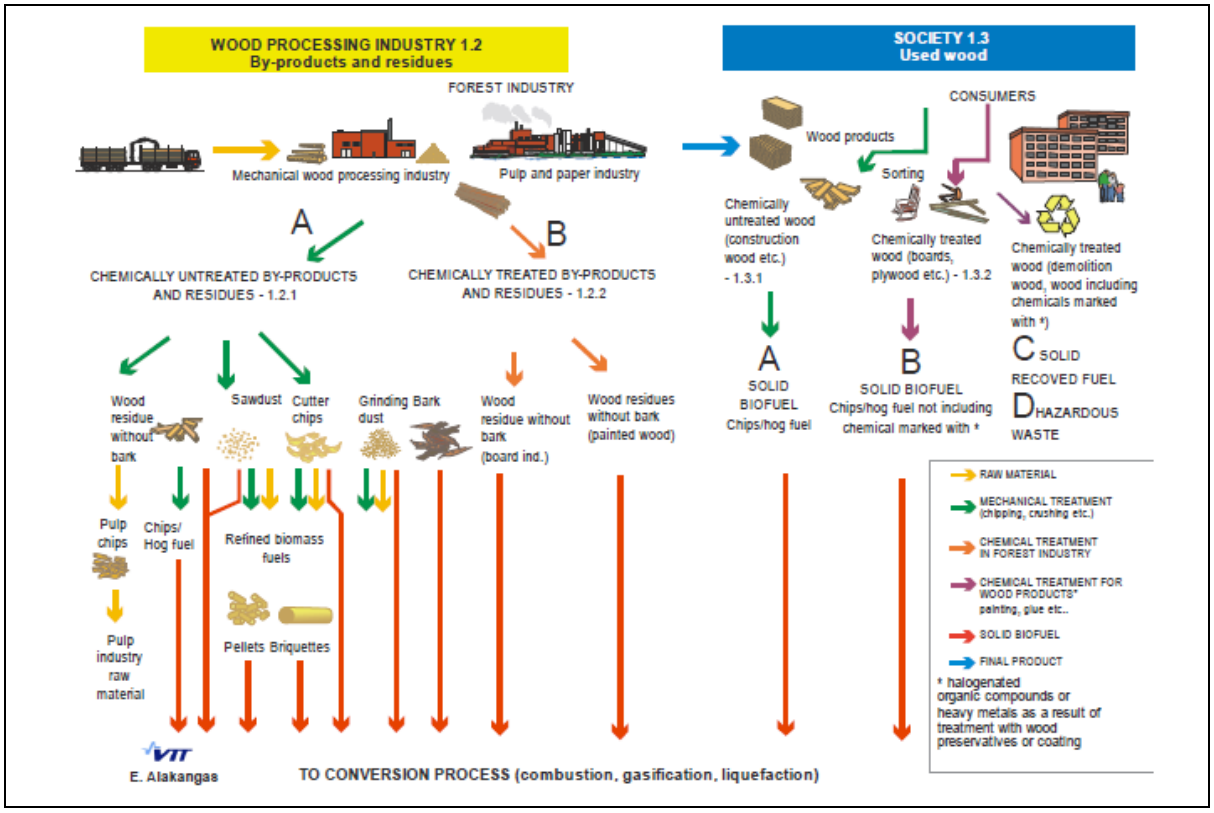
Figure 2 shows how the value chains are different from the viewpoint of wood processing industries and society. The perspectives are still linked together in accordance with the joining and transforming material flows and properties, true circulation and connections between pre-consumer and post-consumer wood and benefits and challenges of stakeholder integration and collaboration.

Figure 1 Components of value chain dynamics of wood-based side streams



Source: Natural Resources Institute Finland LUKE (2020)

Figure 2 Value chains of wood-based side streams from the perspectives of wood processing industries (by-products and residues) and society (used wood)



Source: Alakangas et al (2016)

In the wood waste supply chain three processes are included: wood waste collection, transportation (road, rail or water) and sorting and processing. Wood waste comes mainly from industry, construction, and demolition as well as from packaging and furniture, and numerous practitioners are involved in the whole value chain[10]. However, differentiation of side streams and wastes in the value chain is many times challenging.

According to a common industrial interpretation, resource efficiency involves materials, energy, work, capital and entrepreneurship in the supply, production and distribution of both primary products and side streams. Raw material, product and energy flows and their efficient and responsible utilisation and upgrading in value chains, are of crucial importance. The first aim of efficiency in wood processing is to maximise yields for volume and grades while optimising the net market value of primary products, such as sawn timber, plywood of other wood-based panels, within the limits of material and energy resources and minimum resource expenses. The second priority is to produce as much side stream material as possible, such as bark, chips, saw and grinding dust, shavings, flakes, off-cuts etc. either as raw materials for other industries, for bioenergy production in the mills themselves, or sold to other users to gain more value for the

[10] Garcia, C. A., & Hora, G. (2017). State-of-the-art of waste wood supply chain in Germany and selected European countries. *Waste management*, *70*, 189-197. Available from: https://www.researchgate.net/publication/320005202_State-of-the art_of_waste_wood_supply_chain_in_Germany_and_selected_European_countries.

enterprises and stakeholders involve. A similar philosophy is applied through the further processing steps in wood-based value chains, such as furniture, joinery, prefabricated housing, building element manufacturing, and demolition wastes. Closed loops toward minimum environmental loading and high degree of cascading and recyclability are targeted in material and energy flow. This is in the line of using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment, providing more with less and delivering greater value with less input (The Roadmap to a resource efficient Europe by 2050).

Woodworking industries primarily include sawmilling, plywood, wood panel, furniture, building component, flooring, particle board, moulding, jointing and craft industries as well pre-fabricated house and element manufacturing. Novel products, markets and stakeholders involved inevitable 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 region and case, production plants and processing enterprises may form different value chains where the degree of integration, concentration and decentralization varies.

Competing uses of raw material side streams is a matter of discussion between stakeholders and decision makers. The EU's waste management directives set pressure for policies in side stream and demolition waste control, urging the development of new options for recycling in companies. Industrial raw material and semi-product uses of bark and chip, dust, shavings and flake form materials include particle, fibre and MDF boards and different forms of bioenergy. The roles of packaging industries, chemical industries and advanced biorefineries are increasing in the utilization of side streams both for techno-chemical bulk products (e.g., adhesives, surfactants, dispersion agents, liquid fuels) and consumer products with specific functionalities (e.g., foods and nutritive agents, health promoting products, detergents and cosmetics).

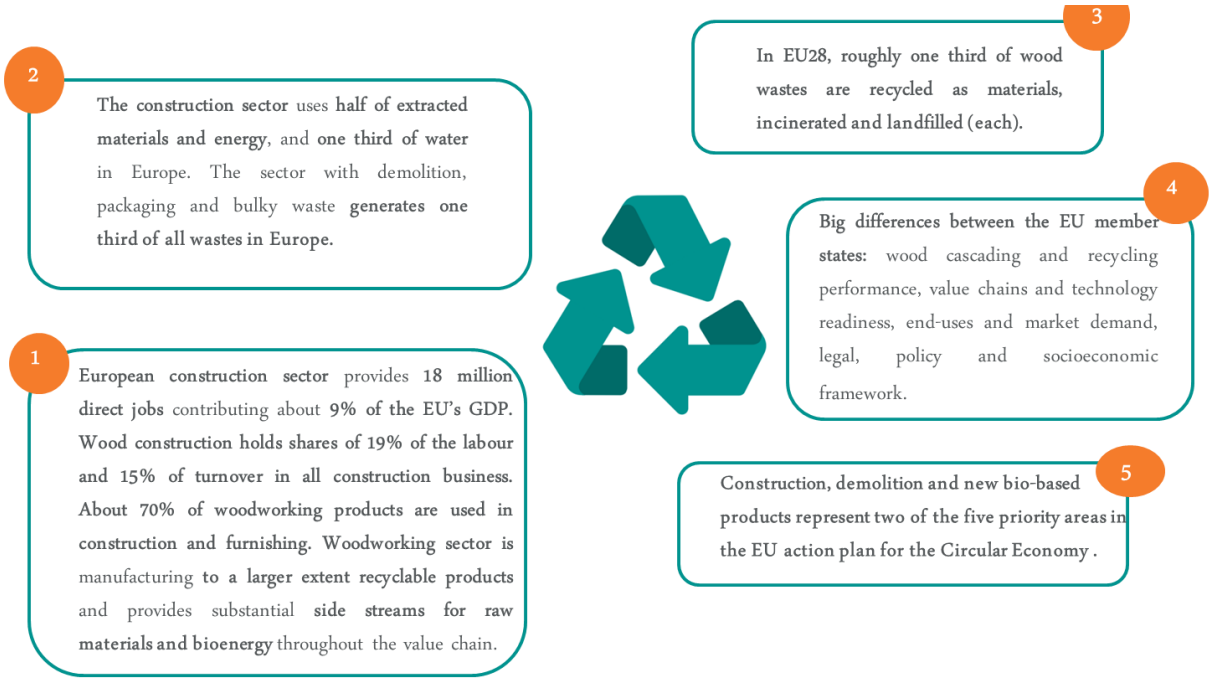
Industrial symbiosis or ecosystem is a whole of several enterprises where companies complement and provide added value for each other by utilizing effectively raw materials, technology, service and energy. Side stream or waste generated in the production of a company can be a raw material for another 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. The ecosystems are under development in side stream utilization and recycling business in many regions in Europe, however, well-functioning examples already exist both on concentrated, integrated and decentralized solutions.

It is essential that scaling of production volume affects essentially the organization of sourcing raw materials or semi-finished products, manufacturing, deliveries and logistics. In a large-volume production of bigger companies, the structure of practitioner 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 concentration, integration and decentralization.

In all, more than 70% of wood products are used in construction or furnishing. In EU-28 roughly one third of wood waste is recycled as materials, incinerated or landfilled (each of them) (Figure 3). Construction, demolition and new bio-based products represent two of the five priority areas in the EU action plan for the circular economy. From circular economy perspective wood-based products as construction material are renewable, largely recyclable and may provide closed-loop manufacturing and utilization processes. Modern building with wood value chains integrate urban development and vitality of rural regions in holistic sustainable development and provide long life cycle and carbon storage in buildings. Good practices are available from European countries, being based on different regional socio-economic needs and business opportunities.

Figure 3 Overall role of value chains of wood-based products and side streams in construction sector in Europe



Source: FCBA & Natural Resources Institute Finland LUKE(2019)

Italy

The supply chain of wooden packaging in Italy operates primarily with the production of the consortium producers at RILEGNO, a large group of actors that moves the circular economic system in Italy. Rilegno is the National Consortium for the collection, recovery and recycling of wood packaging that works within the system CONAI (National Packaging Consortium) and they have designed a dense supply chain network that helps consortium producers to identify the collection points of their products wastes and how the proper transportation logistics to the recycling centres can be maintained.

The fulcrum of the recovery system is the network of consortium platforms, to which private companies and municipal administrations can deliver post-consumer wood packaging free of charge. In particular, 1,987 are the members of Rilegno, with a network of over 400 platforms affiliated with RILEGNO that take care of organizing the start of recycling of waste wooden

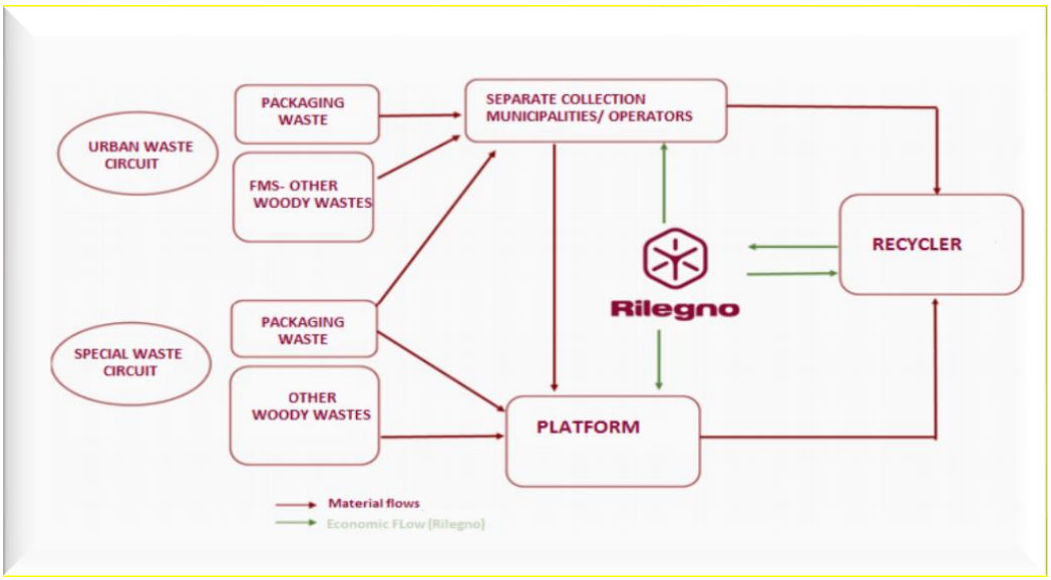
packaging that comes from commercial, craft and industrial activities collection platforms, widespread throughout the territory serving the industrial and commercial sectors:

- Producers (270) manufacturers and importers of materials for wood packaging
- Processors intended as manufacturers and importers of:
    - Pallets and pallet repairers (852)
    - Industrial packaging (634)
    - Food packaging (219)
    - Recyclers / recovering companies (11)

Rilegno has established collaborations and profitable synergies with:

- 1. Private operators: recognized as Platforms;
- 2.Individual municipalities: their aggregations or environmental managers (subjects of public and private sectors responsible for policies and plans development of wood waste collection and recovery systems.

Figure 4 Wood package management sypply chain



Source: Rilegno (2018). Rapporto 2018 Progetti, Innovazioni, Prospettive.

The platforms affiliated with the Consortium are located mainly in the Regions of Northern Italy. Lombardy is the most covered Region followed by Emilia Romagna, Veneto, Sicily and Lazio. The concentration of recyclers in the northern area affects logistics costs, as a result also of the progressive development and implementation of public collections and the activation of new platforms for collection in the entire Centre-South. In 2018 there was a strong increase in coverage in the South with 13 new conventions. In addition to the agreements with the Municipalities, Rilegno has signed agreements with 416 public and private platforms that carry out, directly and/or on behalf of the Municipalities, the collection and withdrawal of wood on the territory, guaranteeing the subsequent start-up to recycling. All the national territory is "covered" by platforms affiliated with the Consortium where it is possible to confer packaging waste; of these at least 165 withdraw post-consumer wood from differentiated collection also

from the public service operators affiliated with the Consortium according to the ANCI-CONAI agreements.

Recycling is carried out almost exclusively by the producers of wood-based panels (particle boards of various thicknesses and thin MDF panels) that receive the material and transform it into products to be used in the furniture wood sector and, to a lesser extent, used for elements for new packaging Wood.

At the beginning of the supply chain, different platforms are selected / contracted to carry out the first selection and volume reduction of the waste wood (e.g. pressed, crushed, shredded or chipped). The main goal of this first treatment is to optimize the transportation of the raw material but also, to deliver functional and ready materials for the subsequently processing in the recycling facility. Additionally, the collection platforms are able to collect other types of waste wood from the furniture industry, construction and demolition, scraps from the wooden packaging industry and other wooden artefacts. The various types of primary, secondary and tertiary wooden packaging came from around 2,000 small and medium-sized enterprises, present throughout the national territory, a cause of the high fragmentation of the market, as in an environment of strong competition. To these are added hundreds of small activities dedicated to the recovery and reconditioning or regeneration of used pallets. Once their function is over, wood packaging that has become waste is collected mainly from private surfaces (85-90%) such as industry, commerce and large-scale distribution, being packaging mainly used for handling and transporting goods.

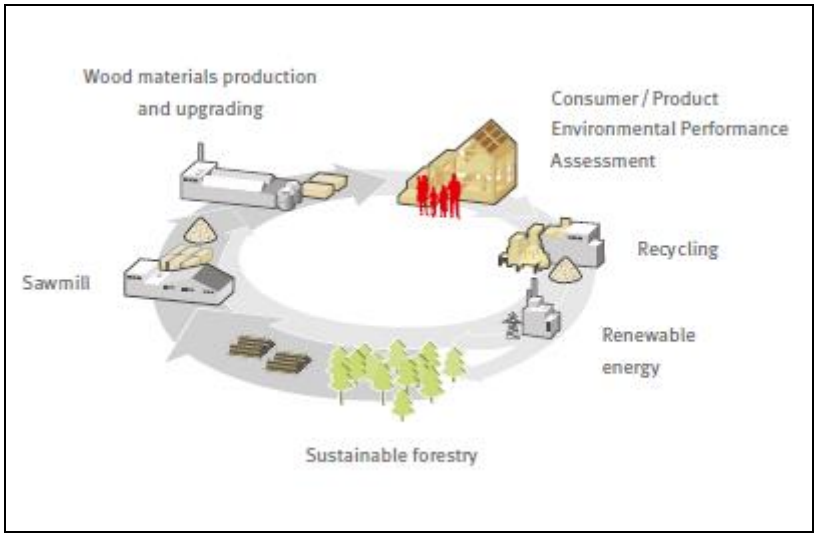
A part of the flows entering the recycling companies and not directly attributable to the operators of the consortium network, is entirely managed by them and the relative data communicated annually to RILEGNO: the quantities of post-consumer packaging sent for recycling are therefore detected mechanical (production of wooden agglomerates, cellulosic pulp, wood-cement blocks for building, elements for pallet assembly) and present within the aforesaid heterogeneous wood-matrix flows. Wood waste managed by third parties is not subject to periodic product inspections, but can be compared with those managed by the consortium system, at least in consideration of the CER codes used for recovery. The information on the physical and product characteristics deriving from the consortium operations, which derive from frequent and repeated inspections on the flows of wood waste delivered in the agreement to the same recycling companies, make it possible to obtain information that is also functional for the identification of the packaging waste component present in the flows sent for recycling outside the RILEGNO system, or in third-party management.

Germany

The supply chain of wood in Germany is composed of different actors that have the main subject in the management of wood waste and recycling. Several facilities exist for the management of wood waste. The recycling of processes wastes is carried out by **private companies** that manage all the processes (collection, sorting and treating) or by third-recycling companies[11]. In the first case, the company collects the wood waste and after the processing of these wastes they re-introduce the wastes in to the production cycle in order to improve the use of recycled material in the production process.

[11] Garcia, C.A., Hora, G. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management (2017).

Figure 5 From trees to product - a closed cycle



Source: Egger, Environment & Sustainability. Sustainable construction and healthy living with Egger wood-based materials (2019)

In the case of third companies, the main roles are to collect the wastes from different collecting points available for customers in order to deliver them in some collection centres. The aim of the collection centres is to collect the wastes and transport them in recycling facilities where they are classified, sorted and treated in a correct way (cleaned and reduced in size). The last step is to submit the wastes to incineration facilities to generate **electricity and heat** (co-generation).

France

As in other countries in Europe, the main side streams within the wood transformation sector are the by-products from sawmills, chips, off-cuts, widely used in the particle board industries, pulp industries and as fuel for heat production in combustion plants or CHP plants.

Other minor uses are also to be mentioned, like mulch and compost preparation.

More specifically, the last decade has also seen the development of the production of pellets from sawdust, either directly as a diversification of sawmills activities, or by specialized companies buying sawdust from these. The market for pellets French producers is mainly the individual household's boilers one. Sawdust is also used, to a limited extent, for wood polymer composites manufacturing.

Trading for these side streams has traditionally been direct between sawmills and users, but the development of the use in the energy sector has favoured the development of intermediates dealing with large amounts of wood fuels, called "Grouped buying platforms".

Concerning wood waste, the situation is quite different as the waste producers are much more diverse and scattered geographically than the by-products producers.

Wood waste can be considered of two kinds[12]:

- Wood industry production waste, i.e. all waste coming from wood and wood based materials transformation into the second transformation industries (about 1.2 million tons per year excluding internal recycling); wood construction products industries are concerned as well as furniture and packaging industries; most of it is produced on production sites, some also being produced on construction sites for the building enterprises.
- Post-consumer waste or waste arising at the end of service life of wood products: this is the case of wood packaging (over 1 million tons per year), mainly pallets, found in a very large number of economic sectors, basically all those receiving supplies on pallets. It is also the case of households, which are furniture waste producers, as well as professional tertiary activities (office furniture). And a major sector of production of post-consumer wood waste is the construction and demolition sector (about 2 million tons per year). End of life wood construction products waste are generated during renovation and demolition of buildings.

The practitioners of the wood waste system in France can be grouped into three categories:

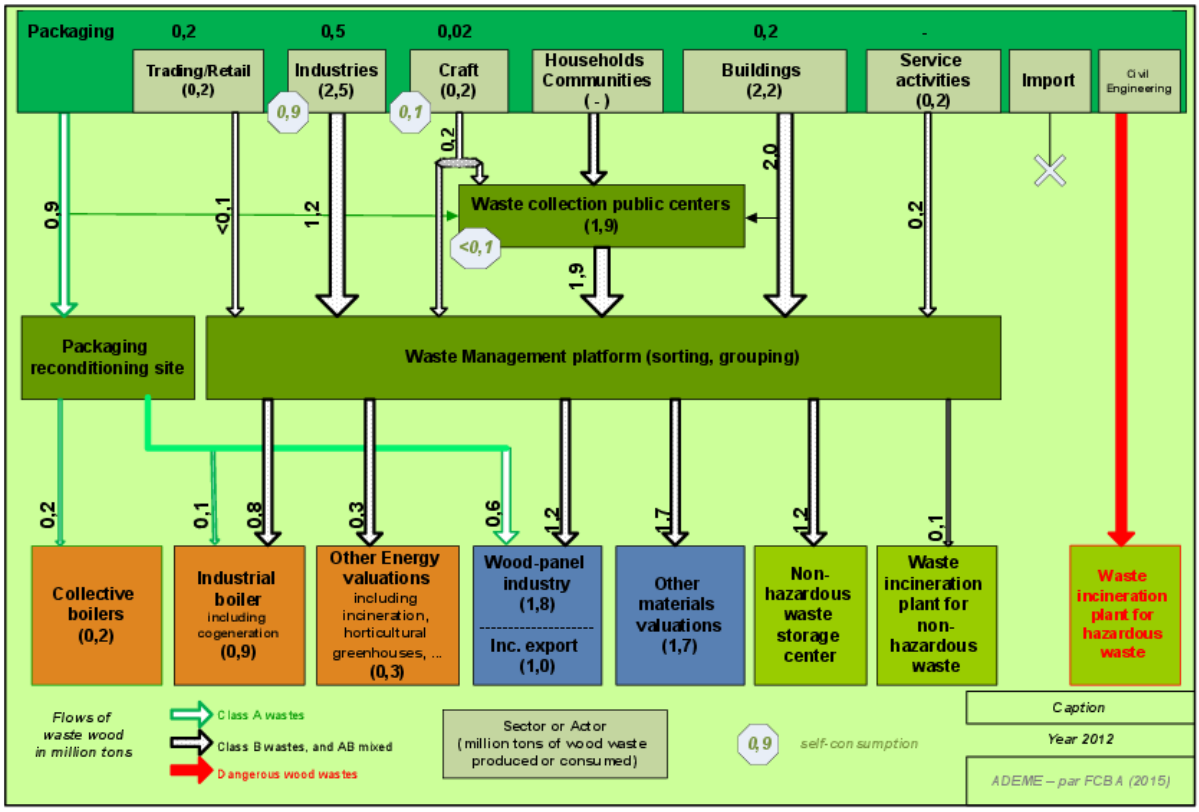
- Producers of wood waste: industry and crafts, construction and public works companies, households and communities, distribution, tertiary;
- Wood waste managers: recycling centres, pallet reconditionneurs, sorting and grouping centres
- Wood waste users and outlets: energy producers (collective boilers and industrial boilers), panel manufacturers, other recyclers, reuse and reuse players, landfilling centres and incineration plants for household waste

The different flows of waste from the producer sectors to the consumer sectors, passing through the different managers of collection-grouping-sorting can be represented as in Figure 6. As it can be seen, the first specific case is the one of packaging waste, and namely pallets. A specialized sector deals with recollection of pallets form all economic activities using these, reconditioning and repairing and selling a large part these on the market (nearly a 100 million pallets per year on the French market). This sector also uses a certain amount of planks recovered from broken pallets to repair about 4 million pallets per year. These companies are also preparing wood chips from non-repairable pallets, for energy.

Apart from that case, a large part of wood packaging (about 2/3 of the total amount) and most of the other kinds of wood waste is recovered and processed by waste management specialized companies : sorting and grouping centres. In the case of households waste, furniture, craftsmanship and small enterprises from the construction sector, the recollection can be going through local collection platforms, either mainly dedicated to household waste or specialized for professionals, before reaching the sorting centres.

[12] ADEME (2015), Evaluation du gisement de déchets bois et son positionnement dans la filière bois/bois énergie; https://www.ademe.fr/evaluation-gisement-dechet-bois-positionnement-filiere-boisbois-energie

Figure 6 Wood waste flows in France



Source: FCBA (2020)

UK

As it can be seen in Figure 7, wood waste arises in UK from different sources[13]:

- construction and demolition: solid wood, particleboard, imported elements, Oriented strand boards (OSB)
- packaging: pallets
- municipal: sawn off-cuts, wood based panels, surfaced wood
- joinery and furniture manufacture: Solid wood and particleboard

Producers of wood waste dispose it in landfill or through wood processors/recyclers or waste management companies. The actors involved in the management of wood waste are[14]:

- the composters, aimed at recovery wood in composting, have their logistic network that permit them to collect the wood waste from collection points
- Local Authority Household Waste Recycling Centres (HWRC) aimed at collecting wastes for residents, limited for wood sorting
- Collection clusters for small and medium enterprises: building collection routes at sufficient density to ensure viability for that do not produce sufficient wood waste to make skip based collections viable[15].

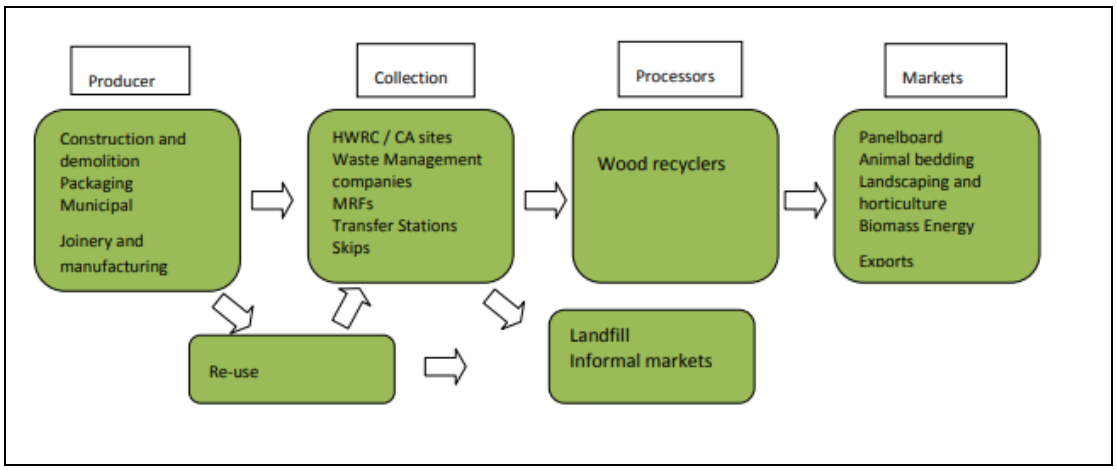
[13] Department for Environment Food & Rural Affairs (2012) Wood Waste Landfill Restrictions in England.
[14] Department for Environment Food & Rural Affairs (2013). Wood Waste Landfill Restrictions in England: Call for Evidence.
[15] WRAP (2012). The business Case for the Wood Waste Collection Hubs.

- Reverse Logistic, aimed to reducing cost of transportation, by using existing transport movements to return wood waste to a collection point for processing to end markets but these practices are not completely implemented yet.

The main markets in the wood waste industry in the UK are:

- wood panel industries and biomass/energy production
- animal/poultry bedding; mulches (soil conditioners and composting), equine surfaces and pathways and coverings
- There is also a growing export market (for recovery) in wood waste

Figure 7 Wood waste supply chain in UK

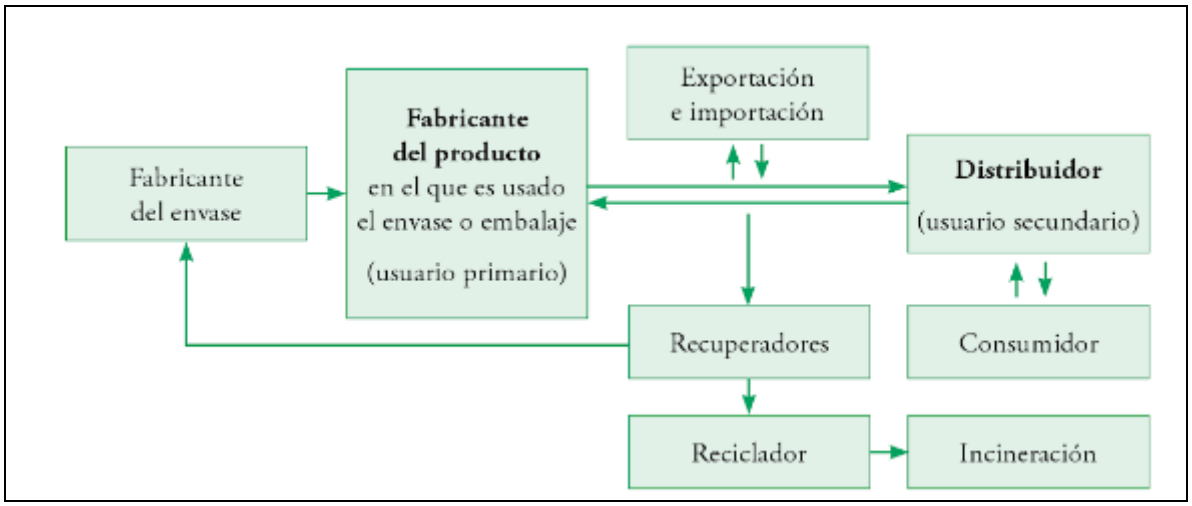


Source: Department for Environment Food & Rural Affairs (2012) Wood Waste Landfill Restrictions in England

Spain

Spain has transposed the directive 94/62/ce in the Law 11/97, 24 of April, on packaging and its wastes. The afore-mentioned law has as a universe of affectation all packaging for domestic, industrial or commercial use. Ecoembes, as a non-profit society, invest everything that enters as wastes by selling material in the recovery of packaging for subsequent recycling. Figure 8 shows the life cycle of the recovery of wooden packaging.

Figure 8 Life cycle of the recovery of wood packaging

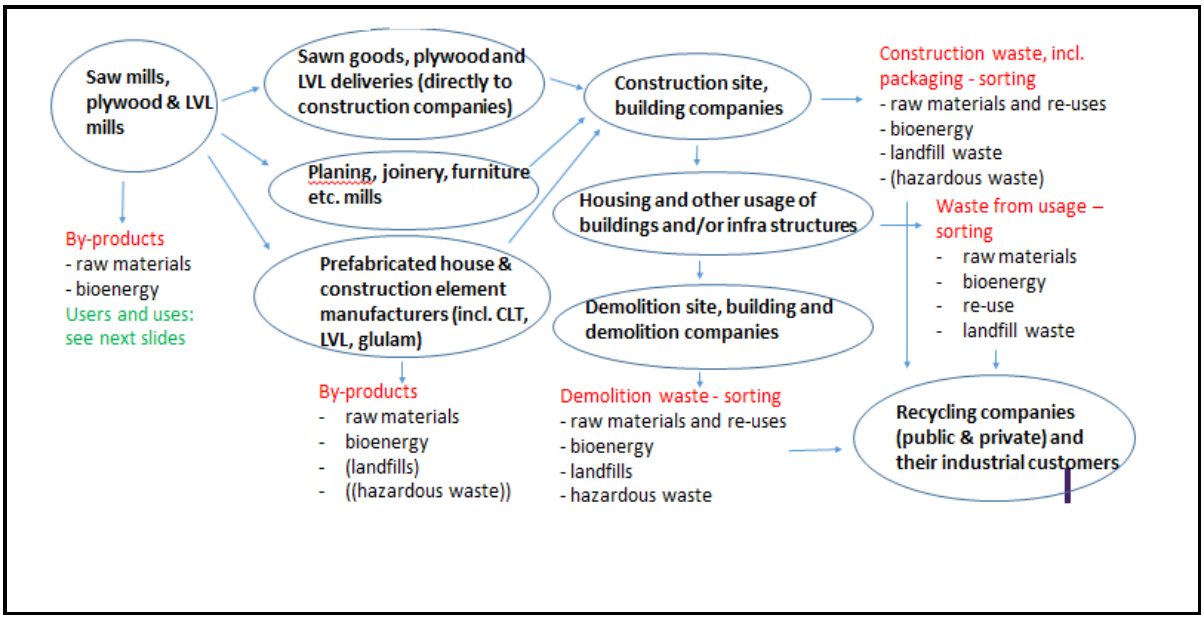


Source: Cabeza (2012) Logística inversa en la gestión de la cadena de suministro. Marge books.

Finland

Value chains of side streams and waste management in North-Europe based on wood products are driven both by the suppliers and by the users, covering the network of wood product industries, green field construction, building demolition and recycling organizations (Figure 9).

Figure 9 Value chains of side streams and wood-based wastes driven from construction in Finland



Source: Natural Resources Institute Finland LUKE (2019)

Different to Central and Southern Europe, the role of saw mills is the most important in Northern Europe as the supplier of their by-products, and pulp and paper mills and big heating and power plants are the definitely largest users. In parallel, the consumption of the few particleboard and fibreboard industries is smaller, although they use nowadays only saw dust,

shavings, off-cut pieces and bark from saw and plywood mills because of their good availability and lower price compared with roundwood from the forest.

The availability of construction and demolition wastes is limited to the vicinity of larger cities; they are few because of the smaller population. Long transportation distances, unprofitable collecting and quality concerns of these wastes have hindered the development of recycling business. Accordingly, the recovery practices may be less developed in comparison to other countries in Europe, but well adapted to the supply and demand[16].

In Finland, the main products starting from saw mill and veneer chips are chemical, mechanical and semi-chemical pulps and the resultant versatility of paper and paperboard grades. The market of green chips is steady, albeit the considerable fluctuation in the market price, and the demand is growing further due to the announced and prospective investments in pulping. The markets of other side streams, mainly saw dust, dry chips and bark are 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.

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. There is locally some demand of side stream materials for green infrastructure building, landscape management, soil improvement, horse stables and other animal houses.

The most novel 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 to replace 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 knot wood and inner bark of spruce and pine are used in small amounts in nutritional, medical and skin care products and cosmetics.

The following five value chains are typical in Finland to demonstrate different industrial ecosystems of side stream utilization where wood product industries are strongly involved:

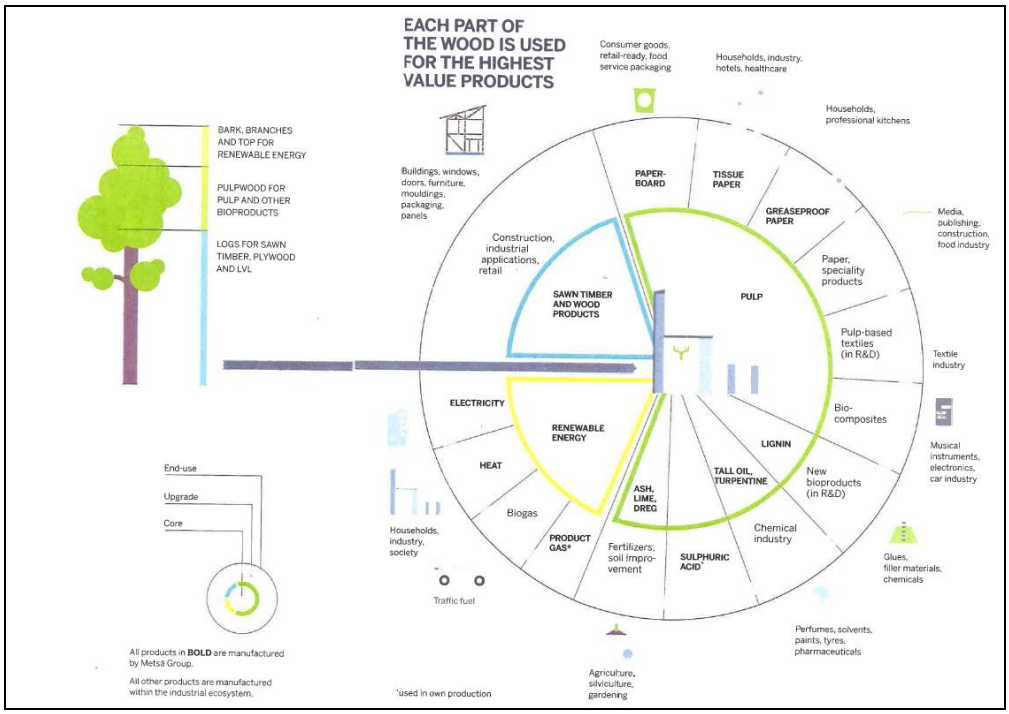
1. Value chain of biorefinery located on the site or in the vicinity of a large manufacturer of chemical forest products which receives side streams from wood product industries and

[16] Garcia, C.A., Hora, G. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management (2017).

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.

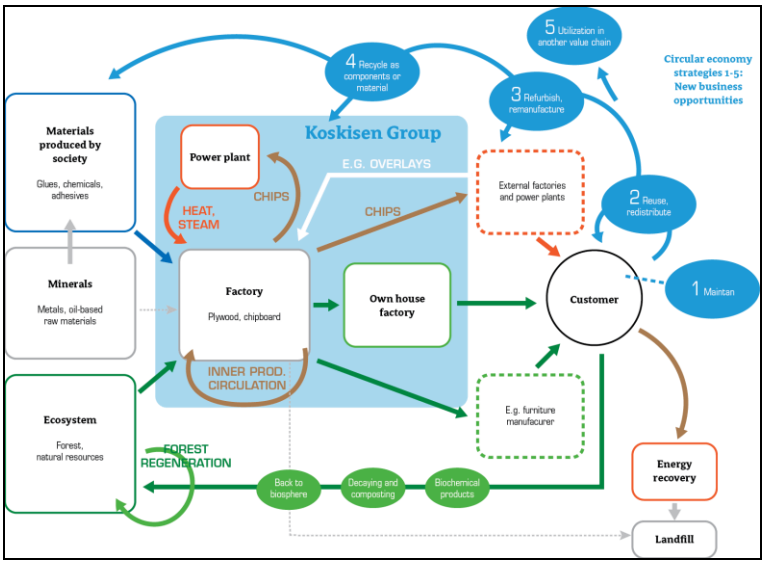
2. Value chain of biorefinery where several chemical industries of large corporation procure raw materials, including side streams, with long-term contracts from a number of wood products industries in a larger area which belong to the company or are independent companies, and supply further processors with their basic products and side streams. RDI platform is strong. Example: Metsä Group, Figure 10.
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, Figure 11.
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, Figure 12.
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, Figure 13.

Figure 10 Value chain of nationally integrated forest industry company



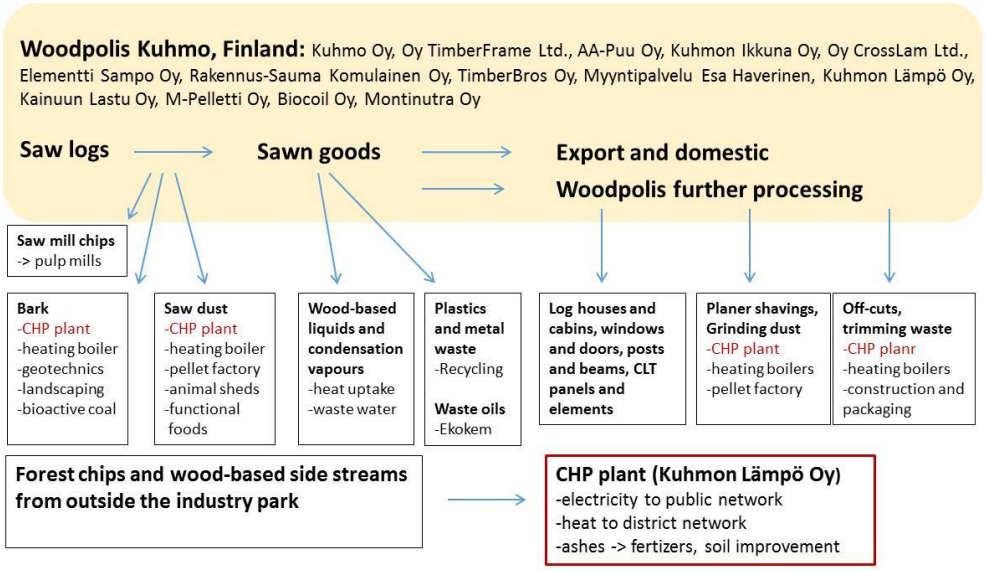
Source: Metsä Group (2019)

Figure 11 Value chain of locally integrated wood products industry company



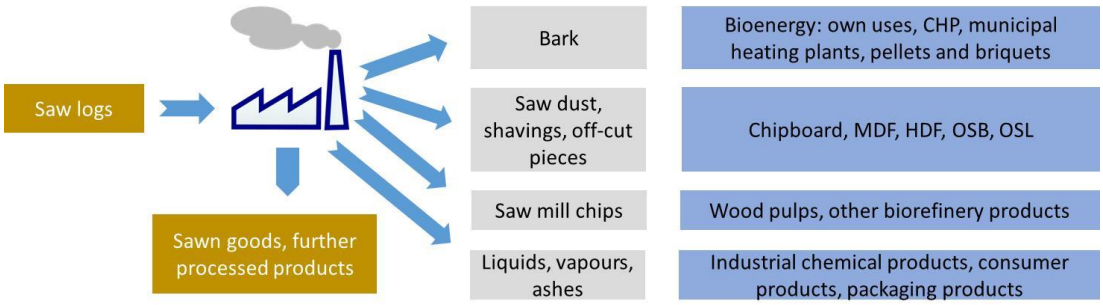
Source: Koskisen Group (2019)

Figure 12 Value chain of industry-park based wood product industries



Source: Verkasalo et al (2019)

Figure 13 Value chain of individual sawmill



Source: Verkasalo et al (2019)

4.3 Raw materials, products, markets and resource efficiency

Main groups of side stream raw materials in building with wood value chains are virgin wood (small wood, non-merchantable wood), by-products and process wastes (solid, liquid, gaseous) of wood product industries, construction and demolition waste materials and packaging materials (see Figure 1).

In EU-28 countries, all wood sources in 2015 were made up of 40% of industrial roundwood for primary wood processing industries, 12% of fuel wood and 7% of bark from virgin sources, 11% of miscellaneous wood residues, 6% of wood pellets and 7% of black liquor from secondary wood processing industries, 4% of post-consumer wood and as much as 13% of unaccounted sources (Table 7). Respectively, the uses were allocated of 22% to solid wood products industries, 9% to wood panel industries, 16% to pulp, paper and paperboard industries and 4% to wood pellets industries, and a total of 39% to heat and power generation. In total, material uses accounted for 51% and energy uses 49% of the volume (Figure 14). In different regions and individual countries, allocation of virgin raw materials as well as by-products varies a lot.

Table 7 Resource balance of virgin wood and residual wood in EU-28, year 2015. Volumetric data of roundwood is expressed over bark

EU-28

Wood Resource Balance 2015 (all units in SWE)

	SOURCES	1000m³	%	%	1000m³	USES	
PRIMARY	Industrial roundwood (conifer): Removals	271,449	29.5%	18.9%	174,100	Sawmill industry (conifer)	MATERIALS
	Industrial roundwood (non-conifer): Removals	79,224	8.6%	2.1%	18,885	Sawmill industry (non-conifer)	
	Industrial roundwood (conifer): Net-trade *	9,410	1.0%	0.3%	2,873	Veneer sheets industry	
	Industrial roundwood (non-conifer): Net-trade *	6,815	0.7%	1.1%	10,001	Plywood industry	
	Fuel wood (conifer): Removals	34,780	3.8%	5.2%	47,734	Particle board industry	
	Fuel wood (non-conifer): Removals	73,811	8.0%	3.3%	30,281	Fiberboard industry	
	Fuel wood: Net-trade *	-535	-0.1%	2.2%	20,324	Mechanical pulp industry	
	Bark	65,731	7.1%	12.5%	114,861	Chemical pulp industry	
SECONDARY	Sawmill residues	87,508	9.5%	0.3%	2,880	Semi-chemical pulp industry	
	Other industrial residues	11,128	1.2%	1.1%	9,848	Dissolving pulp industry	
	Wood chips and particles: Net-trade *	2,982	0.3%	4.1%	37,958	Wood pellets industry	
	Other wood residues: Net-trade *	3,218	0.3%	18.0%	165,930	Direct Wood	H&P
	Wood pellets	37,958	4.1%	24.1%	222,287	Indirect Wood	
	Wood pellets: Net-trade *	15,698	1.7%	6.8%	62,864	Unknown Wood	
	Black liquor	67,153	7.3%				
	Post-consumer wood	36,714	4.0%				
	Unaccounted sources	117,782	12.8%				
	Total sources	**920,826**			**920,826**	**Total uses**	

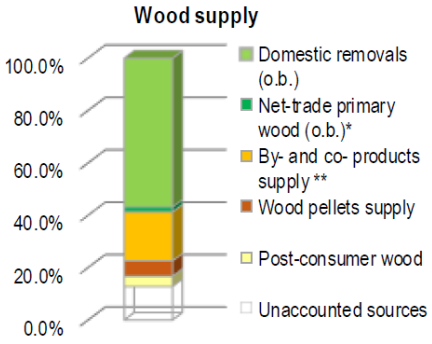
Source: Cazzaniga et al (2019b)

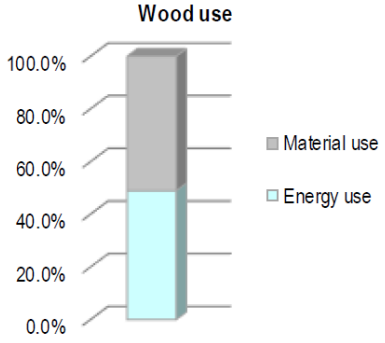
Figure 14 Wood supply and use in EU-28, year 2015. Volumetric data of roundwood is expressed over bark

Summary wood supply and use 2015

Wood supply	1000m³	%
Domestic removals (o.b.)	522,855	56.8%
Net-trade primary wood (o.b.)*	17,829	1.9%
By- and co- products supply **	171,989	18.7%
Wood pellets supply	53,656	5.8%
Post-consumer wood	36,714	4.0%
Unaccounted sources	117,782	12.8%

Wood use	1000m³	%
Material use	469,744	51.0%
Energy use	451,082	49.0%





* negative values indicate net-export

** excluding bark

Material uses	1000m³	%
Sawmill industry	192,985	44.7%
Wood pulp industry	147,913	34.3%
Panel industry	90,888	21.0%

Net annual increment 2015 (1000m³)

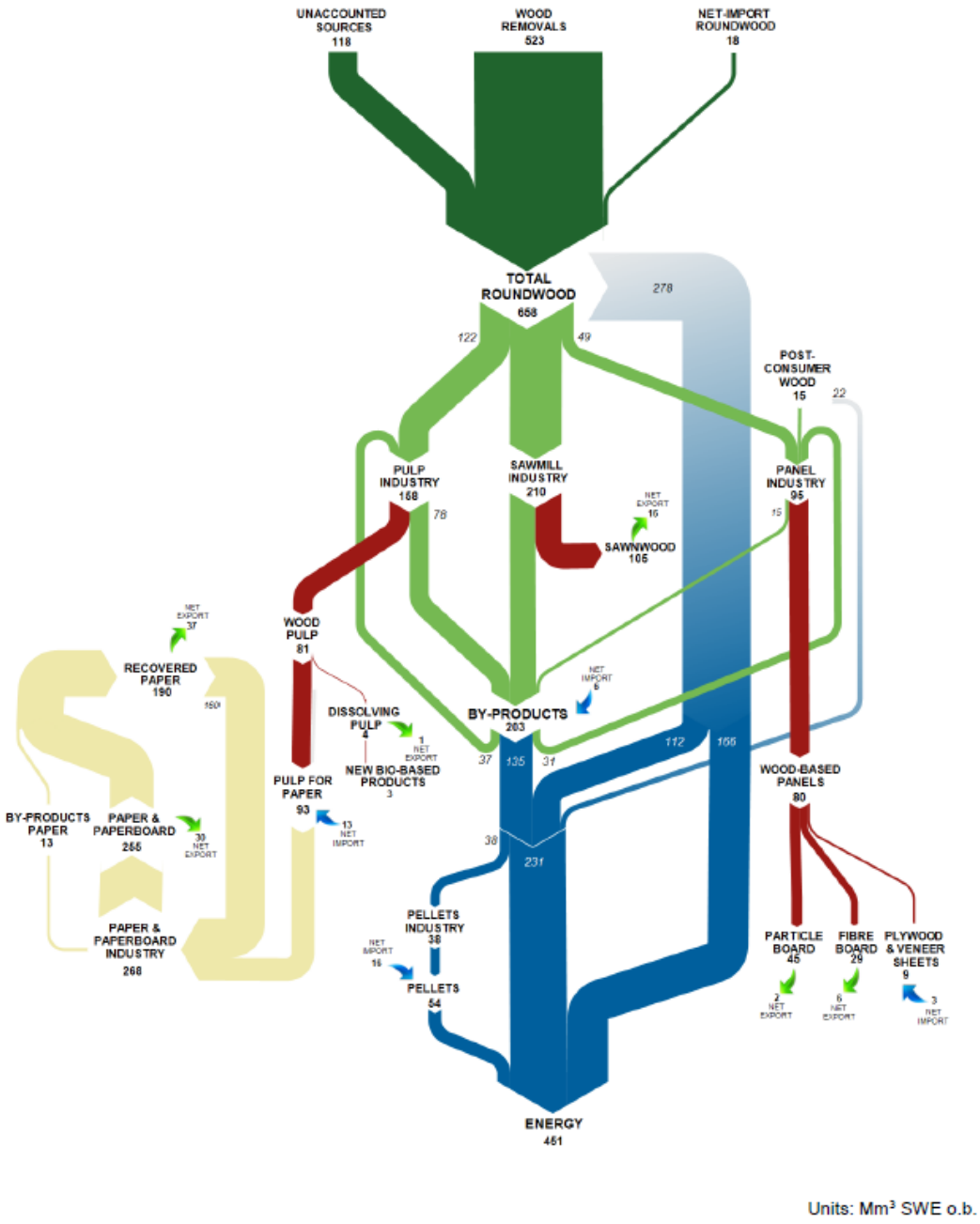
Tree components	all forest	FAWS
Stemwood	706,605	591,614
Other woody components	289,066	242,024
Total	995,670	833,638

Energy uses (H&P)	1000m³	%
Energy transformation	NA	-
Industrial internal consumption	NA	-
Residential sector	NA	-
Other	NA	-

Source: Cazzaniga et al (2019b)

Sankey diagram in Figure 15 shows wood biomass flows in EU-18. Of the total roundwood volume of 658 Mm³, more than half is allocated as by-products to wood using industries or energy.

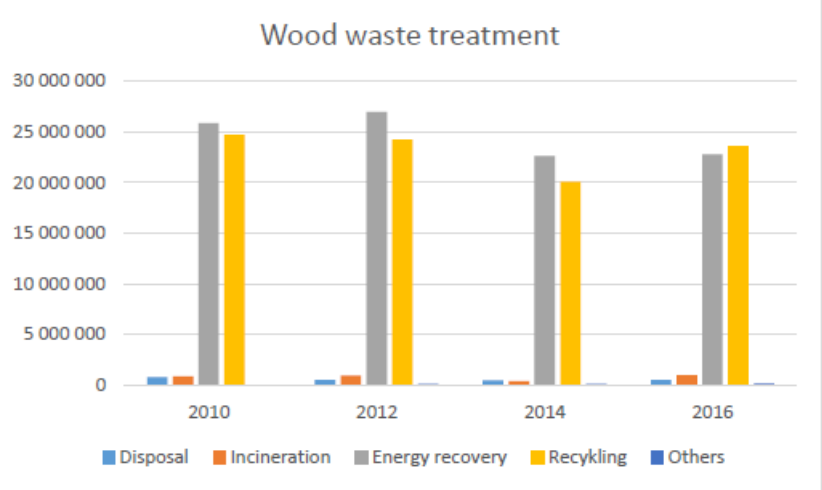
Figure 15 Sankey diagram of woody biomass flows in EU-28, year 2015



Source: Cazzaniga et al (2019a)

Several categories of wood waste treatments are present. As a whole, the most usual way to treat waste wood is energy recovery or recycling (mostly wood panel industries). In 2016 recycling reached the first time higher value that energy recovery (Figure 16).

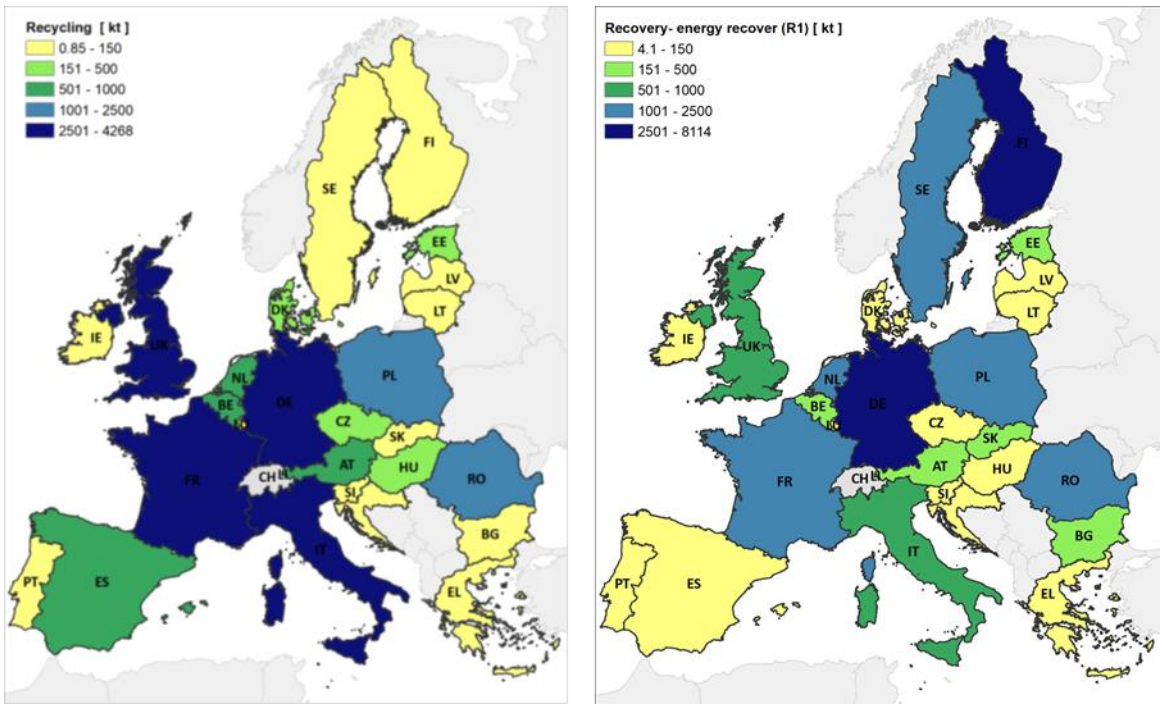
Figure 16 Development of wood waste treatments in EU-28 countries and Switzerland from 2010 - 2016



Source: Borzecka (2018)

In individual countries, the recycling rates (Figure 17) and the relationships of energy recovery and recycling can be totally different (Figure 17 and Table 8). It is worth noting the fact that in some countries, level of wood waste treatment is higher that their production, because of import of wood waste (Table 9). This is related to the fact that large proportion of wood waste is not a real waste; they are still suitable for use as a full value product or as by-products.

Figure 17 Recycling rates and energy recovery rates from wood-based side streams in EU-28 countries, year 2016



Source: Borzecka (2018).

Table 8 Wood waste treatments in EU-28 (2016).

GEO/WST_OPER	Waste treatment	Disposal - landfill and other (D1-D7, D12)	Disposal - landfill (D1, D5, D12)	Disposal - incineration (D10)	Disposal - other (D2-D4, D6-D7)	Recovery - energy recovery (R1)	Recovery - recycling and backfilling (R2-R11)	Recovery - recycling	Recovery – backfilling
European Union	48 010 000	490 000	490 000	970 000	0	22 800 000	23 750 000	23 600 000	150 000
Belgium	1 310 319	65	65	61 967	0	495 362	752 925	752 925	0
Bulgaria	307 518	636	626	466	10	185 603	120 813	120 813	0
Czech Republic	308 280	4 812	4 812	251	0	21 476	281 741	281 118	623
Denmark	330 742	2 228	2 228	0	0	50 401	278 113	278 113	0
Germany	10 802 911	0	0	2 351	0	8 113 985	2 686 575	2 686 575	0
Estonia	379 492	236	236	0	0	200 048	179 208	178 901	307
Ireland	127 962	4 310	4 310	0	0	42 121	81 531	69 439	12 092
Greece	59 675	40 959	40 959	0	0	5 496	13 220	13 220	0
Spain	1 069 621	17 646	17 646	0	0	74 429	977 546	977 546	0
France	6 412 266	315 004	315 004	95 810	0	1 733 861	4 267 591	4 267 591	0
Croatia	18 332	1 086	1 086	0	0	4 562	12 684	12 684	0
Italy	4 883 725	707	707	2 379	0	874 182	4 006 457	4 006 440	17
Cyprus	7 732	5 415	5 415	0	0	130	2 187	2 187	0
Latvia	13 403	4 429	4 429	0	0	6 700	2 274	2 232	42
Lithuania	97 159	1 586	1 586	0	0	16 335	79 238	79 238	0
Luxembourg	35 538	0	0	0	0	34 688	850	850	0
Hungary	217 840	532	532	119	0	16 051	201 138	201 138	0
Malta	8 850	8 829	8 829	0	0	0	21	21	0
Netherlands	2 277 404	49 257	49 257	1 930	0	1 323 079	903 138	903 138	0
Austria	1 263 759	0	0	114	0	424 212	839 433	839 433	0
Poland	3 607 312	32	32	236	0	1 426 406	2 180 638	2 180 638	0
Portugal	129 345	1 003	1 003	223	0	4 001	124 118	124 118	0
Romania	3 283 896	291	291	6 079	0	1 708 745	1 568 781	1 568 781	0
Slovenia	99 406	13	13	18	0	91 881	7 494	7 494	0
Slovakia	330 708	1 853	1 849	72	4	222 396	106 387	106 387	0
Finland	3 286 631	41	41	3 205	0	3 160 819	122 566	122 566	0
Sweden	2 100 233	0	0	45 560	0	2 032 437	22 236	22 236	0
United Kingdom	3 959 847	28 291	28 291	745 645	0	609 329	2 576 581	2 439 508	137 073

Source: Borzecka (2018).

Table 9 Production of wood-based waste in European countries by main uses (2016)

Country	Wood waste production	Energy recovery	Disposed/not recycled	Material recovery potential	Import	Export
Austria	1.636.000	768.920	196.320	670.760	200.000	
Belarus		-	-	-		
Belgium	3.623.422	1.739.243	398.576	1.485.603	1.000.000	
Bulgaria	316.578	117.134	101.305	98.139	-	
Croatia	91.293	32.865	30.127	28.301	-	-
Czech Republic	237.281	45.083	154.233	37.965	-	
Denmark	505.444	252.722	60.653	192.069		20.000
Estonia	434.266	91.196	52.112	290.958		
Finland	4.728.395	2.458.765	567.407	1.702.222	500.000	300.000
France	6.381.725	2.999.411	765.807	2.616.507	-	690.000
Germany	11.697.156	5.497.663	1.403.659	4.795.834	1.100.000	300.000
Hungary	160.000	27.200	19.200	113.600		
Italy	4.475.395	1.745.404	537.047	2.192.944	500.000	-
Latvia	70.345	11.959	8.441	49.945		
Lithuania	142.662	29.959	17.119	95.584		
Luxembourg	49.385	22.223	5.926	21.236		
Netherlands	2.534.898	1.292.798	304.188	937.912	-	1.250.000
Norway	791.645	372.073	94.997	324.574		324.574
Poland	2.560.395	307.247	307.247	1.945.900		
Portugal	332.821	53.251	39.939	239.631	-	
Romania	3.283.172	558.139	393.981	2.331.052	-	
Russia	4.500.000	2.115.000	540.000	1.845.000		
Slovakia	414.023	132.487	49.683	231.853		
Slovenia	148.160	63.709	17.779	66.672		
Spain	1.068.116	309.754	128.174	630.188	100.000	
Sweden	1.707.575	853.788	204.909	648.879	800.000	
Switzerland	817.000	383.990	98.040	334.970		200.000
UK	6.039.830	2.053.542	724.780	3.261.508		1.509.958
	58.746.982	24.335.526	7.221.650	27.189.806		

Source: IKEA Purchasing Services Italy, 2019.

Wood waste potential depends on many factors. Country size and population have strong impacts on the quantities of wood wastes. Big countries like France, Italy and Germany produce

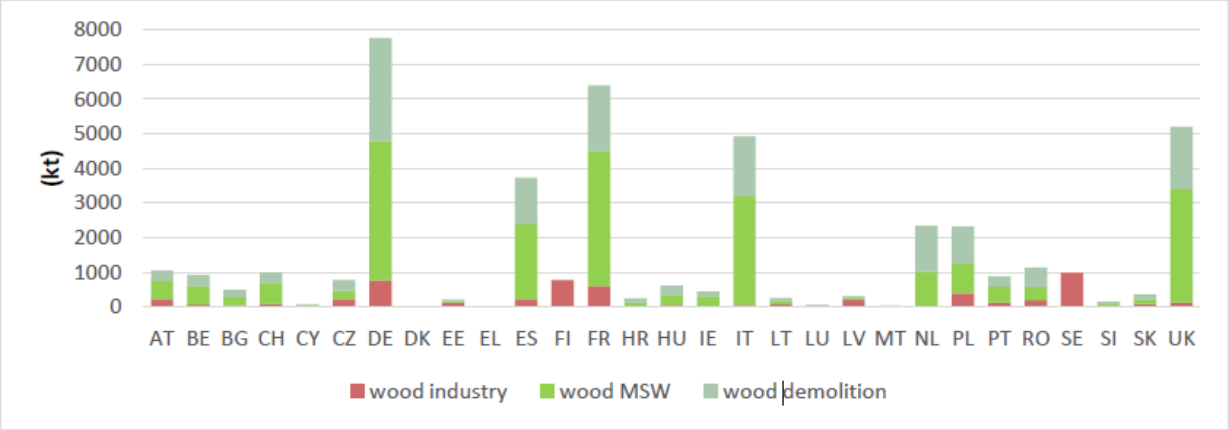
more waste than smaller ones like Malta or Estonia (Figure 18). Development degree of wood product industries also affects wood waste potential. Countries with high expand of this sector have big potentials of wood wastes from the industries.

Borzecka et al (2019) estimated the total theoretical potential of wood waste from wood industry, municipal solid wastes from wood (MSW) and demolition wood at around 45 million tons per year. The highest total theoretical potential of biomass from wood waste is in countries like Germany (7.8 million tons), France (6.5 million tons), United Kingdom (5.2 million tons) and Italy (4.9 million tons. Data from Eurostat regarding outlets for wood wastes (energy, recycling, landfilling) show orientations in terms of valorisation or elimination of wood waste of the different countries in Europe and provides information on the valorisation rate. However, these data do not consider, or they probably minimize certain bad practices like household heating (fireplaces) or open burning, and thus probably overestimate the real global valorisation rate.

The largest technical potential of biomass from wood industry waste is in countries like Sweden, Finland, France and Germany. Those countries have well developed forest industry sectors and large forest areas which affect the quantity of wood waste. Analogically, small countries with not so well developed wood industry sectors have a low potential.

The highest theoretical potential of biomass from construction and demolition wood is in countries like Germany, Italy, United Kingdom, Spain, France, Poland, Netherlands. Those countries generated the biggest amount of construction and demolition waste which affected the quantity of wood waste. Analogically, small countries which generated little amount of waste have low potential like Malta, Luxemburg, Estonia. No data was absorbed for Denmark, Greece, Finland, Sweden in that study.

Figure 18 Total theoretical potential of wood waste in EU-28, year 2016



Source: Borzecka (2018)

Northern European countries can be considered as a good model for side-stream generation and utilization among wood product industries. Wood-based side streams are an important part of business income of these companies. In Finland, by-products of wood currently constitute around 15% of the revenue of large and medium-sized saw mills, and 7-12% of the income of plywood industries. Similar or little higher shares have been reported in Sweden, Norway and Baltic countries as well as in the advanced companies of France, Spain, Austria and Germany.

In Finland, on average 30–55% of the saw or veneer logs ends up to side streams depending on the final product. In Central European and partly Southern European and Eastern European countries the percentage is often smaller, sometimes down to 20%, due to the larger log diameters and shorter lengths, and sometimes higher because of less advanced sawing and rotary-cutting technology, especially when processing hardwood logs. Of the logs with bark, Finnish 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%) (Verkasalo et al 2019).

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 Finnish 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 (Verkasalo et al 2019).

Wood panel industries, mainly particle board industries, fibreboard industries and MDF plants are large users of wood-based side streams, both fresh chips, saw dust and bark and recycled wood. In Europe, there are finding of their share of 20% - 100%. Generally, fresh raw material is more uniform and of better quality, but recycled material is more inexpensive. These industries provide little side-streams, mainly off-cuts of panels and damaged panels, which make up of less than 10% of their raw materials.

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. 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. Practical observations indicate that European furniture industries relying on solid wood provide wood-based wastes of 10% - 50% and those relying on particle boards or MDF panels 5-30% of their raw material.

Some wood-based side streams contain 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.

The main factors found to influence 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. Wood chips, sawdust, and bark are considered the most valuable side streams because of their relatively high quality and solid form, but to date they have been mostly used in energy generation and partly in pulp and wood-based panel production in Europe.

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 particle board and fibreboard production. However, a range of new potential uses should be available in the chemical, biofuel, modified wood and composite industries, along with 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.

Italy can be considered a good model for management and utilization of post-consumer wood in Europe. In particular, the wood-furniture supply and value chain is one of the most avantgarde in terms of circular economy both compared to the level of other countries in Europe and other manufacturing sectors in Italy. Recovery and recycling are the main pillars: every year in Italy over 2 million tons of wood are recovered and sent for recycling, deriving from urban and industrial recycling processes.

Unlike what happens in other countries, where post-consumer wood is mainly incinerated to energy, the Italian system has allowed to regenerate energy of almost 30% of the recovered wood, and to recycle the more than 70%. This has allowed the production of furniture panels without any need of virgin wood or raw materials in general. In environmental terms, this has led to a saving in CO_2 release of almost one million tons, which is 2% of the total CO_2 caused in Italy. This is an important positive environmental effect, accompanied with the ability to create rural development and employment. The economic impact on national production of the activities of the post-consumer wood recovery chain is estimated at around 1.4 billion euros, while the contribution on employment is almost 6,000 jobs supported overall in Italy.

The system has created value for the entire wood-furniture supply chain, guaranteeing the furniture industry, through the supply of the particle board panels, an important quantity of material that has allowed the closure of using virgin wood which suffers from scarcity as an industrial raw material in Italy.

Italian wood furniture companies have undertaken two different development paths in terms of sustainability, the first on design and planning, betting on increasingly eco-compatible products, using and researching recycled and recyclable materials with the least possible environmental impact. The second concerns the companies and the production phases, for example through the use of renewable energy or the disposal of waste in a way facilitating their recovery.

The Italian supply chain is among the most advanced in the world in terms of recycling percentages: over 95% of the wood collected is recycled within the supply chain, and the panels are made almost entirely from recovered wood. Moreover, in many cases wood scraps generated in production processes are used to generate electricity and heat for on-site use (panel manufacturing).

In Italy, the annual total of wood waste is around 4.5 million tons: only 0.8 million tons are of urban type and 3.7 million tons come from industries. Respectively, the wood scraps make up of 5% of the total urban waste and 3% of the total industrial waste. The Rilegno consortium is able to independently track about 2 million tons a year, independently from the type of waste (urban or special). In 2018, almost all waste wood was subjected to recycling processes for the production of raw material for panels or reprocessing for new packaging products (Table 10). Much smaller quantities were used for composting treatments and for energy production after incineration. The latter, perhaps included, is the true side stream that can be identified in the

whole recovery processes. As it is stated by several recyclers, about 10% of the recycled material waste is used to obtain energy and heat and that is used entirely in the panel production plants.

Table 10 Wood wastes released to consumption in Italy, year 2018.

Usage	Wood wastes tons	Proportion of material released to consumption (3.03 miilion tons), %
Recycling as raw material	1,106,909	36.45
Reprocessing	780,278	25.70
Composting	38,997	1.29
Energy recovery	73,081	2.41
Total recovered (recycling + Energy recovery)	1,999,265	65.84

Source: Rilegno (2020*)*

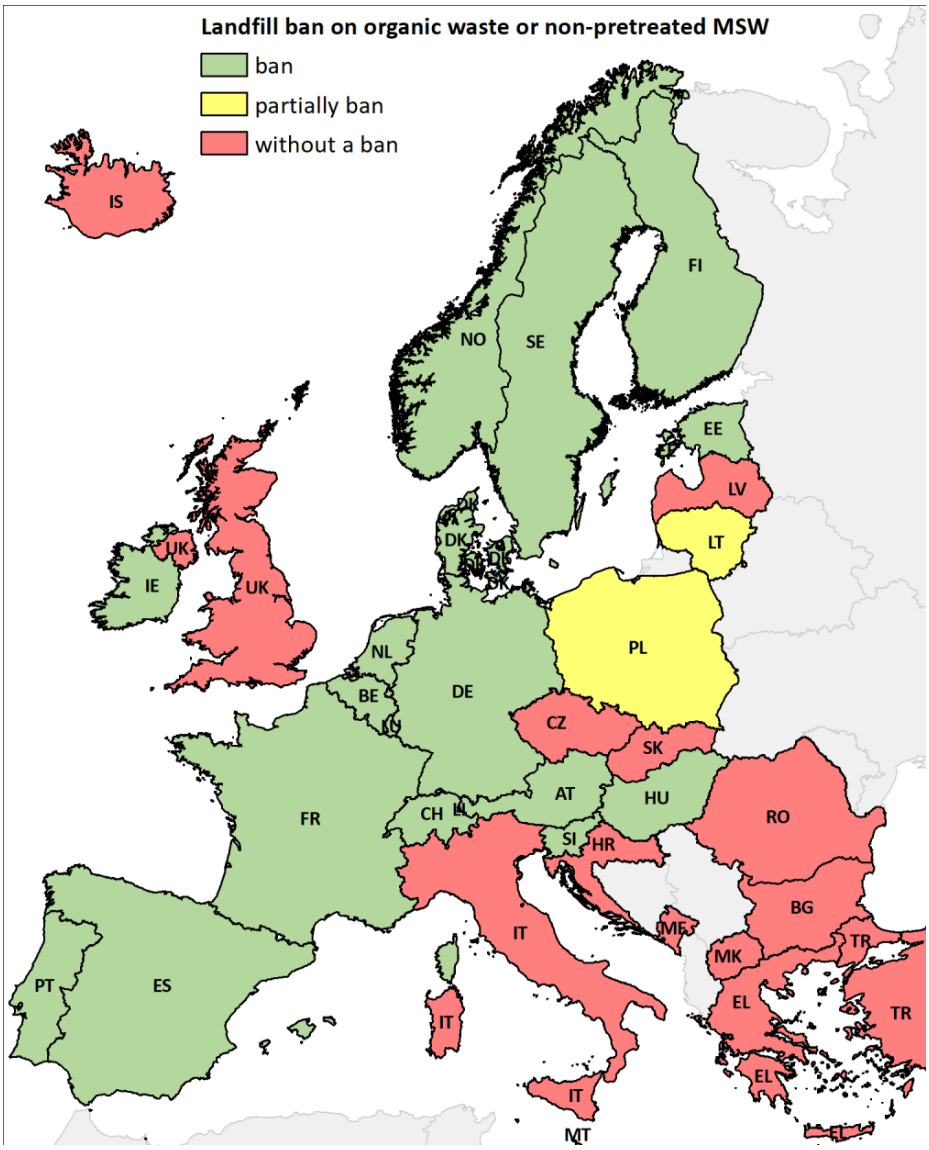
Although there is an encouraging starting condition in Italy, a great part of opinions among industries declare that, to really support the shift towards a fully circular economic model, important measures are needed on taxation that really incentivize companies to change their strategies.

More in general, wood is widely used in Italy and its utilization also concerns the production of paper and energy: in these specific cases, virgin wood is used, coming mostly from abroad (85-90%). According to the data from the Ministry for Agricultural Policies, Italy is the EU country with the lowest degree of self-sufficiency in the supply of wood raw materials. Import of wood for industrial uses in the last 5 years has averaged around 12 million cubic meters per year, against the use of domestic wood of hardly over 2 million cubic meters. Italian industrial timber is mainly coming from three regions: Lombardia, Trentino Alto Adige and Calabria (66% of the total). This critical issue is due to the political concept according to which forest resources only constitute an economic-environmental reserve to be preserved rather than to be managed also for timber production purposes, according to the concept of sustainable forest management. Furthermore and unfortunately, the Italian forests have been under-managed, and there is not timber stock available that would be mature enough for industrial utilization.

In many EU countries landfilling organic waste or non-pre-treated municipal waste are banned (Figure 19). In Poland and Lithuania only biodegradable waste is banned from landfilling. In Europe less and less waste ends up on landfills. Some countries, such as Germany, have decided to introduce a zero-waste policy, completely forbidding storing of waste. It is important to note that the ban is theoretical in some countries. In France for example, landfilling is prohibited for non-recyclable wastes “under current economic and technical conditions”: in the end, operators may justify the non-recyclable character of a waste, and resort to landfilling, and this in compliance with legislation. Besides, it is complicated to make out limit between pure incineration (waste treatment without energy recovery) and waste to energies plants (incinerators with high recovery valorisation rate) at European scale. Therefore, it is likely that energy recovery rate is overestimated.

In all, disposal of wood waste is at a low level in Europe. But still there are wood wastes which can be treated in different ways. Not all wood wastes are still recovered. In addition, it should be remembered that large part of wood waste is not collected and segregated, and some are used in households in an inappropriate way (combustion in open fireplaces, etc.), or even burnt outdoor in demolition or construction sites. According to Borzecka et al (2019), all this represents unused wood waste potential and because of lack of data it is hard to completely be characterized.

Figure 19 Landfill ban on organic waste or non-pre-treated municipal waste in European countries, year 2016



Source: Borzecka 2018.

4.4 Processing and recycling techniques

Standard mechanical screening technology is applied at saw mills, veneer mills, plywood mills and other mechanical wood processing plants to provide pulp chips, saw dust, planer chips and uneven planer chips or bark for sales to different customers. Commonly accepted standards

which are based on particle size distribution and maximum bark content are used in the trade of by-products of mechanical wood processing for chip quality, for example in Nordic and Baltic countries, probably throughout Europe. The undesirable chips are sorted out for other uses than pulping, mainly internal use as energy or energy material to be sold for customers. Saw dust is also screened to remove the undersized grains and oversized particles when it is sold to pulp mills, following the quality requirements set between the supplier and pulp mill. In incineration processes, chips, saw dust and planer shavings are used as they are. Bark which comes out from the debarking process as long stripes is crushed to small-fraction material before it is delivered to incineration, landscape management, geoconstruction or animal bedding. In some new installations at cogeneration plants of heat and electricty, for example at CHP plants, saw dust and bark are dried before using them. For the technological options, see Varis 1998.

Pulp chips is re-screened, bark content and other quality parameters are controlled at pulp, paper or paperboard mills using dedicated mechanical and optical technologies. Chips from mechanical wood processing plants are fed to the process or stored in large silos as their own assortment of raw material. It is used as pre-planned mixture among Roundwood chips for different pulp grades to meet the desired fibre quality and optimize pulp yield and chemical consumption in pulping and bleaching operations. For the technological options, see Koskinen 1999.

Nowadays, a multitude of technology is available for incineration of wood materials: conventional and advanced boilers, cogeneration plants (CHP, fluidized bed, etc.), slow and fast pyrolysis plants and Fischer-Tropsch plants. Bioethanol and bio-oil manufacturing plants based on using wood materials are either under progress or construction. Both incineration and chemical conversion and extraction plants have specific requirements for the raw material as regards their general quality, foreign particles, contaminants and moisture content.

In Italy, there are today very precise processing and recycling technologies that allow to confer a second, and often a third or fourth life to the materials. They provide immediately tangible effects on the environment: a brake on the deforestation of the planet, credible deterrents to the cementing, safeguarding for the air health.

In this way, wood is confirmed as a dynamic material, even after a significant and heterogeneous number of processes. The recycling process absorbs a fairly large conglomeration of wood-based materials: wood construction, furnishing and packaging wastes, including particle boards, OSB boards, pallets, fruit boxes, packing cases, demolition beams and panels, poles for electric and telephone cables, old furniture and utility items, reels for electric cables, pruning waste, in addition to miscellaneous wood processing wastes (wood chips, sawdust, particle board waste). The waste materials are often intended for a specific use. The materials are collected in companies or as result of urban separate collection, and subsequently conveyed in special waste management platforms that belong to different consortia, to begin the reconfiguration process.

In the waste management platforms, the first coarse cleaning is followed by mechanical crushing using special machines that result in roughly chopped wood. Impurities such as nails, screws and other jointing items are removed from these materials, so the wood is shredded in an even more capillary way. The artificial drying and dry cleaning operations follow. There are standard mechanical sorting and cleaning systems available that are used as a routine. New cutting machines allow minimizing scraps.

Automation and robotics have been applied to the sorting processes, for example in Finland. Non-destructive systems and artificial vision tools have been developed for identifying unwanted pieces and materials from the material flow, applying for example near-infrared spectroscopy (NIR) in France.

In Italy, the products from the previous phases are then collected by wood panel manufacturers. Their facilities receive a semi-finished product which is sufficiently fine to be used in the production of particle boards. Using a binder (glue or resin), the chopped wood is amalgamated, providing proto-panels, i.e., semi-finished elements ready to be subjected to the last phase of processing, cold and/or hot pressing. Then, the stable and compact wood panels are obtained. Panel surfaces are coated with veneer or melamine, or treated with other materials or chemicals. The panels are used for the production of furniture and cabinets, interior or exterior cladding, or other wooden products.

5 Fact finding interviews and stakeholder integration

5.1 Involvement and structure of stakeholders

Fact finding interviews were done and questionnaires were presented to different stakeholders following three different methodologies to collect information: face to face during visits to the organizations, telephone interviews, direct compilation of data by the recipient. The stakeholders individuated by partners were relevant companies, industry associations or federations, public development organizations, municipalities and other actors involved in the value chain of side streams and wood waste management.

For this purpose, two different versions of the questionnaires were elaborated: a short version with the essential information to collect and a long version to present the answers more detailed (Table 11). The typologies of questions used were: open-ended questions, multiple choice questions and questions based on a Likert Scale. The decision to use two different questionnaires was justified by the need to adapt the questionnaire to the channels of data collection, the competences of the stakeholders interviewed and the level of involvement in the value chain of side stream utilization and wood waste management. The choice allowed flexibility to apply the fixed structure of questionnaire and customize the interviews in order to optimize the collection of data. By the way, the written questionnaire represented a reference to follow during telephone interviews or face to face in order to guarantee the collection of the essential information which regarded:

1. Resource efficiency and value chains of wood products industries and use of lateral flow
2. Recycling
3. Policy impacts on companies and their strategy and innovation towards circularity

In particular, the information regarded the following topics:

- The role of the stakeholder in the wood value chain;
- Types of processed material with special focus on the physical, mechanical and chemical characteristics and presence of contaminants;
- Methods of recycling of wood-based side flows and relative opportunities (recovery and power generation);

- Recycled quantities and efficiency percentages;
- Technologies used during processing waste;
- Strengths and weaknesses of the processes implemented;
- Opportunities and threats of the processed implemented;
- Other quantitative data such as: level of investment, estimated costs and benefits;
- Awareness and perception of the effectiveness of policies.

Table 11 Questionnaire structure, short and long versions

Short Version Questionnaire	Long Version Questionnaire
General information 1. Managing waste wood and side streams 2. Resource efficiency and value chains of wood product industries and side stream utilization 3. Policy impact on businesses, strategy and innovation towards circularity	General information 1. Managing waste wood side streams 2. Technologies for wood processing of side streams 3. Resource efficiency and value chains of wood product industries and side stream utilization 4. Side stream utilization: products, markets, competitive ability, sustainability, other business factors 5. Projects involvement

The purpose of the interviews and questionnaires was to collect specific information from the stakeholders perspectives in addition to those already obtained with the general analysis of the state of the art. In particular, the output expected is a detailed analysis of the internal and external factors that can influence the processes implemented by the stakeholder involved in different levels of the value chains of side stream utilization and waste management. The analysis of the results from interviews and questionnaires highlights both general and special aspects in the different countries that can be of more relevance in some contexts than others.

It was aimed in the project to collect 10-15 interviews or questionnaires in 1-2 countries in each region in Europe. In total, the following numbers of interviews were achieved: southern 32, central 44, northern 21, eastern 2, all regions 99 (see Table 12).

The analysis of interviews covered stakeholders at different levels of the value chains from Italy, Spain, Slovenia, France, Germany, Austria, Switzerland, Belgium, Finland and Sweden. In particular, the following actors were involved: saw mills and interior product manufacturers from solid wood, joinery and construction element manufacturers, pallet and packaging industries, wood panel, bio-composite granulate and adhesive industries, furniture industries, wood fibre producers, construction and demolition companies, public and private waste storage and disposal platforms and companies, machine manufacturers for wood chipping, crushing and shredding, sorting and cleaning of wood-based wastes, wood panel and saw mill industries.

The composition of interviewed stakeholders as regards the industry sector varied much by country. For example, solid wood transformation and further processing had large cover in Spain and Finland, wood panels and biocomposites in Germany, furniture manufacturing in France, and wood waste collection and processing in Italy. The extent of reporting varies between the regions varies due to the complexity of different value chains and the typology of stakeholders interviewed in each country.

In addition to the interviews and questionnaires, three fact finding workshops were organised to gather information on recycling, waste wood management and side stream valorisation activities from both technical and regulatory perspectives (Table 12). Warsaw workshop on 30th January – 1st February, 2019 aimed at mapping the basic situation and development needs in EU13 countries, with the representation of 14 experts from industry federations and public research and development society. Helsinki workshop on 10th of April in 2019 focused to the role, opportunities, challenges and needs of sawmill and wood product industries, 14 and 2 representatives from industry companies and federations being present, respectively. Cologne workshop on 13th of November, 2019 gathered 6 representatives from wood panel and bio-composite industries and their machine manufacturers. See chapters 5.2.2 – 5.2.3 for more detailed description and achievements of the workshops.

Table 12 Number of interviews and participants of workshops for fact finding in different regions by stakeholder group

Region	**Wood transformation**		**Furniture manufact-uring**	**Construct-ion and demolition**	**Wood waste collecting and processing**	**Machine manu-factu-ring, chemi-cals**	**Federations, development bodies**
	Solid wood	Wood panels, biocom-posites					
Southern							
***Italy**		2	1	1	15		2
***Spain**	9	2					
***All**	9	4	1	1	15		2
Central							
***France**	6	2	11	3	1	1	
***Germany**	2	6		1	1	3	
***Austria**	2	1					1
***Switzerland**		1					
***Belgium**		2					
***All**	9	12	11	5	2	4	1
Cologne Workshop		2				2	2
Northern							
***Finland**	4	1		2	3		8
***Sweden**	1				1		1
***All**	5	1		2	4		9
Helsinki Workshop	14						2
Eastern							
***Slovenia**	1				1		2
Warsaw Workshop							14

5.2 Results by stakeholders

The results of the interviews and questionnaires are summarized in four geographic groups: Southern, Central, Northern and Eastern European countries. The analysis will mainly follow the structure of the questionnaire focusing on the practices of managing and using industrial by-products and waste wood materials, technologies and processes, organization of value chain and involvement of companies. For the implementation of the results, strengths and opportunities, obstacles and threats, and research and development priorities in the circular economy context are compiled and reported.

5.2.1 Southern Europe

In this region, 34 answers provided by the stakeholders from Italy and Spain were collected. They included companies of solid wood transformation from Spain (production of wood planks, plywood and secondary products, side streams comprising bark, sawdust and splinters) and wood panel producers from Italy and Spain (production of particle boards and MDF boards), and platforms of wood waste collection and processing from Italy (which work with packaging, working scraps, dismissed furniture and construction material). The main wood-based input material used by the companies is virgin wood in the case of solid wood transformation, and recycled wood in the case of wood panel producers and wood waste collection and processing platforms.

Among wood product industries of Spain, primary product manufacturers, i.e., saw mills and plywood mills typically generate much more side streams than secondary wood processing plants such as pallet, glulam, building element, blockboard or flooring manufacturers. While the yield of by-products ranges from 20% to 60% in primary processing, it is estimated to 10-30 % in different types of further processing. Side streams of secondary processing also contain much more often hazardous agents; this is a challenge both regarding regulations, technology and costs. By-products provide anyway income especially for saw and plywood mills.

With regard to the side stream utilization, the companies answered that the side streams are used mostly for:

- production of heat in biomass boilers or co-generation facilities
- production of paper mills or pellets
- production of chips and particleboards

Special to wood product industries, wood chips and part of saw dust are sold to pellet, panel and paper manufacturers. Most of bark, saw dust and splinters go to internal use of energy (heating, wood drying), or are sold for energy generation or, in a smaller amount, to gardening and animal bedding. CLT and glulam manufacturing is rising in Spain, like in many countries in Europe, with a special side stream composition mainly consisting of large and small leftover (off-cut pieces from beams, panels and window and door holes). These should provide potential as material for special solid wood products and composite products (wood-wood, wood-plastics).

In general, the side streams are sold as firewood and biomass, or they are purchased from recyclers and wood suppliers. Here we can put in evidence a substantial difference between the countries: while in Italy almost all side streams are used for heat and energy production, panel manufacturing process or for the biogas production through composting (small part), in Spain

there is the tendency to use side streams in biomass boilers to generate heating or to produce pellets.

With regard to the implementation of specific materials, processes or efficiency practices, the answers showed a general tendency of the companies to implement the practices through introduction of new technology. The tendency is very evident among the Spanish companies, but this may depend on the nature of the firms involved: most of the companies interviewed were large enterprises of wood products manufacturing with plentiful resources available. In particular, the companies claimed that they have adopted new practices in order to implement the necessary classification of side streams, and improve the use of virgin wood. This should allow a greater competitiveness.

Another practice implemented regards the use of by-products for the realization of agglomerated boards or pellets, in order to recirculate materials throughout the processes until the material is no longer usable. Some companies have introduced biomass boilers that contribute to savings in energy cost. These practices have a positive impact on the economic performance of the companies that are investing in material improvement or, more in general, in efficiency practices. All before-mentioned actions are contributing to the lowering of production costs, and in parallel to increasing the production capacity. Moreover, these solutions are speeding up the deliveries to customers with consequent financial benefits.

With regard to the technologies used for processing side streams, the answers showed a general tendency to introduce specific technologies especially for mechanical treatment of wood to increase the volumetric solid content. In particular the following technologies have been introduced: wood crushing machines (splinter crusher), shredders and iron-removing equipment, new cutting machines that allows minimizing scraps, artificial vision tools for optimizating wood cutting at mills, automatic gluing lines and presses. A smaller number of companies affirmed that they have not implemented any kinds of resource efficiency practices, but showed willingness to improvements in the near future.

The companies were asked to give their points of view about the main obstacles in the development and implementation of wood-based side stream utilization for recycling and waste management of residues. The main obstacles are linked to some factors attributable to virgin raw material such as general availability and tree diseases that may influence the quality, but also to some issues concerning direct side stream context.

One of the biggest obstacles concerns logistics, especially in terms of transportation costs and delays in timing that may affect the supply system. Waste legislation implies to the vulnerability of the system through the dependency on the eventual modifications in standards and laws that may influence the management of the processes. Among companies there is a general perception that environmental management is complex regarding administration, and involves too many documentary requirements that may limit operations and cause losing the business idea.

Another big challenge is related to the sector itself which is very competitive. The sector is characterized by SMEs that do not produce large amounts of wastes to supply material for the panel manufacturers, for example. Further issue concerns the general suspicion of consumers about whether discarded or recycled wood can guarantee the same product performance as virgin wood, also when the material is properly selected and processed. The general perception that discarded wood is good only for heating or other energy uses needs to be changed. This

should happen by designing, developing and promoting sustainable products, that, as affirmed by the companies, should have relevant characteristics in terms of sustainability and circularity combined with high-quality performance. The same facts are related to vintage products which some companies mentioned potential in the context of reuse and recycling.

According to the answers, the companies know and understand the relevant policies for the sector, but a major support from the public decision makers and policies is needed. In fact, most of the interviewed think that EU and national regulations do not provide the required incentives to adapt business practices and services with circular economy principles.

5.2.2 Central Europe

In this region, the answers were provided by the stakeholders from Germany, Austria, Switzerland and Belgium and from France. In detail, 43 companies were interviewed including entities involved in the solid wood transformation activities, wood panel producers, public bodies and federations as well as furniture, machine manufacturing and construction and demolition companies. In France, the answers were more detailed than in other countries, so they are analysed here more deeply.

The main wood-based input material depends on the field of company and operation: virgin wood in the case of solid wood transformation companies, recycled material (waste wood such as off-cuts) sawmill residues or sawmill by-products and postconsumer wood in the case of wood panel producers, wood waste collection and processing platforms.

Germany, Austria, Switzerland, Belgium

With regards to the side stream utilization, the companies reported that wood-based side stream materials are mostly recovered as energy in on-site plants, or reprocessed to obtain basic raw materials. Some furniture firms show practices to sell their wood-based side stream to service providers, which collect the production off-cuts with the aim of recycling into particleboard production. Clean wood chips are sold to pulp mills, pallet manufacturers and sometimes to particleboard or fibreboard companies, or they are used for energy purposes. On the other hand, among construction and demolition companies there is a very different approach. For instance, in the case of construction elements the side streams have a low share in the production, so recycling practices are not usual.

Some important companies use wood side streams and post-consumer wood for quite innovative purposes like animal feeding, food industry filter aids, fillers or functional fibres up to biocomposites. Distance of the side streams is important also here for the economic efficiency. Wood fibre processors have similar products, animal feeding being concluded as a huge and growing market. Generally, post-consumer wood is considered suitable for technical applications only. For food and medical applications only fresh side streams are usable.

There are nowadays users of pine wood for antibacterial applications such as medical storage boxes. Demand is growing for antibacterial solutions of biocomposite compounds in niche markets for food, toys, pharmacy and cosmetics area. Markets for biocomposites compounds for injection moulding in several markets are growing.

Lignocellulosic raw materials are largely available in Germany, Europe and globally. There is an unused potential of lignocellulosic residues both from forestry and wood products industries.

Experience is available for decomposition processes for lignocellulose, and for chemical and biotechnological conversion of carbohydrates. A range of activities aimed at investigating and developing diverse biorefinery paths are in various stages of realization in Germany. First pilot and demonstration plants for lignocellulosic biorefineries are in operation or under construction. All specialize in very specific feedstocks, like beech, spruce or knot wood of spruce or pine.

Insulation materials are already manufactured from saw dust in Germany; instead, milled wood fibres or post-consumer wood have not proven suitable. One construction company applying pre-fabrication uses fillers and functional fibres from fresh side streams as insulation materials. There are also on-going incentives to produce high-value activated carbons from MDF waste, using a pyrolysis technology. Other kinds of side streams such as OSB and particle boards can be used there.

Some techniques related to the implementation of specific material efficiency practices appeared to be common among the entities interviewed. Take back system has been introduced for the procedures of wood-plastic composites (WPC). Here, the companies take back old wood terrace planks and use them after shredding as raw material for the production of new planks. Pencils and painting brushes are another well-known WPC application but with not any take back procedure.

Green biomass provides a residue-free utilization of wood converted into sustainable energy for drying wood and generating electricity. Therefore it is a strong competitor to bioenergy from wood-based side streams. In general, the results of interviews indicated an overall trend towards the introduction of environmental certification to guarantee the sustainability and the high standard of quality of the products.

Under the technological point of view, advanced systems for recycling local side streams from post-consumer wood have been implemented and companies have aimed investments in modern technologies for energy production, air/water purification and rail logistics. However, most of the solutions for the near future seem to be focused on improvements to control environmental effects. Technologies for the mechanical treatment of wood-based materials such as extrusion and injection moulding technologies, grinding and granulating machineries, filtration, separation and shredding tools are also implemented by the companies.

The perceived obstacles and challenges for full implementation of wood-based side streams for recycling and waste management are mostly linked with cost-related factors, competitive status of the sector, and legislation and policies context. The cost-benefit balance needs to be improved to compensate the high cost of raw material and recovery process. Turning by-products into energy is not as profitable as selling them for manufacturing new products. Some materials like dry chips cannot be recovered economically as biomass for heat production, but it goes mainly to pellet manufacturing etc.; this is considered a significant disadvantage among the companies. Furthermore, high investments to recycling processes and plants are needed to optimize the use of different off-cut materials of wood products.

An issue strongly affecting the competitive ability of the side stream sector is the fact that the main market of clean wood chips for pulping is dominated by a small number of players composed of large corporations. The competitive ability is aggravated by the fact by the pressure of social acceptability of products made from wood wastes. This point concerns also regulatory

control: very stringent requirements and procedures have been set for products made from recycled and reused materials. Therefore many improvements in the value chain and investments to societal communication are needed.

However, the companies are largely aware of the general regulations, energy policies and circular economy with relevance to their industrial sectors. In fact, life cycle assessment calculation rules, construction requirements and labels and schemes of furniture wastes are in fact well known by most of the interviewees. Nevertheless, there is a generally perceived need to promote and increase local policy initiatives regarding the industrial issues.

France

Interviews were matched in France more to the role, profile and interests to circular economy among the companies than in other countries. Therefore the questionnaire was slightly different, and more emphasis was put to the approach, understanding and communication means regrading circular economy. The composition of the interviewed companies was also versatile, except only one company representing waste collecting and processing.

Table 13 shows what did the circular economy mean to the interviewed companies as regards their general interest and effects. In all, reuse and recycling, responsible approach for the future and ecology and sustainability raised the most attention, and financial impacts and implementation difficulties the least. Company size did not seem to affect much the approach. Instead the industrial sectors seem to differ: the more a company has further processing and the closer it is to the end user of the products, the more versatile is the interest, the more do the communication approach matter and the more attention there is to reuse. All sectors seem to emphasize the responsibility for the future.

Table 13 Meaning of circular economy to the companies in the interviews in France by industrial sector.

	Wood transformation		Furniture	Construction and demolition	All sectors
	Solid wood	Wood panels and biocomposites			
A. Reuse – recycling of wood at the end-of-life, production scrap	4	2	11	3	20
B. Ecology, sustainable development, eco-design	4	3	8	2	17
C. Giving a second life to wooden products: donation, resale…	2	2	7	2	13
D. Negative financial impact, taxes, production costs	2		2	1	5
E. All stages of the circular economy (sorting, recycling, repair, maintenance, sustainability …)	4	1	5	1	11
F. A need for implementation and development	1	2	5	2	10
G. Difficult to implement		1	4		5
H. Responsible approach / future	5	2	8	3	18
I. Positive financial impact, economy	3	1	2	2	8
J. Local development - creating jobs	2	1	5	2	10

Most of the companies (16) viewed that circular economy of wood products has emerged smoothly but gained more visibility during the last two years. Four of them indicated that the situation has taken a turn to better, whereas three of them thought the sector to still struggle to find its place and consolidate its position in circular economy.

Circular economy was included to the business strategy of 16 companies, under planning or consideration in three companies but not included at all in four companies. Strategic planning practices of the companies were not necessarily in line with their general understanding and ranking of circular economy issues, and the practises were actually derived from quite different arguments that lead to a different focus. Actually, only three companies had quantified objectives and four of the companies considered to establish such objectives for the progress or development of circular economy.

Despite this situation, a majority of the companies (13) reported to raise circular economy issues when communicating with their customers, but as many as 10 of them did not pay any attention. The most common means were website information and social media. Point-of-sale communication, product brochures and information on product labels and / or packaging were also used. Some larger companies include the information of their circular economy approach also to their annual reports and customer presentations.

The most common specific objectives of the companies related to circular economy were to adopt the approach of Corporate Social Responsibility (CSR) or convey a better image or communication (Table 14). Thereafter, other objectives seemed almost equally important. Regulations are important in all industry sectors, but not really among solid wood product companies. Companies largely target for innovation approach, albeit less interest among furniture industries. Circular economy means to retain employees and gain market share were important for wood construction related companies and to a less degree for solid wood product companies; these industries also work much together in the value chain.

French companies reported to perform themselves quite many types of actions toward the following targets circular economy (total number of statements):

- Sustainable supply 20
- Recycling 18
- Eco-design 11
- Extension of product life 10
- Responsible consumption 8
- Industrial and territorial ecology 5
- Functional economy 3

Solid wood product industries performed actions especially toward sustainability and responsible consumption, wood panel and biocomposite companies and furniture industries toward recycling and eco-design. Construction related companies focused to very different actions. Of the companies, seven reported only 1-2 types of actions and 10 1-3 types of actions, reflecting either concentration to few targets or limited volume of actions. Furniture industries showed most variety as regards the number and focus of actions.

Table 14 Specific objectives of circular economy in the strategy of the companies in the interviews in France by industrial sector

Objective	Wood transformation		Furniture	Construction and demolition	All sectors
	Solid wood	Wood panels and biocomposites			
A. Adopting approach of Corporate Social Responsibility (CSR)	4	2	7	3	16
B. Conveying a better image / communication (positive communication, differentiation, CSR commitment)	5	3	5	3	16
C. To comply with the regulations (the corporate social responsibility is the subject of regulation)	1	2	5	2	10
D. Adopting an innovation approach	4	3	3	2	12
E. Customer retention (build trust with your customers and strengthen that connection across a community of interest)	2	2	4	2	10
F. Retaining your employees (giving meaning and increasing employee commitment through a community of interest)	3	1	1	3	8
G. Gain market share (strong leverage on the company's attractiveness in the market)	3	2	4	2	11
H. No specific objectives			2		2

In France like in many other countries, the expectations, strengths, opportunities and obstacles related to side stream utilization and wood waste management look out very different from the perspectives of industrial sub-sectors. Therefore their views are presented separately as follows.

Solid wood product industries prioritize the recovery of their main products (in economic context), thus minimizing the amounts of by-products and wastes. Growth in their recovery and valorisation and decrease in the generation of wastes is anticipated in the near future. The market is expected to grow for a while, and then maybe decrease because the supply decreases thanks to more efficient processes and better yield (resource efficiency). The companies consider low carbon economy the biggest strength and opportunity for their future. This is supported by the sustainably managed forests which provide high-end social and environmental products.

There are strengths in some successful bioenergy technologies (novel boilers, clean pellets or briquets) and utilization of side streams and recycled materials (compressed pallet blocks) and novel green chemistry applications (by-products from plywood industry). Self-sufficiency in

heating the industry plants thanks to side streams is an advantage. There is a large market for side streams and low value wood to particle, fibre and MDF board industries.

Importance of side streams will emerge, but it depends on the importance of the circular economy in the society. French politicians have a will to support bio-based products and local supply chains. Some companies feel that individual business initiatives exist but not at the national level. There, in view of the competitive context, profitability is the key risk.

Evolution of oil price over time should increase the competitiveness of side streams in energy products and chemical industries. The more we reinforce wood waste valorisation, the more we can have remote platforms for their utilization.

However, more ambitious ways than energy are needed for valorisation. Valorisation of the wood carbon index and footprint is anticipated for an advantage in the future. Increase in product recovery from side streams was proposed as: a) intermediate fractionation and recovery of value-added materials or compounds before energy recovery, b) finding suitable local species for chemical recovery. This may be combined with the incentives to gradually replace plaster and concrete in building activity, leading to new markets for materials and products from side streams and wood wastes.

Problems and challenges to solve are in performance and costs related to logistical organisation (transportation, storage) and investment costs to by-product transformation processes (drying, sorting). Transportation distances from providers of side stream to their users and recyclers are often long. Drying of materials should be developed to reduce weight in transportation and improve energy generation. Sorting and screening methods and equipment are basically enough good, but they should be updated. More important, the knowledge of classification systems and other regulatory issues of side streams and wastes should be communicated and expanded among the industries. Some manufacturing companies aim to improve the recyclability of their products by limiting the use of harmful chemicals. Reviewing the specifications of incoming materials at the machining and profiling level was proposed to limit treatment costs. At the same time, they are seeking for finger-jointing and face-gluing technology to make new products from off-cuts and prevent waste generation.

There is also the dust issue, risk of explosiveness in storage and certain environmental risk (treatment chemicals, paints, glues). Some mills feel the separation of paint and glaazing from wood as a problem. Therefore, research is needed, for example, in the field of adhesives and surface silicones for wood products. The main environmental concern is the waste qualification that restricts the use to one and only, energy. Evolvement of legislation should open more possibilities.

There is much fluctuation in the prices in relation to supply and demand which hampers economic planning of side stream business. In energy sector, the demand of heat varies much between seasons, almost like in Nordic countries, and the supply of electricity from different sources varies for many reasons. Rising wood prices are expected, and they will show up in side stream prices as well. Competition is still complicated with fossil materials. Further increase in waste taxation is feared among some companies. This may force them to seek new solutions and create the markets. Public policies to re-structure the management of by-products and wood wastes may impose higher costs but no profitability because of low value outlets.

Some threats come from the concentration of the customers for by-products particularly in the wood panel industries with high impact to the market. There are difficulties in raw material supply due to an increase of costs, thus leadign to the scarcity of sawmill by-products. Collective biomass boiler project or briquet manufacturing co-operative in the municipality were proposed as a part of territorial policy to be developed.

Some companies want more visibility to the destination and actual recovery of both by-products (fresh wood, dry shavings and off-cuts) and wood wastes, after they have been received by the recycler / contractor. Research should aim to better recovery of wood waste beyond current practices of collection companies. Recovery network should be developed to multiply local collection points with clearly defined bins for wood wastes.

In saw mills companies, the sales of by-products represent 15% of our turnover, which might increase. In secondary processing, side streams are not a true source of revenue, but they rather cause costs through waste management (secondary processing). By-product management tends towards financial equilibrium.

Among plywood industry, complex technologies for valorised products from side streams and necessary knowledge from their markets were felt challenging. Chemical extraction technology is emerging toward higher added value, but still slowly (with patents). Access to different raw materials should be made easier. Public administration should facilitate industrial development, instead of focusing on inspection and repression. Product-specific rules should be better controlled. Differently to sawn timber based industries, infrastructure and logistics are viewed operational for common applications and energy applications from by-products competitive with oil-derived fuels. They have diversified their offer of by-products. However, the main market for by-products, chips for pulp mills, is dominated by a few large players. Valorisation strategy aims to find opportunities of markets for by-products with higher added value and lower risk on demand. There are still inherent risks with the development and industrialisation of new markets. Typically, share of by-products from turnover is between 10% and 20%. Products are made up half of plywood products and by-products, each.

Wood panel industries (particle board, fibre board, MDF) use a lot of by-products from solid wood processing and recycled wood, their mutual shares varying between 20-100% in different companies. Particle board mills receive also off-cuts, saw dust and chips from furniture manufacturers to recycle them to manufacturing their boards. Virgin wood is still used in variable amounts at individual mills, but the volumes have decreased.

The main contribution of the industries in side stream context is not to provide by-products but consume them. The few by-products and off-cuts from particle board mills are valorised in energy production. Bark is used for own energy needs or sold to local energy plants, wood dust to pellet manufacturing. Side stream business and use of recycled materials is profitable today, but long-term competition on raw materials could change the game.

A particle board plant was primarily concerned with supplied by-products. As the panel as finished product is essentially made from by-products and recycled materials, the customer's requirements are met by using the right material mix and having a manufacturing process adapted to meet the specific application requirements of our customers. The performance criteria of the panels are subject to harmonized standards in Europe.

By-products are generally of homogeneous and known composition which easily allows a clear choice between recyclable or not. On the other hand, the recycled wood is of much more (too) varied composition, and for recycled wood the major problem is the absence of contaminants in the available products.

For particleboard, there is no difference in performance at equivalent particle size between a wood particle from the forest and that from sawmill by-products. The panel is not intended to use wood that could be used for solid wood products. There is still concern about keeping the good properties of the panels, if the proportion of recycled material still increases from the current average of 80% (in France). If particleboard manufacturers incorporate too much recycled wood, more glue and chemicals will be needed to compensate for performance loss, so a compromise has to be found between technical performances and sustainability.

The question of SWOTs for panel industry is more related to the recycling of end-of-life wood than to that of by-products. Good acceptability of the panels incorporating recycling requires an absence of undesirable substances in the recycled wood and call for such products by the users and the consumers. The quality of the sorting of wood for recycling must be maintained or even improved, otherwise it will be difficult to meet the necessary sanitary requirements (legislation). The impacts of recycling on pollutant emissions should be verified, followed by the availability and feasibility of sorting technologies. The shortest circuit between the producer and the user should be made as a normal practice with direct relationship. For wastes, it is a (too) vast subject.

Some companies feel that the different regulatory authorities do not work enough together, but they make decisions that can sometimes interact negatively with one another. For example: Integration of more recycling in panels, i.e., potential introduction of VOC pollutants and heavy metals, may be against more severe indoor air quality) requirements.

High-pressure laminate industry uses wood panels from virgin wood and recycled wood, kraft paper (primary 90%, recycled 10%), and generate wastes through downgraded products, damaged panels, saw dust and dry paper. Downgraded products are used internally for packaging, damaged panels and saw dust are sold for energy recovery and dry paper waste to paper traders (end of collection).

Lack of detailed knowledge of the composition of glues and efficiency of sorting processes are felt as problems. Exchange of knowledge between industries at local scale is wanted (industrial and territorial ecology). Nowadays an efficient solution is not available for value chain. Regulatory evolution is felt as a threat, rather, simplifying licensing procedures for incinerators is needed. There is a risk that composite products contain chemicals that are difficult to recycle. The traceability of chemical substances is difficult and some substances might affect health and environment.

Increasing the use of secondary materials and taking back customers' waste are opportunities. The revenues from selling dry paper waste are currently very low. Using production scrap for packaging does enable some savings on potential costs.

Furniture industry is large and versatile in France, consisting of several sub-sectors and large and small companies with moderately differing approaches to the side stream issues. Basic raw

materials may consist of sawn timber and other solid wood products, more from hardwoods than softwoods), but more frequently MDF or particle boards.

Mills manufacturing solid wood furniture generate large and small off-cuts and some saw and grinding dust and chips which are most often incinerated in the boilers of the mills, or sold for local energy companies. Large off-cuts without gluing or finishing are sometimes donated to employees or charity organisations. Depending on the product, the proportion of waste from wood material used may vary from 10% to 50%.

These mills did not report any major problems of their side streams. Current concerns are related to the risks associated with the used adhesive and finishing products (e.g. shift to waterborne products) and tightening of regulation regarding what can be burned and in what type of facility. They could be impacted indirectly through the price of the raw material. An opportunity may be finding recovery solutions on a local scale, by sorting and allocation of by-products according to customers. In one company discussions with potential buyers in the past showed that their waste volumes were too small to raise interest. However, no actual profits seem to exist from side stream business, but savings of potential costs are achieved.

Mills using particle boards, MDF and HDF do not seem to recover actively for recycling. Depending on the product, the proportion of wastes from wood material used varies from 5% to 30%. In some companies, the assembled furniture that are downgraded or used for quality control testing are donated to associations. Depending on the production site, sawdust and panel scrap are either recovered by service providers or burned in the boiler of the company. Some particle board suppliers take wood wastes from furniture mills to manufacture their panels.

Some companies in furniture sector, like among particle board industries, argue that competition with the energy use of by-products and recovered wood increases their costs. Social acceptability of products made from secondary materials as well as image of recycled wood for end-products consumers raise questions.

Problems of side streams among these industries are caused by: 1) big volumes of generated waste with limited outlets, 2) high transportation costs, 3) impure wastes, for example for collective boilers, 4) valorise the wastes because nobody really wants them. MDF and HDF wastes do not have a true value chains for recovery or reuse.

Side streams do not provide profits for furniture industries, but either savings opportunities or high costs for individual industries. A solution should be found to get rid of waste without excessive costs. CHP plants work with a good yield, provide a solution for saw dust, but are an expensive solution. Logistics applications depend on for what purposes they are purposed. Local platforms may be useful, but may not be profitable (opinion of one company). Extension of service life of furniture is targeted among some companies by improving the recyclability and repairability.

Finding solutions for value chains of MDF wastes, developing sorting out and eliminating disadvantages of undesirable substances and disposal of ashes from biomass combustion are important. Regulation and classification systems of furniture industries are wide depending on the adopted point of view. The ICPE law for the combustion of wood waste in industrial boilers can be mentioned.

Since the implementation of the EPR scheme on furniture waste, the company has to pay another company for the disposal of particleboard, whereas it was free of charge before. Instead, according to one company, the products that travel over long distances should be taxed more. Another company proposed the permits to sell downgraded products with lower commercial responsibility (warranty, hidden defects, spare parts availability, etc.). Third company claimed research a well as freedom from regulations to find the materials suitable for their products and targeted to closed-loop recycling. Fourth company viewed that the French regulation is pushing towards burning clean wood in biomass boilers and recycling panel waste, which is an inconsistent future. Market balance is becoming unstable since the EPR scheme on furniture waste will bring more and more wood waste to recycle or valorise.

Construction industries in the interviews were rather small, and some of them were simultaneously in carpentry business. That is why their views were rather close to secondary processing of solid wood. It is notable that regional policies towards the construction of high schools with local timber is facilitating their activity.

The companies generate wood-based wastes as different left-overs, off-cuts and shavings from sawn timber, wood panels (also OSB and HPL), cladding and packaging (paper, paperboard, decks). Clean solid wood and shavings were transformed into wood briquettes or sold to individuals and distributors. Treated solid wood, cladding and were sold to industrial boilers or sometimes burned in own mills for energy recovery.

Some companies have sorting equipment of construction and demolition wastes to separate wood from other materials (metals, plastics, inorganic impurities, paperboard and paper). Some companies consider to initiate or participate to local shared CHP plants, build own biomass boilers, pellet or briquet factories or instalk photovoltaic solar panels. Recovery processes have been identified, but not implemented at large scale because of the lack of pathway leaders (orchestra conductors) and pioneering companies.

Assessment of the recovery potential of wood-based construction and demolition wastes is quite a new issue (French building federation). In addition, optimising the waste management (revenue vs. costs) is under R&D in many regions. Some companies say to rely on other practitioners in the wood construction value chain to improve recycling.

Many regulations concern wood construction companies: 1) On the products: French DTUs (standardised technical documents) or ATs for innovative products (technical approval documents), European Construction Products Regulation, French "Constructions Bois 21" label for quality and environmental performance of timber constructions; 2) On the industrial site: French ICPE regulation on wood preservation, European Biocides Regulation, 3) On wood supply: PEFC label. Regulatory control of exhaust gases of biomass boilers is felt as a challenge, calling for advanced technology.

In many companies, waste management currently enables them to save potential costs and is even a source of revenue, but it is a cost in some companies. However, the companies do not have precise data, because they cannot distinguish between the revenues coming from that disposal and the revenues coming from by-product management.

Companies are rather optimistic for the positive development of side stream management, including valorisation for added value. They seem to think that the efficiency of the by-product

management will increase in the future, and new technological choices might improve the economics (more leftovers could be recovered). Local recovery is considered a strength.

Generally, construction companies seem to have low concern on SWOT issues, probably because the operations of recycling chain are largely in the hands of the recycling companies and their contractors. However, they are not fully satisfied with the way they currently manage their by-products regarding economic and environmental stakes. Few threats are viewed in the social acceptability of the products made from recycled materials and chemicals and glues included to them. No special threats for the energy recovery seem to be in the sight of the companies.

The point of view of **Waste management companies** is that many regulatory drivers are leading to a strong increase of wood waste recollection (furniture, construction and packaging waste), which is well managed through a development of sorting capacities, but faces an important lack of outcomes. Incineration and landfilling are decreasing in direct application of policy objectives, but material recycling into particle boards and combustion for energy recovery are not increasing at a sufficient rate. Therefore, French waste management companies are exporting a significant share of their production of recovered wood. These companies are therefore in need of R&D efforts to develop new recycling options, and policy actions for opening the recycling market. The potential for the development of energy recovery seems high in France, provided the policy is implemented (Renewable energy targets).

5.2.3 Northern Europe

Interviews

In this region, 21 answers provided by the stakeholders from Finland and Sweden were collected. They included industry federations and public development organisations, companies of solid wood transformation (sawn timber and secondary wood product manufacturers, multi-product corporations of chemical and mechanical wood industries), plywood and particle board manufacturers), construction companies and platforms of wood waste collection and processing. The composition of the interviewed companies was versatile, and the answers were detailed.

Large companies report not to build their business development on subventions from the society. Medium-sized and smaller companies are interested in public support, with the provision to minimize regulatory effects. Carbon neutrality in the production and all business to be fully achieved in 2030 is a key target, exhibiting a strong statement and message to the society.

Wood products companies currently prioritize the recovery of their main products both in volumes and revenue, maximize the yield of their main products and minimize the amounts of by-products and wastes. Among the companies, the role of side stream business is anticipated to grow along with circular economy, replacing fossil raw materials and products and tackling climate change. At saw mills, commercial by-products from side streams comprise currently bark, pulp chips, saw dust, planer chips and dry chips.

Forest industry corporations have a strong role in Nordic countries in the forest sector and side stream business, and they have also the best strategic resources for value chain management and R&D activities. Their saw mills and plywood mills largely concentrate on the primary production and use or deliver their side streams to other processes of the corporation.

Private saw mills have typically also secondary processing up to construction and furnishing components and elements and small house manufacturing. That is why their side stream composition is different. They sell much of their by-products to domestic pulp, paper and paperboard mills, the few wood panel factories still existing in the countries (Finland, Sweden) as well as to a multitude of bioenergy operations (municipal heating plants, CHP plants and other power generation plants, pellet and briquette manufacturing). Of bark, a part is lost during the wood procurement chain. One third of the received bark is incinerated as an on-site energy source, rest is sold. Of saw dust, one fourth is sold to pulp mills, rest is incinerated on-site or sold for pellet and briquette manufacturing and for animal beddings. Planer chips is sold to pulp mills or pellet or briquette manufacturers. Dry chips is used on-site or sold for incineration.

Almost all companies have own heating plants to supply the heat energy needed in their manufacturing processes (wood drying, wood impregnation, heat treatment process) and heating of buildings. The companies have often partnerships in local district heating plants or CHP plants. One integrated wood products industry of saw mill, plywood mill and particle board mill uses all chips and saw dust on site for particle board production and 97% of heat energy is generated from saw dust and bark. Some companies dry sawdust for heating and briquet production. Crushing, mixing, cleaning and dyeing of wood residues and bark are standard operations at the mills or in the energy plants. Saw and plywood mills always screen and sort wood chips that is delivered to pulp, paper and paperboard mills.

The balance of supply and demand in the side stream markets strongly depends on economic cycles, and more uses are wanted both in volumes and uses especially in the regions where the population is decreasing (district heating is reducing) and transportation distances to current delivery points are long (profitability is questionable). There is a large domestic market for saw mill and veneer chips, and the profitability is generally excellent for chemical wood processing and satisfactory for saw and plywood mills. Instead, bark, saw dust and wood shavings and splinters have more fluctuating markets, and oversupply and weak prices have been experienced among wood transformation industries.

Among the large and medium-sized companies, customer-based value chains are essential and business revenue is prioritized, well-being and other value-add follow as a bonus. The idea is to build on the existing expertise and structures of the companies and identify knowledge and potential within the company itself to apply in new ways. Internal and external networks are important.

At large saw mills energy co-generation is not any longer a strategy in the future, but it is a by-business only with no plans for investments. In integrated operations, pine tall oil and electricity from pulping process are used as a source of energy. Most important users of tall oil are in chemical industries (Arizona Chemicals, Forchem). Some companies in wood product sector have different aims of by-products for biorefining, such as sorting out and supplying internal knot pieces to HMR-lignan products for the respective industries. Organic materials recovered from wood side streams along with the processes are planned to use through biogasification to a multitude of products, first fertilizers. As a rule, solid organic components are generated in too small volumes, except maybe CODs. Starting from fibres would be more useful to generate new materials.

Integrated production of heat and electricity has been the flagship of bioenergy sector in Nordic countries since Mid-1990's. Nowadays electricity production is beyond economy without supported rates. New generation CHP plants are expected for better efficiency and more product options. There are new but still piloting initiatives are in bio-ethanol (saw dust), tall oil and pyrolysis oil manufacturing. Promising but almost non-realized options are in extraction, for example with hot water (hemicelluloses, tannins). Markets for them are not yet available, but maybe in coming years.

The following strengths of the current situation were reported by the companies:

1) High resource efficiency: there are uses for almost all side streams, very little wastes from the mills;

2) Well-functioning and stable value chain; still a priority to stay competitive in the main products and invest in its development;

3) Public regulation mostly OK; however, climate and environmental argumentation should be based on facts and expertise - there may be a small risk for unfavourable regulation and decisions for this economic cluster in EU, and national implementation and choices are important. For example, wood dust from some hardwood species is hazardous for health, then all wood dust may be interpreted hazardous;

4) Public infrastructure investments and subventions to industry should aim to provide opportunities for the industries to be present and operate on rural districts and whole country. Infra and potential should be aimed there where the activity is on stable and sound economic and societal basis. Subventions should not go to support individual wood processing plants;

5) Side stream utilization as a collaboration of big primary-processing industries and different partnership companies is an advantage -> industrial symbiosis of existing companies, spin-off enterprises, mutual value chains and service operations, optimized material and energy flows, ownerships and logistics and marketing practices.

There are general obstacles/hindrances in the strategic and operational environment in Nordic countries. In the forest industry sector, insufficient understanding of business is felt a big weakness (strategic focus, logistics). Volumes, key customers and identification of development pathways are important. Companies should have piloting and demo facilities and key development personnel, also by themselves, and target markets should be clear. For example, individual saw mills are too small actors from the viewpoint of side stream customers and the available raw material volumes are too small (for example wood extractives). The production wastes are in liquid form of highly moist, and the logistics costs and small volumes lead to the avoidance of transportations and centralization of processing. Maximum transportation distance is 100-150 km for side streams.

Saw mills and plywood mills view the price competition with forest residues a hindrance for the marketing of their solid by-products, therefore relatively low volumes of side streams are beyond economy. Side stream business development is left for saw mills, but it is not in their immediate interest - log price/quality ratio is more important. Companies trying to develop side stream business have not enough resources for fast development and innovations. There is the

risk that if incineration will be abolished (which is anyway improbable), no substituting demand for side streams exists.

Some companies view that time-consuming regulation and permitting practices must be understood and accepted, this is not different to other industrial sectors. Important question is how we can generate standardization and methodological development to make the product acceptance process easier. In regulation process, the authorities should carefully listen to the experts to fasten the process and base it to proven facts. Landfill taxes have been sometimes experienced as threats, but now they do not seem like that.

Principles of sustainable development are necessary, recommendable and good to be in use already now. However, public customers and authorities should show an example in the implementation of new sustainable materials and products ("role models"). If cascading of side streams in material uses will develop, then the holistic sustainability should be studied (economical, ecological, societal).

Research on recycling wood side streams toward wood-plastic composites as well as their recycling could be useful. Design of power plants should be more foresighted to consider the availability of different fuels and build them less sensitive for raw material variations than they are still nowadays.

The following general threats were reported by the companies:

1) How is wood material seen in energy uses parallel with material cascading: R&D should objectively justify the acceptance - Denying wood as a source of energy does not still seem too big a threat now;

2) Transportation economy of side streams is problematic (light-weight material, water content, utilization rate of vehicle capacity, costs of logistics);

3) Limited storage space and new processing options of side streams call for all-season terminal areas;

4) Versatile utilization of energy raw materials requires mill and plant investments;

5) Uses of side streams should be based on free market economy and business logics, not unpredictable regulation rules with short notifications, to ascertain stable operational environment, long-term development actions and continuity of business.

Non-fossil raw materials and fuels are felt as a significant driver for manufacturing volume-based products, such as sawn timber and pulp. There is still much to improve in the activities of the companies as regards sourcing and use of energy in production plants and working machines. Use of plastics should be reduced drastically (packaging), because they are difficult to recycle. Recycling of plastics is highly important, but who will take the responsibility to organise it better than now - this may be a start of new business.

According to some companies, bark is probably the most prospective side stream raw material. Now it goes almost solely to conversion for energy, where the price follows the energy markets. Added value varies there much according to volume of demand, season and transportation costs. Material use should be the first option of development. However, evaluation and criteria of

different bark solutions is important. Gasification of bark is a well-functioning technology and already in use. Manufacturing chemicals (oils) from bark is difficult, because dry matter content varies, conversion efficiency is low and processes are complicated and costly compared to heating value. If this will be subsidized in the future by the society, the market may be economically viable. Maximal value add should be targeted, for example to gasification for electricity, heat generation and pellets; wood oils and alcohols could be included, but they also need markets (=customers). Saw mills can provide fully one-species bark with no source from small wood, making it homogeneous compared with pulpwood bark.

Something more should be developed around the saw mills, where integration of manufacturing processes is an advantage. Integration of management and logistics of main products and side streams would be beneficial both for increasing value add and managing different wastes. In big integrates, build-up and use of infrastructure can be optimized (steam, electricity, logistics, testing services, etc.). Win-win solutions should be sought also in the value chains of wood construction. Hybrid materials will obviously be the future; there, critical properties and controlled composition are essential when combining different materials. Wood-plastics composites are an option, for example combining wood fibres or bark with stone material to replace plastic tubes. Well advanced characterization techniques of materials contribute this option.

Volume of raw materials and side streams from saw mills is rather large, which might enable further sorting of focused raw materials and rise their quality and value add according to the uses. Integrated production sites could carry large-scale further production of bioplastics or advanced biofuels. Logistics issues and deliveries to large processing plants and distribution channels and chains to the market are crucial. Saw mills have most often own uses and deliveries to local customers which reduces the volume that can be sold to outside customers. Despite the scales benefits of integrated solutions of processing, also decentralization, limited concentration and mixed industrial symbiosis provide options to investigate case by case. These accelerate piloting and implementing new value added uses for side streams.

Log house industry is a North-European speciality sector of wood product industries which manufactures and supplies residential houses and second residences as well as public buildings (kindergartens, schools, hospitals, care homes, office buildings). Raw materials are either large-sized logs or sawn timber. By-products make up of 55% of the raw material volume (saw mill chips, cutter chips, planer shavings, off-cuts. Chips, saw dust and bark go mostly to different energy plants, some to pellets and briquettes, and planer shavings also for animal bedding. Integration of district heating facilities to production lines are used for efficiency to supply back energy for the process. Also bedding producers are integrated with supplies. There are very few opportunities to use recycled materials at factory level, but log houses are easily recyclable or removable.

As an advantage, side streams generated in log house factories are generally homogeneous and free of contaminants. This could benefit their uses in pyrolysis / torrefaction for biochar and other applicable products. Wood based insulation materials (hard insulation boards and traditional fibreboard products) should provide new opportunities as well, but the technology is still underdeveloped. There should be options Pricing of the side streams is felt challenging, thus not necessarily giving enough incentives for investors. Price competition with forest chips from

thinnings and harvesting residues is considered an obstacle for the implementation of current and coming opportunities.

Construction companies which fully focus on building with wood and those where this type of building is one option among others differ much in their strategic business approach, but the views on wood side stream management are largely similar. In volume wood wastes are most often the largest individual group of wastes in house construction, but not always in mass. Demolition operations usually yield more mixed wastes and concrete/steel wastes, both in volume.

The most important drivers of construction companies to build with wood are in the sustainability and other ecological issues. Some companies want to differentiate from their competitors by implementing circular economy, low carbon infrastructure and good quality of life targets, and actions in the design and construction and services offered for the customers (customer promise). Some companies have identified in their strategy that carbon footprint and emissions in house construction come in the first hand from manufacturing and usage of cement and steel.

Construction companies build small houses, residential block houses and public service buildings and office buildings from wood, along with concrete frame houses (reinforced with steel), steel frame houses, stone and bricks houses, and different hybrid structure houses. The same companies are often responsible for demolishing old houses from the construction sites (partly), usually organised as sub-contracting to demolition companies. Many companies have own mills to manufacture building elements (from concrete or wood).

Building with wood has been promoted and raised during the last 20 years, in large element, space element and traditional on-site buildings both. CLT, LVL and other mill made elements from engineered wood have been learned to use in building projects.

Typical composition of wood-based construction wastes is as follows: 1) building forms (moulds), this includes metals (nails etc.) and crushed concrete, 2) off-cut pieces of sawn timber, plywood and other wood products used on the construction site, 3) packaging materials (concrete building sites, in particular), paperboard boxes of home equipment and machines, paper and plastics wrapping, wooden pallets, and plastics and metal bindings). Wooden pallets and racks make a large volume of wastes. Domestic made pallets are reused (to a maximum amount) and foreign made mainly go to crushing.

Construction wastes are transported to local waste stations, either municipally owned or private, by their contractors. The statistics about the amounts of wastes can be obtained by company and construction site from the waste station, but construction companies normally have no access to the information about the percentage of incineration for fuels and material cascading of the waste materials.

Recovery of wood-based wastes in the construction projects is close to 100%. Wastes are sorted on interchangeable platforms of trucks according to the instructions of the recycling company which is responsible for the further transportation and management of wastes. There are typically four platforms for different wastes on a construction site. Most construction companies have so far applied sorting on the construction or demolition site only. The largest companies have their own crushing or chipping sites for the wastes.

Wood-based wastes and plastics wastes are crushed to fuel chips with mobile equipment. Pressure-impregnated wood is delivered as hazardous waste to nation-wide recycling companies which sell it to specific facilities of hazardous and toxic wastes. Construction companies often separate and collect the metallic wastes themselves and sell to nation-wide recycling companies.

Recycling or utilization of wood-based construction wastes, either plastics or mixed wastes, is not any actual business for construction companies. Wood wastes are not a source of income, in contrast to more valuable metal wastes. Currently, competitive ability for energy or raw material is not too good compared with clean wood residues from manufacturing industries. Large investments to pulp mills and saw mills may affect even negatively to the economic balance by bringing more industrial residues to the market.

Strengths of the current system:

1) Quite easy for construction companies, because the recycling company takes care of waste logistics, handling and re-processing, construction companies are responsible of on-site sorting only;

2) Rather functional and straightforward organisation and operations in greenfield construction sites, but not in demolition sites;

3) For some reasons, recycling of construction wastes were felt more efficient when building small houses was dominant compared to the current modern block house era;

4) Regulation on recycling and waste management has not caused any actual problems for construction companies. Other construction regulations have had considerable effects, for example in public building.

Weaknesses and obstacles of the system:

1) The main problem in construction sector is the lack of conformity of recycled materials. There is no procedure/standard for that.

2) Too small storage sites for construction wastes and too few waste types to be sorted, for example gypsum board and plastics materials;

3) Surface treated wood material, for example fire protected wood, is an issue of environmental and working safety (toxic paints are hazardous wastes;

4) Much wastes from cutting window and door spaces from wood panels on the construction sites - pre-fabrication of components and elements should be increased;

5) High demolition costs of old buildings from construction sites;

6) Lack of merchants selling recycled wood-based products from construction in most towns and cities;

6) Expensive transportation / transfer of waste bins especially in block house areas - more presses are needed to compress for example paper board waste, or it should be crushed on-site;

7) Decision makers of cities tend to give expressions of opinions in the first hand to city image, but circular economy seems to be a second-hand issue. Instead, environmental authority takes into account the minimization of carbon emissions when allowing sites for construction companies;

8) Customer feedback from public websites about the quality of apartments/houses and service offered for the customer is variable. This indicates that the companies aim to build rapidly and with almost minimum efforts for service on transformation and repair works. This reflects also negatively to resource efficiency, increasing material waste and weakening waste management.

Construction companies have identified many opportunities to upgrade the value chain:

1) Manufacturing and supplying to construction sites more pre-fabricated, dimension-optimized and final-treated components and products to minimize material wastes;

2) Solid wood (CLT, LVL, wooden logs) obviously increase in market share in public building projects, leading to lower material wastes;

3) Waste management and recyclability could be added to the pre-planning of construction sites to make recycling more systematic and easier: pre-estimates about wastes to the documents on deed of conveyance of the construction site to building company and service books, and recycling and waste management aspects to inspector's book of the building project;

4) Recycling of plastic materials is just starting, and their sorting should provide clean wood waste with higher value and more potential to green building approach;

5) Definitions for recyclability should be developed (for example, new hard insulation materials can be recyclable);

6) Clarifying classification of recycling materials (vs. energy and landfill materials) and sharpening sorting of construction wastes - they should be added to the regulatory requirements;

7) Waste management rules can increase sorting and maybe value-add: recycling potential should be investigated in each building project;

8) New reuse opportunities and specified companies for walls and mid-floors, and other larger parts of buildings are wanted;

9) Education of professionals is needed for wood construction, also regarding recycling and cascading (construction designers, architects and foremen of construction sites, professional builders adopt the things rapidly);

10) Recyclability of materials and transferability of buildings are clear advantages of wood construction and solid wood in building houses, especially compared with concrete - standard connectors are made of metals and of good functionality for recycling; however, instead of nails, screw connectors should be used;

11) Almost all material and installations of house yard and environmental building could be recycled from construction wastes;

12) New organizational innovations and utilization options are needed among the recycling companies;

13) Carbon footprint analysis is obviously becoming mandatory to the planning of new construction sites which is beneficial for the market position of building with wood. Industrial pre-fabrication leads to a lower carbon footprint than traditional on-site construction, especially in building with wood.

14) Economy of wood construction could be realized in a modern societal environment. According to some companies, wood construction should be located in residential small house and row house areas. Carbon neutrality, traffic and mobility etc. discussions and demands related to carbon sinks focus to the downtown and circle areas of the cities thus raising the opportunities of wood. It is necessary to take these issues into account also in more rural areas (scattered residential areas) to further increase the competitiveness of wood there as well.

15) Discussion link between the decision makers and authorities of the cities, R&D society and companies should be improved to make the networks permanent and well-functioning.

Recycling platforms and companies are well-developed and organised in Northern Europe. Avfall Sverige is the Swedish Waste Management and Recycling association with 400 members from both the public and the private waste management and recycling sectors covering all country. Preventing the creation of waste is the first step in their waste hierarchy which is consistent with the European and Swedish legislation. Exceptions to this hierarchy may be necessary for technical, financial or environmental reasons. According to the definition in the Swedish Environmental Code (1998), waste is any matter or object that the bearer disposes of, intends to dispose of, or is obligated to dispose of. There are different methods for treating waste:

- material recycling
- biological treatment
- energy recovery
- landfill

The waste is treated through anaerobic digestion (treatment without access to oxygen) or composting (treatment with access to oxygen, which is known as aerobic treatment). Energy recovery is still the most used method, because it is ideally suited for waste which cannot be recycled in any other way. Landfill is a treatment method for waste that cannot or should not be recycled. Landfill entails waste being stored in a manner that is safe in the long-term. Sending organic or combustible waste to landfill is prohibited. Among wood materials from industrial or construction uses, urban wood biomass made up of municipal green waste coming from urban forest and waste wood products are received and recycled.

As an example, KSSR (KalmarSundsRegionens Renhållare) is a municipal federation is responsible for the collection and treatment of household waste within Kalmar, Mörbylånga, Nybro, Oskarshamn and Torsås municipality in south-eastern Sweden as shown and they have eight recycling centres. KSSR collects all types of wastes from industries, municipalities and

households. Bulky waste and hazardous waste, such as furniture, construction wood, branches, painter colours, and light sources, are collected from the households at recycling centres. Collected waste wood is chipped into wood chips and used as a fuel for heat and electricity production in CHP plants. Wood chips from waste wood must be incinerated in boilers with permits to incinerate waste fractions, according to Swedish environmental legislation.

In Finland, there are both municipal and private waste management centres receiving and managing wood-based wastes. According to the Finnish waste legislation, municipalities are obliged to organise waste management in their territory, but the volume of their service activities for companies is restricted to 10% of annual turnover.

Oulun Kiertokaari Oy is a typical but one of the most successful municipal waste management companies, owned by one bigger city, Oulu (90%) and 8 smaller neighbouring municipalities (10%) in the region of 270,000 residents and the entities owned by the municipalities, and from private companies according to separate contracts. The company may pay max. 49% dividends of the annual return to the shareholders, the rest is used for development activities.

Operations of wood waste management cover sorting, storage, crushing, and separation of metals from the wood waste. Crushed wood ends up to energy production, biogas facilities and other miscellaneous uses. Clean wood material is chipped for sales to industrial customers (heat and electricity generation).

All kinds of wood materials are received, also impregnated wood. Explosives or radioactive materials are not received. Households are the biggest supplier of wastes containing wood. Some construction companies (SMEs) supply construction waste. Large construction and demolition companies in the region, e.g. YIT and Lehto Group, have their own routes for wastes: own sorting and chipping stations as well as direct supplying connections to end-users, or country-wide / regional supplying contracts with private recycling companies, e.g. Lassila & Tikanoja Oy.

Most construction and demolition companies sort on site the most valuable components and sell further. Therefore, Kiertokaari gets on average worse-quality waste, e.g. those containing mineral insulation wools and different impurities. Some amounts of clean wood wastes and garden and other green wood wastes are received from both private households and other customers. Forest residues and small wood are received occasionally from the forest and garden department of the city, but this is not profitable ($\pm$0).

Kiertokaari is developing an industrial ecosystem that supports circular economy. This kind of activity has started also in Lahti and Tampere, which are favourably located along good transportation connections and lively construction districts.

Kiertokaari produces bioenergy, biogas and chips for customers as well as geo-construction, landscaping and animal bedding with competitive technology. The company is active in RDI collaboration, follows and reacts to potential end-uses. The on-going expansion of waste sorting site expansion includes an area to be rented to collaborators and innovators, first to Oulun Energia Oy. This area is the key when searching for new technology, products and customers.

Other recent projects include: 1) Production of fertilizers and other added-value bioproducts from putrefaction residues of Gasum Oy and wet wastes of forest industries, 2)Developing building materials from local industrial side-streams, cinders of metal industries and mineral

wool waste (polymeric treatment toward insulating materials and ground plates), 3) Processing method on side-stream fractions containing cellulose toward new bio-products, 4) Robotics in waste sorting, 5) Effects of changing waste and procurement legislation: composition of unsorted mixed and construction wastes received to the waste sorting area and different techno-economic alternatives in the collaboration of Kiertokaari and Oulun Energia.

Now it looks that waste wood does not have any specific competitive ability and it is not wanted to material recycling. Therefore, the company aims to focus on deliveries to advanced energy uses. However, the situation may change but not rapidly. Efficient detection and separation of harmful fractions would improve the competitiveness. Re-use becomes further difficult if hybrid materials rise (wood-plastics, etc.).

A year, 35 000 tons of construction and mixed wastes are received (50/50), including 7000 tons of clean wood. Contractors find the routes to usable fractions and are allowed to supply 15,000 tons to Kiertokaari. Contractor separates inorganic materials from mixed wastes; then they are paid 50% more for the material wastes compared to wastes for direct incineration. Clean wood waste from private households and garden residues from the city and private customers total to 1000 tons and 3000-4000 tons a year, respectively. Forest residues are received occasionally.

Main part of the products is crushed or chipped for energy uses. Considerable amount of clean wood is delivered for industries (better-paying energy uses). Pressure impregnated wood has a special recycling system (delivered to Demolite Oy). Waste management technology comes largely from Italy, but there are also significant suppliers from Finland: Wärtsilä, Molokki, Fortum, Tama, Vaisala, Zen Robotics.

Kiertokaari has embarked a long time on biomass putrefaction technology to bioenergy and biogas, using household wastes and commercial food wastes. In addition, Gasum Oy in the area uses considerable amount of organic wastes. Kiertokaari generates biogas of 3.3 mill. m3 in total, of which 2.3 mill. m3 is pumped from old landfills and 1.0 mill. m3 is purchased from Gasum Oy. Biogas is sold also as vehicle fuel, for process heat, e.g. treatment of oily waste waters, and for district heating of Rusko industrial park, allocated to own uses (heat and electricity). Utilization of old landfill wastes can be extended with new technology to increase the recovery of methane (although the content has lowered).

There should be many opportunities in biorefinery fields, but economic reality often hinders the implementation (no profitability). Obvious lack of direct contacts to building and demolition companies and end-users of upgraded wastes limit the development. Modern biogas technology and automatic detection and sorting technology have developed further, and will be implemented in Kiertokaari. It would be beneficial to get more information on the waste material before sorting.

Of the construction and mixed wastes sorted on the site, 40% goes after crushing/chipping to direct incineration for energy and 55% to sales to customers. Only 3% is landfilled (<1000 tons), this is mainly insulation waste containing inorganic materials of 10& maximum amount. Contractor sells forward 6000 tons of wood-based wastes. Clean wood wastes (chips) that are sold to companies are used for energy generation to their own needs and partly to district heating pipeline network of the city of Oulu (100 MW a year).

Other uses for wood-based wastes: 1) pallets to re-use (EURO pallets, FIN pallets), amount of one-use pallets has increased, neither are they wanted for energy uses (mixed composition and structure). There are construction companies that re-use their pallets at element factories and transportation, without delivery to recycling companies; 2) Crushing to geo-construction, landscaping and animal bedding; 3) Compressed products from demolition wood; 4) Private customers can take residual wood for firewood for 20€ per car or tractor trailer load.

Wood-based wastes are a profitable business for Kiertokaari, because the clean wood wastes especially provide high-quality chips and generate sales income. The situation is not the same in all municipal waste service companies in Finland. Demand of waste wood products is sensitive to economic fluctuations – the materials may occasionally accumulate in storages. Accordingly, variation in the sales price of energy fractions by year and season is big (±50%), according to the demand. Profitability of concrete and brick waste is much worse (±0). Business principles of Kiertokaari are the following: 1) Clean wood waste can be delivered to waste area with no charge, 2) Receiving treated wood is moderately charged, 3) Long-perspective strategy to develop Rusko waste management area and increase collaboration with other companies, 4) Sound business development in the framework of EU and national legislation.

Kiertokaari lists the following strengths of their activities:

1) Most of sorting is done on one big site and contractors/companies are active to search for new utilization and customers for recycled products;

2) Biogas provides a huge business potential and environmental efficiency (long-perspective development work of 23 years);

3) Sales of clean wood chips and biogas have enabled low prices for waste management (in the Finnish scales);

4) Treatment facility of liquid wastes – High-Tech (100 % material efficiency);

5) Well-working collaboration with contractors: boosting efficiency with premium prices of material wastes encouraging for continuous development);

6) Stable economic status and high assets;

7) Long-term customer service: results of customer satisfaction study reached 4.1-5 (2018);

8) Favourable carbon footprint (CO_2 eq. -10 000 tons), no new landfilling waste;

9) Competent and experienced personnel, incl. development manager and environmental manager, RDI projects.

The following opportunities are high-lighted:

1) Increasing and upgrading sorting of wastes in construction and demolition sites;

2) Separation of CO_2 from biogas: 5-year project, method has not yet been implemented;

3) Utilization of old landfilling areas – urban mining is a considerable geo-heating potential and provides valuable metals from cable rollers, for example;

4) Solar electricity park on an old landfilling area (1 hectare -> 65 MWh solar panels);

5) Utilizing the expansion of sorting site;

6) Increasing automatization and robotics (waste sorting, process control);

7) Utilizing good customer feedback in marketing;

8) Possible new material products from wood-based wastes: innovation and business partners are needed.

The following obstacles and bottlenecks were identified:

1) Finnish waste management legislation restricts too much the utilization of business potential with private sector;

2) Changes in legislation cannot be predicted, they depend even on government policies;

3) It is very difficult to achieve 70% material recycling rate of wastes in construction;

4) Considerable weaknesses in organizing the waste transportation: a) total municipal competition instead of individual contracts of customers with private transportation companies would improve sorting on construction and demolition sites; b) maybe the fees of receiving the wastes should be higher than now, c) tonne fees instead of bin fees;

5) Quality of sorting on construction and demolition sites should be improved;

6) Treatment chemicals in construction, demolition and wood product wastes are a big problem for recycling. Glass waste does not have a good address of recycling either.

7) Demand and price of waste wood products fluctuate much (also clean wood chips);

8) Recycling and waste management companies have insufficient knowledge of available wood wastes and poor contacts to construction and other manufacturing companies (mostly through contractors);

9) Recycling and waste management companies like the suppliers have insufficient knowledge of the waste material when it comes to recycling or re-use – an ecological risk;

10) Demolition companies have sometimes unsound business practices and even illegal activity which hampers the supply market;

11) Recyclability of construction materials should be considered before the building project is started, and improved in the manufacturing stage (dismantling and reassembling, mixed composition and impurities in waste material) – EU seems to set requirements to the upper ends of value chain only;

12) EU countries have different methods and requirements in keeping statistics on material and energy wastes – Eastern and Southern Europe may classify the wastes more easily to material wastes than Finland (instead of energy wastes);

Concluded from the previous statements, the following R&D needs can be identified:

1) Compiling public data bases on industrial wastes (availability and flows, utilization opportunities);

2) Better organising of logistics and improvements of transportation economy;

3) Performance and benefit-cost analysis of sorting on construction and demolition sites, and improvements of sorting methods and systems;

4) Improving recyclability of construction, demolition and packaging wastes and wood product side-streams, including techno-economic studies;

5) Detection and separation of wood wastes including hazardous or toxic agents;

6) Applications of automation, robotics and digitalization in handling and valorisation of wastes;

7) Effects of EU and national regulation on the development of circular economy and business of recycling companies;

8) Education and dissemination projects among the value chain (between stakeholders).

Impregnated wood has an internationally unique system for recycling in Finland, which makes the recycling easy for wood, construction and demolition industries, consumers and public and private recycling companies. Demowood Oy is a trade association owned by the wood product industry companies. It takes care of recycling impregnated wood and other hazardous and toxic wood materials, and supplies them to wood waste users, currently to Fortum Wastes and Solutions treatment facility for incineration, and partly to export. The material is mostly pressure impregnated sawn timber, of which 70% - 80% is impregnated with CCA and 20% - 30% with copper-based media. Small amounts of creosote impregnated poles and railway sleepers are received as well. The costs are covered by legislative recycling fees and waste collection charges from companies, about 50% from each source. The costs for companies can increase in the future, while the utilisation for energy with the special technology is expensive. The recycling fee is not reflected in the price of the new products, so the producers feel that they are paying for it. The system is exploited to benefit consumers, and free reception for private consumers will continue in the future.

Wood packaging waste is recycled in Finland up to 24% (2019), when reuse and repairing is counted. This is very close to the requirement of 25% in 2025 and 30% in 2030 by EU legislation. But, the higher the requirement of recycling rate, the more expensive is recycling and the lower the profitability of the product.

PPK Oy, the Finnish Recycling of Woodpackaging Ltd. is a non-profit company owned by different producers in packaging industry with the assignment for tasks ordered by the Waste Act in force and related Government decision and regulation. The company takes care of and is responsible for the recycling and recovery of wood packaging in Finland. The company has no production, actual work is done by member companies.

Of recycled wood packaging, 85% are used for bioenergy. Recycling as repair of wood packages, mainly pallets, reaches 10%. Wood chips from packaging materials are used also as dry material in composting (5%). For recycling, the material goes through chipping, separation of impurities and metals and sorting by member companies. Customers comprise waste recycling companies

and companies repairing wood packages. It is aimed to maximize the recycling times and repairing, while minimizing the number of one-use pallets. Recycling of rented pallets with micro-chip for monitoring is the most efficient.

Transportation distances and impurities in the material are the biggest obstacles to increase recycling of packaging. Currently **t**here is no recycling fee for wood packaging waste in Finland. It would boost the recycling. Recycling opportunities and new products, such as wood or mixed composite panels, should be developed also from packaging waste (technical alternatives, profitability). The amounts of packaging for recycling are growing. Package materials need upgrading in image, while being suitable because of their lower emissions compared to fresh wood.

Public national and regional development bodies largely share the views of companies for the current status and future of circular economy and recycling in the value chain of wood construction and wood products industries.

The main message from the Finnish and Swedish ministerial level is that the legislation and regulations will inevitably push more and more the industries to circular economy and cascading. The companies should consider it as an opportunity for them that recycling and reuse will gradually become obligatory. Logistics problems and lack of material recycling practices and incentives are expressed as obstacles. Challenges exist especially in cascading use of construction materials and in getting business value from carbon storage.

In two regions in Finland the following current and future strengths are identified for wood side stream issues: 1) Large biomass and side stream volumes (raw materials); 2) Lots of knowledge and expertise (processes, technology); 3) Triple Helix collaboration works well if the stakeholders want to be active – there are unexpectedly many active companies in bio-circular economy.

Weaknesses for side stream issues include: 1) Upscaling from research to commercialization does not really proceed; 2) Company ownerships and risk taking; 3) Lack of market knowledge and fruitful markets; 4) Lack of demo factories/concepts, piloting infrastructure do exist but service prices and existing patents are bottlenecks; 5) Too much individual working (without collaboration); 6) Lack of self-confidence and appreciation of own capabilities, raw materials and products (selling with too low prices, lack of branding); 7) Rural location and long transportation distances.

Several opportunities are obvious: 1) Climate change mitigation is a big opportunity for northern bio-circular economy; 2) Political and legislative instruments can provide more resources for R&D; 3) Smaller flexible business units can be developed to the economic system; 4) New systemic thinking: green investments have already grown and may grow further; 5) More ambitious business earning logic, self-respect in the pricing of own products and high-level branding can be created; 6) Transfer in public coordination from after control to proactive guidance and planning could proceed: stakeholders do more than what the regulations require if the aims are well motivated; 6) Side stream processing could support regional employment.

Possible threats for the development were expressed as: 1) Current weaknesses will not be intervened (external or internal); 2) Large production units and increasing transportations add to the environmental loading; 3) Producers do not find side streams as an business opportunity;

4) Low regional interests; 5) Few companies have resources to invest on long and uncertain R&D processes; 6) Funding options to companies remain too challenging – current public funding models do not work well enough; 7) Financial responsibilities of stakeholders/partners, funding organisations and ownerships of raw materials to hinder investment decisions; 8) Basic use of saw dust, bark and planer shavings has been solved in principle (bioenergy); 3) Universities and research institutions put hindrances for developers/companies (price of service, IPRs); 9) Laboratory, testing and piloting infrastructure that were funded with public money will not be easily available to developers and companies - low-barrier for development activities and better information and dissemination for potential users are needed.

Helsinki workshop for saw mill industries

Workshop was held in Finland on 10th of April, 2019. The focus was in the role of sawmill and wood product industries for value chains of side products: the present business models, partnerships and cooperation in the production and utilization of side streams. Table 15 summarizes the main findings in the value chains of wood product industries emerged during the workshop.

The most successful technologies and product groups deployed to utilize the side streams of the saw mill and wood product industries:

- Local biorefinery is an interesting option but the profitability depends on the choice of right technology, increase of production volume to an adequate level and proof-of-concepts to convince investors and industries. Biorefineries need big investments, but inexpensive funding may not be available.
- Production of bioethanol and cellulose based textile fibres need to be high volume production and require investments from big companies and government subventions.
- Composite products are an interesting option if saw dust is possible to be utilized as filler. Wood plastic composite (WPC) has the problematic plastic part, which should be replaced by some biodegradable material.
- There are numerous valuable compounds in the bark but their separation and purity are challenging.

The most promising customer groups and uses to utilize the side streams of the sawmill and wood product industries, either now or in the near future

- Energy production of the big growth centres after the renewal of the plants to get rid of coal and heating oil. They could use all the saw dust and bark from the saw mills of southern Finland in the future, but the national economic aspect needs to be assessed.
- CHP production would be a reasonable way for electricity production from the point of view of national economy. Condensing heat could be used for drying of other side products.
- Finland is the pioneer country in the bioethanol and biodiesel production, however, the market is fully driven by the Biofuel obligations scheme (BOS) and national targets of liquid biofuels.

Table 15 Main findings in Helsinki workshop

Strengths and competitive advantages	Challenges and bottle necks
- Fresh wood chips are very wanted wood raw material for pulp, paper and paperboard mills due to the long, high-quality fibre and well-established end-uses. The market price is now moderately good and competitive for all trading parties. The situation of other side streams is fluctuating, the prices have been generally low but they have recently increased. - The side streams and by-products of saw mills are more uniform of quality than those of other side stream materials or forest chips. The quality can be further improved by sorting for different purposes of use, e.g. 1. incineration, 2. biorefining, 3. small volume production of high-value products, e.g. medicinal or nutritional substances or consumer cosmetics. - Wood as a whole is a renewable, climate smart and healthy material, which advance the demand of both basic products and side streams.	- The lack of knowledge about alternative and future uses and their profitability of side streams among saw mill industries. - The need to assess which prices the customers are really willing and capable to buy. Until now the uses of side streams are strongly steered by the public support. - Pure wood saw dust is as good a raw material as wood chips, but its image should be raised more in order to improve the demand and the value chain. The demand and prices are also dependent on the price of emission allowances. - (As a consequence of lobbying by the forest industries), public support is directed to forest chips but not to side streams of saw mill. Note that forest energy could not compete with saw mill residues without public support, because its supply chain is too expensive. - CHP production is currently at low level. Power transmission costs are a big problem. This requires for example a city grid close to the mill. Generally, the efficiency of small scale electricity production is low. - Production of wood based panels is not competitive because they are now domestic market products with limited market size and a lot of import, and the competition from other use (e.g. energy use) raises the raw material price to too high level. - There are difficulties in getting funding for the development activities of small companies.
Prospects and future options	**Obstacles and threats**
- Economical assessment on which new products and at which size category the production is profitable would benefit the strategic decisions among the companies. - The companies need proof-of-concepts where the functionality of technology, business unit integration, and market prospects are clarified. - Policies made by tax money have a big role: abolition of the support for peat, stumps and logging residues would increase the demand of side streams. - Voluntary emission trading: carbon trading with wood, carbon credit, production of sawn timber for carbon sink, long-term carbon storage in wooden buildings, low carbon footprint. - Promotion of wooden constructions especially in public procurements would support both the demand of the main products of saw mills but also side stream utilization and product development for the construction sector. - Increasing need to replace plastics with sustainable, naturally degradable materials calls for considerable use of side streams and recycled materials.	- Too little human and financial resources for the RDTI work. Saw mills do not have enough economical resources or know-how on side stream development. Therefore, there is a need for public input and a concentrated centre of excellence. - New innovations that work on a small or pilot scale have not been made enough to work on industrial scale. - The benefits of work of RDTI projects are usually available only for the participating companies. They could be also manufacturers of machines and industrial equipment. - New products need big investments in relation to the production volume which is a risk for the profitability. - Production of unprofitable products from the side streams may happen, if there is not enough knowledge of the markets or technology. - Public policies and regulations should be predictable, as stable as possible and not restrict the future opportunities related to technical development and launching of new products. - Lobbying by the competing industries, e.g. plastic or concrete industries, inhibits the market development. - Possible regulation of wood burning is an economic risk. Allowable emission values of wood burning are getting tighter. - There is a potential risk of not to assess wood as renewable raw material – discussion and future definition of carbon sinks vs. sustainable cuttings.

The main best practices emerged during the workshop:

- Good overall management of raw materials, side streams and all kinds of wastes through integrated procurement and supply of different wood-based materials – in large integrated industries in particular
- Wood industry park approach and regional solutions provides local markets and profitability
- Triple Helix collaboration in RTDI and policy/regulation implementation, rather large number of active companies and public stakeholders (in some regions)
- High utilization rate of raw materials and close-to-zero generation of wood-based wastes (almost closed loop).
- Approach of carbon sink principle and renewable bioenergy in wood product industries
- Local CHP-plants producing renewable energy. In the larger scale also the security of energy supply increases.
- Projects to reach the same level in electricity and heat production as in Central Europe and Baltic countries using investment aids, feed-in tariffs etc.
- Profitable drying technology for saw dust and bark to increase the value in energy generation and lower the transportation costs, efficient treatment of combustion gases to improve the recovery of energy from the side stream materials and highly improved the resource efficiency.
- Projects to start bioethanol and bio-oil industries in the side stream utilization
- Projects to start industries based on activated carbon and bioactive coal
- Utilization of knot wood: sorting of chips gives knot fraction which is a suitable raw material for medicinal and cosmetics products

5.3.4 Eastern Europe

Slovenia, Poland

The analysis shows that both in Slovenia Poland, the wood waste generated from the production is used as a heating source. One company reuses discarded wood from demolished rooftop beams, old windows and production waste in window scantlings. Poland has a large particle board and MDF industry which use wood waqstes similatrlt to sych factories in France, Germany, Austria or Italy. They also import by-products and recycled wood for raw material.

Practices to implement efficient procedures in the production process, in general to achieve the "slim production", are implemented through the reorganization of the working stations, material organization and preparation of the production flow, in order to reduce the production time. Several efficiency procedures introduced regard the reuse of all coating liquids that are collected during the process via special channels with the aim of a multiple reusing; in order to reduce the excessive glue consumption, predefined gluing capsules are used too. For side stream processing, production technology like CNC machines, band saws, presses, and grinding machinery to produce wood chips from waste wood are used.

The biggest obstacles regard the customers' perception of quality of the products obtained from recycled material. The main challenge is to convince customers and companies those products provide the same quality as those obtained from fresh roundwood and by-products of wood product industries.

Generally, the companies have a positive perception regarding EU and national policy related to environmental regulations, recycling and material sourcing. The major concern is about the higher costs related to the implementation of practices in line with EU and national regulation, and the need to an active participation of EU in supporting the demand for circular products.

Warsaw workshop for EU13

Workshop was held in Warsaw**,** Poland, 30th of January - 1st of February 2019, with the aim to gather preliminary information on recycling, waste wood management and side stream valorisation activities from both technical and regulatory point of view in the EU13 countries (EU13 referring to Bulgaria, Croatia, Cyprus, Czech Republique, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia as countries which joined the EU after 2004). The workshop participants, including project representatives and stakeholders, established a preliminary overview of the current situation of wood-based value chain management in the EU13 countries.

During the fact finding discussions between stakeholders and project representatives, two groups with separate sessions gathered together to answer the pre-set questions and share state-of-art information, opinions and perspectives. Stakeholders from Poland, Romania, Slovenia, Slovakia and Ukraine and project representatives from Finland, Slovenia, Germany and France participated. Many findings were similar in Group 1 (Side streams in the wood processing value chains) and Group 2 (Recycling/waste management, side stream valorisation). The main findings that emerged in these sessions were the following:

- The lack of official data available about the side streams, waste wood and recycle wood or value-chain flows in EU13 countries.
- The lack of regulations to define the side streams, post-consumer or pre-consumed wood products, contamination level etc. in EU13 countries. No descriptions are available to define which side streams go for energy production, which are used for recycled products and which are used for landfilling.
- The lack of technological development especially in the recycling of waste wood and valorisation of side streams for value added product development.
- In EU13 countries, the companies and other stakeholders are still not aware about circular bio economy. They need demonstration about why Circular bio economy is important for the future development of their countries. Wood residues and wastes are basically used for energy purposes in public and private sectors, but they are far behind in terms of technology and legalization of energy polices. Progress of cascading needs demonstration, technology transfer and good practices.

Group 3 was focused on the influence of policies on circular wood-based economy in the different countries. It was established that among the EU13 countries, the starting point is very fragmented – the countries and regions are in very different stages in side stream utilization and waste management. The main finding was that there is a need for movement towards better collaboration and closing the gaps in the knowledge chain, present and educate what are the advantages and opportunities in circular economy for the wood sector and boost the role of wood sector in bio-economy. Overall policy is a very interrelated and complex topic, it changes utilizing incentives rather than sets restrictions. Policies toward more bureaucracy are not wanted. Across the discussions, the lack of data and information was a common hindering factor.

Strengthening the wood sector and its role in bioeconomy

A common consensus was that the agricultural sector is seen a priority compared to forest sector. Agriculture is typically the main sector of economy in EU13 and it is seen as the main contributing sector to bio-economy. Importance of forest sector is not acknowledged and, generally, there is a lack of strategies for forest and wood-based industries. Forest sector needs to be made more visible among the bio-economy sector. Forest sector is typically based on small entities, such as family owned sawmills. Supporting networking and partnering would be important, as the wood working industries would be motivated by facilitated and informative conversations and discussions.

Unawareness and need for information

Especially the SMEs and entrepreneurs are not aware of circular economy, and there is also unawareness among the politicians and decision makers as well as the final market players and consumers. Circular economy strategies or roadmaps do not seem to exist, but they were felt as options to support the transition to circular economy. Especially the information on cascade use, secondary and pre-treatment processing, wood residues, side and waste streams as well as new products and business models would be useful if they were provided in an open, public database.

A classification and standardization system for wood residues, waste wood and side streams and potential to create high-value products was valued in the discussions. In many cases, wood is exported as roundwood rather than adding value to it before export. Quality certificates were seen as an important tool if they were supervised properly. Overall, the lack of data was highlighted as an issue across the value chain: availability and uses of raw material, logistics, export, amount and uses of side and waste streams, etc.

Social factors

The markets and consumers do not value wood-based products; especially housing made of wood is not perceived with safe, modern, unique or fancy way of living, and recycled wood-products are not felt safe to use. For consumers, the main factor is the price of the product. For wooden products, the price needs to be lower with the same properties that the alternative products provide, or have better properties with a slightly higher price. The consumers need to be educated on environmental impact and sustainability to attend to the current state of lack of markets. Public sector should promote wood use and help the raw material establish a respected role. In addition, labelling of wooden products similarly like the energy efficiency labelling of machines could be seen as a positive tool to support the education process and creation of market demand. For example, the label could describe the circularity index of the product.

Political drivers, regulations and incentives

Climate change is not seen as a main driver for policy makers in EU13. In some of the countries it is present in the discussions, but not a driver. For example, new buildings are not seen as potential CO2 storages. The policy makers should be influenced with science-based facts and arguments. Corruption was highlighted as a problem in several discussions, for example in cases relating to current certificates and lack of overall and accurate data.

In the discussions, it was also established that there are problems relating to EU regulations. The regulations are officially implemented, but in many cases not actually practiced or followed. However, there was a consensus that following the EU regulations would be useful and necessary. For example, landfilling is still authorised and does not support the utilization of side streams. It could be generalized, that the forests are not sustainably managed and harvested. In conclusion, there is a need for regulations and actual implementation of them.

Overall, incentives were preferred over restrictive policies. Incentives would be needed for both wood construction and utilization of recycled wood. Good examples of existing incentives were given, for example in Slovenia, there is a governmental system called Green Ordering for wood construction to support building wooden houses. Public procurement could be the promotor in the transition to circular economy and initiate change in the industries as well. Good incentives could be refund systems or ecotax-systems. Nonetheless, it is important that enhancing regulation and implementing different incentives would not add to the amount of bureaucracy – rather lower it. It would be necessary to coordinate policies within the forest sector and make sure to take into consideration the regional, national, European and external markets.

The main findings of the general discussion of the workshop are summarized in Table 16.

Table 16 General findings in Warsaw workshop

• Creating a good database on side streams of companies (by-products, wastes)
• There is a lack of proof of concepts, the lack of data and pilots hinders the process and interest among investors and companies
• There is a difference in strategic thinking and operative solutions between bigger and smaller companies (e.g., international particle board and furniture companies vs. saw mill and packaging product companies)
• There are regulations missing, mostly in the sense of the lack of classification, standardization and labelling, but there is a lot of bureaucracy, thus there is a need to reduce red tape
• There is a lack of awareness of availability of side stream markets and opportunities and development needs to create markets
• The idea of industrial ecosystems and value networks of companies is not really there
• B2B needs to be improved … a need for collaboration and new partners to find incentives
• Public procurement is a good tool to promote side stream usage

6 SWOT analysis

6.1 European level

Strengths

One of the main strengths to highlight regards the common perception of the efficiency of the value chains of wood waste management, and the well-functioning networks that involve a large number of active companies and stakeholders. A fundamental aspect is the high degree of resource efficiency in the countries involved in terms of good overall management of raw materials, side streams and all kinds of wastes, the use of renewable raw materials and the use of alternative sources. In some cases, like the Italian one, the recycling rate of wood waste material reaches almost 100%, ensuring a system with no waste material. Modern woodworking mills are also near close loops of material use in their production, but this depends much on the current markets of side streams which differ considerably between the countries (bioenergy, particle and fibre boards, pulp and paper, value-added chemical products, other special uses).

Another main strength that is in favour in the implementation of circular approach is the general positive attitude from society and decision makers for cascading and sustainability: circular economy and sustainability in general are becoming more and more popular and companies that follows these approaches are supported by policies and recognized by institutions. The policies and regulations are rather well known by the companies of the sector (except in Eastern Europe). The general perception of them in environmental terms is positive. Sustainability and climate-smart approach is accepted and promoted among the companies and policy makers.

Weaknesses

One weakness is related to the large share of side streams of the basic production of the companies, the different wood species and dimensions and scattered availability and high transportation costs that make it difficult to manage the different kinds of wood wastes to be recovered. Another negative point is linked to the lack of technical knowledge and practices regarding the phases of wood processing like the management of wood dust or the fumes deriving from drying processes. This varies according to the type, size and technology of the industries, in the supplying and utilizing companies both. Wood-based products are not typically designed to meet an easy recyclability, which limits the attractiveness among the manufacturers and users of subsequent recycled materials and products.

Some processes like cleaning of wood involve substantial investment costs, high energy consumption, and high wear of machinery and consequent maintenance costs. In addition, special treatments are often needed to sort the side stream and waste materials or upgrade their quality. The high expenses have a negative influence on the level of development of the processes, aggravated by the low investment resources available in the companies of this sector.

Lack of uses and markets for side streams and wastes is a common obstacle for the development of side stream and waste management sector in the different regions of Europe. Albeit bioenergy sector is generally growing Europe, in some countries like Italy the wood-based wastes are not used for energy production. Instead, some countries are characterized by well-established uses, high level of technology and knowledge in wood-based bioenergy. For example in Germany and Finland there is a good availability of special technologies, whereas in other countries like Spain

or Italy there is a need to increase the efforts in developing new technologies for processing of wood waste materials.

Green field construction and demolition produce larger quantities of different wastes, wood-based wastes among others. Generally, the sorting and flowing to recycling is rather easy for the construction companies as long as good sorting instructions are available and the transportation costs to recycling are reasonable. According to the construction companies, the logistical systems or pre-planning of waste management of the construction and demolition sites are not well-developed, and call for more regulation and standards. While the recycling companies or associations, either public or private, are finally responsible for recycling and waste management, the few markets of the waste-based products is are a challenge for them.

Many wood product companies (and federations) view the fluctuating market, low prices and few uses and customers of their side streams as a big problem. More demand and innovations and investments among potential users have been proposed, but expected to be done by the users in the first hand. Potential companies need proof-of-concepts about the profitability of the investments, this evidence is lacking in many cases. It is a clear weakness that the innovation and product development system is slow, and the public financing systems work with a varied intensity and financial basis.

Steady and long-perspective policies in the public policies of regulation and subsidies are also stressed by both the supplying and processing companies. This regards both the status of different raw materials, acceptable uses and relevant EU laws and directives their national interpretation. Clear and balanced approach to bioenergy vs. cascading is wanted by the companies and federations.

Opportunities

The main opportunities for this sector regard the possibility to extend the markets to new end of life options and new customers: bio-refineries, composite products, plastics and coal replacing products, modern implementation of bioenergy, new ways of composting, soil and water purification, landscaping, etc. Wood fibre producers have an expanding market potential and a possibility to extend the target markets in terms of export. In material procurement it is possible to implement practices like shared procurement, delivery and use of different woods, including forest energy. The fact is that in some countries the wastes are not used for energy production – this is an aspect that should be implemented.

Generally, the recyclability of wood-based materials and products, including construction products, should be upgraded and the on-site sorting should be developed to raise the attractiveness among the potential users. Demonstrations, pilots and proofs-of-concepts have shown to be efficient ways to promote novel business models and products, so they evidently work also in side stream and recycling business. This should include also the development of criteria and methods of LCA.

With regards to the lack of knowledges and skills, the companies should focus and invest on professional training for experts in the different areas, to improve the capacities that are not well-developed. The system and product certifications are central in this context: these kinds of practices can be helpful to increase positive perceptions between producers and customers. This

has been observed in the participation in projects on recycling and sustainability that can support the transition from typical linear economy approaches to the circular ones.

Regarding policy measures, appreciating the local preferences about wood utilizations and recycling and increasing consumer knowledge and behaviour about side streams products should be major opportunities to support the business. Recommendations or requirements for the public acquisitions and investments of governmental and municipality organizations could be used to promote products made of recycled materials and convince the markets in private and consumer sector, the green building initiatives policies being a good reference. Full implementation of the Triple Helix innovation and development system in regional and national work could be a way to accelerate the knowledge development and sharing, collaboration between the stakeholders and product and market development.

Threats

There are many difficulties that the companies involved to side stream supply and utilization and wood waste management have to face. First of all, in some regions the presence of competition on some side streams between the different uses and companies increase the raw material costs, although in some regions the lack of demand and uses is still obvious. In both cases, these are aggravated by the high costs of transportation due to the long distances between all the phases of the value chains.

Second threat can be the lack of collaboration among companies and policy makers, and poor reliability of companies on certain systems that are inevitable for the society but crucial for the business and profitability in the sector (accessibility to raw materials, build-up of costs). As it has been underlined before, the sector is well aware of the policies and regulations. It was observed that the compliance with the EU and national regulation may lead to higher costs for companies, customers and final users, and is often technologically demanding. These aspects are linked with the complex administrative-environmental management that may limit the operations of the companies and distance the companies from the purpose.

Some threats are associated to the profitability of the operations and the role of final users. With regard to the first point, the market is characterized by low market price and unprofitability of wood-based electricity, in particular. There is a common perception that recycled wood is just for heating energy, so the biggest challenge in the sector is to convince customers that recycled wood has similar quality as new wood if it is properly selected and processed and the product is relevant. The role of the customers is crucial and the evidence is similar in all countries.

6.2 Regional specifics

6.2.1 Southern Europe

As shown in Table 17, there are positive and negative aspects related to the implementation of circular economy approach individuated by the stakeholders interviewed in Southern Europe. While companies in general are aware of the opportunities related to circular economy practices, with the consequent creation of a high recycling and resource efficiency system, there are still some obstacles that curb the firms and need to be overcome. In particular, companies find some difficulties related to the high investment or processing costs, as well as the

availability of raw materials and the limited appreciation of customers on the efforts undertaken by a company in the field of circular economy. There are also issues related to the lack of awareness of the economic and environmental benefits, in replacing raw materials with other recyclables (due to regulatory constraints).

Table 17 SWOT analysis on the management of wood-based side streams in Southern Europe

Strengths	**Weaknesses**
• High recycling efficiency (almost 100%) - high resource efficiency • Well-functioning value chain • Large number of active companies and stakeholders • Efficiency wood waste management network • Large total volumes of side-streams, renewable raw material • Implementation of material and process efficiency practices and optimisation of using wood and side streams is inherent in forest and bioenergy sectors • Increasing interest in research, new products development and use of developed technologies • High quality products obtained from recycled wood • Positive perception of policies in environmental terms • Market for pellets • High-level and long experience in machine manufacturing for waste management	• Logistics costs and delivery delays • Small amounts and scattered raw materials, side streams and semi-finished products per supplier • Preferred use of energy due to large investments already done • Competition among firms • Vulnerability from and poor reliability of the legislative systems • Lack of specific technical know-how on fuel gas filtration plants, deriving from drying, wood dust and separate collection • High energy consumption in production processes • Wear and high maintenance costs of the machinery • High delivery costs of wastes resulting from wood cleaning • Large quantities of recycled wood and higher processing costs • Implementation of efficiency practices is still limited to some companies • High presence of SMEs
Opportunities	**Threats**
• Eco-attitude and circular economy in society • Green deal agreements between private and public parties for sustainable development • Large number of unexploded residue types with huge potential for new uses and upgrading • Use of recycled wastes in high-value products • Improve the waste management for energy production • Environmental certification, professional qualification • Raise the awareness of companies of circular economy issues • Create demand for circular materials and products • Investments in biomass boilers for internal uses of energy • Reducing costs of recycling through the improvement of processes (collection, treatment, re-manufacture of panels) • Implementation of 100% circular economy processes involving post-consumer wood • Implementation of solutions to improve the organization and material flows	• Diseases of trees affecting the raw materials • Lack of raw materials • Very demanding legislation • Complex administration of environmental management • Low quality perception of products made from recycled material • Modification in standards and laws leading to process or requirement variation • New competitors in the market with low prices • Slow and expensive development of new products and uses for side-streams • Public bodies are just starting with their concern about circular economy (some countries)

In detail, from the stakeholders point of views, the main success factor in the general organization of the management of wood waste and side stream utilization is the common perception and existence of well-functioning value chain, that bring together different active companies and key stakeholders that work in a symbiotic collaboration to functioning of all the processes. The efficiency of the network it is translated in the efficient management of the waste from beginning of the whole value chain. Another strong point regards the fact that the 100% of the waste managed it is sent to panel producers, ensuring a system with no waste material.

There are strengths through some successful technologies for the mechanical treatment of wood wastes (wood crusher machines) and improve the screening and classification of the by-products, a fundamental step for their recycling and novel technologies for the densification of residues for the realization of pellets and combustion for self- consumption. There is a large potential market for the products obtained by recycled wood due to the high quality and characteristics associated, very similar to the ones created with virgin wood; therefore, its potential for use is identical. This very important aspect is related to the well-management of the entire supply chain, starting from the implementation of systems (separate collection, mechanical treatment in storage centre) that reduces the risk of contamination and allows to obtain a higher value for the material, up to the final processes implemented by panel producers. There is a large application of these products in the furniture industry: for example, by using particleboard with recycled wood, it is possible to produce furniture that could be reused and/or re-assembled instead of incineration or disposal in landfill. It is important to highlight that during the implementation of collection, treatment, re-manufacture of panels the cost is increasing due to a higher quantity of recycled wood.

The latter is an important issue and it is related to the costs of logistic organization, energy consumption for the waste treatment and those related to the wear of machinery and high costs of maintenance. Transportation is an impediment to sell by-products because the costs are increased and other opportunities are not viable; transportation distances are often long, and there can be delay in the delivery of the materials. Competition between firms is still a problem: the sector is characterized by the strong role and the narrowness of final recycling plants. Linked to these barriers, the implementation of efficiency practices is still limited within some companies.

Some threats are linked to the availability and the quality of raw material itself. A potential issue can be the spread of tree diseases, coming from fungi or bacteria, that can compromise the quality of the wood material due to the need to use pesticides. The lack of the materials is a problem from the viewpoint of panel producers due to the big presence of small companies that do not produce a large amount of waste to supply the board manufacturers.

The presence of a very demanding legislation and eventual modification in standards and laws leading to process variation is perceived as an external obstacle: too many documentary requirements limit the operations and cause the loss of purpose. Other threats are the excess of bureaucracy, the difficulty in meeting the specifications technical or regulatory, the lack of experience and the lack of competences and technical know how.

In terms of opportunities, in general, the companies can move towards two directions regarding the management of wood waste. The first path concerns the improvement of waste dismission to facilitate its recovery, and the use of renewable energies for the production activities. The second path is related to design and planning: companies can invests in the design of products made with eco-sustainable, recycled and recyclable materials with less impact on the environment.

The most ambitious objectives are related in fact to the implementation of 100% circular economy processes through the achievement of self-efficiency as regards the energy in internal plants (better management of waste wood, investment in novel biomass boiler for internal energy) and reducing cost of recycling thought the improvement of the processes (collection,

treatment, re-manufacture of panels). There is a strong need to invest in plants capable to recover material and energy from the various supply chains, in order to create closed systems in line with circular economy approaches. Then, there is a need for large investments for the redesign of processes, technology and training.

While the sensitiveness to circular economy approaches is growing between the customers, the need to stimulate the demand for circular materials and products is still necessary. The system also requires to improve the perception of the products obtained with recycled wood and more in general to stimulate the growth of that market segment related to recovered materials. In this direction, a tool perceived as a great opportunity to communicate with customers is the use of environmental certifications that can be useful to put in evidence the environmental impacts along the life cycle of goods and services or to guarantee the quality of the products. Moreover, since the quantities are not so relevant, the development of new products and uses for side-streams is not a priority but could represent an opportunity under the environmental ad economic point of view.

6.2.2 Central Europe

Generally, many options are available or under development in side stream management and utilization in Central Europe (Table 18). Selective sorting seems to be quite broadly implemented for wood by-products as well as for other by-products, maybe less for packaging waste. Manufacturers of finished products have already made great efforts, for example in wastewater recycling and waterborne products. Downgraded products and products from after sales services or showrooms are donated to associations.

Wood-based by-products are sold as co-products, e.g. peeler cores from plywood manufacturing to saw mills. Some reuse options are available, like dismantling of planks to repair pallets are repaired. Recycling activities cover, for example, plentiful raw materials of and take back of particle boards from furniture manufacturers, compressed pallet blocks, wood plastic composite products, pulping and green chemistry, absorbents, mulch, potting soil, animal bedding, etc. Energy recovery is versatile, given as wood fuels to employees, manufacturing of pellets or briquettes, and supplying for internal boilers for heating and process heat, CHP plants and local incinerators, greenhouse growers and cement plants.

Particle boards are made from by-products and waste from the whole forest-wood chain (thinning wood, sawmill by-products, pre-consumer recovered wood) and post-consumer recovered wood. By-products are recovered internally as energy. Metals from post-consumer recovered wood are recycled. Recycling is profitable today for particle board manufacturers. But, except for particle boards and energy, there are not yet any large-volume recycling options for wood-based aside streams or waste materials. For some furniture manufacturers using particleboards, many opportunities do not exist for reuse processes, except the take-back to particle board mills. Currently, the material properties are recovered only partly (down-cycling).

One success factor in the general organization of wood waste management and side stream utilization is to achieve self-sufficiency in heating through internal energy generation among the industries. In most companies, wood-based side-stream materials are recovered for energy generation within the plants (process and heating system). This provides waste-free utilization of wood that is converted into sustainable energy. Utilization of side streams is common and

innovative technologies are implemented for material and energy uses. Investments have been made in new machinery as well as in the reorganization of layout of the plants.

Demand for side streams of wood processing industry is concretely large. In addition to business-as-usual products, they are used, for example, in the utilization of high-quality chemical compounds for sophisticated functional wood fibre products by manufacturers of high tech fibres and construction and insulation materials. There is a large use of wood and side stream materials in different industrial sectors, such in furniture industries where there is a large demand of wood-based panels.

Many barriers that do not allow the full implementation of circular economy approach still exist. General priority is often given to energy recovery, but material recovery enables higher resource utilisation efficiency on the long-term, In addition, for some companies the heat generation is not an option in summer. There is also inconsistency between the quality of by-products and waste and the treatment options. Expensive clean flows with long fibres are sometimes recovered as energy in collective boilers (without flue gas treatment equipment) whereas cheap low-quality pre-consumer or post-consumer flows are recycled as particleboard (with more and more sorting equipment.

Many companies perceive limited profitability of recovery options due to often limited volumes of by-products and low prices proposed by service providers (or end customers when internally recycled). By-product management often enables relative savings compared to disposal options, but is rarely a source of revenue.

The high costs of materials and processes, except those for particle boards, as well as the expensiveness of transportation due to the long distance circuits and low solid content of the materials and sometimes limited storage space affect the cost-benefit balance the practices. Purchasing wood wastes is considered sometimes expensive because of the poor quality of the material which must be upgraded by sorting to be in compliance with quality standards and requirements of regulation. For the manufacturers of finished products, few and expensive bio-based raw materials are available only. Wood transformation companies and end consumers are not really willing to pay for recycled materials, and there is not too much development of recycling practices because market is not ready (vicious circle).

Furthermore, there is a strong competition of the raw materials between energy sector and material usage, especially on clean by-products. This is aggravated by the instability of markets and fluctuating and low prices of side stream raw materials. The organization of the value chain is a further issue: some recovery processes exist but they are not implemented at a large scale, because there is a lack of organisers of pathways and pioneering companies.

At certain sectors, like construction, demolition and households, still a significant share of post-consumer waste wood is disposed of (landfills) or incinerated but with lower yield than at dedicated combustion plants. Companies that outsource by-product management have lack of knowledge of the fate of by-products and wood wastes, which removes their responsibility of the business and development.

While the companies are largely interested in the implementation of circular economy approach, they perceive that they do not get the right support from public policies, either at national or local levels. All companies are not aware of the regulations relevant to their business or

operations, not to talk about circular economy or bioeconomy strategies. This situation is however different among different sub-sectors. Generally, the closer the company is to the end-user, the more processed products it offers to the market, the bigger and more global it is, the better it knows the regulations and strategies. Most companies are somehow aware of the national strategies relevant to their sector and of the regulations that directly affect their everyday operations.

In fact, there is a lack of valorisation of the strategies at national level. Territorial policies need to be developed especially with respect to the local wood supplies. The system is affected by high taxation of waste disposal, high costs imposed to the management of by-products, unpredictable legislation and standards and access difficulties to raw materials. The administration, relying on the proximity of companies located in the territory, should make an effort to understand the priorities of local development and focus on industrial development instead of inspections and repressions. Providing public financing to and promoting investments in the projects of the companies that are engaged in circular systems are concrete actions to support their development and societal purpose of actions that encourage bioeconomy.

In general, it is possible to identify four focus areas that could be improved representing real opportunities for the implementation of circular approach in the wood side stream sector: research and training, public policies and interventions, better regulation, improvements of infrastructure and network.

Wood side stream sector has great opportunities in R&D that is oriented to circular economy, such as development of environmentally friendly adhesives and finishing agents to improve the abilities for extended product life, repairing, disassembling and reassembling and recycling and recovery compatibility, along with improvement of clean production processes and new recovery solutions and better valorisation for energy products. Development of new recycling technologies is needed for MDF. Potential process improvements may include review of expected raw material specifications at every step and for final products (e.g. standardisation of structural products), yield optimisation, steps in order to avoid glued or coated off-cuts, broader use of waterborne finishing products, better selective sorting, etc. Implementation of BIM practices is available at large scale for construction companies to manage circular economy all along the life cycle of buildings.

These are just some examples of the eco-design opportunities available in this sector together with the possibility to rethink new side-stream-based or waste-based products and users. Training of professionals and entrepreneurs working in the different supply and manufacturing stages has an important role in the transition to circular economy. This is a prerequisite for the acquisition of knowledge related to production and logistics processes, waste management, design and innovations.

Better European and national legislation and regulation in terms of their uniform application are proposed by the companies. Simplifying the regulations with fewer, more easily understandable, stable or at least predictable rules would be beneficial for business and investments. Making it possible to sell downgraded products with lower commercial responsibility was proposed (warranty, hidden defects, spare parts availability, etc.).

For energy recovery, increase of taxes on carbon emissions is expected. Simplifying licensing procedures for combustion plants classified as incinerators is needed. Particle board

manufacturers perceive the ICPE regulation of biomass boilers very restrictive. Development of a regulatory classification allowing the recovery of clean fraction of post-consumer waste wood as energy in combustion plants should be possible.

Specific to particle board industries, influence of recycling on indoor air quality is a question that should be verified, because thermal regulations push to reduce the renewal rate of air in houses. Also, the new extended producer responsibility scheme on furniture waste could jeopardise the quality of post-consumer recovered wood.

Introduction of a true European harmonization that could help to overcome the quality problems of the products obtained from recycled materials is seen as a chance. The rules could include, for example, European wide end-of-waste criteria, better control of product-specific rules and to avoid country-wide interpretations and associated market distortions. Harmonisation between regulations on products and on wastes containing hazardous substances is needed.

Development of transverse legal wood waste classification would help to avoid unclear and varying by-product specifications between service providers, leading to zero risk sorting strategies and avoiding over-quality. Hindrances to industrial development caused by site-level policies could be overcome as well.

For material recovery, valorisation option through temporary carbon storage could be a target. Change in UNFCCC rules on carbon accounting was proposed so that carbon storage in wood products would be accounted for where wood products are used and not where timber is harvested. Now, countries importing timber or wood products have not any incentive to promote cascading use of wood resources. It is also little possible that forest health and climate risks call into question the value of by-products and wood wastes. Radioactivity of timber found in Eastern France was linked to Chernobyl radioactive cloud, and subsequent contamination of ashes.

A big challenge is to organize a well-functioning supply chain and stakeholder network and to improve the relationships among the different actors. Currently there is lack of trust and collaboration between companies to build industrial ecosystems. Better cooperation is assumed, for example between companies of energy sector, panel producers and side stream suppliers.

Furthermore, it is crucial to develop infrastructures to support circular economy. New platforms for the recovery and redistribution of scraps and wastes and introducing new biomass boilers and biorefinery plants are needed at municipal level. It is necessary to rethink the logistic and transport systems and create efficient logistics network that is capable to interconnect a multiplicity of geographic areas, even distant from each other. The aims should be the best economical ways to reduce the high costs of transportation and storage and reduce the logistical circuit.

Table 18 SWOT analysis on the management of wood-based side streams in Central Europe

Strengths	**Weaknesses**
• Large total volumes of lignocellulosic materials and side stream (certified) • High resource efficiency and markets in certain value chains (e.g., wood chips, pallets) • Selective sorting broadly implemented for by-products from wood, less for packaging waste • Circular approach: self-sufficiency in heating the industry plants • High quality products from fresh side streams • Overall good perception of the policies in the sector (in some regions) • Implementation of analytical quality control of waste carried out by third party • Using selected raw materials to have minimal ecological impact • Recycling of washing water from each manufacturing process • Eco-organization for the extended responsibility schemes: services related to layout planning, take back of furniture wastes and used furniture • Innovative development of sophisticated products with appropriate resources available (in some countries) • Leading technology in innovative machine engineering and plant design in wood and bioenergy sectors (Germany, Austria) • Fair-priced recycled materials for wood panel and energy industries (comp. virgin wood) • Almost no landfilling of wood waste	• Markets mainly restricted to natural wood and clean residues with no other substances • Few true recycling options now, except particle boards • Small volumes of wastes (some countries) • Saturated competition on side streams for some industrial sectors (energy-panels) • Unpredictable costs and low profitability, unfavourable cost-benefit balance • High raw material cots (purchase, processing) • Dust emission issues, filtering costs of combustion gases • Missing territorial and insufficiency public policies to improve local wood supply (in some regions) • Difficulties in defining clear and quantified objectives among companies (need for external assistance) • Low innovation potential and R&D investments in sawmill and plywood industry • Value chains not well organized, export less developed (some countries) • Controls carried out from a national point of view with national interpretations • Low customer perceptions of product quality from recycled materials • High costs of waste treatment: quality of sorting must be maintained to comply with regulations • Long transportation distance between producers and users, limited storage space
Opportunities	**Threats**
• Large and growing demand of several side-streams (some countries) • New products and customers of multitude are available for side streams • Improving sorting and requalification of waste fractions suitable for energy or raw materials • Developing better ways to valorise side streams for energy, wise recovery of wastes • Full passage to clean production processes • Reducing wastes and hazardous agents (LCA) • Upgrading cogeneration to produce electricity • Local shared biomass boiler projects and recovery projects • Different recovery solutions of local scale, also for wastes of wood panel industries • Improving local manufacturers' and recovers' networks and co-operation between different industrial sectors (energy-panels-suppliers) • Reducing transportation distances and creating circuits of producers and users • Growing pre-fabrication industry, houses and products with upgraded recyclability • Improving abilities to disassemble and reassemble wood products • Developing and using ecological adhesives and water-born finishes for better recyclability • Sustainable managed forests: high-end social and environmental products • Implementing low carbon strategy, shared actions to encourage circular bioeconomy • Raising awareness of consumers on products from recycled wood • Developing European harmonization for uniform application of legislation and regulation • Implementing product-specific standards (CE marking, EPDs)	• Unstable markets and low prices for side streams, excluding clean chips (for suppliers) • Unpredictable raw material and product prices • Lack of demand or benefit from the customers in the market • Lack of professionals and entrepreneurs • Problematic financing of investments • Environmental risk by using some types of adhesives, finishes and treatments • Strict regulations with multiplicity • High waste disposal taxes • Modification of standards and regarding the type of installation to be used • Lack of valorisation strategy at national level • Low knowledge and few good practices to recover materials • Lack of cohesion and agreement between the actors in forestry • High costs imposed by public policies to structure the management of by-products, but no profitability because of low value outlets • Difficult access to raw materials. The administration should facilitate industrial development instead of focusing on inspection and repression. Product-specific rules should be better controlled • Site-specific rules hinder investments • Specific requirements of different markets for products of recycling • Negative image of wood harvesting

6.2.3 Northern Europe

SWOT analysis is presented separately on by-products of wood product industries (Table 19) and construction and demolition companies and waste management centres (Table 20), because of their very different approach and value chains regarding wood-based side streams.

Circular economy and bioeconomy have a strong support from public decision makers and authorities in Finland, Sweden and Norway for forest, wood, energy and all economic sectors where side streams are present, both at governmental, regional and mostly municipal levels. Main drivers for utilization of wood side streams are climate change mitigation and carbon sequestration, the four levels of sustainability (ecological, economical, social cultural), integration of rural and urban development, and progress of citizens' society.

Carbon sink approach, green policy incentives as well as getting business value from carbon storage, climate change mitigation and voluntary emission trading are big options for the industries. Green deal agreements between private and public parties to achieve sustainable development goals seem to raise discussion, so far they have not perceived to benefit industrial forest sector. Anyway, markets and technology are developing in cascading. Adoption of new practices from other industrial sectors is often raised, and newly also from European and East-Asian economic giants.

Plentiful virgin wood materials are available, but more recycled material use is needed due to the simultaneous increase in the needs of wood raw materials for forest industries, sustainable energy to replace coal, oil and, in the future, earth gas, biomaterials to replace current plastics, textile fibres and vehicle fuels and building materials to replace those materials that load the climate and environment. Biodiversity and ecological pressure to limit the cuttings of virgin wood is present, pushing to use recycled raw materials and energy.

Large total volumes with certified wood resources are available, but there is much competition about the best materials as regards technical-economical competence. Shared wood procurement for mechanical and chemical forest industries and bioenergy and efficient supply chain are a Nordic speciality, and definite competitive advantage. This has made the integrated forest companies very resource efficient and largely contributed to their (normally) high profitability.

Nordic wood products industries represent high resource efficiency with high yields of primary products, in relation to the smaller log size, and less accumulation of by-products and especially wood wastes. By-products of mechanical wood processing are highly appreciated as raw material and bioenergy due to their uniformity and (too) competitive price-quality relationship. Well-functioning market for chips and consumption of saw dust, planer shavings and bark in the heating and processing of the mills and supplies to local heating and power plants and district heating pipeline systems has provided almost zero closed loops for the factories and brought significant incomes to the supplying companies.

However, varying profitability and lack of capital, investments and RDI activity aggravate the progress of side stream business among wood product and bioenergy industries, except corporations and large energy companies. Lack of knowledge of valorisation and pricing of alternative products is obvious, especially among SMEs and in further processing companies. Competition and costs of side streams are critical in some regions for the users. Logistics costs and scattered sources of raw materials, semi-finished products and side streams burden also the

users. Weak durability of the few material products of side streams is complained both among manufacturers and customers.

In principle, the versatile uses as energy products have provided demand and markets for side streams, but with low prices for suppliers. During 2010's, energy cogeneration through power plants started to suffer from low electricity prices and image difficulties of peat as an energy source and demand for district heat has turned down because of decreasing population in rural towns. Wood panel industry which is an important user of side streams in other regions of Europe has almost disappeared since 1970's, except the mills of IKEA/Swedwood (partial demobilization from Eastern Europe and Asia).

Recent progress has been more positive, and should provide growing markets and profitability both for wood side streams and less-demanded virgin wood: 1) Rapidly increasing production and use of wood pellets at the energy plants of bigger cities to replace fossil fuels; 2) Credible incentives and investments to the production of liquid fuels (tall oil, pyrolysis oil, biodiesel, bioethanol); 3) Renewing CHP and other cogeneration plants with new technology towards more freedom from electricity price and added-value raw materials for different chemical industries (BtoB and BtoC); 4) New demand for side streams in biorefinery industries while pulp mills are turning to industrial ecosystems where primary processing of the hosting company is added with further processing of wood-derived fibre and chemical materials toward different specialty products (like in energy cogeneration plants; 5) New demand for saw dust to specialty pulps for biodegradable, glue-free paperboards; 6) New demand for biogas and biochar products (big potential), and for health, well-being, nutritional, cosmetics and detergent products (from wood residues and/or bark).

Regional solutions of wood side stream utilization are proceeding in those parts of the countries where there are many motivated companies of different size and future-oriented product development, industry park and ecosystem thinking has started, RDI activity, knowledge and expertise are present and public authorities are positive and provide support in Triple Helix networking, R&D and investment financing and regulatory problems. Upscaling from research to commercialization still proceeds slowly, and there is a lack of demo factories, proofs-of-concept and branding, piloting infra exists but it is not in full service.

Generally, trustful company relationships and collaboration are present (+). Different supply interests and resource potential cause anyway different views to incentives among integrated forest products companies and SMEs. It should be noted that Nordic "SMEs" are on average much bigger than in Southern and Eastern Europe for example, being family owned companies of different size. Companies in wood product sector generally know well the national strategies of economy, and the command of regulations is mostly at a good level, but they are (often unnecessarily) afraid of the coming requirements. Anyway, landfill ban raises a real concern about the future costs caused by painted, chemically treated and glued wood, contaminated wastes and most of ashes. Companies perceive the regulations and standards unpredictable and laborious, and IPR and licensing complicated and expensive, similarly to other European countries. They also miss better classification, sorting and knowledge of side streams and end-of-waste criteria (suppliers, users. There is a lack of market and customer surveys, economic assessment of alternative products and proofs-of-concept. Concretely, longer life-cycle, better durability, better recyclability as well as LCAs and EPDs are targeted for side-stream based products.

Table 19 SWOT analysis on the management of by-products and wood wastes of wood product industries in Finland

Strengths	**Weaknesses**
* Circular economy and sustainability approach in the Nordic society and among decision makers * Large total volumes of side-streams, renewable raw material and bioenergy sources (certificated) * High-quality, uniform by-products for industrial and bioenergy uses (comp. other side streams, forest chips) * Shared procurement and delivery with other wood assortments, efficient comminution and bioenergy technology * High resource efficiency and almost closed loops (+) * Well-functioning value chain and market for chips (+) * Efficient integrated forest products companies * Versatile markets in energy sector * Regional solutions and public support in RDI, investments and regulatory work (Triple Helix) * Much knowledge and expertise, future-oriented product development (esp. forest industry corporations, industry parks, municipal and private energy companies) * Many companies of different size in the business (in some regions)	* Varying profitability and lack of capital, investments and RDI in wood product and bioenergy industries, except corporations and large energy companies * Lack of knowledge of valorisation and pricing of alternative products (SMEs, further processing) * Unstable markets and low prices for side streams, except chips (for suppliers), saw dust depreciation in material uses * Only two wood panel industries provide no demand for side streams * Competition and costs of side streams are critical in some regions (for users) * Unprofitability of wood-based electricity generation, esp. CHP plants * Logistics costs and scattered sources of raw materials, semi-finished products and side streams * Landfill materials (most of ashes, painted, treated and glued wood) and contaminated wastes * Weak durability of some side stream based products * Different interests and resource potential for incentives of integrated forest products companies and SMEs * Upscaling from research to commercialization proceeds slowly: lack of demo factories, proofs-of-concept and branding, piloting infra exists but not in full service, laborious and costly licensing
Opportunities	**Threats**
* Positive perspective for circular economy: aims and attitudes of society and decision makers * Carbon sink approach and green policy incentives * Getting business value from carbon storage, climate change mitigation and voluntary emission trading * Positive and predictable regulation development * Green deal agreements between private and public parties to achieve sustainable development goals (+) * Globally limited biomass resources call for cascading * New side-stream based products and users: value-added biorefining products, chemical and composite products (BtoB and BtoC), bioplastics, replacing coal and oil in energy generation with biogas, pellets and other wood-based products, renewable liquid fuels, biochar (> 60 known uses), uses for off-cut pieces of secondary products, building elem. and furniture billets, wood panels, construction insulation products (+) * 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 and end-of-waste criteria (suppliers, users) * Longer life-cycle and better durability, LCAs and EPDs for side-stream based products * Markets and technology are developing in cascading * Market and customer surveys, economic assessment of alternative products, proofs-of-concept * Increasing and disseminating knowledge of alternative side stream products, esp. for secondary wood processing * Adoption of new practices from other industrial sectors, and Europe and Eastern Asia	* Slow reactions to changing product and customer markets in company strategies and public policies: basic use of chips, saw dust, bark etc. has been solved in principle (bioenergy) * 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 * Unpredictable regulation and subsidizing policies of bioenergy and waste management (EU, Finland) * Decreasing district heating outside urban districts * Large production units and increasing transportations add to the environmental loading * 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 and carbon sink approach in strategic planning and dissemination to the different stakeholders and big audience * Eventual lack of professional workers and entrepreneurs in the supply and manufacturing stages of the value chains (in some regions)

The general political and operational environment in Northern Europe regarding wood wastes is largely similar to industrial by-products. Still, the change toward new systematic thinking in wood construction and demolition is bigger than in wood products sector. Construction of small houses, secondary homes and home yards from wood has a tradition of centuries, whereas multi-store residential houses, office and commercial buildings, schools, kindergartens, care homes and hospitals in urban areas as well as bridges and wind and snow barrier walls are something new.

There is a clear public incentive to support urban building with wood, which should, in principle, increase the amounts of wood-based construction and demolition waste. However, the prevailed concrete-steel building practice consumed much wood, being actually a pre-mature state of hybrid building, bringing out wood wastes through leftover and off-cuts from on-site cutting of sawn timber, plywood, particle and fibre boards, wooden posts and beams, packaging materials, building supports, moulding forms, etc. Accordingly, demolition waste has also contained much wood.

Perceptions of construction and demolition waste have been poor throughout the value chain, but long life cycle, high carbon sequestration and positive health and well-being effects of wood products and buildings should support also the image of their side streams. Recovery of wood-based wastes in the construction projects is close to 100%. Some construction companies have own building element factories which may use their wood wastes.

Delivery systems to both municipal and private waste centres are quite easy for construction and demolition companies, in principle, because the instructions and requirements come from the centre. Some construction companies would be ready for more detailed on-site sorting, for example gypsum board and plastics.

Waste centres are easy to access, but lack of space is a disadvantage in many centres. Organisation and operations are rather functional and straightforward organisation and operations in greenfield construction sites, but not in demolition sites. There is most often a well-working collaboration between waste management companies and their contractors.

Finnish system to collect and recycle impregnated wood through a nationwide non-profit organisation which is owned by the member companies is unique. Waste management companies participate, and can deliver their impregnated wood in this route. There is also a well-functioning recycling system for wooden packaging materials coordinated by a non-profit company.

Nordic waste management companies are generally profitable. Many of them get income from selling clean chips for forest industries, incineration materials to advanced conversion to bioenergy, and, nowadays also to biogas. They have also own biopower plants and biogas facilities for supplies to municipalities and private customers. Biogas and biochar provide huge opportunities for their business development and environmental efficiency. The best waste management companies have typically a positive total carbon footprint, wood wastes contributing to the result.

As a whole, small amounts of construction and demolition wastes that are typical for sparsely populated Nordic countries lead to non-interesting and unprofitable business potential, except in the areas of the biggest cities. There are considerable weaknesses in organisation and

economy of waste transportation, even as the costs of waste bins in block house areas. Rural location, scattered sources and high logistics costs of construction, demolition and packaging wastes aggravate further.

Recycling or utilization of wood-based construction wastes, either plastics or mixed wastes, is not any actual business for construction companies. Therefore wood wastes are not any source of income, in contrast to more valuable metal wastes. The situation is even worse in demolition, where the costs are high because of the need of special machinery, expensive transportation and unwanted material among the users (inferior quality, much sorting). There are treatment chemicals and impurities in construction, demolition and packaging wastes (incl. concrete as mix). MDF waste and glass cannot not be recycled at all.

Because energy uses are dominant in waste management business, varying profitability and fluctuating prices of energy products are the most important factor for the competitive ability of construction and demolition waste for energy or raw material. The competitiveness is not too good compared with clean wood residues from manufacturing industries.

Currently, recycling and waste management companies have insufficient knowledge of available wood wastes and their properties, and poor direct contacts to construction and wood product industries. Instead, wood wastes by company and construction or demolition site is a practice at waste centres, and available also for the construction and demolition companies.

There is a severe lack of material recycling practices and incentives, according to one source, even in self-confidence and appreciation of own capabilities. Raw materials and products are then sold with too low price. There is lack of branding and too often unclear financial responsibilities of stakeholders/partners, funding organisations and ownerships of raw materials. Low sorting quality on construction and demolition sites has been observed. All these disadvantages may hinder investment decisions.

Current public funding models are concluded not to work well enough. Decision makers of cities are concluded to be interested in the visual image of building projects, but not in circular economy. Slow upscaling from R&D to commercialization, lack of merchants selling recycled wood-based products from construction in most towns and cities

The unpredictable regulation that is bound also to governmental policies may affect the waste management business. So far the regulations have not caused problems for construction companies (like adoption of wood building codes), but they have resulted in much work for waste management / recycling companies. In fact, national waste management legislation restricts too much the business potential of public waste management companies with private sector companies. Waste disposal (landfilling) and treatment of hazardous and toxic wastes is considered expensive. Definitions for recyclability and classification of recycling materials should follow the development of construction materials, e.g., counting new hard insulation materials.

In all, opportunities for wood waste utilization in the future are smaller than those for industrial by-products, although the basics are more or less similar. Maybe smaller flexible business units could be developed to the economic system. It is very difficult to achieve 70% material recycling rate of wastes in construction and demolition. For impregnated wood and packaging materials, it is much easier to reach the targets set in waste legislation.

Political and legislative instruments can provide more resources for R&D. Improving discussion link between decision makers, authorities, R&D society and companies could make the networks permanent and well-functioning. Lowering access barriers to publicly funded laboratory, testing and piloting infra would be beneficial. Public data bases on industrial wastes would improve the knowledge of their flows, availability and utilization opportunities. Also here, education and dissemination projects for professionals and stakeholders are needed.

There are good reasons and also stakeholders' incentives to more detailed sorting. In this respect, waste management rules should order the practitioners to investigate recycling potential in each construction and demolition project and establish recycling plan prior to the start-up of the project. Accordingly, transfer in public coordination would proceed from after control to proactive guidance.

In technical context, construction companies expect similar improvements to recyclability and reusability as secondary wood processing companies. Recycling and reuse of materials and installations of house yard and environmental building should be an easy bonus. New reuses and specified companies are expected for walls, mid-floors and other larger parts of buildings. Performance and benefit-cost analysis of sorting on construction and demolition sites are recommended.

From the viewpoint of recyclers, sorting out of plastic materials would provide clean wood waste with higher value and, thus, more potential to green building approach. Construction and insulation materials from extracted or liquefied products can be an option. More applications of automation, robotics and digitalization in handling and valorisation of wastes, including detection and separation of hazardous and toxic materials can be realized. Fair competitions of waste transportation contracts, improvements of transportation economy of construction and demolition wastes and better overall organisation of logistics and is needed.

The most obvious threat for the progress of wood waste management is if the current weaknesses, either external or internal, will not be intervened. Omitting societal requirements in strategic planning and dissemination to the different stakeholders and big audience and slow reactions to the opportunities of product and customer markets in company strategies and public policies would be mistakes. Low profitability and weak appreciation of recycled products can still continue and producers may not find wood wastes as a business opportunity. Most probably, requirements on recycling rate and fees for companies are increasing in the future

Large investments to pulp mills and saw mills bringing more wood residues to the market may decrease the competitiveness of wood wastes. Large production units and increasing transportations add to the environmental loading. Too low price of district heat or electricity, or lack of alternative products threaten the business.

Few companies have resources to invest on long and uncertain R&D processes, proofs-of-concept and IPR. Therefore, not-too-challenging public and private funding is needed. Financial responsibilities and ownerships of companies, especially start-ups, should be enough clear not to hinder investment decisions. Subsidizing policies of bioenergy and waste management has much effect to the profitability and competitiveness.

Table 20 SWOT analysis on the management of construction and demolition wastes and activity of waste collection centres in Finland

Strengths	Weaknesses
* Circular economy programs and incentives * New systemic thinking: green investments have already grown and may grow further * Regional solutions and public support in RDI, investments and regulatory work (Triple Helix) * Long life cycle, high carbon sequestration and positive health and well-being effects of wood products and buildings support also the image of their side streams * Advanced conversion and supply of wood wastes in bioenergy (versatile options) * Recovery of wood-based wastes in the construction projects is close to 100% * Quite easy waste delivery systems for construction and demolition companies, in principle * Rather functional and straightforward organisation and operations in greenfield construction sites, but not in demolition sites * Some construction companies have own building element factories which may use their wood wastes * Waste centres are easy to access (municipal, private) * Revenue from clean chips and biogas make waste management companies profitable (most companies) * Favourable carbon footprint in wood waste management * Biogas provides already now a huge business potential and environmental efficiency * Well-working collaboration between waste management companies and their contractors * Unique recycling system of impregnated wood * Well-functioning recycling system for packaging material	* Changes in legislation cannot be predicted, they depend even on government policies; so far they have not caused problems for construction companies (≠wood building codes) but much work for waste management / recycling companies * Lack of material recycling practices and incentives * Lack of self-confidence and appreciation of own capabilities, raw materials and products: selling with too low prices, lack of branding * Unclear financial responsibilities of stakeholders/partners, funding organisations and ownerships of raw materials hinder investment decisions * Challenging funding options to companies: current public funding models do not work well enough * Slow upscaling from R&D to commercialization: lack of demo factories, proofs-of-concept, piloting infrastructure does exist but not in full service * Decision makers of cities are interested in the visual image of building projects, but not in circular economy. * It is very difficult to achieve 70% material recycling rate of wastes in construction * Much wastes from cutting window and door spaces from wood panels on the construction sites * Rural location, scattered sources and high logistics costs of construction, demolition and packaging wastes * Recycling or utilization of wood-based construction wastes, either plastics or mixed wastes, is not any actual business for construction companies; wood wastes are not a source of income, in contrast to more valuable metal wastes * High demolition costs of buildings * Varying profitability and fluctuating prices of energy products: competitive ability of construction and demolition waste for energy or raw material is not too good compared with clean wood residues from manufacturing industries * Lack of merchants selling recycled wood-based products from construction in most towns and cities * Costly landfilling of hazardous/toxic wastes * Low sorting quality on construction and demolition sites * Too small storage sites for construction wastes (view of some companies) and too few waste types to be sorted, for example gypsum board and plastics can be missing * National waste management legislation restricts too much business potential of public waste management companies with private sector companies * Considerable weaknesses in organisation and economy of waste transportation, also for waste bins in block house areas * Inferior quality and appreciation for recycled products * Treatment chemicals and impurities in construction demolition and packaging wastes (incl. concrete as mix) * MDF and glass cannot not be recycled * Recycling and waste management companies have insufficient knowledge of available wood wastes and their properties and poor direct contacts (waste management and recycling vs. construction and wood product industries

Opportunities	Threats
* Limited biomass resources call for more cascading * Markets and technology aof cascading develop * Legislation and regulations will inevitably push industries more and more to circular economy and cascading: opportunities for wood-based wastes, incentive to more detailed sorting * Green deal agreements between private and public parties toward sustainable development goals * Political and legislative instruments can provide more resources for R&D; side stream processing could also support regional employment * More ambitious business earning logic, self-respect in the pricing of own products and high-level branding can be created * Smaller flexible business units can be developed to the economic system * Improving discussion link between decision makers, authorities, R&D society and companies to make the networks permanent and well-functioning * Compiling public data bases on industrial wastes (availability and flows, utilization opportunities) * Utilization and further development of statistics on wood wastes that are obtainable by company and construction site from the waste stations * Lowering access barriers to publicly funded laboratory, testing and piloting infra * Education and dissemination projects for professionals and stakeholders among value chains * Waste management rules to increase sorting and maybe value-add: investigate recycling potential to in each construction and demolition project * Getting business value from carbon storage, climate change mitigation, LCA and EPDs * Transfer in public coordination from after control to proactive guidance and planning could proceed: recycling plans of construction materials before building projects are started * Pre-fabrication of wood components and elements to reduce cutting waste on construction sites and improve recyclability (EWPs, CLT, LVL) * New uses to different cut-off pieces of wood * Improvement of recyclability of construction products during manufacturing stage (dismantling and reassembling, mixed composition, impurities) * New reuses and specified companies for walls, mid-floors and other larger parts of buildings * Recycling of plastic materials should provide clean wood waste with higher value and more potential to green building approach * Better classification, sorting and knowledge of side streams and end-of-waste criteria (suppliers, users) * Definitions for recyclability and classification of recycling materials to follow the development of construction materials, e.g., insulation materials * Recycling and reuse of materials and installations of house yard and environmental building * Better organising of logistics and improvements of transportation economy of construction waste (for example, on-site compressing or crushing) * Performance and benefit-cost analysis of sorting on construction and demolition sites, and improvements of sorting methods and systems * Optimized integration in wood waste utilization: industry	* Current weaknesses of wood waste utilization will not be intervened (external. Internal) * Omitting societal requirements, renewable raw material branding and carbon sink approach in strategic planning and dissemination to the different stakeholders and big audience * Slow reactions to the opportunities of product and customer markets in company strategies and public policies * Producers do not find side streams as an business opportunity * Large production units and increasing transportations add to the environmental loading * Large investments to pulp mills and saw mills may decrease even more the competitiveness of wood wastes * Few companies have resources to invest on long and uncertain R&D processes, proofs-of-concept and IPR * Public and private funding options to companies remain too challenging * Financial responsibilities of stakeholders/partners, funding organisations and ownerships of raw materials remain too weak and hinder investment decisions * Unpredictable regulation and subsidizing policies of bioenergy and waste management (EU, Finland) * Continuing low profitability and weak appreciation of recycled products * Requirements on recycling rate and fees for companies are increasing in the future * Lack of trust and collaboration between companies to build industrial ecosystems * Strict IPR and service price policies of universities and research institutions put hindrances for company developers * Eventual lack of professional workers and entrepreneurs in the supply and manufacturing stages of the value chains (in some regions) * Decreasing district heating outside urban districts * Too low price of electricity or lack of alternative products to upgrade CHP plants

park approach, industrial ecosystems of large companies and SMEs * Huge expansion potential of biogas and biochar * Upgrading CHP plants (aiming to new products) * New product areas: construction and insulation materials, extracted or liquefied products * Applications of automation, robotics and digitalization in handling and valorisation of wastes, including detection and separation of hazardous and toxic materials	

6.2.4 Eastern Europe

The basic prerequisites for side stream utilization seem to be positive in Eastern Europe if we take into consideration, in general terms, the purely technological aspect. In fact, the procedures are generally concluded efficient with respect to the recycling of materials and production processes, partly thanks to a good level of basic knowledge. In this sense, some interviewees declare that they have already adopted new processing technologies. In general, the role of the forestry sector, also considering the characteristics of the region with different levels of resources, is considered central. In some specific cases there are public and foreign incentives and investments to encourage the implementation of good practices (Table 21).

However, unitary and structured industrial strategies are not perceived. This critical issue can be attributable to different factors, such as the lack of awareness of SMEs on the potential of a transition to a circular economy as well as to a purely financial issue: there are in fact high costs for companies to comply with the legislation and wood products do not seem to be so accessible on the market. This is also aggravated by a fragmentation in small local authorities/entities which consequently determine a great variety of skills, funds and policies. Furthermore, with specific reference to the recycling of wood waste and the enhancement of side streams, there is a lack of technological development, thanks to public investments, which could be focused on the issue of circularity.

Despite these difficulties, there are several opportunities that seem to converge in the same direction even if pointed out by subjects coming from different areas and countries. The best solution, in fact, seems to be the creation of a network between the actors of value chain, in order to encourage the exchange of knowledge and collaboration, also with the aim to intercept funding of European origin and to encourage and stimulate local governments to introduce further financing measures for actions aimed at greater circularity of wood management processes.

In parallel, well defined regulation is required to define quality criteria for wood waste and side streams, perhaps taking inspiration from good practices found in selected countries. All this shall be the necessary remedy that should lead to a structured and coordinated public-private strategy, involving for instance public bodies, associations, universities, companies, technological and research centres, aimed at the definition of simplified and harmonized regulations, the establishment of dedicated public funding with consequent increase in the perception of companies and consumers about the potential of the circular economy, which would generate a virtuous circle based on new and continuous investments. It is important to point out that in some regions, the smart specialization strategy is already aligned with topics related to circularity. These areas should represent the reference for the above described transition.

Table 21 SWOT analysis on the management of wood-based side streams in Eastern Europe

Strengths	Weaknesses
• Implementation of efficient procedures in the production process (i.e. .slim production) • Implementation of material efficiency procedures (i.e. most efficient finish coating consumption) • Use of new processing technologies (in some regions) • Central role of forest sector • Good incentives by public bodies (in some regions) • Diversity of forest resource types and manufacturing strengths across regions • Lower labour costs • Foreign Direct Investment in forest value chain present and increasing • Smart specialisation alignment on topics related to circularity already exist in the region	• Lack of technological development in recycling waste wood and valorisation of side streams • Lack of awareness of companies (especially SMEs) and stakeholders about circular bio economy • Lack of strategies for forest and wood-based industries • High price of wooden products • High costs to comply with regulations • Few industry actors willing to invest – waiting for government support • Forest value chain split internationally; primary processing mostly done outside the country limiting recoverable side streams • Export of wood waste for energy production limits local value • Industrial interest in meeting consumer demand not centred on environmental/circular goals • Historically risk adverse sector
Opportunities	**Threats**
• Raise awareness of the end consumer • Active participation of EU in supporting the transition to circular economy • Improvement of the collaboration in knowledge and value chain • Improvement of the visibility of forest sector • Supporting networking and partnering would be important • Improvement of the classification and standardization system for wood residues • Quality and environment certification • Promotion of wood use by public sector • Implementation of tools like labelling of machines • Encourage incentives for the promotion of the transition to circular economy (refund systems, ecotax systems) • Related sectors could offer potential models to achieve higher levels of circularity (e.g., paper) • Forest increment greater than harvest – resource availability is increasing	• Lack of data and information about side streams, waste wood and recycle wood • Lack of harmonized regulations to define the side streams, post-consumer or pre-consumed wood products • Regulation not actually practiced and followed • Lack of coordination policies within regional, national and European markets. • Perception of the consumers about potentiality of the products • Lack of demand of circular products • Overall perception of policy as a complex topic • Lack of awareness on circular economy strategies • Lack of awareness on environmental impact and sustainability • Corruption or government instability

7 Good practices and conclusions

7.1 Proposed practices

As it was already mentioned, one main scope of WoodCircus project is the individuation of best practices from different regions, so as to encourage a future diffusion where they are not yet implemented in Europe. This information is based on the activities previously illustrated, the interviews with stakeholders and the consequent identification of the aspects deemed most positive and highly significant in the furniture sector, especially in a perspective of replication.

The analysis of the various cases also highlight the necessities and needs of the entities involved, pointing out shortcomings and weaknesses in various areas, also considering the amount of interviews carried out: technology, organization, know-how, innovation, policies, availability of resources are only some of the aspects for which improvements and progress are required. In this context, an element of interest emerges: among the good practices selected, there are numerous and diversified projects, processes, actions, initiatives, etc., whose dissemination and / or replication in other areas would be a solution or at least a significant support in relation to the critical issues claimed.

With the aim of an easy consultation in the future, the best practices individuated in the four zones in the focus (northern, eastern, central and southern Europe) are grouped by reference area of application: products and materials, processes and technology, management and innovation, considering the relevance and the significant amount of wood generated and utilized. A specific focus is also dedicated to constructions and demolition.

Products and materials

1. Particle board and other wood panel industries have affordable raw material and high-level technology available, and they are commonly used in the factories. Especially in southern Europe, the organization of the whole value chain guarantees the disposal in landfill of a very low amount of wood waste and at the same time high-quality particleboards, made with almost 100% of recycled wood and suitable for the furniture and construction sector. The process can be considered as 100% circular, with the concrete possibility of successive replication, at the same time avoiding or minimizing the need to use virgin wood, especially in countries where the supply could be difficult for availability of resource and costs. This particularly efficient system is found also in central Europe (Belgium), where panels are manufactured not only with post-consumer wood but also using internal side-streams, unlike other cases where these latter are incinerated for energy generation internally exploited for the manufacturing processes or premises heating. Take-back system of particle board wastes from furniture mills in France aims to the same targets.

2. In Finland, special pulps are manufactured from sawdust for packaging and tissue materials. Especially, biodegradable, non-plastic food packaging and catering products are good demonstration of sustainable and environmental friendly processes. Sawdust is also suitable and largely used for pellets (replacing coat and heating oil), animal bedding, geo-construction and landscaping. It is also used for composite decking boards, as successfully demonstrated in France.

3. Wood can also be combined with other materials to obtain composites. Wood-plastics composites (WPC) are manufactured for different end-uses for BtoB and BtoC sectors. In a case

in northern Europe (Finland), wastes from the manufacturing process of thermally modified wood (Thermowood®) are mixed with a type of plastics and binders to obtain high-quality material with good dimension and form stability, resistance of water and vapours and cost efficiency for kitchen cabinets, inner parts of vehicles, etc. An excellent case is represented by a company in central Europe (Germany) producing normal and coloured pencils and painting brushes, today made with wood-composite materials, including recycled domestic fibres instead of tropical virgin wood.

4. There also other kinds of combined materials applications. In northern Europe, binders for groundworks in infrastructure building applications have been made from side streams of forest industries and fly ashes to replace cement, for example in clay soils to prevent loss of humus.

5. Pallets for transportation and storage of goods, especially if duly reused and / or reprocessed, represent a good practice in a large scale, since positive cases are individuated both in northern and southern Europe. Their reuse, repairing and recycling are also organised efficiently in most European countries.

6. A new trend emerged both in southern and eastern Europe, is related at first to a new furniture design concept: thanks to new solutions facilitating assembling and disassembling of elements, some companies are trying to extend the life cycle of products. In this way, it will be possible to easily separate modular components with the aim of reuse, recovery or recycling, as well as to reassemble these latter to create a new piece of furniture: then, a chair can be transformed into a bedside table, a desk in a bookcase, etc., according to the various needs of the different end users. The concept has been introduced to manufacturing windows, doors, outside furniture and some other products of furnishing and construction.

7. In the field of materials, a certain dynamics is found in central and northern Europe where side streams are the starting point for realizing functional fibres or chemical extracts up to bio-composites or bio-refinery products. In some specific cases, wood fibres are used as extract cellulose mainly as a filter aid for the food industry. Other appreciable uses of fibres are in animal feeding, fillers and medical applications. Concerning bio-composites, it is also possible to use compounds made with pine wood for antibacterial application and specifically for medical storage boxes but even for toys, pharmacy and cosmetics areas. One plywood factory is a partner in a consortium to valorise their side streams through chemical extraction (patent confirmed).

8. Furthermore, it is possible to confirm that lignocellulosic raw materials are largely available in Germany, Europe and globally, with specific regard to unused potential lignocellulosic residues from forestry and wood working. There is experience available for decomposition processes for lignocellulose, and for chemical and biotechnological conversion of carbohydrates, lignin and extractives First pilot and demonstration plants for lignocellulosic biorefineries are in operation or under construction in Germany.

9. Still today, many wood products companies of France, Spain and Italy consider incineration of wood residues, bark and construction and packaging wastes for internal and local heat generation as a good, sometimes the only available practice. Waste management centres in Finland and Sweden have been thinking like that as well, but with more advanced and stratified strategy on customer and product palette.

Processes and technologies

1. Most advanced processes for wood treatment are found in central and northern Europe. One positive example is the extrusion of wood-plastic composites: since the take back system is mandatory for the producers, there is a company (Germany) managing products like megawood terrace planks for shredding and the subsequent realization of new planks.

2. Another interesting process, even not yet implemented, is experimented in Belgium, where wood residues will be converted into high value activated carbons: in detail, MDF waste but also other side streams, will be subjected to pyrolysis process so to have carbons to help cleaning water, air and soil.

3. CHP plants and cogeneration of heat and electricity have been a success story since 1990's in northern and central Europe. In many cases, they have been crucial for the local use of low-value by-products from mechanical wood processing and less-demanded virgin wood from forests. Many of them are now approaching their commercial and technical end of life, and require modification or total upgrading to follow the available and profitable product portfolio and customer base.

4. Bio-gasification has a huge potential, and it is produced already now in northern and central Europe applying putrefaction technology for organic wastes and by-products, wood residues and bark included, and pumping methane from old disposal sites of waste management centres. Biogas is sold for cogeneration of heat and electricity, district heating of industrial sites, process heat for industries and material treatment companies and vehicle fuels for ground transportation and working vehicles, in the near future, also for vessels. Material use is under planning for a multitude of products, first forest fertilizers. Utilization of old landfill wastes can be extended with new technology to increase the recovery of methane.

5. Biochar production from organic raw materials through pyrolysis process is at starting stage in northern Europe. Wood wastes and saw mill residues can be easily used in this process, and technology is reliable and free from emissions. More than 60 applications as raw materials, energy or treatment media have been detected. First commercial uses are as briquettes, growth media and nutrient component in nurseries and greenhouses, soil conditioning agent and management of storm waters in cities, for example in Stockholm.

6. Sorting processes such as robotic waste sorting and recycling technologies are available in different European areas for a diversity of waste types, including wood-based scraps coming from commercial and industrial activities, municipalities, construction and demolition, packaging, etc. Some techniques apply advanced non-destructive detection methods (mechanical, optical) and implementation of the most modern automatization and digitalization. Robotisation and teleoperation on wood waste sorting is a way to modernize and improve social dimension of wood waste recycling.

7. Specifically, in southern Europe it is common to deal with facilities and platforms efficiently implementing essential mechanical treatment to reduce volume and increase solid content of different types of wastes.

8. There is global excellence in different countries in the design, production and marketing of machinery to increase the quality of wood processing through yield optimization, minimization

of off-cuts and zero generation of residues in panel and furniture production, for big but also for small processing entities.

9. Globally leading manufacturers of machinery and automation technology for the processes among biorefinery, bioenergy and wood product industries are born, owned and located in northern and central Europe. They offer special technology with high resource efficiency for providing side stream raw materials and their large-scale utilization among processing industries: wood panel production, pulping and advanced biorefining, sawing, rotary cutting, engineered wood production and other woodworking, combustion and cogeneration for bioenergy, production of biogas, biochar and liquid fuels.

Management and efficiency

1. Both in northern, central and southern Europe, the side stream and waste management value chains are rather efficient and well-functioning, even if structured in different ways. High utilisation rate of virgin raw materials and close-to-zero generation of wood-based wastes are typical for Finnish, Swedish, German and Austrian saw mills and plywood mills, along with minimum side stream accumulation and almost closed raw material and energy loops. Moreover, forest industry corporations have a good overall management of raw materials, side streams and all kinds of wastes. In Finland and Sweden, there are steady markets for fresh chips to pulp, paper and paperboard mills and clean chips from different wood wastes for uses as bioenergy. Instead, saw dust, bark and other side streams often face marketing problems (demand, price, logistic costs).

2. Collaboration among stakeholders of value chains is often at a good level. In Finland, for example, Triple Helix collaboration between public and private entities and academic and research society is performed jointly in RTDI activities and policy and regulation implementation. Also in Italy and Spain, the collaboration between public and private stakeholders is efficient, thanks also to the active role of associations and dedicated consortia; moreover, policies and regulations are well understood and companies benefit from stability in this field.

3. Some wood industry parks are organised as actively and decisively created business environments where the expert organization provides training and product development services for the present companies with the support from the city and region. In one example from Finland, being part of the business cluster and the brand has been recognized as an advantage to the companies, if they can and want to take advantage of it.

4. New industrial ecosystems of bio-refining among forest industries offer secondary raw materials and location in a factory area for smaller entrepreneurs in side stream utilization. There are examples in northern Europe where pulp production is surrounded with refiners of high value added chemicals for medical and nutritional products and pellet or biochar plants integrated with mechanical wood processing.

5. In integrated mechanical wood processing plants the wide range of primary production, such as sawn goods, plywood, chipboard, pre-fabricated houses and/or construction elements, offers more options for the use of side streams. In one example in Finland, heat, steam and power, pellets and raw materials are supplied from sawmill and plywood mill to particle board mill, landscaping and greenhouse and garden products.

6. One interesting solution is the experimentation carried out in Slovenia, implying the utilization of a specific app for consumers to upload the location of unneeded/recovered wood, which foresees reverse logistics optimisations to reduce environmental burden/complication of recovering wood. The app includes also screening for species, quality indications, and each user has the chance to upload photos from and to the website system.

7. Regarding voluntary regulation, exemplary practices exist about adopting LCA protocols (life cycle assessment) and FDES (environmental and health declaration sheet), especially among furniture and flooring industries (France). Carbon impacts of transportation have been recorded here, as well, partly to promote indirectly the local economy and employment policy. Certification of origin is available also for industrial by-products, in primary industries along with roundwood (FSC, PEFC).

Innovation

Innovation is probably the most important need for the whole sector. In this regard, it appeared in the analysis that certain dynamics prevail in the different areas of side stream utilization, and several initiatives, projects and funding are implemented. In southern, northern and central regions of Europe, national and/or regional collaboration between industries and their associations and federations, research and development organisations and public decision-making and financing bodies works, better in some districts than the other ones, and incentives for development may come from any of the stakeholder groups. In eastern Europe the system largely relies on institutions (universities and research organisations) with the competence of carrying on research and development activities. In all regions, governmental RDI funding is available to address the topics of side stream utilization, since the smart specialisation strategy is now aligned with circular economy initiatives.

Interesting and innovative projects are developed in many parts of Europe, and increasing interest is present in most of the regions. One project has the objective to combine fresh wood, natural resins and energy from renewable sources to produce hardboard that stands for responsibility and healthy living. The lignin from fresh wood is acting as natural binder making the boards non-toxic and recyclable or reusable.

Research and development actions are also realized for the creation of insulating materials from renewable raw materials for residential and building construction as well as for urban interventions. For this purpose, small amounts of PUR resin, paraffin and mineral-based inorganic fire protection agents are added to wood chips from untreated fir and spruce wood from the Black Forest.

Another interesting outcome from this project is that, by flaming under defined conditions, the wood carbonizes in its upper layer and changes its properties. By further development and variation of the processing methods, different forms of carbonized wood become possible; the combination of carbonization, structuring and glaze creates an independent appearance, in which the natural wood structure is the focus. In this way, the refinement method completely eliminates the need for treatment with chemical wood preservatives.

Both in central and northern Europe, many others project are aimed at the substitution of traditional fuel with alternative solutions (biomass fuel, bioethanol, bio-oils).

All these initiatives shall be supported by targeted policies and public funding. In this regard, for example in Italy, France and Finland, many initiatives at national and regional levels are created with the scope to promote the transition to circular economy. In Italy, the most relevant result is that, in those regions where the wood-furniture district has a significant relevance under the occupational and economic point of view, the public body directly addresses these opportunities to the companies of this sector.

Construction and demolition

As it was previously mentioned, a specific focus is dedicated to construction and demolition, because of their new role in circular economy and strong relevance in terms of materials used and waste generated. In this context, companies in France are particularly dynamic for the environmental issue: some of them are known to recycle or recover almost everything or for sorting the different types of production wastes in a well-organised way. Those companies with own wooden element manufacturing make also briquettes or use internally or sell wood residues and clean construction wastes for sustainable bioenergy.

In parallel, in the northern area, pre-fabrication of wooden elements for building is now proceeding. This reduces construction wastes to minimum, shortens construction time, improves the quality of building, helps to keep cleaner the construction site and built environment and improves the abilities to recycle, disassemble, reassemble and change the location or use of the building.

In Finland and Sweden, mainly municipal and partly private recycling companies take care of construction and demolition waste logistics, handling and re-processing. On the other hand, construction and demolition companies are responsible of on-site sorting according to the instructions and criteria only. Organizations and operations are rather functional in greenfield construction sites, but with a bigger potential to upgrade sorting and enable more options for economic waste utilization.

Innovation activities are carried out for this specific sector. In Germany there has been development of sawdust as well as milled wood fibres for insulation materials, and there is a construction company producing entire walls, ceilings and roof elements with functional fibres. This allows the realization of 100% eco houses with high energy efficiency. Production of a two reference products was started in Finland more than 10 years ago to manufacture insulation materials either from softwood kraft pulp or recycled paper, added with binder. One waste management company is currently a partner in a project to develop building materials from local industrial side-streams, cinders of metal industries and mineral wool waste through polymeric treatment, both insulating materials and ground plates).

Finnish system for recycling impregnated wood is internationally unique and makes the recycling easy for industries and consumers. Here, impregnated wood is returned to be recycled to the same place where new impregnated wood is for sale. Waste management centres are able to receive and forward the recyclable impregnated wood, then the product is very homogenous for further uses. Non-recyclable wood is sent for incineration to the commercial centre of hazardous materials. There is a clear indication that the additional cost of the voluntary system provides a collective way of organizing industry responsibility.

7.2 Development needs and recommendations

Strengths and opportunities mapped in WoodCircus project indicate a multitude of needs for research, development and innovation actions to support the adoption of circular economy and sustainable management and utilization of side streams and wood wastes among the stakeholders. While there is a general positive approach, **weaknesses and threats** limiting the potential are acknowledged as well.

Although circular economy is prevalent in practically all Europe, differences between EU-28 member states are present in the status and performance of wood cascading and recycling, structures and functionalities of supply and value chains, readiness of technology, availability and cost-benefit potential of raw materials and end-uses, current and prospective market demand as well legal, policy and socioeconomic frameworks. Regions and countries have different opportunities and specialities, pros and cons, which should be appreciated when setting policy actions and development priorities.

The most important targets toward circular economy in the value chain of wood construction should cover:

- Implementation and promotion of carbon neutrality and compensation of emissions through carbon sequestration in the value chain of building with wood
- Promotion of holistic sustainability and further development of green building chains: economic, ecological, social, cultural
- Integration of health and well-being with life-cycle sustainability toward resilient living and working environments (buildings & infra)
- Further improvements in resource and energy efficiency in material processing (virgin wood & cascading materials)
- Providing advanced waste management and circular economy solutions for built urban environment and infrastructure
- Providing new business concepts and platforms related to side stream and waste utilization, and more start-up projects
- Helping progress toward fully closed loops of materials, waters and gases – maximizing recycling (materials and energy), minimizing waste disposal (EU Landfill Directive 2018/850 -> national codes) and hazardous/toxic wastes (EU Waste Framework Directives 2018/851, 2008/98/EC)
- Helping progress toward more advanced demolition waste management and material recycling of wood-based products
- Promoting overall system performance assessment and good practices identification and implementation for cross-border transfer and Triple Helix collaboration that provide benefits for the society and different stakeholder groups, including business sector and citizens

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, the longer value chains and the more companies or other stakeholders present, 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, logistics issues (transportation, storage), breakdown of value chain operations between the companies and needs of collaboration and responsibilities of the actors. 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 several types of industrial ecosystems and value chains that are suitable for the management and utilization of by-products of wood product industries and wood-based wastes of construction and demolition. Examples of them are 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. Among the sector of this project, the value chains are also relevant to the three scenarios of side-stream utilization by Kunttu et al (2019): (I) Wood pulp, particle boards and/or 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.

Wood product industries manufacturing solid wood products find their role as suppliers of by-products for raw materials and bioenergy to other industries. While the companies are mainly small or medium-sized, located apart and scattered and have small resources to generate new initiatives for circular economy and cascading, they are apt to shift the responsibility of development in side stream issues to other participants of the value chain, public development bodies and research institutions. Resource efficiency of the main products is in the core of their strategy, but more value and markets are sought for by-products (now max. 20% of income). That is why they need customer and market surveys on side streams. Closed loops and zero wastes are already rather close, except chemically treated wood, non-wood ashes and inorganic waste materials where they need solutions.

Product development and testing service toward novel uses with positive market outlook and competitive ability are wanted for side streams of secondary wood processing, in particular (e.g, CLT, glued, painted and surface treated wood, scrap pieces of different dimensions). Among them, finding methods and technologies to improve recyclability and repairability of the products toward longer product life are needed. Feedback from disassembling and recycling companies is important to feed ecodesign practices. Finding technological innovations to minimize the amount of by-products is one priority.

Economic assessment of alternative products and proofs-of-concept is crucial, but options of bioenergy should be kept available, because it is important in many regions in Europe, albeit the

great variation between countries and even provinces. Finding solutions to the current problems of logistics, small volumes, dimensioning and upscaling of production and total economy is important. Synergy in collection, processing and utilization of side streams of further processing and construction and demolition waste has been proposed (and targeted).

Wood panel and furniture industries are actually users, not really suppliers of recycle materials, therefore, their R&D needs are different than those of solid wood industries. In some countries with few or no wood panel industries, the economic viability should be explored because of their potential role as markets for by-products, less-used virgin wood and recycled wood. More knowledge is needed on the impacts of additives to recyclability and energy recovery, and on the impacts of recycle products to indoor air emissions, as well as on the qualification of recovered wood from furniture demolition waste to allow uses as material. Classification of wood wastes integrating specifications of the main user and options for the management of risks from chemicals into recycled products, like traceability of chemicals into products through their life cycle are needed. Advanced sorting technology for particle board waste should be implemented more, this is available, for example, in Italy, Belgium and Finland. Technology and recommendations are needed for improving the control of dust and explosion risk when storing and handling wood waste. Adaptation of energy recovery regulations to make it easier and economically viable to burn low contamination waste wood is an option as well.

Wood construction and demolition industries have roles to serve as suppliers of wood wastes and other wastes to their responsible managers, recyclers and users. Activities of all actors are more or less controlled by legislation and regulations. Recycling companies and their contractors take care of waste logistics, handling and re-processing. Construction and demolition companies are mainly responsible of on-site sorting only, albeit some companies can use the wood waste that is suitable for incineration in their own element factories. They should be motivated more by regulation and economic incentives to an active role towards more detailed and better quality of on-site sorting. There are incentives that waste management and recyclability should be set mandatory to pre-planning of construction and demolition sites.

While the transportation costs of construction waste and especially demolition waste are high and the storage sites are often limited, waste management should probably go to even more centralized solutions and load efficiency. This is a particular challenge in countries with small and sparse population where small and scattered amounts of construction and demolition wastes are available.

Clarifying classification of recycle materials is needed to sharpen sorting of wood-based and other construction wastes. This means adding regulatory requirements and investigating the best protocols to upgrade sorting of wood wastes for more wanted products and environmentally friendly fractions. Pre-fabricated wooden elements are becoming more usual at construction sites, and are beneficial for minimizing the volume of construction and later demolition wastes and improving the recyclability of the material. Developing options of problematic materials in buildings should be supported, MDF and glass materials as the most crucial now.

Waste management centres and platforms perceive construction and demolition wastes as only one and not a very wanted source in the variety of recycle materials. Operative and product certificates and LCA are crucial issues for them. All development actions that contribute to the

delivery of clean wood wastes, maximum utilization of wastes as energy or materials and minimum disposal of landfills and hazardous and toxic wastes are important for them. Improving management and reducing costs of transportations and upgrading detection and separation of hazardous and toxic materials are also big issues. This together with storage space issue has an influence on the ambition for more detailed sorting. The dilemma between centralized and decentralized solutions of waste management should be studied analytically. Ergonomy, traceability and quantification of recollection of wood wastes should be developed as well. Advanced sorting technology could be implemented throughout Europe, suppliers being available in Italy, Belgium and Finland, at least.

Creation and promotion of new business and valorisation of products should be targeted in the physical and economic environment of waste management platforms and centres. More development is needed for the management of demolition waste and separation of more valuable molecular materials, fluids and gases from all wood based side streams. Start-up projects on the business in composting, decomposting and chemical re-processing and modification are wanted. Finding and/or developing economically optimal technology for recovered wood that is not suitable for recycling should be considered.

Consistent, predictable public regulation and support policies are must for all wood side stream business - this should be guaranteed with harmonization of regulation and raw material and product standards in Europe. LCA and EPDs are needed and they should support consistence with regulations and protect from unexpected disturbance in customer markets. Quantification of environmental benefits of the actions to improve circularity properties of any product is beneficial. Development work and consultation is needed to find ways for proactive reactivity to landfill bans. Education of professionals and administrators is needed at all levels to improve knowledge of the options of recycling and cascading.

In the societal thinking, change from carbon footprint to carbon handprint is needed to acknowledge the big role of side stream value chains of wood construction, including wood product industries and waste managers and recyclers. This would mean full consideration of carbon stored in wood products and constructions during their life cycle when accounting carbon balance. Extending public low carbon strategies into practical valuing of carbon storage of products, higher taxes for products that travel over long distances and/or short supply chains could be favoured. Also, the stakeholders should know more about social acceptability and economic sustainability of the products made from industrial by-products and recycled materials, and about opportunities of voluntary emission trading and green deal agreements. Development and communication of social value assessment and analytical tools for establishing environmental, social and economic balances of by-product and recycling options are needed.

To develop and support the utilization of wood-based side streams as a part of local economy, especially in rural areas, steady collaboration between Triple Helix actors should be supported. Local wood supply, use of local species and competitive offers to substitute long distance imports might be some options to raise the business. Cost incentive systems should be studied for the development of recycling, for example, criteria for ecodesign, subsidies for waste recovery equipment, etc. In the context of cascading, material uses should be prioritized before energy uses, but with careful approach.

7.3 Potential for novel applications, cross-border transfer and policy recommendations

We compared the good practices that we found in our review with those prioritized in the guidance of European Commission (2018a) (Table 22). Some similarities can be observed, but our approach which did not consider virgin wood provided more comprehensive analysis of wood-based side streams.

Table 22 Selected good practice examples of the cascading use of woody biomass, according to Guidance on cascading use of biomass proposed by European Commission

Wood as wood

Sawmilling industries:

Wood-based panel industries

1.1 Sawmills and industrial preparation of wood, including packaging
- World's fastest sawmill
- Non-toxic treatment of wood and woody biomass products
- Pallets on the move — bridging value chains and grasping new opportunities

1.2 Panels, boards and woody composites
- New innovations boost panel industries — environmental friendliness is key

1.3 Wooden construction
- Buildings from wood
- ReWin — Wooden windows and doors made from old discarded wood

1.4 Harnessing wood residues
- Biochar — high-value, climate-friendly soil improvement material made out of woody biomass

1.5 Utilising bark residues
- Wood bark extracts for glues and pharmaceuticals

1.6 Woody bio-fuels
- New stove technologies — better energy efficiency and lower emissions
- Utilisation of wood ash in forestry

Wood for chemicals

3.1 From hemicellulose to chemicals and bio-fuels
- Hemicellulose-based chemicals and bio-fuels — high added value from waste
- Ethanol for bio-fuels

3.2 Tall oil for chemicals and bio-fuels
- Crude tall oil - going for high added value or pure profits?
- Crude Tall Oil — the feedstock for high added-value and sustainable bio-based chemicals

3.3 From lignin to chemicals and bio-based products
- Lignin — Eldorado of the near future?
- Sulphite processing — the ligno-sulphonate path to multi-product manufacturing
- Kraft pulping — Cracking the lignin-based platform for chemicals
- Cost-effective, lignin-based carbon fibres — ultra-strong and ultra-light

3.4 Bio-oil production
- Fast pyrolysis bio-oil production in commercial scale

3.5 Bio-based plastics and composites
- Degradable PLA reinforced with glass fibre — compostable to harmless minerals

Technological advances

4.1 Big data — services for all in the value chain
- Supplying wood for processing and end-products with the most value
- A big data system for the forest-based sector
- Electronic roundwood market platforms

4.2 Advanced processing technologies
- Advances in processing technologies — like a rolling stone …

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