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Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector

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Abstract

Goal, Scope and Background. Wood has many applications and it is often in competition with other materials. Chipboard is the most common item of wood-based materials and it has attained the highest economical development in recent years. Relevant up-to-date environmental data are needed to allow the environmental comparison of wood with other materials. There are several examples of Life Cycle Assessment (LCA) evaluations of some wood products and forest-technology systems, but no comprehensive Life Cycle Inventory (LCI) data for particleboard manufacture is available in the literature. The main focus of this study is to generate a comprehensive LCI database for the manufacture of resin-bonded wood particleboards.

Methods. In this work, International Organization for Standardization (ISO) standards and Ecoindicator 99 methodology were considered to quantify the potential environmental impact associated to the system under study. A Spanish factory considered representative of the 'state of art' was studied in detail. The system boundaries included all the activities taking place inside the factory as well as the activities associated with the production of the main chemicals used in the process, energy inputs and transport. All the data related to the inputs and outputs of the process were obtained by *on-site* measurements.

Results and Discussion. LCI methodology was used for the quantification of the impacts of the particleboard manufacture. The inventory data of the three defined subsystems are described:

- Wood preparation: a comprehensive inventory of data including storage, debarking, particle production, storage and measurement of particles, drying and combustion of the bark for energy purposes.
- Board shaping: data related to particle classification, resin mixing, mattress formation and the pressing stage.
- Board finishing: cooling data, finishing, storage and distribution of the final product.

The system was characterised with Ecoindicator 99 methodology (hierarchic version) in order to identify the 'hot spots'. Damage to Human Health was mainly produced by the subsystem of Board finishing. The subsystem of Board shaping was the most significant contributor to damage to the Ecosystem Quality and Resources.

Conclusions. With the final aim of creating a database to identify and characterise the manufacture of particleboard, special attention was paid to the inventory analysis stage of the particleboard industry.

A multicriteria approach was applied in order to define the most adequate use of wood wastes. Environmental, economic and social considerations strengthen the hypothesis that the use of forest residues in particleboard manufacture is more sustainable than their use as fuel.

Recommendations and Outlook. In this work, particleboard was the product analysed, as it is one of the most common wood-based materials. Future work will focus on the study of another key wood board: Medium Density Fibreboard (MDF). Moreover, factors with strong geographical dependence, such as the electricity profile and final transport of the product, will be analysed. In addition, the definition of widespread functional unit to study the use of wood wastes at the end-of-life stage may be another issue of outstanding interest.

Keywords: Chipboard manufacture; end-of-life stage; life cycle inventory (LCI); particleboard; wood products

Introduction

The production value of the forestry industry in the European Union in 1998 rose to 300,000 million euros, which means 10% of the total manufacturing sector [1]. Wood has many applications and it is often in competition with other materials such as concrete, steel or plastics [2–3]. Different primary and secondary transformation factories make up this sector. Chipboard, the most common item of wood-based materials, has attained the highest economical development in recent years, for two reasons: i) this process uses wood residues, and ii) the commercial products are currently used in other areas such as carpentry, building, furniture or decoration. In Spain, the demand for chipboard is expected to increase exponentially.

With the development of the substitution principle, the environmental burdens of all the products throughout their life cycles will be clearly demonstrated. It will be possible to design products, their use, recycling and disposal in such a way that the environmental burdens are minimised and reduced to levels that are competitive and may even outperform potential substitutes [4]. A new approach with uniform perspective is needed to make effective comparisons between different materials and their substitutes. Material and energy burdens that arise from the products with their cradle (raw materials) to their grave (as disposed waste) must be considered and evaluated. Life Cycle Assessment (LCA) applied to a product makes it possible to assess the overall environmental burdens, identify the 'hot spots' of the life cycle and predict the effects of the proposed improvement actions. It may be a powerful tool for increasing the efficiency of resources and energy utilisation and also lead to significant cost savings. However, the drawbacks of this environmental tool are related to the fact that it is not possible to determine the specific causes of the greatest environmental burdens in the life cycle until all the stages have been evaluated and the quality of the data used has been fully verified.

Relevant, up-to-date, environmental data are needed to allow the environmental impact of wood to be compared with that of other materials. LCA and ecolabelling in forestry and the wood chain have complementary roles in the environmental policy when assessing the environmental impacts of forest management [5]. There are important differences regarding specific objectives, coverage, assessment and interpretation, but there are also complementarities which offer possibilities for the rationalisation of data collection. A major research challenge, however, is the LCA-based comparison of wooden products and their substitutes to provide adequate information for guiding sustainable consumption patterns. Jungmeier et al. (2002) discussed different solutions for the treatment of allocation in the descriptive LCA of wood-based products [6–7]. From this work, it is concluded that the influence of different allocation procedures on the results may be very significant. They identified ten different processes in LCA evaluations of wood-based products where allocation problems may occur. There are several examples of the use of LCA techniques to assess the environmental load associated with some wood products and forest-technology systems [8–9], but no comprehensive Life Cycle Inventory (LCI) data for particleboard manufacture is available in literature. The main focus of this study is to analyse one of these processes in the wood chain: the particleboard industry.

1 Goal and Scope

1.1 Objectives

The objective of this study was to examine a primary transformation sector of wood in detail. Chipboard production was the process analysed, as it is one of the most common wood-based materials. This work aims to compile a comprehensive Life Cycle Inventory (LCI) for the manufacture of resin bonded wood particleboards. In a previous work, several factories were analysed and minimal differences in the global inventory data were found (around 5%). A Spanish factory considered representative of the 'state of art' was selected to study the process in detail.

1.2 Functional unit

This unit provides a reference to which the inputs and outputs are referred [10]. The particleboard factory under study has a production capacity of 680 m^3 finished particleboard per day. For an easier comparison with other works, the functional unit chosen was 1 m^3 of finished particleboard.

1.3 Description of the system under study

A particleboard is a panel made from small discrete wood elements, mainly wood processing waste, with a water-resistant adhesive binder mainly for indoor uses [11]. According to the specifications required by consumers, a huge variety of particle size and board thickness is manufactured. As an example, typical sizes are 4,880 mm×2,440 mm or 2,440 mm×1,220 mm, and thickness can range from 8 mm to 45 mm.

There are two main sources of wood raw material: forest thinnings and sawmill residues such as slab wood, hacked or pulp chip, dockings, planer shavings and sawdust (**Fig. 1**). Each chipboard factory has its own process conditions; however, the general flow sheet is common in all of them. The process chain can be subdivided in three main subsystems. The material input is refined, classified and dried (subsystem of wood preparation) and then blended with binding agents and pressed (subsystem of board shaping). Following this blending operation, the material is cut and sanded into the final product (subsystem of board finishing). Auxiliary subsystems that must be computed are the transport activities involved, chemicals used and energy consumption. Three main scenarios are considered for the final disposal of the particleboard: landfill, energetic use and recycling.

The description of the system evaluated is presented in **Fig. 2.**

Subsystem of Wood Preparation

Storage. Materials from diverse origin are stored outdoors awaiting use in the manufacture process. Around 80% of the material used is pine wood (mainly *Pinus pinaster* and *Pinus radiata*), followed by black poplar and eucalyptus, together with branches, small pieces and waste coming from sawmills and other wood industries (chips, shavings and sawdust). Lumber mill residues or lumber processing residues consist of edging, slabs, shavings, trimmings, sawdust and pieces of wood. Round wood from forest slash of a typical diameter smaller than 12 cm, which are inappropriate for sawmills, is used as the main raw material in the factory studied.

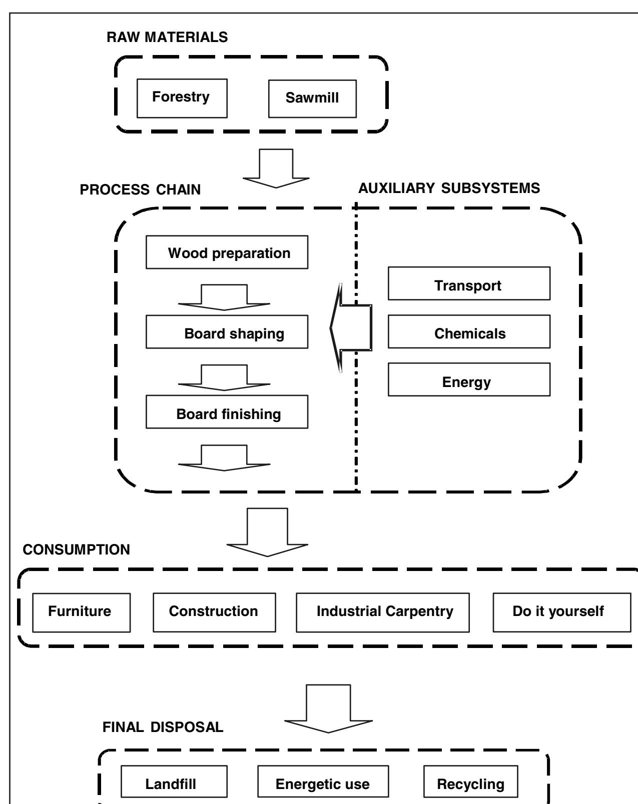

Fig. 1: System boundaries and process chain under study

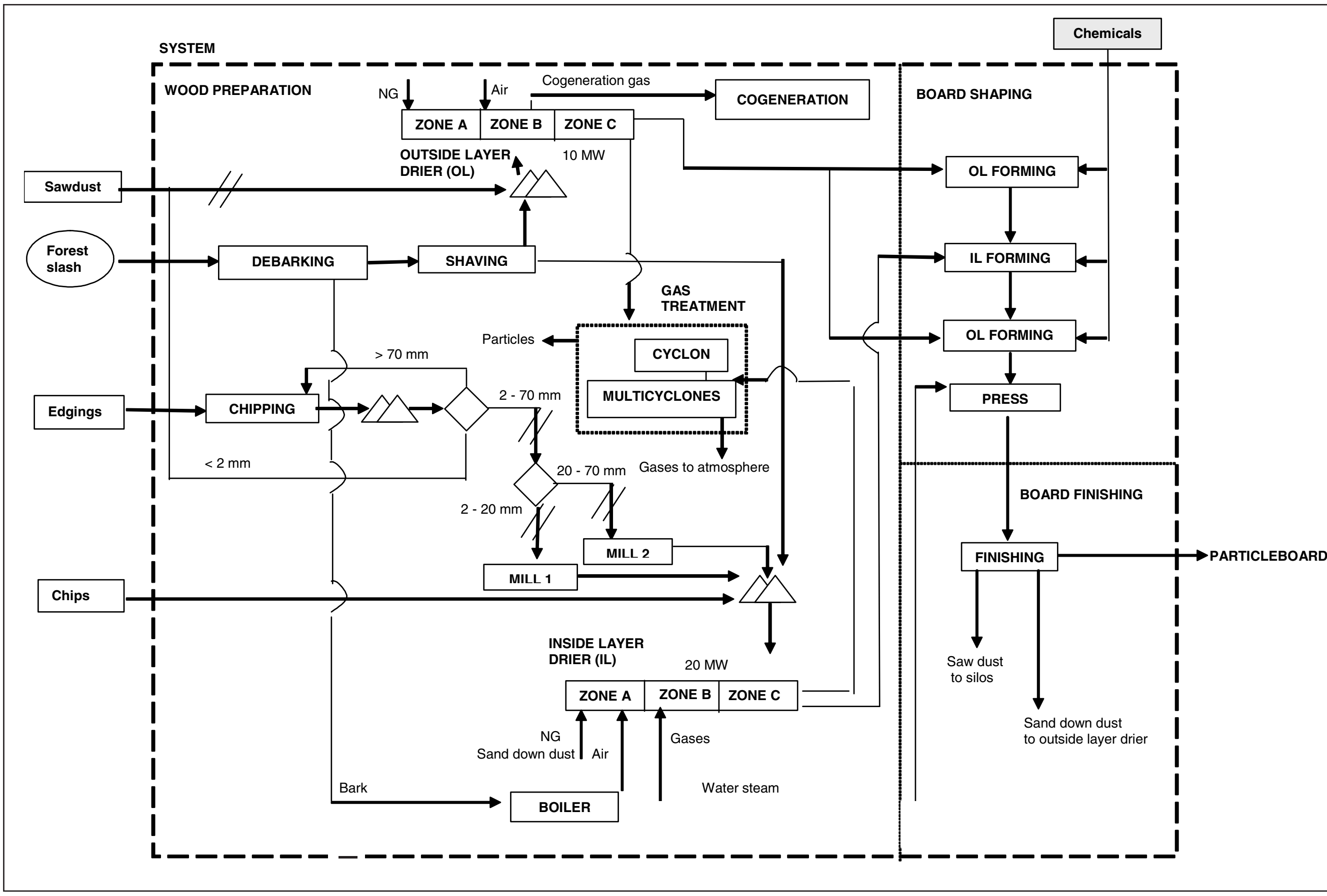

Fig. 2: Flow sheet of particleboard manufacture. Symbols: NG: natural gas; (△): silo; (--//--): screening unit; (◊): classification unit

Debarking. Bark must be removed from the logs as it is considered to be an impurity in the final product. The bark obtained is sent to the boiler for energy recovery.

Particle production. Final product quality utterly depends on the shape and the humidity of the wood particles. Shaving machines and chippers cut the debarked logs into flakes of a desired, final particle size, the oversize being returned for further breakdown.

Storage and measurement of particles. There are different silos in which to place the particles with diverse sizes and humidity and also to adjust the mass flow entering the units of the process. The particleboard is manufactured with a three-layer structure: fine particles on both surfaces for smoothness (outside layers) and coarser particles in the core for strength (inside layer). The process is divided in two parallel lines, which will achieve different levels of dryness (higher at the interior sheet). While the silo of the inside layer is fed by shavings and chips, the one of the outside layer uses shavings and sawdust.

Drying. The particles from the silos are dried in driers through direct contact with hot gas from the burners. Gas from the cogeneration unit is also used in both driers and the exhausted gas from the boiler is driven to the one on the outside layer. The sand down dust is burnt in the same drier.

Boiler. It is possible to benefit from both the bark and the wood wastes for energy purposes. Heat produced by the bark combustion is used to produce steam for the press. Moreover, exhausted gas is utilized at the drying stage to reduce the humidity content of the wooden particles.

Cogeneration. Many board factories are nowadays aware of the favourable consequences of cogeneration to produce both electrical and thermal energy for the process. Therefore, this stage of the process is being considered.

Subsystem of Board Shaping

Resin mixing. The binder (resin or adhesive) and its dosage play a key role in the stability of the final board. The most commonly used resins are urea-formaldehyde (UF), melamine-formaldehyde (MF) and phenol-formaldehyde (PF). UF resin is the cheapest and easiest adhesive to use and it cures to a clear film. It is by far the most dominant adhesive for boards that are not exposed to moisture [12–13].

The colloidal aqueous solution of UF with a solid content of about 65% is normally modified by means of the addition of additives to obtain a final mixture with improved characteristics: Paraffin wax is added to provide water resistance and to control swelling caused by temporary wetting. Both hardeners and catalysts control the resin-curing rate during pressing. The process of glue addition is usually known as blending. Resin in a liquid state and other glue additives are forced through nozzles and sprayed onto the particles. Frequent checking of flow rates and particle moisture contents ensure consistent blending.

Mat forming. After the resin mixing, the mat is formed. The glued particles are metered out of a feeding bin and fall onto a conveyor or a tray. The movement of either the forming station or the conveyor/tray forms a long mat of each layer to be formed separately.

Press. The preformed mats of glued particles are transferred to the hot press for pressing and curing. The mats may be pre-pressed before the hot pressing to reduce their thickness. At the pre-press, the parallel lines are joined again: an outside layer is initially laid down, then a layer of coarse core particles is placed on top, forming the inside layer, followed by a second fine surface layer. The press is the nucleus of particleboard manufacture. As soon as heat is applied and reaches temperatures of 140–220ºC, the glue curing process begins and a maximum pressure between 2 and 3 MPa is instantaneously applied to attain the desired thickness.

Subsystem of Board Finishing

Cooling. The hot boards are removed from the press and further conditioned to equilibrate moisture content and to stabilise and fully cure the resin. The board temperature must be controlled at 30ºC, at which the intensification of resistance is produced.

Finishing. The cooled board is directed to the sander, where it is reduced to the desired thickness. Moreover, the smooth flat surfaces of the board are obtained and the dust is removed. After the surface treatment, cutting takes place according to customer requirements regarding board length and width. Waste cuttings are sent to the chipper or used as fuel in the boiler.

Final Product Storage. Particleboards ready to be delivered must be stored under adequate conditions of temperature and humidity; otherwise their quality can be seriously affected.

Ancillary activities

Chemicals. The production of UF and transport to the factory were considered in the subsystem of board shaping.

Transport. Chips from Brazil are transported by ship and the other raw materials by truck. The distribution of the product finished is performed by trailers.

Energy. Energy consumption in the subsystems of wood preparation, board shaping and board finishing was included in their respective inventory data.

1.4 Data Quality

High quality data are essential to make a reliable evaluation. All the data related to the inputs and outputs of the process were obtained by *on-site* measurements. The subsystem linked to urea-formaldehyde (UF) resin production was inventoried from bibliographical data considering data from the PRé Consultants Database [14]. Routes of UF transport were also computed.

The electricity profile is of major importance as it broadly affects the environmental impacts assigned to energy-consuming steps. The electricity generation profile of the year 2004, obtained from the data available from the Spanish Government, was considered [15]. The assignment of the environmental loads associated to the different sources of electricity was made from the IDEMAT 2001 database [14].

The infrastructure of the chipboard production facilities was not taken into account as it is assumed that the differences are negligible compared to the overall environmental impacts of the infrastructure for processing other materials with the same function [16].

2 Life Cycle Inventory Analysis

The inventory data of the subsystems of wood preparation, board shaping and board finishing are shown in **Tables 1** to **3**. For the purpose of this work, wooden materials used in particleboard manufacture were considered waste from other activities. Therefore, they had no environmental burden allo-

Table 1: Wood Preparation inventory for 1 m³ of particleboard processing

Inputs from Technosphere			
Materials (kg)		**Energy (MJ)**	
Forest slash	892.82	Electricity for machine	
Sawdust	257.03	From the grid	58.97
Edgings	125.57	From cogeneration	92.23
Chips	40.58	Total	151.20
Saw waste	36.76	Drier Exterior Layer	
		Natural gas	276.24
		Gas from cogeneration	760.96
		Total	1037.20
		Drier Interior Layer	
		Biomass (sand down dust)	1123.45
		Natural gas	560.86
		Water steam from boiler	390.11
		Total	2074.41
		Transport (t·km)	
		Truck	110.96
		Sea Ship	284.08
Outputs			
To Technosphere		**To Environment**	
Materials for board shaping (kg)		**Emissions to air (kg)**	
Chips and shavings (int. layer)	444.09	Nitrogen Monoxide	0.12
Shavings and sawdust (ext. layer)	222.04	Nitrogen Dioxide	0.04
		Carbon Dioxide	58.24
Avoided energy (MJ)		Carbon Monoxide	1.31
Bark to boiler	1570.20	Sulphur Dioxide	$3.53 \cdot 10^5$
		Dust and particles	0.41
		Water Steam	561.98

Table 2: Board Shaping inventory for 1 m³ of particleboard processing

Inputs			
From Technosphere		**From Environment**	
Materials (kg)		**Raw materials (kg)**	
Chips & shavings (int. layer)	444.09	Water	19.69
Shavings and sawdust (ext. layer)	222.04		
UF-Resin			
Ext. layer formation	44.84		
Int. layer formation	23.10		
Total	67.94		
Paraffin			
Ext. layer formation	1.41		
Int. layer formation	0.72		
Total	2.13		
Ammonium sulphate			
Ext. layer formation	0.49		
Int. layer formation	0.25		
Total	0.74		
Energy (MJ)			
Water Steam from boiler	724.49		
Electricity for machine			
From the grid	14.74		
From cogeneration	23.06		
Total	37.80		
Outputs			
To Technosphere		**To Environment**	
Materials (kg)		**Emissions to air (kg)**	
Particleboard shaped	730.44	Water Steam	14.98
		Formaldehyde	0.06

Table 3 Board Finishing inventory for 1 m³ of particleboard processing

Inputs from Technosphere			
Materials (kg)		**Energy (MJ)**	
Particleboard shaped	730.44	Electricity for machine	
Transport (t·km)		From the grid	73.71
Trailer	464.04	From cogeneration	115.29
		Total	189.00

Outputs to Technosphere	
Products and Coproducts (kg)	
Board finished	640.00
Waste to drier of external layer (kg)	
Sand-down dust	53.68
Waste to recycle (kg)	
Waste from sawdust	36.76

cation from previous processes and only their transport and further processing were computed (see Table 1). It is pointed out that the recycling of waste from the subsystem of board finishing was considered (see Table 3) and this internal recycling implied an input from the technosphere to the subsystem of wood preparation (see Table 1). The mean value of the gas supply from cogeneration was estimated on the basis of the variability of the moisture content of the raw materials (see Table 1), which depends on the environmental humidity (more than 90% as average). Bark removed from logs, used for energy purposes in the boiler, implies avoiding the use of other energy sources to obtain steam for the press and hot gas for drying (see Table 1). The emissions to air coming from the gas treatment were measured in the laboratory of the factory during a three-year period. The dosage of additives to each layer was quantified separately and it is specified in see Table 2.

3 Discussion

Even though LCA is now becoming accepted as the most effective environmental tool to carry out a comparison of relative environmental burdens between different productive systems, there is controversy concerning certain aspects of its methodology, which requires further research and development. Another major concern relies on the availability and quality of data. In this sense, there are some previous reports regarding particleboard manufacture [17]; however, the consumption of the main chemicals used was merely estimated based on generic data, regardless of important parameters such as the thickness of the layers. Damage-oriented, impact-assessment methodology has received attention in recent years [18–20]. This approach, however, does not only provide characterisation (potential impacts of impact categories such as climate change), but also damage assessment for safeguard subjects such as human health [21]. In this work, the impact assessment was performed with the Ecoindicator 99 methodology, which reflects the state of the art in LCA [22]. In this work, only the phases of classification and characterisation were studied, as this represents the most objective approach.

3.1 Classification and characterisation

Human Health (HH), Ecosystem Quality (EQ) and Resources (R) are the three conditions considered. Modelling and estimation of an environmental indicator for each category or issue are carried out at this stage. Damages to HH are expressed in Disability Adjusted Life Years (DALY). Damages to EQ are expressed as Potentially Disappeared Fraction (PDF) and Potentially Affected Fraction (PAF) of

Table 4: Characterisation and Damage Assessment of particleboard manufacture/Eco-indicator 99

		Characterization step			
Category	**Unit**	**Wood prepared**	**Board shaping**	**Board finishing**	**Total**
Human Health					
Carcinogens	DALY·10^6	–30.0	1.1	6.3	–22.6
Respiratory organics	DALY·10^8	12.8	7.3	22.1	42.2
Respiratory inorganics	DALY·10^5	4.2	0.6	8.1	12.9
Climate change	DALY·10^5	–1.3	0.2	1.4	0.3
Ozone layer	DALY·10^9	14.2	0.4	0.9	15.5
Ecosystem Quality					
Ecotoxicity	PAF·m^2yr	–5.8	2.9	118.0	115.1
Acidification/ Eutrophication	PDF·m^2yr	0.7	0.5	4.8	6.0
Land use	PDF·m^2yr	–11.0	61.4	7.9	58.4
Resources					
Minerals	MJ surplus	–0.24	0.01	0.05	–0.19
Fossil fuels	MJ surplus	7.5	141.0	76.6	225.1
Damage Assessment					
Human Health	DALY·10^6	–1.6	8.3	102	108.7
Ecosystem Quality	PDF·m^2yr	–10.9	62.2	24.5	75.8
Resources	MJ surplus	7.3	141.0	76.7	225.0

species due to an environmental impact. The PDF and PAF values are then multiplied by the area size and the time period necessary for the damage to occur. Damage to R is expressed as the surplus energy for the future mining of resources.

The characterisation step analyses the contribution of the different subsystems to the impact categories, essential to detect the 'hot spots'. The results for the characterisation step and damage assessment are shown in **Table 4**. Carcinogens, Respiratory organics, Respiratory inorganics and Climate change categories exhibited a high contribution in the Board finishing subsystem, which accounts for 93.8% of the damage to HH. The main contribution to these categories was related to energy consumption. Thus, board finishing had the greatest impact on the categories mentioned, as it is the subsystem most dependent on the use of electricity. Negative values shown for the subsystem of wood prepared were the result of using bark for energy purposes. The contribution of the emissions of the gas coming from driers (subsystem of wood prepared) was the most significant contributor to the Ozone layer category with the highest value (91.9%).

In the categories of Ecotoxicity and Acidification/Eutrophication, the subsystem of board finishing had the greatest impact and the Land use category was predominantly affected by the UF manufacture included in the subsystem of board shaping. The board shaping subsystem was a great contributor to the damage to EQ: 82%.

The category of minerals had a minor weight when compared with fossil fuels. Natural gas consumption linked to the manufacture of UF stood for the highest contribution, the most significant being the subsystem of board shaping (62%).

3.2 Particleboard versus biomass fuels

What if wood wastes are used for energy purposes instead of particleboard manufacture?

Particleboard uses forest residues as well as sawdust and small wood particles. Forest, which is a renewable energy resource, is important not only for the environment but also for the energy sector. The use of biomass fuels accounts for 14% of worldwide energy consumption, ranging from 1–3% in industrialised countries and approximately 43% of the primary energy requirements in developing countries [23]. Despite the belief that biomass energy is of a poor quality, statistics have shown the importance of wood fuel in the energy sector [24]. The equilibrium between consumption of natural resources and their regeneration requires a more effective and efficient use of wood, including optimised process technology and products with longer service life and an aptitude for repairing, material recycling and finally incineration with energy recovery [25]. Although reuse and recycling of wood must be encouraged, it is evident that the more the wood is reprocessed, the more restricted its potential applications are. Moreover, the investment of non-renewable energy and material is necessary to restore physical-chemical properties [26].

There is a growing consensus about the suitability of a multicriteria approach when dealing with natural resource management problems and environmental planning, areas in which there are many contradictory interests. Economic-environmental evaluation and decision-making problems are conflicting in their nature, and the attempt to satisfy all criteria becomes complicated. The planning process has turned out to be a very complex matter in technical, physical, social and economic aspects [27]. To define the most adequate use of wood materials, several basic steps must be taken into account: the determination of the availability of the materials and their characteristics as well as the selection of the appropriate technology, the evaluation of market for the product obtained and the assessment of the relative economics.

The mosaic approach breaks the concept of 'sustainable development' into three main components [28]: ecological, economic and social sustainability.

Ecological sustainability. Ecological sustainability has to be assessed from two points of view: the comparison between particleboards and competing materials as well as the comparison between biomass fuels and other energy sources.

Petersen and Solberg (2004) [2] made an extensive review of the environmental and economic impacts of substitution wooden products and alternative materials. In that study, wooden materials had less impact on global warming if they were not landfilled after use. Moreover, they presented advantages regarding energy consumption, emissions of SO_2, waste generation and the use of non-renewable resources.

The environmental effects of alternative and plausible scenarios to obtain energy have to be considered. In previous studies, emissions from wood combustion have been shown to be highly variable and they depend on many factors related to burning conditions, fuels and appliances [29]. Complete combustion is difficult to achieve; thus, during incomplete combustion several by-products are consequently formed including polycyclic aromatic hydrocarbons (PAHs) and particulate matter [30]. Moreover, the formation of markedly hazardous compounds such as dioxins (PCDDs) and other related compounds (PCDFs and coplanar PCBs) was observed [31].

As a first approach, 1 TJ heat obtained from wood versus 1 TJ heat obtained from natural gas was characterised with Ecoindicator 99 methodology in order to compare environmental impact (**Fig. 3**). The inventory data for the analysis were taken from the BUWAL 250 database. Energy obtained from gas appears to be favourable for the categories of Respiratory inorganics, Ecotoxicity and Acidification/Eutrophication. Bearing in mind the damage modelled as the computation of all the individual contributions of the categories, the damage to Human Health and to Ecosystem Quality is more significant when using wood as fuel. The damage to resources, which only considers the categories of Minerals and Fossil fuels, is obviously caused by the use of natural gas. This analysis may be complemented with those from other methodologies such as Exergetic Life Cycle Assessment (ELCA). ELCA uses the same framework as LCA, but the distinctive principle is life cycle irreversibility, the exergy loss during the complete cycle. Exergy is defined as the work potential of a material or a form of energy in relation to its environment and provides a natural basis for assessing the efficiency of resource use and identifying possible trade-offs and cost effective opportunities for conservation. In a recent work, ELCA was used to quantify depletion of natural resources in a case study of different wood waste treatment routes. ELCA showed that the production of chipboard caused less depletion of natural resources than co-combusting wood waste in a coal power plant [33].

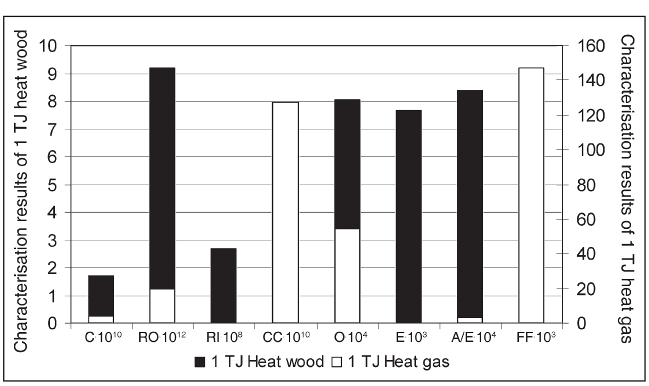

Fig. 3: Comparative characterisation of 1 TJ Heat energy obtained from wood vs. natural gas. **C**: Carcinogens (DALY); **RO**: Respiratory organics (DALY); **RI**: Respiratory inorganics (DALY); **CC**: Climate change (DALY); **O**: Ozone layer (DALY); **E**: Ecotoxicity (PAF·m²yr); **A/E**: Acidification/ Eutrophication (PDF·m²yr); **FF**: Fossil fuels (MJsurplus). % 1 TJ Heat wood; % 1 TJ Heat gas

Economic sustainability. In Spain, all the forest residues, sawdust and small wood particles available for particleboard manufacture are utilised for this purpose. To satisfy the demand for particleboard, chips and wood particles are also imported to complete the demand for raw materials necessary to supply the sector. On the other hand, there are some wood wastes that only can be used for energy purposes: very fine forest slash, bark and sand-down dust. These wastes may be utilised in particleboard manufacture as energy source for the factory. Thus, particleboard manufacture accomplishes a thorough use of wood. Recycling wood waste for particleboard manufacture has an advantageous ratio between investments and benefits when compared to the energy obtained in biomass power plants. According to data from the Energy Institute of Catalonia [34], the cost of extraction and transport of both forest slash and waste from the cleaning of forests rises to 54.1 E/ton and 162.3 E/ton, respectively. The increased, associated value of particleboard allows the affording of this cost. When considering the cost associated to biomass power plants, the system is viable only if public incentives are applied.

Social sustainability. It is necessary to assess how populations, which are forest dependent, use their resources and their long-run viability. There is a need to enhance the understanding of how people depend on, interact with and utilise their local environment for survival. The so-called Sustainable Livelihood is related to capabilities, assets including both material and social resources and activities required for living [35]. The forestry industry represents the 2.5% of the employment sector in the European Union, with 3.7 millions of jobs located in rural areas [36]. Regarding the significant decrease of work suffered in these areas in the last three decades [34], the activity of primary transformation processes in the wood sector is playing a crucial role concerning rural development.

4 Conclusions

The main focus of this work is to create a database to identify and characterise one of the most important wood-based products: particleboards. Special attention was paid to the inventory analysis stage of the particleboard industry because of its relevance as a primary transformation process in the wood sector. The results of the detailed quantification of particleboard manufacture may serve as a basis to evaluate products, their use, recycling and disposal in such a way that the environmental burdens are minimised and reduced to levels that are competitive and may even outperform potential substitutes.

However, particleboard uses forest residues that may also be exploited by the energy sector. When comparing biomass fuels and other energy sources, ecological sustainability seems to be favourable for the use of natural gas instead of biomass. Nevertheless, a comprehensive analytical effort must be made to analyse the emissions from wood combustion as they strongly depend on many factors. Economic and social considerations strengthen the hypothesis that the use of these materials in particleboard manufacture is more sustainable than its use as a fuel.

5 Future Outlook

In this work, particleboard was the product analysed, as it is the one of the most common wood-based materials. Future work will focus on the study of another key wood board: Medium Density Fibreboard (MDF). Moreover, factors with strong geographical dependence, such as the electricity profile and final transport of the product, will be analysed.

In addition, the definition of a widespread functional unit to study the use of wood wastes at the end-of-life stage may be another issue of outstanding interest.

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