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Industrial Symbiosis potential for wood waste
in the Centro region
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Technical report by the Urban Metabolism group
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Gothenburg, December 2019

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1 Introduction

The implementation of industrial symbiosis is a possible way to develop circular economy in regions. This concept is based on the idea that industries can share their wastes as inputs to be used in other industrial processes (Chertow, 2000). Industrial symbiosis can include material, water and energy exchanges or services and infrastructures sharing. This process of resource optimization through circulation reduces the need for the extraction of natural resources, and therefore mitigates environmental impacts.

One of the most important factors for industrial symbiosis partnerships to occur is that companies are located close to each other. Therefore, applying this concept in the Regional context, will increase the possibilities of finding partnerships because regions have a higher amount and diversity of companies and there is a higher probability for companies to be closely located.

The exchange of by-products is a common practice within the forestry industries where materials or energy are shifted between adjacent facilities or companies (Wolf, 2007). Examples of exchange materials include woodchips and sawdust to be used to produce plywood, fuels, or to be used as soil fertilizer. A real-life example can be found in Mönsterås, Sweden, in a collaboration between a sawmill, a pulp mill, a pellets production facility and the Municipality. The cooperation involves exchanges of steam, electricity, bark, sawdust and wood chip. Additionally, district heating is provided to the municipality (see Figure 1). This is a good example of a collaboration with multiple benefits for the different actors, as well as the region. The benefits are not just limited to the reduction of generated wastes, but also the increase of side markets, jobs creation and increased collaboration between actors.

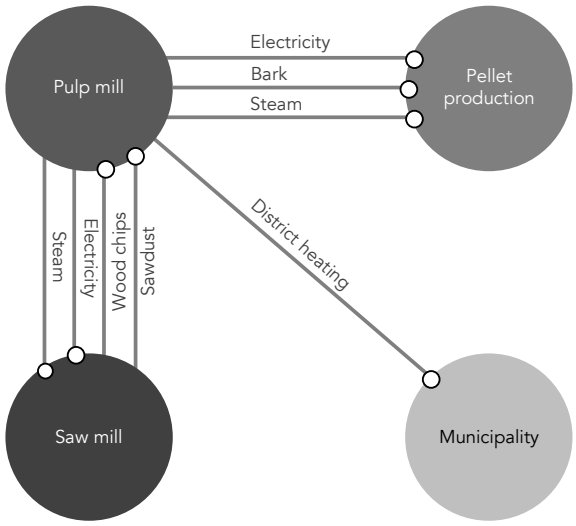

Figure 1 – Industrial symbiosis example for wood sector in Sweden

2 Aim and objectives

The purpose of this report is to present and examine potential sustainable uses of wood related wastes generated by industries operating in Centro Region. In order to achieve that, the wood-based products supply chain for Centro is mapped. The mapping includes identification and quantification of common wood-based inputs and outputs used or

generated by industries, using system methods. The methods are limited to material resources exchanges, and do not consider flows, such as energy or water. The method allows for a quick mapping of potential industrial symbiosis without having to interview individual companies. This means that the results presented in this report should be considered a first step towards the implementation of industrial symbiosis, and that an extensive dialogue with individual actors should be considered as one of the next steps towards implementation.

The case study on wood serves to illustrate the method, which means the approach can be used to study other resource types.

3 Method

Top-down approaches use available statistical data or other data sources to study and analyse a system. This study uses this approach to estimate and account wood-based products and how can they be circulated between industries operating in Centro Region. The main method used is Material Flow Accounting, a methodology that not only allows to account for amounts and types of industries inputs and outputs, but also allows the analysis of potential relationships between industries, for wood related materials exchanges. Furthemore, the method can be used for other types of resources.

The method (see Figure 2) developed in the report encompasses the following steps:

Step 1: Identification and quantification of the types of wood-based flows. This include raw materials and intermediate products, used by the economic activities operating in the Centro Region and corresponding produced products. The UMAn method is used to derive the information (Rosado et al. 2014);

Step 2: Identification and quantification of the main wood-based wastes for each economic activity operating in the region. The Waste selection and characterization method is used to obtain the waste quantities in the Centro region (Patrício et al. 2019);

Step 3: Design of wood-based products value chain, by constructing a network diagram of the materials exchanges between economic activities. The Value chain mapping method is used to describe the relationships between the activities (Patrício et al. 2020a);

Step 4: Selection of case study wastes and matching them to substitute raw materials in different economic activities. A literature review to identify existing symbiosis for wood wastes is conducted and an extrapolation of the possible symbiosis is done with the Matching method (Patrício et al. 2020b);

Step 5: Mapping of the potential symbiosis in the Centro region, with the location of producers and users of selected wastes. Selection of priority areas will be made through a clustering process. GIS method will be used to map symbiosis.

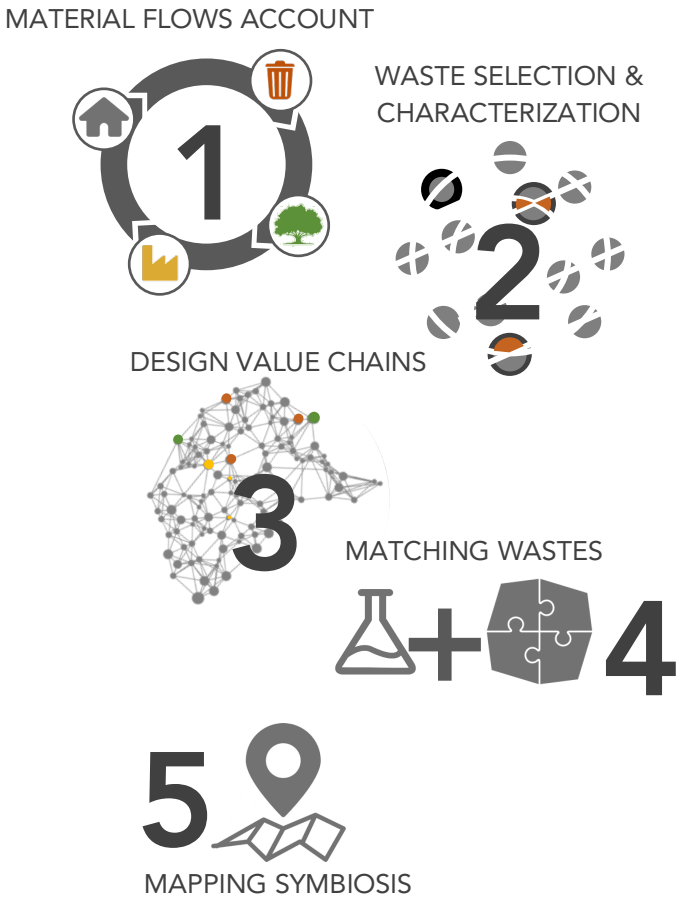

Figure 2 – Methodological steps to identify potential industrial symbiosis

3.1 Terminology

In this report industries, products and wastes are classified using Eurostat standard nomenclatures. Each of the used nomenclature is explained in more detail below:

Industries

Industries are classified by using the Statistical classification of economic activities in the European Community nomenclature, abbreviated as NACE. This is the classification of economic activities in the European Union. More specifically, NACE rev. 2 at 3 Digits is used, which encompasses approximately 270 economic activities. As an example, NACE code 310 stands for "manufacture of furniture". The entire list of NACE codes can be found in supplementary information table 1.

Products and materials

Combined Nomenclature (CN) is the classification used in the European Commission for collecting and processing data on foreign trade. This is the classification used in this study to classify products. 4-digit disaggregation is used as few year-to-year changes occur at this disaggregation level. In total, 4-digit codes includes around 1250 different products. As an example, CN code 4407 stands for "wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-jointed, of a thickness of > 6 mm". The complete CN 4 digits list can be found in supplementary information table 2.

Wastes

The industrial wastes are classified according to the Euorpean Waste Catalog and List of Wastes (LoW) nomenclatures, also developed by European Union. The LoW nomenclature encompasses aproximately 800 wastes types. As an example, LoW code 30101 stands for "waste bark and cork". The complete LoW list can be found in supplementary information table 3.

3.2 Data collection

The main data provider of data is Statistics Portugal (INE), the central body responsible for the production and dissemination of official statistics in Portugal, according to Law no 22/2008 (Official Journal no. 92 1st Series, of 13th May 2008). Most data are freely available at INE's website (INE, 2018) or can be requested free of charge to the same institution through an online form (INE, 2018). However, for specific datasets, such as International Trade and Industrial Production (INE 2014), microdata is only available to Approved Researchers. Data gathered in this way is subject to a confidentiality agreement and cannot be disclosed.

For employment data by industry (NACE 4 digits), the main source is Gabinete de Estratégia e Planeamento (Ministério do Trabalho, Solidariedade e Segurança Social). These data are not subject to any confidential agreement.

Eurostat data on Waste by sector for Portugal, without considering mineral wastes, for 2016. Total amount of waste generated by industrial sector, used to estimate the amount of waste generated by each industry, using waste per sector per employee as predictor factor (Eurostat 2019).

In most cases, data is available at NUTS 2 level (corresponding to Região Centro) with the product disaggregation level requested.

4 Results

4.1 Quantification of wood-based flows

Flows of resources include all the wood-based materials that are used by all economic activities in the region. The next subsection will introduce the types as well as quantities of wood-based materials used by the industries operating in the region. The materials were accounted using the material flow accounting methodology.

Main wood-based product flows indicators

Material inputs into the system are divided into domestic extraction and imports while product outputs are given by the industrial production, the exports and waste of wood-based products. Additionally, the consumption of wood-based products is also included to provide an estimation of how much it serves the local demand (Figure 3).

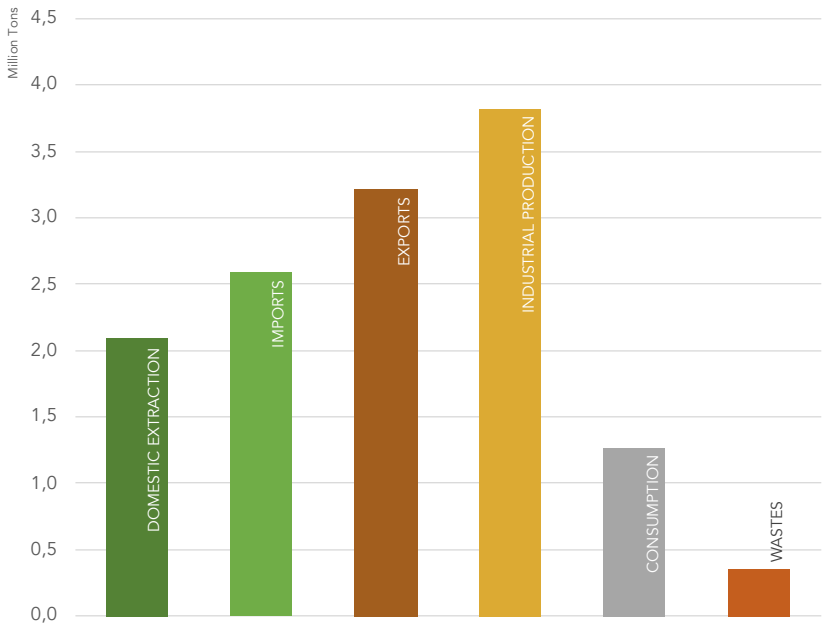

Figure 3 – Main wood-based flows indicators for the Centro region in 2013 (million tons)

Note: Industrial production might include double counting of wood, since some products accounted are transformed in others. Wastes statistics refer only to wastes produced by manufacturing activities

In the Centro region, wood-based products can be considered an important activity with inputs of wood-based products amounting for more than 10% of the total inputs of materials in the region. It can also be seen that industrial production plays a large role, which is also reflected on the significant amount of exports. If we look at the total amount of wood wastes it can be seen that it represents approximately 17% of the domestic extraction and slightly less than 10% of the industrial production of the region, which is an important amount. The indicators for the flows of wood-based products indicate therefore that there is room for using wastes as secondary raw materials, either to replace imports of wood-based materials or to reduce the dependency of the local forest. It can also support the development of circular strategies of a maximum of 10% for the wood manufacturing sectors.

Identification and quantification of the types of wood-based inputs

Material inputs into the system are divided into domestic extraction and imports. For Domestic Extraction, the available information at product level is organized by function and type of tree (fuel wood vs. timber from coniferous vs. non coniferous trees). Details can be seen in Table I.

Table I – Domestic Extraction of wood in the Centro region in 2013 (tons) by CN code.

CN2013	CODE DESCRIPTION	TONS
44 01 1000	FUEL WOOD in logs, billets, twigs, faggots or similar forms	115 571,91
44 03 2099	TIMBER WOOD of pine in the rough	908 791,40
44 03 9190	TIMBER WOOD of oak in the rough	137 136,98
44 03 9930	TIMBER WOOD of eucalyptus in the rough	777 869,10
44 03 9995	TIMBER WOOD of others in the rough	148 116,22

The vast majority of wood extracted in the Centro region is wood for manufacturing, opposed to roughly 5% of wood for fuel purposes.

The imports of wood-based products are largely dominated by the same type of products extracted in the region (Figure 4): Wood in the rough and fuel wood, which account for more than 70% of all wood mass needed. This indicates that there is a good opportunity to understand the possibility of using wastes as substitute materials.

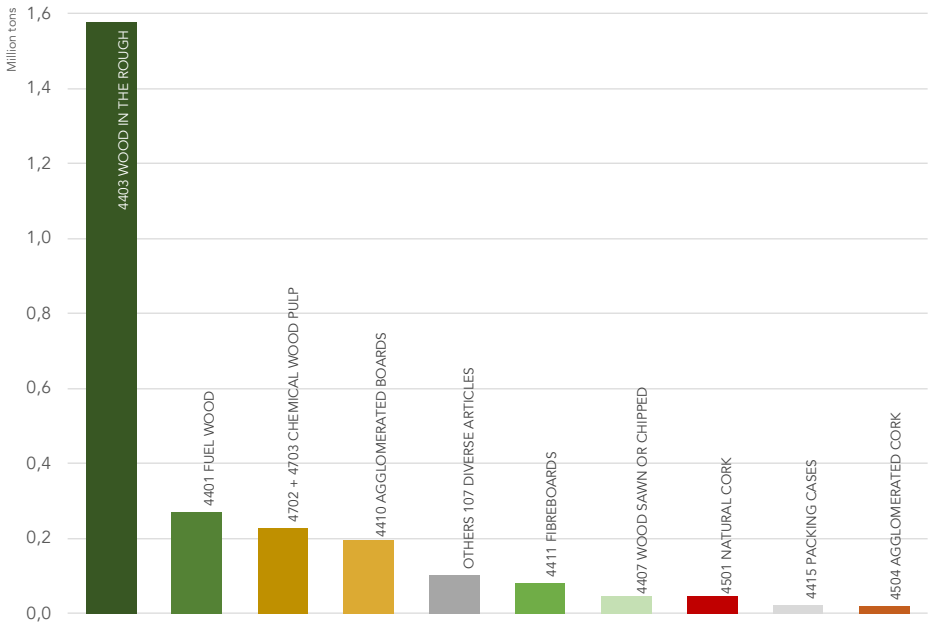

Figure 4 – Top ten imports of wood-based products in the Centro region in 2013 (tons) by CN code (4 digits)

Identification and quantification of the types of wood-based industrial production

The amount of wood-based products estimated to be produced by manufacturing industries in the Centro region amounts to 3,8 million tons. The industries that produce the most wood-based products can be seen in Table II. Main economic activities that produce wood products are 11, which manufacture 36 types of products, ranging from monomaterial in wood to complex products. Fuel wood, wood boards and chemical wood pulp are the most commonly manufactured products. Seats and furniture are also produced in significant amounts.

Table II – Main wood-based products manufactured in the Centro region in 2013 (tons) by CN code and NACE.

		SAWMILLING	MANUFACTURE OF PRODUCTS	MANUFACTURE OF PULP	MANUFACTURE OF PAPER AND BOARD	MANUFACTURE OF BASIC CHEMICALS	MANUFACTURE OF CUTLERY AND TOOLS	MANUFACTURE OF COMMUNICATION EQUIPMENT	MANUFACTURE OF DOMESTIC APPLIANCES	MANUFACTURE OF FURNITURE	MANUFACTURE OF TOYS	OTHER MANUFACTURING
CN	NACE	161	162	171	172	201	257	263	275	310	324	329
4401	FUEL WOOD	1 527 490										
4402	WOOD CHARCOAL					7 416						
4403	WOOD IN THE ROUGH	87 206										
4404	PILES, PICKETS AND STAKES	38 243										
4406	RAILWAY SLEEPERS	472										
4407	WOOD SAWN OR CHIPPED	63 515										
4408	SHEETS OF WOOD		2 713									
4409	SHAPED WOOD	9 814										

CN	NACE	161	162	171	172	201	257	263	275	310	324	329
4410	PARTICLE BOARDS		236 689									
4411	FIBREBOARDS		162 505									
4412	PLYWOOD PANELS		20 016									
4414	WOODEN FRAMES		298									
4415	PACKING CASES		127 937									
4418	CARPENTRY WORK		37 535									
4502	NATURAL CORK		5 681									
4503	ARTICLES OF CORK		2 328									
4504	AGGLOMERATED CORK		9 395									
4601	PLAITS AND SIMILAR PRODUCTS		19									
4701	MECHANICAL WOOD PULP			98 289								
4702	CHEMICAL WOOD PULP			318 251								
4703	CHEMICAL WOOD PULP			915 059								
4704	CHEMICAL WOOD PULP			44 598								
4823	OTHER PAPER				3 180							
8201	HAND TOOLS						105					
8202	HAND SAWS						71					
8205	HAND TOOLS						2					
8210	HAND-OPERATED APPLIANCES											
8414	AIR OR VACUUM PUMPS								25			
8448	AUXILIARY MACHINERY											
8483	TRANSMISSION SHAFTS											
8516	HEATERS								19			
8525	TVS AND RADIOS							76				
9401	SEATS									11 746		
9403	FURNITURE									86 438		
9504	TABLE GAMES										244	
9603	BROOMS AND BRUSHES											2 150

4.2 Identification and quantification of the main wood-based wastes

During the industrial process, there are many wastes and by-products generated. This section estimates the types and quantities of wood-based wastes generated within each industrial process. Non-hazardous wastes within EWC 07.5, 09.2 and 12.4 waste categories were selected for further analysis. Table III shows the waste categories.

Table III – Types of wood based wastes by EWC and LoW

EWC42	EWC84	LoW	Description	Waste examples
07.5 Wood wastes	07.53 Other wood wastes	30101	waste bark and cork	Bark, Cork
07.5 Wood wastes	07.52 Sawdust and shavings	30105	sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04	Chipboard, Chairs - wooden, Sawdust, Sawdust - contaminated, Shavings - wood, Timber - untreated, Dust - sander, Hardboard, Wood, Wood cuttings, Furniture -Off specification, redundant stock
07.5 Wood wastes	07.53 Other wood wastes	30301	waste bark and wood	Bark, Wood, Wood cuttings
07.5 Wood wastes	07.51 Wood packaging	150103	wooden packaging	Containers - wooden, Crates - wooden, Empty used containers, Packaging - wooden, Pallets, Timber - untreated, Wood, Wooden containers - contaminated
07.5 Wood wastes	07.53 Other wood wastes	170201	wood	Chairs - wooden, Cork, Railway sleepers (timber), Sleepers - railway (timber), Timber - untreated, Hardboard, Wood, Wood cuttings
07.5 Wood wastes	07.53 Other wood wastes	191207	wood other than that mentioned in 19 12 06	
07.5 Wood wastes	07.53 Other wood wastes	200138	wood other than that mentioned in 20 01 37	Civic amenity waste, Cork, Pencils, Timber - untreated, Wood, Wood cuttings

09.2 Green wastes	09.21 Green wastes	20107	wastes from forestry	Trees, Wood cuttings, Wood, Green waste, Plant tissue, Tissue - plant, Forestry waste
09.2 Green wastes	09.21 Green wastes	200201	biodegradable waste	Civic amenity waste, Animal faeces, Bark, Grass, Excrement - animal, Manure - animal, Garden waste, Green waste, Horticultural waste, Plant tissue, Parks and garden waste, Tissue - plant, Trees, Trimmings - hedge and tree, Vegetation, Weeds, Wood

The quantification of industrial waste is based on the assumption that waste generation is co-related to the number of employees. Using available National data per industrial sector, it is possible to account regional industrial waste per industry sector. The total amount of wood-based waste generated within the region is estimated to be around 167,000 tons (excluding wood waste from construction and demolition activities). Figure 5 shows the estimated wood wastes disaggregated by waste type, following the waste categories presented in Table III. Waste LoW 30105 (sawdust, shavings, cuttings, wood, particle board and veneer) is the waste expected to be generated in larger quantities, contributing approximately 38% of the total wood waste. Waste LoW 150103, which stands for wooden packaging, including wastes such as pallets and wood containers, constitutes approximately 26% of the total wood waste. LoW 30301, that stands mostly for bark waste, represents 11%.

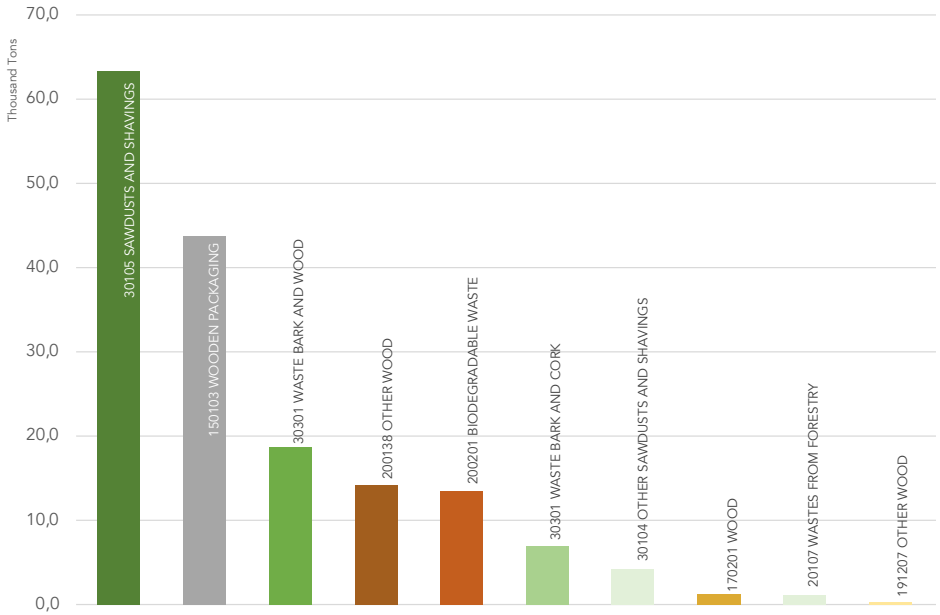

Figure 5 – Wood-based wastes in the Centro region in 2013 (tons) by LoW

The waste data for the aforementioned categories was disaggregated according to industrial activities, by using profiles of wastes typically produced by industries. Table IV show the detailed list of industries as well as the amount of generated waste. Amongst the industries with the most wood-related waste production in Centro are: NACE 31.09 – Manufacture of other furniture, 16.10 – Sawmilling and planning of wood, and 16.23 - Manufacture of other builders' carpentry and joinery. Together, these industries account for approximately 35% of total wood waste.

Table IV - Main wood waste generating industries in the Centro region in 2013 (tons) by NACE

NACE	Description	Wood wastes quantities (tons)	%
162	Manufacture of products of wood, cork, straw and plaiting materials, except furniture	32,032	19%
310	Manufacture of furniture	28,045	17%
171	Manufacture of pulp, paper and paperboard	18,621	11%
161	Agricultural service activities	18,505	11%
72	Mining and preparation of non-ferrous metal ores	13,322	8%
271	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	4,105	2%
233	Manufacture of ceramic building materials	3,775	2%
222	Manufacture of plastics products	2,897	2%
293	Manufacture of parts and accessories for motor vehicles	2,828	2%

The distribution of the types of waste produced by activity is presented in Figure 6. It can be seen that there is a prominence of Sawdust and shavings in 3 of the 4 largest waste producers in the region, while the production of bark is mostly coming from manufacture of pulp and paper.

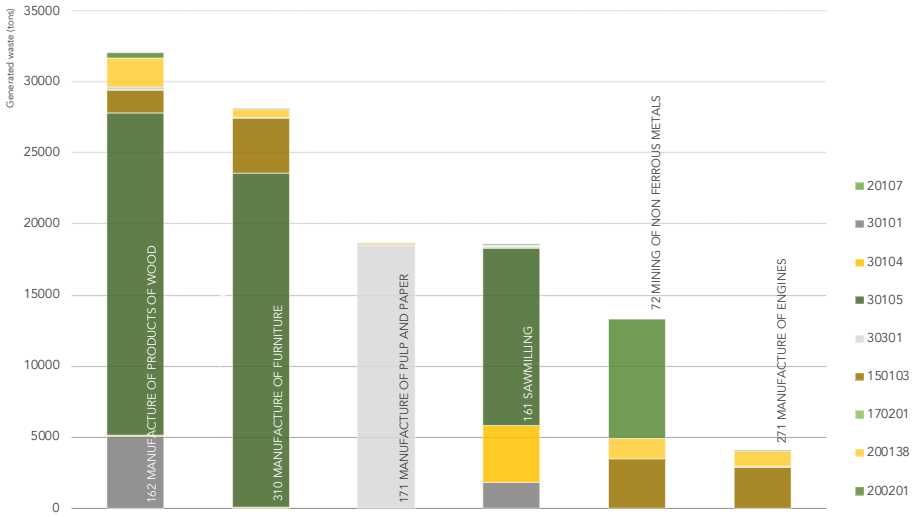

Figure 6 – Wood-based wastes in the Centro region in 2013 (tons) by NACE and LoW

4.3 Design of wood-based products value chain

To design the wood-based products value chain for the Centro region the relationship between NACE codes was mapped in order to understand who are the receivers of the different types of products. It was assumed that extraction activities will not receive any products and that final consumers and producers of finished goods will not send any products back to the main intermediate producers, which are the focus of the study since these activities are the main responsible for the amounts and types of wood waste being produced in the Centro region. Figure 7 presents a scheme with the wood value chain.

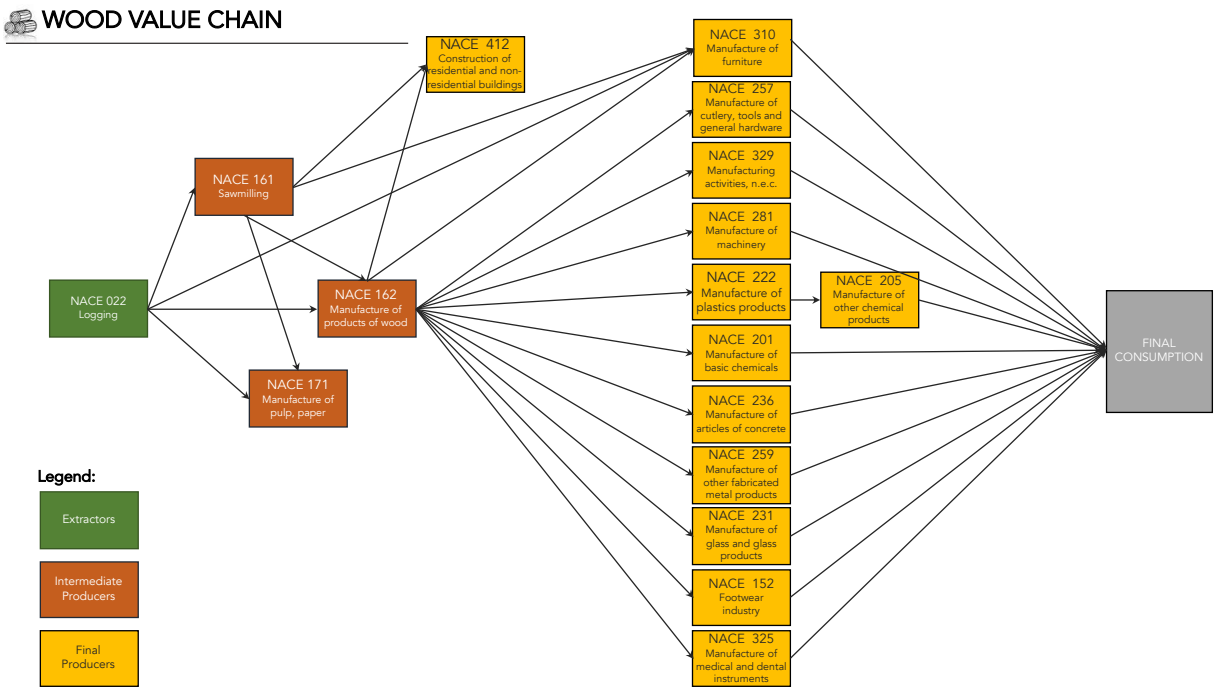

Figure 7 – Wood value chain by NACE

It can be seen that the value chain for wood is focused in 3 intermediate producers where NACE 162 is the main responsible to send out products to the highly diverse mix of final producers. Looking in more detail to a specific part of the network, and assuming that wastes produced earlier in the value chain are easier to reutilize, and also amount for larger quantities, it can be seen 3 intermediate producers are involved producing 10 types of products, and 6 types of waste (Figure 8).

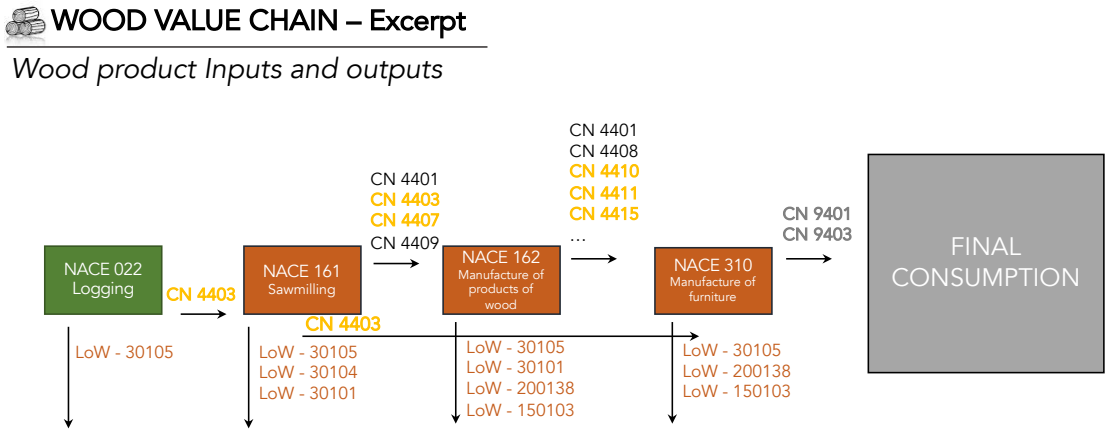

Figure 8 – Excerpt of the Wood value chain by NACE, CN and LoW

4.4 Selection of case study wastes

The selection of case study wastes to be studied is done considering the ranking of waste quantities, existing symbiosis technologies and potential receivers of the waste in the region.

Waste selection

Wastes from the wood processing industry can be used for many purposes, for example, it can be used as a component for new wooden material, combustion material for heating etc.

(Harkin, 1969). It can also be used for more innovative solutions. As previously mentioned, waste types that are produced in larger amounts are: Bark, Sawdust and Shavings. Different applications can be applied to these types of wastes, depending on their size and moisture content. Wood wastes can therefore be categorized by those criteria (Figure 9).

Figure 9 - Categories of wood residue according to FAO 1990

	Bark	*Sawdust*	*Shavings*
(%)Size (mm)	1-100	<1	1-12
Moisture content	25-75	25-40	10-20

These type of wastes were therefore selected. If we try to select other wastes based on the activities in Centro region, only a handful of other wastes are left. Amongst them, the forestry waste, which could be utilized in 2015 – Manufacturing of fertilizers, which has a moderate presence in the region.

Conventional uses for the selected wastes

There are several conventional uses for wood wastes. In this section the most relevant ones are highlighted.

The use of bark, sawdust and shavings waste as unrefined biofuel is a possible application. However, it is an inefficient process and more modern ways of using these waste include refining it into pellets or briquettes making the raw material more efficient as a fuel. This reduces the cost and space of storing, transporting and burning it (Nilsson & Bernesson, 2008). A good wood waste for producing pellets is cutter shavings, a by-product when plaining wood (Vida energi, n.d).

Wood boards such as fiberboards or OSB (Oriented Stranded Board) are produced with different components from the wood processing waste e.g sawdust and shavings (Vida energi, n.d). According to Porschitz and Schwarz (2000), wood shavings can also be used as an ecologic alternative for insulation. The shavings showed a thermal conductivity = 0.045 W/mK which is comparable to other insulation materials. Moreover, wood shavings can be used for animal bedding. However, some types of wood such as Cedar and walnut is not recommended because it can be dangerous to some animal (Kovalick, 2014).

One good input material to the production of paper (except the pulpwood) is wood chips from wood industries (Skogsindustrierna, 2016). Wood chips can also be used for smoking meat and fish. Leaf trees are well suited for this sort of use. Birch and fir are on the other hand not very suitable (Grillkoll, n.d).

Innovative uses for the selected wastes

There are currently several innovative projects looking at how to use wood wastes in different applications. In this section, the most promising ones are identified.

Studies have shown that sawdust can be used in concrete, replacing fine aggregates with up to 10 %. The concrete is not recommended to be used as a structural concrete but does work fine as a lightweight concrete (Abdullahi, Abubakar, & Afolayan, 2013).

According to Op de Beeck et al. (2015), attempts have been successful at extracting liquid straight-chain alkanes from cellulose. These alkanes can be converted processed into gasoline. Op de Beeck et al. (2015) say that the wood waste does not need to be raw wood, waste from furniture and other products with paint and other impurities can be used as well. This process is however still on the research scale.

Rahman et al. (2013) has conducted experiments with sawdust in the production of plastics. They showed that it is feasible to produce flat pressed composite plastics with the right mixing ratio of sawdust and PET. However, they do recommend for further improvement that additives are used together with the mix to achieve a better result.

White (2016) writes in an article from the Pacific Northwest National Laboratory that the micro-biologist George Bonheyo has reinvented the sawdust as an oil absorbent. Bonheyo has chemically modified sawdust to work as a "superabsorbent" for oil. The research team believes that this will be a very important addition to the traditional remediation methods available, especially in colder climates.

Table V shows an excerpt of possible application of wood waste in different economic activities, including information about the readiness level of the technology.

Table V - Potential wood waste applications for the Centro region by NACE

NACE	DESCRIPTION	WASTE	TRL (1-5)
10 200	Preparation of fish and shell fish (smoking)	Wood chips	5
10 130	Cured meat production (Smoking)	Wood chips	5
014	Raising of animals (bedding)	Wood shavings	5
16 291	Production of pellets	Wood shavings, Sawdust	5
35 300	Combustion	Bark	5
17 112	Pulpmill	Wood chips	5
32300	Used in playground areas	Bark	5
23 610	Concrete production	Sawdust	3
20156	Production of plastics	Sawdust	3
19 200	Gasoline production	Wood chips	2
20 592	Superabsorbent for oil	Sawdust	2

4.5 Matching of wastes for Industrial Symbiosis in the Centro region

The identification of the potential uses of the selected wastes allows the selection of the economic activities present in the Centro region that can be engaged in Industrial Symbiosis potential schemes (see Figure 10).

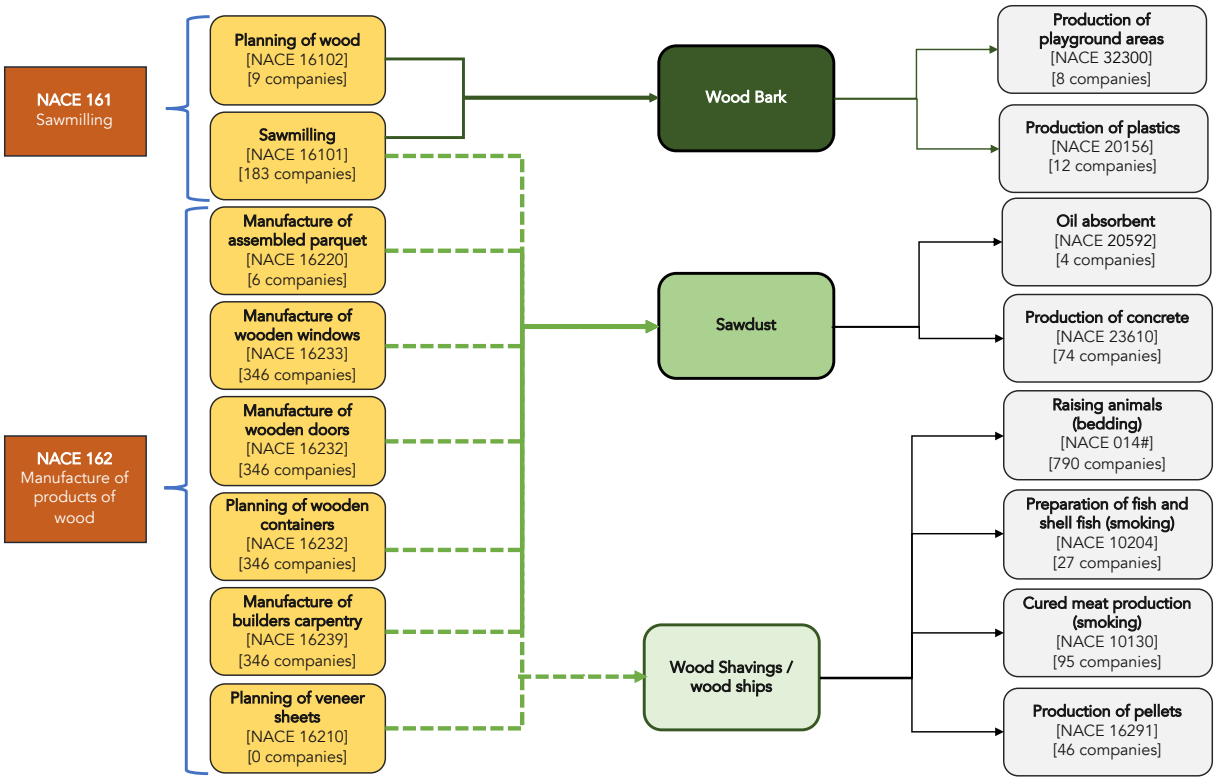

Figure 10 – Potential Industrial Symbiosis schemes for the Centro region by NACE and selected wastes

8 types of economic activities can supply the 3 main types of wood waste. These 3 wood wastes can be potentially used by 8 receiving economic activities. While the suppliers of wood waste come directly from the manufacturing of wood industries, the receivers are more diverse and include food and animal production, construction materials and chemicals and plastics manufacturing. Furthermore, it can be seen that around 550 companies in the Centro region have the potential to supply wastes, while approximately 1050 companies can receive the wastes.

5 Conclusions

The aim of this study was to identify potential industrial symbiosis schemes for wood base wastes in the Centro region. To do that, a thorough analysis of the wood-based flows in the region was examined, including input, output and waste indicators, to understand the importance of the wood value chain.

Results show that wood-based products amount for more than 10% of the total inputs of materials in the region, approximately 4,5 million tons. Domestic extraction of wood products was approximately 2,5 million tons. The large majority of the extracted flows were used within several industrial processes operating in the region. Consequently, industrial production of wood-based products total around 3,8 million tons.

Being an important industrial activity in the region, wood-based industries produced a significant amount of wood wastes. The total amount of wood generated wood wastes was 355,000 tons, representing 17% of the domestic extraction and 10% of the industrial production. The large majority of the generated wood wastes were wood bark, sawdust and wood shavings. Many conventional and innovative uses can be found to recover the wastes.

Some conventional applications include: using waste as bedding for animal raising, production of pellets, or smoking of food products. More innovative uses include: using to produce plastic or concrete.

The study identified industrial symbiosis potential actors, by selecting around 550 companies as potential wood wastes suppliers, and approximately 1050 companies that can receive the wastes.

The next step in the work is to map all companies that produce waste and can potentially receive waste to identify clusters where the highest potential for industrial symbiosis schemes can occur.

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