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Life Cycle Assessment for particleboards with recycled wood in an industrial context

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Abstract. The issue of depletion of natural resources carries side effects on human health, the ecosystem, and the planet itself. It is necessary to develop mitigation policies to reverse the actual climate trend. Both actions on small and large scales can make a relevant contribution to that problem. This paper aims to investigate two different approaches of the Life Cycle Assessment in an industrial context, in particular "ex-post" LCA is carried out for particleboards manufactured by a company using 100% recycled wood, while "ex-ante" LCA study is referred to a hypothetical particleboard manufactured equally to the previous product, but using 100% virgin wood, instead of recycled. The outcomes of the comparison of the two LCAs highlights that there are very relevant aspects to take into consideration when the environmental performance of a product is evaluated. In fact, CO2 emissions, which are one of the most concerning environmental impacts nowadays, and which is also orienting European policies, are not the only indicator that affect the impacts related to the human health, the natural environment, and the natural resources. The LCA tool is a complete tool capable to provide all-round environmental impacts of the studied object; in this research the results from the comparison of the two products' LCA, pointed out how the "land use" increases in the case of the product made with only virgin wood, which is more than 20 times superior compared to the "land use" in the case of particleboard containing 100% recycled wood. The application of the two LCAs is structured on "cradle to gate" system boundary to highlight the impacts of the production process. For both ex-ante and ex-post application an interpretation is conducted to evidence their benefits, but with awareness of possible limits when they are utilized.

Keywords: life cycle approach, service life, circularity, environmental impacts, recycled wood, particleboards, alternative materials

1. Introduction

The concern about climate change is challenging researchers and companies to find more sustainable alternatives for products and processes. A quantification of environmental impacts is increasingly needed to analyze the possible actions aiming at improving environmental performance. The impacts can be quantified considering many different factors, for instance resource depletion, land use, greenhouse gas (GHG) emissions and the possible consequences on the ecosystem, the human and environmental health. Europe is orienting restrictive laws and plans to prevent social, economic and healthcare crises which are a potential result of climate change and its consequences on the global environment, economy and population. For example, the European Green Deal [1] shows the possibilities

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for future European scenarios in terms of climate mitigation, in which one of the most challenging goals is to reach zero GHGs emissions no later than 2050 and adopts policies with a scope of at least 55% (considering the 1990 level) reduction of GHGs before within the 2030. This kind of agreements and regulation this intend to engage different industrial and productive fields, and also the building sector shall provide adaptation to comply with European trends. The building sector, in fact, is responsible for 37% of overall GHGs emissions [2]. It has shown a strong development during the last decades, related to the urbanization phenomenon [3], which caused an expansion of cities and a rise in demand for bigger buildings that allowed more people to live less spread. This increased the demand for the construction of new buildings. Due to that, the sector started to use materials that nowadays are classified as "conventional"; in particular, reinforced concrete and steel because of their versatility and their mechanical performance. This phenomenon led to a massive depletion of resources, and this is one of the main reasons that drives the global need to estimate the environmental impact of existing products and take into consideration the impacts that a new product or a change in existing ones can have. Currently, the application technologies improved a lot and maximize the processes of production already consolidated. This is why more than ever it is the time to prioritize the environmental problems and find solutions to mitigate them, using precise and measurable actions, opting for product with lower environmental impacts in buildings as well as the construction sector.

The choice of materials has a huge impact on this value, by using components with a lower environmental impact in their whole life cycle and minimizing the waste production during the processes, the pollution environmental performances can be improved. The environmental sustainability of a product or a process is mainly associated with its CO2 emissions, but multiple aspects may be taken into consideration when industrial processes and products are created and their environmental effects are estimated. The Life Cycle Assessment is a tool that provides a detailed description of environmental impacts using 16 main impact categories, and sub-indicators for some of them [4,5]. For instance, following the Environmental Footprint (EF) 3.0 method, CO2 emissions with LCA can be more specifically classified into three different sub-categories which address the specific emissions of fossil, biogenic and land use change. The LCA can suit both ex-ante and ex-post applications on processes and products [6], it is used for Environmental Product Declarations (EPDs).

In this paper the LCA is applied ex-post to an existing particleboard manufactured by an Italian company using 100% recycled wood, in order to estimate its environmental impacts. An alternative scenario ex-ante introduces the hypothesis of the use of virgin wood instead of recycled, without interfering with the production process. The LCAs show how it can be applied; not only as a tool for estimation, but also as an orienting tool for decision-makers.

2. Materials and Methods

2.1. Specifics of the Life Cycle Assessment

The LCA study is conducted following the actual standards EN ISO 14040:2006+A1:2020 [7] and EN ISO 14044:2006+A2:2020 [8] on an existing product manufactured by an Italian company and on a possible variation of it. According to the standards, the investigation focuses on the four main phases of LCA:

- Goal and scope definition;
- LCI – Life Cycle Inventory;
- LCIA – Life Cycle Impact Assessment;
- Interpretation.

LCA can be used not only to quantify the actual company's product environmental impact and the main factors that influence its sustainability, but also to predict how a change in the product's input may affect its environmental performance. LCA can be considered a tool that can give inputs ex-post, as its usual applications, or ex-ante [9], which can bring innovation and orient decision-makers and build possible future scenarios. The impact is quantified by taking into account the categories defined by the Joint Research Centre (JRC) in the dedicated technical report about the characterization factors of recommended Environmental Footprint (EF) LCIA 3.0 methods [10].

2.2. Object of the LCA ex-post study

The starting product is a raw chipboard composed using 100% recycled wood, which is collected especially in the North of Italy with a dedicated network system coordinated by the manufacturer company itself. The binder used is made with urea and formaldehyde, in particular formaldehyde comes as a result of an internal factory process. The average (water) moisture of the finished product is 5% and the density is 692 kg/m^3 (Figure 1). The reference year chosen to collect data from the company is 2023, in order to have the most recent finished year which is not affected by anomalies in terms of production flow. COVID-19 affected a lot the production and the market in certain periods from 2020 to 2022. Data gathered for the analysis come from direct information from the company's members and documents. Because of the many sites that compose the company and their slight difference in processes, inputs and outputs, it is opted to investigate only one specific site, located in Italy in the province of Pavia. The functional unit of the system declared is "1m^3 of raw panel with an average density of 692 kg/m^3 manufactured in 2023 in the site in the province of Pavia (Italy)".

Figure 1. Raw panels object of the study retrieved from https://www.saviola.com/prodotti/custom-tech/pannelli/grezzi.html

2.3. Impact Assessment development

The approach used for the LCA study, according to the standard BS EN 15804:2012+A1:2013 [4] is "Cradle to gate" considering the "product stage" (modules A1-A3 defined by the standard [4]). The software used for the study is Mobius supplied by Ecochain, using the method EF 3.0 (EcoInvent version 3.8 Cut-Off), without considering long-term emissions (beyond 100 years).

Two LCA are conducted with the intention to have the state of the art of the company's product (particleboard with 100% recycled wood), which is a classical ex-post approach. It analyzes an identical product with an identical manufacturing process, but using 100% virgin wood, instead of recycled wood. The second scenario aims to give a reliable iterative output that quantifies, in terms of environmental performance, how a transformation in the product affects its total impacts. This use of LCA intends to support decision-makers by creating a recurring trial and error process, in particular this case has the features of a consequential assessment [9] starting from an existing product. It is worth also mentioning that the recycled wood used by the company would be otherwise disposed as waste. This is a crucial aspect of the circularity of raw materials which does not happen in the case of the virgin wood particleboard. The company also provides a dedicated network responsible for the collection of recycled wood.

3. Results

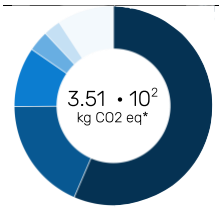
3.1. Impact categories (LCIA output)

The LCA results for 1 m^3 of raw particleboard manufactured in 2023 (Table 1) show that the main factors of impact are the fossil resource use, the ecotoxicity of freshwater (divided into its sub-categories) and, with lower values, the land use, the climate change and the water use. In particular, Table 1 shows that the main impact of all the impact categories is given by the use of urea-formaldehyde as binder for the particleboards. Table 2 represents a possible different scenario in which virgin wood is used instead of recycled wood, as a replacement, without changing the process, but excluding the cleaning process required for

recycled wood. The results in term of kilograms of CO_2 equivalent in Climate change are reported in Chart 1 and Chart 2, which are the sum of the respective values in Table 1 and Table 2, do not show significant differences.

Chart 1. Breakdown of highest contributors in impact category *climate change* of 1m³ of raw particleboard with *100% recycled wood* – GMS method:

Raw material – UF binder	56.5 %
Raw material – Recycled wood	18.4 %
Electric energy – Mat press	9.7 %
Transport – Urea	3.4 %
Raw material – Ammonium sulphate	2.8 %
Other	9.2 %



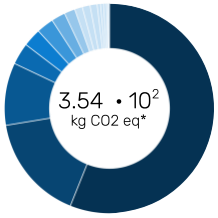
Made with Mobius
mobius.ecochain.com

*Method: EF 3.0 Method Ecoinvent version 3.8 Cut-Off

modules A1-A3

Chart 2. Breakdown of highest contributors in impact category *climate change* of 1m³ of raw particleboard with *100% virgin wood* – GMS method:

Raw material – UF binder	56.5 %
Raw material – Virgin wood	16.3 %
Electric energy – Mat press	9.6 %
Transport – Urea	3.4 %
Raw material – Ammonium sulphate	2.8 %
Transport – Paraffin emulsion	2.7 %
Transport – Virgin wood	2.2%
Transport – Ammonium sulphate	1.7%
Other	5.4 %



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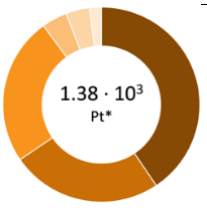
*Method: EF 3.0 Method Ecoinvent version 3.8 Cut-Off

modules A1-A3

In spite of kg of CO_2 eq. emissions outcomes, the use of LCA highlights a significant difference in terms of land use indicator (Chart 3 and Chart 4). More specifically, the indicator is increased 23.4 times when virgin wood is used; this outcome shows that the use of virgin wood has a weight of 96% in the overall contributions. The results come mainly from the need of space for tree planting which LCA takes into consideration in evaluations.

Chart 3. Breakdown of highest contributors in impact category *land use* of 1m³ of raw particleboard with *100% recycled wood* – GMS method:

Raw material – UF binder	40.6 %
Raw material – Recycled wood	24.9 %
Heat production – Wood chips burning	24.5 %
Electric energy – Mat press	4.2 %
Raw material – Ammonium sulphate	3.9 %
Other	1.9 %



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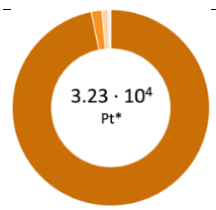
*Method: EF 3.0 Method Ecoinvent version 3.8 Cut-Off

modules A1-A3

Chart 4. Breakdown of highest contributors in impact category *land use* of 1m³ of raw particleboard with *100% virgin wood* – GMS method:

Raw material – Virgin wood	96.8 %
Raw material – UF binder	1.7 %
Heat production – Wood chips burning	1.0 %
Other	0.4 %



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*Method: EF 3.0 Method Ecoinvent version 3.8 Cut-Off

modules A1-A3

Table 1.

Life Cycle Stages and Modules from EN 15804 "product split" (cradle to gate system boundaries) of raw particleboard 692kg/m^3 with 100% recycled wood - GMS method

	Item	Type	Amount per **1m^3 of panel**	Unit	**Acidification** [mol H+ eq]	**Climate change** [kg CO2 eq]	**Climate change** - Biogenic [kg CO2 eq]	**Climate change** - Fossil [kg CO2 eq]	**Ecotoxicity, freshwater** [CTUe]	**Ecotoxicity, freshwater** - inorganics [CTUe]	**Ecotoxicity, freshwater** - metals [CTUe]	**Ecotoxicity, freshwater** - organics [CTUe]	**Eutrophication, marine** [kg N eq]	**Eutrophication, terrestrial** [mol N eq]	**Ionising radiation** [kBq U-235 eq]	**Land use** [Pt]	**Photochemical ozone formation** [kg NMVOC eq]	**Resource use, fossils** [MJ]	**Water use** [m3 depriv.]
A1- Raw material supply	Ammonium sulphate	Raw material	5,28	kg	4,26E-02	9,90E+00	1,03E-02	9,89E+00	1,98E+02	1,67E+01	1,80E+02	7,94E-01	5,62E-03	6,70E-02	2,20E-01	5,38E+01	2,23E-02	1,43E+02	7,41E-01
	Paraffin emulsion		5,86	kg	3,15E-02	3,87E+00	1,42E-02	3,85E+00	5,03E+01	3,28E+00	4,67E+01	3,10E-01	5,37E-03	5,99E-02	5,10E-02	1,24E+01	2,05E-02	3,01E+02	2,86E+00
	Recycled wood		918,97	kg	1,80E-01	6,47E+01	4,44E+01	2,03E+01	3,64E+02	1,04E+02	2,37E+02	2,24E+01	8,62E-02	8,30E-01	9,83E-01	3,43E+02	2,57E-01	2,77E+02	-1,97E+00
	UF binder		85,14	kg	9,76E-01	1,98E+02	2,01E-01	1,98E+02	3,05E+03	5,75E+02	2,42E+03	5,49E+01	1,50E-01	2,23E+00	5,25E+00	5,60E+02	5,74E-01	5,09E+03	3,50E+02
A2 - Transport	Ammonium sulphate	Truck 40/44 tons	96	km	3,65E-02	5,86E+00	0,00E+00	5,86E+00	1,68E+00	3,61E-01	1,27E+00	4,77E-02	1,50E-02	1,65E-01	9,07E-02	0,00E+00	4,11E-02	0,00E+00	-4,63E-02
	Paraffin emulsion		153,5	km	5,84E-02	9,37E+00	0,00E+00	9,37E+00	2,69E+00	5,78E-01	2,04E+00	7,63E-02	2,39E-02	2,64E-01	1,45E-01	0,00E+00	6,58E-02	0,00E+00	-7,41E-02
	Recycled wood		125	km	4,76E-02	7,63E+00	0,00E+00	7,63E+00	2,19E+00	4,71E-01	1,66E+00	6,22E-02	1,95E-02	2,15E-01	1,18E-01	0,00E+00	5,36E-02	0,00E+00	-6,03E-02
	Urea		194	km	7,39E-02	1,18E+01	0,00E+00	1,18E+01	3,40E+00	7,31E-01	2,58E+00	9,65E-02	3,02E-02	3,34E-01	1,83E-01	0,00E+00	8,31E-02	0,00E+00	-9,36E-02
A3 - Manufacturing	Mat press	Electric energy	131,27	KWh	4,73E-01	3,40E+01	1,91E-02	3,40E+01	2,96E+02	7,78E+01	1,89E+02	2,86E+01	2,09E-01	2,29E+00	1,97E+00	5,77E+01	5,99E-01	4,56E+02	4,25E-01
	Panel cutting		3,74	KWh	1,35E-02	9,69E-01	5,43E-04	9,69E-01	8,42E+00	2,22E+00	5,39E+00	8,14E-01	5,95E-03	6,52E-02	5,61E-02	1,65E+00	1,71E-02	1,30E+01	1,21E-02
	Wood chips drying		2,87	KWh	1,03E-02	7,44E-01	4,17E-04	7,43E-01	6,46E+00	1,70E+00	4,14E+00	6,24E-01	4,56E-03	5,00E-02	4,30E-02	1,26E+00	1,31E-02	9,96E+00	9,29E-03
	Wood chips burning	Heat production	100	kg	3,09E-02	1,85E+00	2,66E-02	1,82E+00	2,11E+02	3,44E+00	2,08E+02	4,72E-01	1,25E-02	1,41E-01	6,91E-02	3,39E+02	3,56E-02	2,33E+01	1,39E+00
	Aluminium + brass	Waste	1,26	kg	3,49E-04	5,31E-02	1,65E-04	5,29E-02	7,81E+02	1,91E+00	7,79E+02	2,29E-02	8,64E-05	9,64E-04	2,63E-03	9,45E-01	2,85E-04	7,55E-01	1,84E-02
	Iron		1,5	kg	7,85E-05	1,34E-02	5,83E-06	1,34E-02	1,64E-01	4,21E-02	1,09E-01	1,21E-02	2,84E-05	3,13E-04	8,99E-04	1,73E-01	8,87E-05	2,05E-01	7,24E-04
	Plastic		0,52411	kg	2,08E-04	5,98E-01	4,64E-05	5,98E-01	1,73E+00	1,15E+00	5,68E-01	1,27E-02	1,24E-04	9,47E-04	8,34E-04	1,69E-01	2,59E-04	2,52E-01	2,94E-02
	Sand		0,32	kg	9,52E-06	1,03E-03	2,33E-06	1,02E-03	1,27E-02	2,02E-03	9,97E-03	6,99E-04	3,75E-06	4,12E-05	4,98E-05	7,10E-02	1,20E-05	1,28E-02	2,11E-05
	Wood chips		22,42	kg	4,22E-03	1,50E+00	1,00E+00	4,98E-01	8,81E+00	2,75E+00	5,58E+00	4,85E-01	2,06E-03	1,85E-02	2,87E-02	9,91E+00	5,53E-03	7,67E+00	3,15E-02

Table 2.

Life Cycle Stages and Modules from EN 15804 "product split" (cradle to gate system boundaries) of raw particleboard 692kg/m^3 with 100% virgin wood - GMS method

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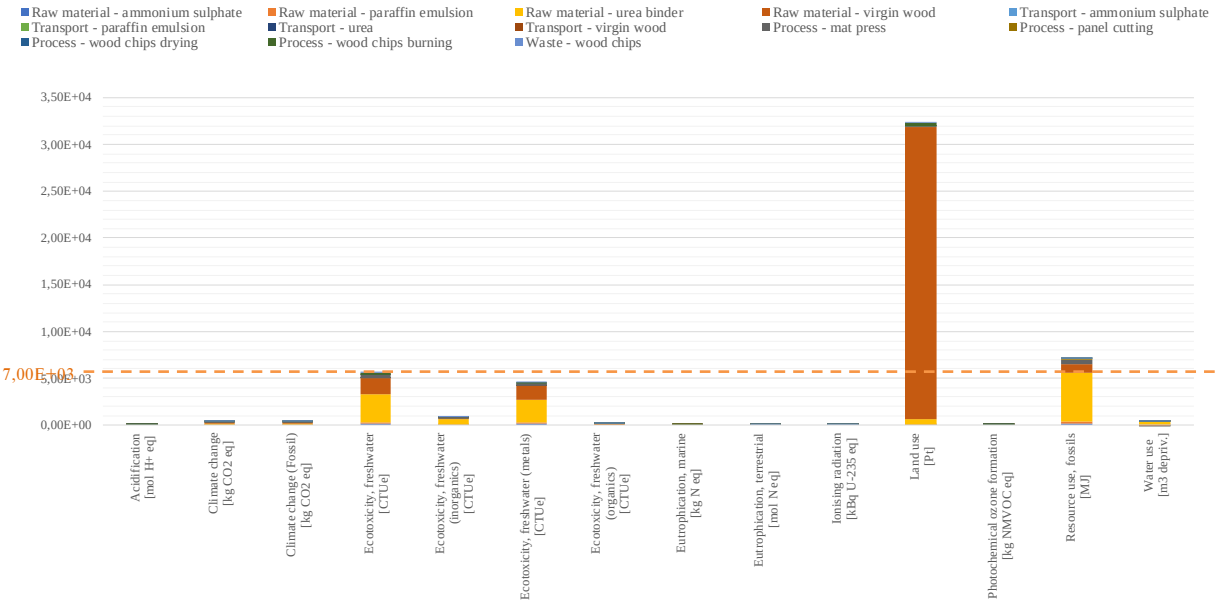
	Paraffin emulsion		5,86	kg	3,15E-02	3,87E+00	1,42E-02	3,85E+00	5,03E+01	3,28E+00	4,67E+01	3,10E-01	5,37E-03	5,99E-02	5,10E-02	1,24E+01	2,05E-02	3,01E+02	2,86E+00
	Virgin wood		918,97	kg	4,35E-01	5,78E+01	3,02E-01	5,71E+01	1,75E+03	1,62E+02	1,54E+03	5,16E+01	1,36E-01	1,54E+00	5,39E+00	3,13E+04	4,76E-01	1,04E+03	4,29E+01
	UF binder		85,14	kg	9,76E-01	1,98E+02	2,01E-01	1,98E+02	3,05E+03	5,75E+02	2,42E+03	5,49E+01	1,50E-01	2,23E+00	5,25E+00	5,60E+02	5,74E-01	5,09E+03	3,50E+02
A2 - Transport	Ammonium sulphate	Truck 40/44 tons	96	km	3,65E-02	5,86E+00	0,00E+00	5,86E+00	1,68E+00	3,61E-01	1,27E+00	4,77E-02	1,50E-02	1,65E-01	9,07E-02	0,00E+00	4,11E-02	0,00E+00	-4,63E-02
	Paraffin emulsion		153,5	km	5,84E-02	9,37E+00	0,00E+00	9,37E+00	2,69E+00	5,78E-01	2,04E+00	7,63E-02	2,39E-02	2,64E-01	1,45E-01	0,00E+00	6,58E-02	0,00E+00	-7,41E-02
	Virgin wood		125	km	4,76E-02	7,63E+00	0,00E+00	7,63E+00	2,19E+00	4,71E-01	1,66E+00	6,22E-02	1,95E-02	2,15E-01	1,18E-01	0,00E+00	5,36E-02	0,00E+00	-6,03E-02
	Urea		194	km	7,39E-02	1,18E+01	0,00E+00	1,18E+01	3,40E+00	7,31E-01	2,58E+00	9,65E-02	3,02E-02	3,34E-01	1,83E-01	0,00E+00	8,31E-02	0,00E+00	-9,36E-02
A3 - Manufacturing	Mat press	Electric energy	131,27	KWh	4,73E-01	3,40E+01	1,91E-02	3,40E+01	2,96E+02	7,78E+01	1,89E+02	2,86E+01	2,09E-01	2,29E+00	1,97E+00	5,77E+01	5,99E-01	4,56E+02	4,25E-01
	Panel cutting		3,74	KWh	1,35E-02	9,69E-01	5,43E-04	9,69E-01	8,42E+00	2,22E+00	5,39E+00	8,14E-01	5,95E-03	6,52E-02	5,61E-02	1,65E+00	1,71E-02	1,30E+01	1,21E-02
	Wood chips drying		2,87	KWh	1,03E-02	7,44E-01	4,17E-04	7,43E-01	6,46E+00	1,70E+00	4,14E+00	6,24E-01	4,56E-03	5,00E-02	4,30E-02	1,26E+00	1,31E-02	9,96E+00	9,29E-03
	Wood chips burning	Heat production	100	kg	3,09E-02	1,85E+00	2,66E-02	1,82E+00	2,11E+02	3,44E+00	2,08E+02	4,72E-01	1,25E-02	1,41E-01	6,91E-02	3,39E+02	3,56E-02	2,33E+01	1,39E+00
	Wood chips	Waste	22,42	kg	4,22E-03	1,50E+00	1,00E+00	4,98E-01	8,81E+00	2,75E+00	5,58E+00	4,85E-01	2,06E-03	1,85E-02	2,87E-02	9,91E+00	5,53E-03	7,67E+00	3,15E-02

Chart5. Referred to “Table 1” values of Life Cycle Stages and Modules from EN 15804 "product split" (cradle to gate system boundaries) of raw particleboard 692kg/m3 with 100% recycled wood - GMS method:

Chart 6. Referred to “Table 2” values of Life Cycle Stages and Modules from EN 15804 "product split" (cradle to gate system boundaries) of raw particleboard 692kg/m3 with 100% virgin wood - GMS method:



The Charts 5 and the Chart 6 give a further visualization of how much the *land use* impact category affects the overall results of the environmental impact in the substitution of recycled wood with virgin. This outcome insists on the different contributions that items have in the quantification of impact categories, the modification of certain items (e.g. differences in raw materials or in processes) can have more or less contribution to the finished particleboard’s environmental impact, due to the impact that the single item has.

3.2. Items contribution in impact categories

Chart 7 and Chart 8 show the percentage of all the items considering all their impacts in each category listed in Table 1 and Table 2 and illustrated in Chart 5 and Chart 6, in the representation items characterized by an overall weight lower than 1% are clustered and their sum is indicated as Other. Both charts are referred to the functional unit of 1m^3 of raw panel. The charts intend to highlight and clarify which items are the most impacting, referring to the functional unit. In order to establish a better comparison between the Chart 7 and the Chart 8, it is indicated the absolute value of the single item’s impacts, obtained by the aggregation of its whole contributions in all the impacts categories.

As a consequence of the increase of impacts due to the utilization of virgin wood in the hypothetical scenario, Chart 8 shows that virgin wood is responsible for 69.6% of the impacts, followed by the UF binder with a value of 24.2%. By a comparison with items contribution of the company’s product listed in Chart 7, it is clear that the use of recycled wood shows an opposite trend. In particular it is liable for 7.7%, while the other items show a comparable pattern.

Chart 7. Items contribution related to the overall impact of the particleboard with 100% recycled wood:

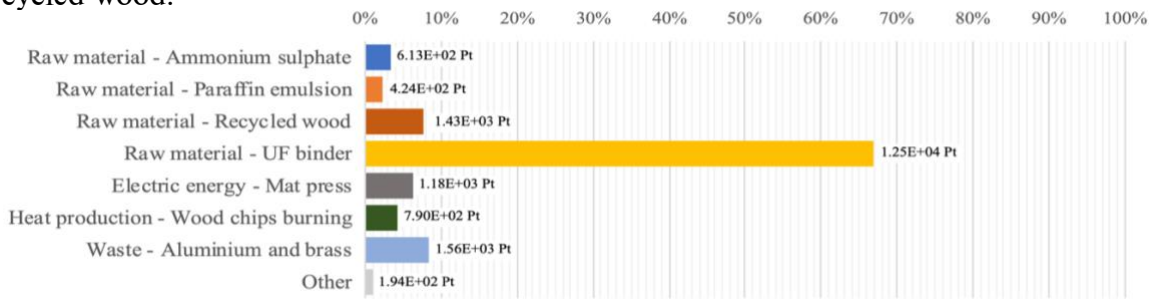
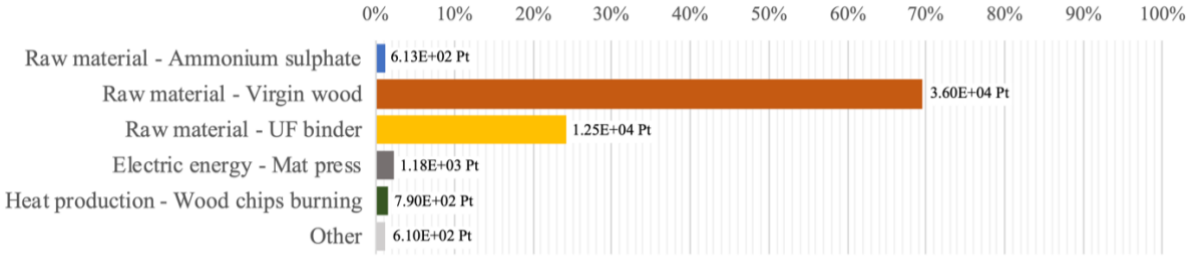


Chart 8. Items contribution related to the overall impact of the particleboard with 100% virgin wood:



4. Discussion

The results show how the use of recycled wood can make a significant contribution to minimizing land use, which is normally needed to provide trees and use their wood for chips used in particleboards. Most incisive indicators suggest that an upgrade of the overall environmental impacts could be provided if a less impactful glue is used, instead of the urea-formaldehyde-based binder. In fact, in both ex-ante and ex-post LCA studies the binder is one of the main contributors to impacts. The item's weighting intends to focus on a possible intervention seeking to enhance the environmental sustainability of the studied object, as the more incisive the items are in overall weighting, the more it can change the impacts of the product.

The main divergence between the results of the two scenarios is related to the land use category which, according to [11], takes into account the land occupation and the land's transformation after the activity in terms of variations of soil properties, addressing five soil functions: biotic production, groundwater recharge, erosion resistance, mechanical filtration and physiochemical filtration [12].

This means that land, which could be suited for forestry, may be used for alternative applications (e.g. agriculture). At any rate, the avoided land use given by the application of recycled wood rather than virgin wood is not the only benefit that the recycled material can lead. In fact, the manufacturer of the particleboard estimates that the application of a raw material which is usually classified as "waste", avoids the methanization process, that normally occurs in wood waste disposal sites, responsible of GHGs emissions [13]. This action also aims to lighten the work needed for the recycled wood disposal.

The manufacturer company of the raw particleboard drew up a previous analysis [14] where discusses on the differences in terms of CO2 emissions comparing the use post-consumption wood for chipboards production instead of the recovery of energy through combustion. The outcomes of this study, which was performed using the method provided by the Intergovernmental Panel on Climate Change (IPCC) during the AR4 cycle [15], show that the use of recycled wood instead of its disposal for combustion could avoid the emission of 728.5 kg CO2 eq for 1m^3 containing 649.34 kg of wood. Moreover, the company manufactures the particleboard using a method which gather the 100% recyclability of the final product. This allows the total prevention of waste production in particleboards itself when it is properly disposed of, both in the case of damage and after the end of its shelf-life. For instance, it is possible to re-integrate the final product at the beginning of the process as a raw material.

5. Conclusion

The analysis highlight important aspects of LCA applications. In particular they remark on the need for equivalent parameters setup when the LCA is used for a comparison between two different materials used for the product. It means that to have a reliable comparison in LCA, it is essential to select the data for the two models which should be the most coherent possible between each other, preserving the differences only in indicators which are the objects of the changing and are intended to be compared in the analysis (in this research the different use of wood). This aspect brings out one of the inner limits of LCA, which is that products from different backgrounds and different manufacturers are not easily comparable. When LCA is conducted for a comparison system boundaries and the

functional unit shall be the same. Also, the year of reference and location may be counted if the aim is specifically an environmental analogy between the same type of product gathered by different suppliers. By that, it is imperative to pay attention to these specific data when consultation or evaluation of LCA is carried out.

Another important aspect is that the LCA ex-ante, which is applied as a comparison starting from an existing product and is based on an existing process, may not take into consideration some additional aspects that could occur when an existing process is industrialized and consolidated. This uncertainty may be minimal but characterizes all the ex-ante LCA analysis and cannot be avoided, regardless of the accuracy of data, as it is an aspect strictly related to estimations on a non-existing product.

It is possible to assert that LCA is an all-around tool for evaluation and quantification of environmental impacts, which shows the aspects that concern human health, natural environment and natural resources as described in International Reference Life Cycle Data System (ILCD) framework [16].

The outcomes of the LCA analysis show that:

- The equivalent kilograms of CO_2 emissions of both products (referred to the functional unit of $1m^3$ of raw panel) do not show a significant difference. In particular, the kilograms of CO_2 equivalent of the panel manufactured using 100% recycled wood are 1.7% lower than the value reached in the panel manufactured with 100% virgin wood;
- The land use shows very different results given using different type of wood, in fact the value of land use for panels manufactured with 100% recycled wood is even 95,7% lower, compared to the panels manufactured using 100% virgin wood. This result of LCA considers both the land occupation and the land transformation [11], in particular, the variation of soil properties accounted are the biotic production, the groundwater recharge, the erosion resistance, the mechanical filtration and the physiochemical filtration [12];
- The items that most affect the environmental performance of the product are the Urea-Formaldehyde based binder and the virgin wood. In fact, the UF binder involves the 67% of all the environmental impacts of the 100% recycled wood panel, and the 24% of all the environmental impacts of the 100% virgin wood panel due to the fact that the value is more affected by the land use compared to values of recycled wood panel, but the absolute values are comparable.

These outcomes aim to remark the importance of considering the totality of the indicators of the environmental performance of a product, in spite of the trend of considering almost only the Environmental Footprint when an environmental estimation of the product is conducted. Especially when the analysis shows a huge divergence in outcomes of some indicators. It is also important to remark that, despite the completeness of categories analysed with the LCA, it is still a tool that allows a high grade of freedom when choosing boundaries and data for the calculus and the system object of the analysis.

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