Life cycle assessment of wood wastes: A case study of ephemeral architecture

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Abstract

One of the most commonly used elements in ephemeral architecture is a particleboard panel. These types of wood products are produced from wood wastes and they are used in temporary constructions such as trade fairs. Once the event is over, they are usually disposed into landfills. This paper intends to assess the environmental effects related to the use of these wood wastes in the end-of-life stage. The Life Cycle Assessment (LCA) of two scenarios was performed, considering the recycling of wood waste for particleboard manufacture and energy generation from non-renewable resources (Scenario 1) versus the production of energy from the combustion of wood waste and particleboard manufacture with conventional wooden resources (Scenario 2). A sensitive analysis was carried out taking into account the influence of the percentage of recycled material and the emissions data from wood combustion. According to Ecoindicator 99 methodology, Damage to Human Health and Ecosystem Quality are more significant in Scenario 2 whereas Scenario 1 presents the largest contribution to Damage to Resources. Between the two proposed alternatives, the recycling of wood waste for particleboard manufacture seems to be more favorable under an environmental perspective.

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1. Introduction

Wood is the most important renewable material and regenerative fuel (Bowyer, 1995). The management and processing of wood generates a variety of co-products and wastes throughout the wood processing chain, from its cultivation in forests, its extraction, sawing and processing to intermediate and finished products, to its recycling, incineration or final disposal. Co-products and wastes generated are residues from thinning, bark, sawdust, shavings, chips and fibers, side-cuts, wood waste and waste of intermedi-
ate products from wood and wood-based industries (Jungmeier et al., 2002a,b).

It is evident that the huge utilization of wood as raw materials needs an appropriate management as a key action to optimize the use of resources and to reduce the environmental impact associated. Sustainable management of renewable resources is defined in a broad sense. One of the most widely accepted definitions was set up in 1993 by the Ministerial Conference for the Conservation of Forest in Europe: “The stewardship and use of forest and forest land in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, viability and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems” (MCPFE, 1993; 2002).

Based on the concept of sustainability, the equilibrium between consumption of natural resources and their regeneration has to be encouraged. This requires a more effective and efficient use of wood including optimized process technology and products with longer service life and an aptitude for repairing, material recycling and finally incineration with energy recovery (Lafleur and Fraanje, 1997). Reuse, recycling and energetic valorization of wood must be considered since the material characteristics of wood after the utilization phase still allow for a variety of options such as material or energy carriers. However, the more often the wood is reprocessed, the more restricted are its potential applications. Besides, the investment of non-renewable energy and material is necessary to restore physical–chemical properties (Fraanje, 1997).

The Life Cycle Assessment (LCA) methodology has proved to be a valuable tool for documenting and analysing environmental considerations of product and service systems that need to be part of decision-making process towards sustainability (Baumann and Tillman, 2004). LCA has been already considered as an important tool to evaluate the environmental impact of wood related products (Karjalainen et al., 2001). Petersen and Solberg (2003) have published an extensive review of several studies of LCA application to wood related products and, there, wood appears to be not only a better alternative than other materials but also competitive on price as a building material. As the LCA studies have all used common methodology but the system boundaries are different, results are not directly comparable. This fact could be considerably improved if the analyses defines a standard functional unit and special attention is paid to the management of the materials and how carbon fixation on forestland is included (Jungmeier et al., 2002a,b).

The objective of this paper is to assess the environmental issues related to the use of wood wastes derived from a worldwide used wooden product: particle boards. These items are currently used in areas such as carpentry, building, furniture, and decoration, among others. Temporary buildings such as trade fairs often use particle boards as a contemporary form of architecture based on mobility and flexibility noted as ephemeral architecture. In this research study, one representative trade fair was analyzed in detail: the trade fair of Barcelona, with an annual waste generation of 8,000 tons, of which 70–80% are wood waste that are mainly disposed in landfills.

2. Methodology

Life Cycle Assessment (LCA) is compiled of several interrelated components: goal definition and scope, inventory analysis, impact assessment and interpretation (ISO, 2000). SimaPro 6.1, which was designed by Pre Consultant, is the software used in this study (PRé-Consultants, 2004).

2.1. Goal definition and scope

2.1.1. Purpose

The goals of this study were to assess and compare the environmental impacts of end-of-life scenarios of a product using LCA methodology. The two scenarios under study were (Fig. 1):

- Scenario 1: Recycling of wood waste for particleboard manufacture and energy production from non-renewable resources (i.e. natural gas).
- Scenario 2: Energy production from the combustion of wood waste and particleboard manufacture with ordinary wooden resources.

The main objectives considered were the identification and quantification of the most important environmental burdens related to the alternatives under
analysis as a basis to discuss the final disposal of wood waste.

2.1.2. Functional unit

This unit provides a reference to which the inputs and outputs are related (ISO, 2000). The twofold nature of wood, commonly used as renewable material or regenerative fuel, is a key aspect to be considered. System expansion and substitution are first priority strategies for dealing with multifunctional situations. As a consequence of the system expansion, a variety of functions are added up to the functional unit (Jungmeier et al., 2002a,b). Experts from industry stated that a recycling percentage of 30% would have no detrimental effect on the final quality of the board, which would result into a lower consumption of wood raw material from forest operations and sawmill. According to Jungmeier et al. (2002a,b), a widespread functional unit was chosen, considering both the possibility of material use and energy recovery from wood combustion. Therefore, 1 m$^3$ of particleboard with 30% of recycled material (0.42 m$^3$ of wood waste, calculated upon the wood raw materials substituted) in combination with the energy generated if the same quantity of wood waste is burned in a cogeneration unit for energy purposes was the functional unit selected: 1 m$^3$ of particleboard along with 260 kWh of electricity and also 1570 kWh of heat.

2.1.3. System boundaries

This term is defined as the interface between the product system and the environment or other product systems (ISO, 2000). The system expansion allows the definition of an extensive functional unit that, in this study, can be delimited using allocation according to one type of material use and energy from the wood combustion (Jungmeier et al., 2002a). The two scenarios are described in Fig. 2, including their different subsystems. Depending on data availability, a process analysis or an economic input–output approach was considered to define the subsystems under study. In both scenarios, the previous activities of manufacture and use related to ephemeral architecture are assumed not to affect to the environmental burdens considered as we are studying an end-of-life phase (Boughton and Horvath, 2004). Infrastructures were not taken into account according to the principle of excluding identical activities for comparative assessments (Consoli, 1993; Werner et al., 1997; Jungmeier et al., 2002a).

Scenario 1 includes the following subsystems:

- Collection of wood waste. The consumption of the forklift truck necessary for recollecting activities was computed with an average value of 3.2 L of fuel per ton collected.
- Transport and crushing. Wood waste has to be crushed and transferred for further processing. Three alternatives were here considered (Fig. 3): Option A represents the existing management of the fair, that is to say, transport of the waste to a recovery center in a semitrailer, off site crushing and final transport for further processing; Option B, proposed as an improvement action, takes into consideration the on site crushing and its further trans-
port to be recycled or used as an energy source; Option C considers the transport of the waste to be crushed and processed in the particleboard or cogeneration plant. It is remarkable that the size of particle required for the recycling process is different from the required size for cogeneration, although there are not significant differences in the energy consumption.

- Forest activities I. The environmental loads associated to both industrial wood and industrial residue wood were considered according to Ecoinvent database (Werner et al., 2003). The consumption of wood per m³ particleboard is around 1.39 m³ of wood materials. As Scenario 1 considered a 30% of recycled material from ephemeral architectural, the inventory data entail the activities related to 0.67 m³ of industrial wood and 0.30 m³ of industrial residue wood, whereas 0.42 m³ of wood waste from the fair fulfils the requirements of raw materials.

- Particleboard processing I. A particleboard is made from small discrete wood elements with a water-resistant adhesive binder (usually urea formaldehyde), mainly for indoor uses in which boards are neither exposed to high temperatures nor moisture (ANSI, 1993). The inputs and outputs related to the particleboard manufacture computing wood waste materials were included in the analysis.

- Conventional energy. The comparison of the scenarios requires the consideration of an equal energy generation in both scenarios. Based on the energy generation from the incineration of the waste wood flow (combustion of 0.42 m³ of wood waste), the cogeneration of 260 kWh of electricity plus 1570 kWh was considered using natural gas as fuel.

Scenario 2 comprises the following subsystems:

- Collection of wood waste. As it was previously defined in Scenario 1.
- Transport and crushing. As it was previously defined in Scenario 1.
- Forest activities II. As defined in Scenario 1, 0.96 m³ of industrial wood and 0.43 m³ of industrial residue wood were considered.
Particleboard processing II. The inputs and outputs related to conventional particleboard manufacture were included in the analysis. According to experts from industry, no significant differences related to energy and additives consumption as well as emissions from the process were found between particleboard processing I and II.

Bioenergy. A typical combined heat and power plant (CHP) operating with biomass were considered, with a standard ratio of electricity/heat of 1:6. The cogeneration of 260 kWh of electricity plus 1570 kWh from wood waste combustion was considered.

2.1.4. Data quality

All the data related to the consumptions of the subsystems of wood waste collection, transport and crushing were obtained from the company, which manages the wood waste from the Barcelona fair. The assignment of the environmental loads associated to these consumptions was made according to Kellenberger et al. (2003) and Spielmann et al. (2003). The subsystems linked to forest activities, particleboard manufacture and energy cogeneration scenarios are inventoried using data from the Ecoinvent database (Werner et al., 2003; Frühwald et al., 1996; Frühwald et al., 2001). The particleboard considered is for indoor use and includes the inputs to the production processes, transport of those inputs and the process emissions (Werner et al., 2003).

The electricity profile is of major importance as it broadly affects the environmental impacts assigned to energy-consuming steps. The assignment of the environmental loads associated to the different sources of electricity was made from BUWAL 250 database (1996). According to data from the Institute for Diversification and Energy Saving (Spain): 35.8% of the electricity is produced from coal, 27.6% is nuclear, 13.9% is hydroelectric, 9.9% is obtained from oil power plants, 9.7% from gas power plants, 2.2% from wind power plants, 0.6% from waste use and 0.3% from biomass use (IDAE, 2004).
2.1.5. Allocation

Allocation is the apportioning of the input or output flows of a unit process to the product system under study (ISO, 2000). The wood residues from the trade fair, as they are considered waste from other activities, have no environmental burden allocation from previous processes and only their transport and further processing were computed. Residues in forest and in the wood industry taken into account for particleboard manufacture, referred here as industrial wood waste, are in fact by-products that can be used as raw materials and fuel (i.e. edgings and chips coming from sawmill). An economic allocation from Ecoinvent database considering the wood resource, CO2 absorption from air and the energy in biomass is used to assign the proper mass, energy and CO2 uptake from nature (Werner et al., 2003). It is remarkable that allocation according to monetary value has the fundamental disadvantage that market prices for forest products have a very volatile variation over time, so it must be revised according to the short-term market disturbances.

2.1.6. Sensitivity analysis

To estimate the variability of the results obtained, two suppositions were considered:

- Proportion of recycled material. Different percentages of recycled material from 10% to 50% were considered with the subsequent modifications of the inventory data associated to the flows of raw materials substituted.
- Emissions data from wood waste combustions. There are various technical possibilities of energy generation from wood waste. Those aspects to be taken into account for the analysis are the conversion efficiency from fuel to electricity and/or heat, the electricity/heat ratio, emissions to air (flue gas cleaning system) and ash treatment (Jungmeier et al., 2003). Three alternatives were analyzed considering the effect of the cogeneration plant scale and the emissions to air. Bioenergy A involves a cogeneration unit of 6400 kWth (option selected in Scenario 2). The same unit is proposed in the Bioenergy B scenario with a stricter control of emissions (filter for particulate matter and selective non-catalytic reduction for NOx). Bioenergy C corresponds to a cogeneration unit of 1400 kWth.

2.2. Life cycle inventory

Life Cycle Inventory (LCI) analysis involves the collection and computation of data to quantify relevant inputs and outputs of a product system, including the use of resources and releases to air, water and land associated with the system (ISO, 2000). The inventory data were collected for each process unit included within the system boundaries. Data sources are indicated in the data quality sub-section and they are detailed in the results and discussion section.

2.3. Impact assessment

Impact assessment is a technical, quantitative and/or qualitative process to characterize and assess the effects of the environmental burdens identified in the Inventory (Consoli, 1993). Damage oriented impact assessment methodology has received attention in recent years (Goedkoop and Spriensma, 2000; Hertwich and Hammitt, 2001; Seppälä and Hämäläinen, 2001; Erlandsson and Lindfors, 2003). This approach provides not only characterization (potential impacts of impact categories such as climate change), but also damage assessment for safeguard subjects such as human health (Goedkoop et al., 1998). This impact assessment was performed with the Ecoinvent 99 methodology, which reflects the state of art in LCA (Itsubo, 2002). The inventory data are assigned to categories that represent basic environmental issues. Three conditions affecting human and environment are considered: Human Health (HH), Ecosystem Quality (EQ) and sufficient supply of Resources (R). Modeling and estimation of an environmental indicator for each category or issue are completed. 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 species due to an environmental impact. The PDF and PAF values are then multiplied by the area size and the time period to obtain the damage. Damages to R are expressed as the surplus energy for the future mining of the resources.

2.4. Interpretation

The interpretation phase may involve the iterative process of reviewing and revising the scope of the
LCA, as well as the nature and quality of the data collected consistent with the outlined goal (ISO, 2000).

3. Results and discussion

3.1. Life cycle inventory

The wood waste collection in the fair reveals a consumption of 3.2 L diesel per ton collected. The main data of the subsystem covering transport and crushing activities are summarized in Fig. 3. Option A entails the transport of wood waste to a recovery plant, located 25 km far from the fair, by trucks with an average load of 2.5 tons; the wood waste is crushed with an electrical grinder and further transported an average distance of 100 km to the particleboard factory or the cogeneration unit by truck with an average load of 17 tons. The proposed Option B comprises a transportable grinder with a processing capacity of 100 tons a day, the consumption of crushing and transport of the grinder covering a round trip of 50 km. In this case, crushed wood is transported to the same destination that Option A (100 km approximately) by trucks with an average load of 17 tons. Option C entails the direct transport of wood waste to the particleboard factory or the cogeneration unit by truck and further crushing there with an electrical grinder. The wastes coming from the crushing operation, mainly plastics, represent only the 3% of the main flow. Emissions generated in the landfill are not considered since they do not significantly modify the global results (Werner et al., 1997). Moreover, equal amounts of waste of the same composition are treated in all scenarios, so the environmental burdens associated to their treatment can be rejected according to the principle of excluding identical activities for comparative assessments (Consoli, 1993; Raynolds et al., 2000; Boughton and Horvath, 2004).

It is assumed that wood particles for conventional particleboard manufacture have to be taken from forestry and sawmill to satisfy the present demand of the particleboard industry (industrial wood and industrial residue wood, respectively). Emissions from the associated activities were considered as well as the environmental burdens allocated to edgings and chips proceeding from sawmill. It is noteworthy that the combustion of wood under a sustainable wood production might be CO₂-neutral, but not CO₂-free. Energy generation avoids natural oxidation (respiration) of biomass by emitting the same amount of CO₂; therefore in a 50-years scenario the carbon cycle might be closed (Jungmeier et al., 2003).

Wood combustion emissions have been shown in previous studies to be highly variable and dependent on many factors related to burning conditions, fuels and appliances (McDonald et al., 2000). Complete combustion is difficult to obtain and it is rarely achieved; during incomplete combustion several harmful byproducts can be formed including polycyclic aromatic hydrocarbons and particulate matter (Kralovec et al., 2002). Moreover, there have been many reports on formation of dioxins and dioxin-like compounds (polychlorinated dibenzo-furans) (Yasuhara et al., 2003). In this work, the module of inventory data for bioenergy describes the combustion of wood chips, including the infrastructure, the wood input, the emissions to air, the transport of fuel and the disposal of ashes. Inventory data also include the substances needed for operation: lubricating oil, urea, organic chemicals, sodium chloride, chlorine and free-CO₂ water. Data from Ecoinvent database have been considered to inventory cogeneration alternatives in order to make feasible a revision for all the readers (Werner et al., 2003); nevertheless the complexity of wood combustion should involve a more detailed and specific analysis of the operational conditions.

3.2. Transport and crushing: on site vs. off site

Fig. 4 shows the environmental fingerprint of options A, B and C. The diagram represents a comparative analysis of the environmental advantages and disadvantages of the three alternatives. For each category, the characterization values were obtained and they are relatively compared, assigning a value “1” to the least favorable alternative in the category under analysis. The possibility of crushing the wood waste in the particleboard or cogeneration plant involves a high capacity of transport, which leads to higher environmental burdens in all the categories analyzed. When comparing options A with B, it is observed that, with the exception of the category of Ozone Layer, the results obtained show a significant improvement in the environmental performance of transport and crush-
ing activities when Option B is considered (from 57% to 80% for the categories analyzed). This fact is explained in simple terms by the saving of diesel in transport when the waste is crushed before being transported. The use of electricity as energy source for crushing would improve the environmental performance but the available mobile grinder consumes diesel as fuel.

The Option B, corresponding to the optimized subsystem of "transport and crushing", is suitable for both Scenario 1 and 2; thus, it is the option that will be further considered in the next section.

### 3.3. Scenario 1 vs. scenario 2

The analysis of the contribution of the different subsystems to the impact categories is required to detect the “hot spots”. According to the accepted LCA protocol of Ecoindicator 99, a methodical procedure for classifying and characterizing the types of environmental effects of each element was performed and potential environmental impacts were assessed (Goedkoop and Spriensma, 2000; Rivela et al., 2004).

The results for the characterization step are shown in Fig. 5. Considering the damage assessment as the computation of all the individual contributions of the categories, damage to Human Health is related to the categories of Carcinogens, Respiratory organics, Respiratory inorganics, Climate change, Radiation and Ozone layer; damage to Ecosystem Quality is associated to the categories of Ecotoxicity, Acidification/Eutrophication and Land use and damage to Resources is related to the categories of Minerals and Fossil fuels. The damage to Human Health is considerably higher in Scenario 2 (1.9 \cdot 10^{-4} \text{ DALY} in Scenario 1 and 5.9 \cdot 10^{-4} \text{ DALY} in Scenario 2). The damage to Ecosystem Quality is also favorable to Scenario 1 (37.3 PDF m^2 year for Scenario 1 vs. 74.2 PDF m^2 year for Scenario 2). On the other hand, Scenario 1 presents the largest contributions of damage to Resource (782 MJ surplus in Scenario 1 and 456 MJ surplus in Scenario 2).

The contribution of the different subsystems to the total impact of each Scenario was analyzed in detail. The subsystems of “wood collection” and “transport and crushing” are common for both scenarios and present a minor contribution to the overall impact in most of the categories analyzed (under 10%); only the contributions of two categories are relevant: Ozone Layer (47.9% in Scenario 1 and 40.8% in Scenario 2) and Acidification/Eutrophication (25.6% in Scenario 1 and 14.6% in Scenario 2). The main differences between the scenarios are explained by the reduction of the environmental impact caused by forest activities.
in Scenario 1. However, it is remarkable that the use of natural gas for energy purposes instead of wood in Scenario 1 turns into a significantly higher value for the category of Fossil fuels.

In order to discuss the obstacles and limitations of this work, a sensitive analysis was carried out.

### 3.3.1. Wood recycling ratios

Technologies available for recycling management were studied in order to establish the most adequate level of recycling. A percentage of 30% was selected as the representative of value considered in industry, but different percentages in a range of 10–50% were analyzed to evaluate the effect of this supposition.

The results obtained for the characterization step of Scenario 1 exhibit a minor influence of this topic for most of the categories studied with a deviation lower than 5%. Obviously, the new scenarios have different inputs of natural gas, according to the energy generated in each case if the same quantity of wood waste

![Diagram](image-url)

**Fig. 6.** Climate Change and Land Use Deviation results for characterization in relation to percentage of material recycled (reference scenario: 30% material recycled). Symbols: (▲) Climate Change; (■) Land Use.

### Table 1

Characterization data of different scenarios for energy generation from 0.42 m$^3$ of wood waste

<table>
<thead>
<tr>
<th>Characterization step</th>
<th>Category</th>
<th>Unit</th>
<th>Bioenergy A</th>
<th>Bioenergy B</th>
<th>Bioenergy C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage assessment</td>
<td>Carcinogens</td>
<td>DALY-$10^5$</td>
<td>4.40</td>
<td>4.43</td>
<td>4.76</td>
</tr>
<tr>
<td></td>
<td>Respiratory organics</td>
<td>DALY-$10^7$</td>
<td>1.27</td>
<td>1.28</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>Respiratory</td>
<td>DALY-$10^4$</td>
<td>3.37</td>
<td>1.01</td>
<td>7.60</td>
</tr>
<tr>
<td></td>
<td>Inorganics</td>
<td>DALY-$10^5$</td>
<td>1.48</td>
<td>2.43</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>Climate change</td>
<td>DALY-$10^7$</td>
<td>1.49</td>
<td>1.51</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>DALY-$10^9$</td>
<td>2.27</td>
<td>2.38</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>Ozone layer</td>
<td>PAF-m$^2$yr</td>
<td>162.00</td>
<td>163.00</td>
<td>175.00</td>
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<tr>
<td></td>
<td>Ecotoxicity</td>
<td>PDF-m$^2$yr</td>
<td>5.00</td>
<td>4.94</td>
<td>6.50</td>
</tr>
<tr>
<td></td>
<td>Acidification/</td>
<td>Eutrophication</td>
<td>PDF-m$^2$yr</td>
<td>15.40</td>
<td>15.50</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
<td>MJ surplus</td>
<td>0.96</td>
<td>0.98</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>Minerals</td>
<td>MJ surplus</td>
<td>19.40</td>
<td>20.50</td>
<td>23.00</td>
</tr>
<tr>
<td></td>
<td>Fossil fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage assessment</td>
<td>Human health</td>
<td>DALY-$10^4$</td>
<td>4.0</td>
<td>1.7</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Ecosystem quality</td>
<td>PDF-m$^2$yr</td>
<td>36.7</td>
<td>36.8</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td>Resources</td>
<td>MJ surplus</td>
<td>20.3</td>
<td>21.5</td>
<td>24.5</td>
</tr>
</tbody>
</table>
used in the particleboard manufacture was burned in a cogeneration unit; thus, characterization results for the category of Fossil Fuels vary from 80.7 to 656.0 MJ surplus. Moreover, two categories show a significant effect of recycled percentage: Climate Change and Land Use. Fig. 6 represents the variation (difference in relation to a scenario with 30% of recycled material) of the characterization results according to the percentage of recycled material considered. Increasing the percentage of recycled material increases the consumption of natural gas as well as reduces the assimilation of CO$_2$ from atmosphere from the raw materials substituted, worsening the results of the Climate Change category. On the other hand, Land Use category improves with the increase in recycling.

3.3.2. Effect of energy emissions

The results from the characterization step of the three alternatives considered for the subsystem of Bioenergy (cogeneration of 260 kWh of electricity plus 1570 kWh of heat from wood waste combustion) are shown in Table 1. The control of emissions coming from the combustion system (Bioenergy B) reduces considerably the damage to Human Health (by decreasing the impact of the category of Respiratory inorganics) as well as the damage to Ecosystem Quality presents nearly the same value that the subsystem of Bioenergy A. The reduction in the scale of the cogeneration plant studied in Bioenergy C increases all the damages modeled. Even more the reduction in the scale plant increases the environmental impact associated to combustion, thus, scattered smaller plants result in lower net transportation impacts. A large regional grinding plant and a large cogeneration versus small cogeneration units with transportable grinder system must be compared to define the best option for particular situations.

4. Conclusions

This paper provides comprehensive data to assess the environmental issues related to wood waste use. The twofold nature of wood was taken into account by considering wood as renewable material and regenerative fuel in the definition of the functional unit. The reduction in the consumption of diesel in transport when the waste is crushed before being transported leads to a significant reduction of the environmental burdens of the process. As a first approach, the recycling of the wood waste for particleboard manufacture seems to be more favorable from an environmental point of view. In this sense, alternative renewable energies should be encouraged to avoid damage to resources.

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