Green technology LCA for wood manufacturing: plywood glued from green veneers technology

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ABSTRACT

Vacuum moulding technologies enable to manufacture plywood. It enables to glue a green state wood, because it can be dried and glued by the vacuum in the same operation. It reduces considerably the number of steps in its manufacturing. The aim of this paper is to propose a Life Cycle Assessment (LCA) in order to validate the use of vacuum process with green plywood in the hulls of boats. The functional analysis focussed on 4 traditional plywood in order to compare them with our product. The environmental modelling is carried out according to norm ISO 14040, starting from existing eco-invent (c) data base enriched with measurements taken during the manufacturing process. The results show the significant interest in the technology of gluing green wood with vacuum process. For an industrial use, this new technology is disadvantaged by the use of consumables which could be reduced considerably in industrial production by using reusable consumables.

1. Introduction

1.1. Context of the study

An efficient and sustainable use of resources requires an integrated assessment of the various aspects related to their exploitation, use and end of life, adopting life cycle thinking as a prominent approach. Innovation strategies are turning to eco-engineering which is being more widely adopted to minimise the environmental impact of new products.

Plywood is a material which can be used for the hulls of boats. Plywood panels have been sold all over the world for over 100 years. Successive innovations have mainly concerned glues and different products for treating the wood (NCASI, 1999). LCAs of plywood were developed in order to discover the impact of the manufacturing of traditional plywood in relation to other products on the market (LifeCycle Database, 2014), (Lippke B., Wilson J.B., 2010, FIBA, 2011), but also LCAs to find where hot point are in manufacturing. (Gonzalez-Garcia S., 2012) (Gonzalez-Garcia S., 2013). The LCA of a furniture was carried out by Mirabella (2014). It shows that a short supply chain allowed drastic reductions in the impacts compared with long distance transport. In wood sector the carbon footprint has recently been the subject of several studies considering the whole industry (Kutnar, 2014). At the same time, data bases were being developed in order to quantify effectively the environmental impact of each product on the market. In the boat building industry, the environmental impact of products in contact with the marine environment encourages manufacturers to turn towards materials which are environmentally clean. LCAs have been carried out on biobased hulls of boats and have shown the environmental interest of these kinds of materials when compared to traditional composites(Réseau EcoNav 2012).

Plywood is a material which is difficult to bend for applications to boat hulls. During the last 30 decades, its use has continued to decline in this activity sector. The aim of the proposed study is, by testing its use in boat building sector, to determine the environmental advantages and the procedures of the manufacturing of plywoods by using green gluing of veneers and vacuum moulding techniques.

The approach consists in designing a new process for manufacturing plywood according to technical and environmental criteria. The life cycle analysis will allow us to hilight the hot-points that impact on the environment and set the directions for research into high efficiency innovation.

1.2. Presentation of the Eco design approach

1.2.1. Green gluing of wood

Interest in green wood gluing grew during the second half of the 20th century. New adhesive formulations have been developed to make possible the gluing of wood in a green state (above the fiber saturated point). Wet wood gluing has mainly been studied for glulam and finger jointing processes. This technology leads to improved material yield and increased wood flexibility. Contrary to the traditional gluing processes, wastes or defects (knots, cut offs etc.) are not dried. Only the final product is dried. Studies of green wood gluing have been carried out with different adhesives (Strickler 1970; Dunky et al. 2000), such as phenol resorcinol formaldehyde (PRF) or melamine urea formaldehyde (MUF). The first results met the requirements for structural use with such adhesives. In France, a one-component polyurethane adhesive was patented in 2002 (Pommier 2006). When applied on wet wood, the polyurethane prepolymer reacts with the free water and with the water bound to the wood, which induces a chemical drying of the wood. The mechanical, morphological and chemical properties of this adhesive are detailed by Pommier in 2006 (2006). Other studies were based on the moisture cure polyurethane adhesives (Ren 2010; Karastergiou et al. 2008; Serrano et al. 2010). All these research studies have shown positive results for the structural use of green-glued wood. Polyurethanes do not release organic volatile compounds to compare with the other structural adhesives.

1.2.2. Vacuum moulding process.

This concerns green plywood manufacturing, associated with the ability for veneers to be glued using neither high pressure nor high temperature during the green gluing process. It can be pressed between moulds or using a vacuum press (Goldman 1946; Ngo and Pfeiffer 2003; Heebink 1953). Examples of bag moulding plywood techniques are illustrated in Fig. 1.

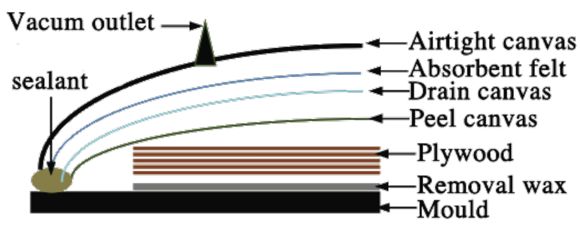

Fig. 1 Positioning of the covers and materials for vacuum gluing plywood (Lavalette 2013)

When the vacuum is activated, a differential pressure is created between the inside and the outside of the bagging film that forces the plywood against the mould. Moreover, the glue migrates through the wood cells. Moolded plywood technology was initiated by the boating and aviation industries at the beginning of the 20th century. It has several technical benefits, such as no dimensional limitations, variable thicknesses and shapes allowed in one product and uniform pressure distribution all over the moulded plywood. The equipment required is also low cost and easy to use. These benefits lead us to use this process in this work for shaped hull manufacture. A limitation of this process is that dry veneers are hard to conform to very curved moulds because they are quite brittle. This drawback could be minimized by using wet veneer. In this study we present the effect of some variables on the panel quality. The panel quality is represented by the ability of the joint to ensure a continuity between two wood pieces, as plywood is an assembly of wood plies. Several parameters play a role in the panel quality and they can be divided into process factors, adhesive factors (Pommier, 2006) (Clouet, 2012), wood factors (Lavalette, 2012) and environmental factors.

1.2.3. Greencanot : 8 m functional prototype

The study was carried out on the model of comparative environmental LCA using different material solutions for the hull according to ISO EN14040 (ISO 2006). The complete LCA appears to the most robust multicriteria instrument to measure the environmental interest and to make progress in our ecodesign approach. This LCA allows us to compare and demonstrate the advantages of the new process with maritime pine compared to 3 other traditional plywood used in boat building: traditional maritime pine plywood and 2 Africans plywood (Okoumé and Sapele). The material developed was tested on a functional prototype. "Greencanot", an open motorboat (8 m) was used in validating this technological innovation. This meets the requirements for boat building (mechanical and durability) in the same way as the other materials in the study.

The research discussed here concerns an LCA and its points as being interesting to improve the process.

2. Material and method

2.1. Framework for environmental evaluation

2.1.1. Methodology

The aim of this study is to compare the environmental impact of the green gluing process to the traditional one. The functional unit is limited to plywood for use in boat hulls. Four plywoods were chosen three of which were woods generally used in marine industries and one other was a test using vacuum moulding technology from veneers at green state (never dried).

This will allow us to quantify the environmental advantages of using green maritime pine and this new process to make plywood. The comparative environmental evaluation LCA cradle to grave was selected in order to take into account both the impact of manufacturing as well as the end of the life cycle. In fact, the mechanical properties and the final usage are seen as being similar. The aim of this study is to focus on differences between traditional manufacturing methods, under pressure, and the method where green wood is glued under pressure in a vacuum.

2.1.2. Functional unit

The study remains fairly general as far as the final use of plywoods is concerned and it excludes a large number of particularities in boat building in order to concentrate on the manufacture of the plywood. That is why we wished to widen the functional unit of the study to plywood used for any kind of construction and not just for the plank of a boat hull which is only one of its uses. The functional unit chosen is the following: *make a plywood one metre square in a way that it can be developed for an outside use.*

2.1.3. Limits of the system

We have chosen to be as exhaustive as possible in the manufacturing phase in order to take into account environmental impacts, as close as possible to reality. In Fig. 2 we have schematized the manufacturing cycle of the system. The starting point for the cycle is the grain of the tree. All the stages in forestry, right up to the maturity of the trees, are integrated into this cycle. Once the tree has been harvested, the process of transforming logs into plywood is analysed and characterized in its entirety.

In accordance with the functional unit selected we set limits to the field of study shown in Fig. 2. Although the research relies on data from the gluing of green wood for a boat, we are not looking at the stages for building the "Greencanot® " boat used in the study.

Moreover, still in accordance with the functional unit, we excluded the life and the end of life steps of the study in order to focus on manufacturing differences.

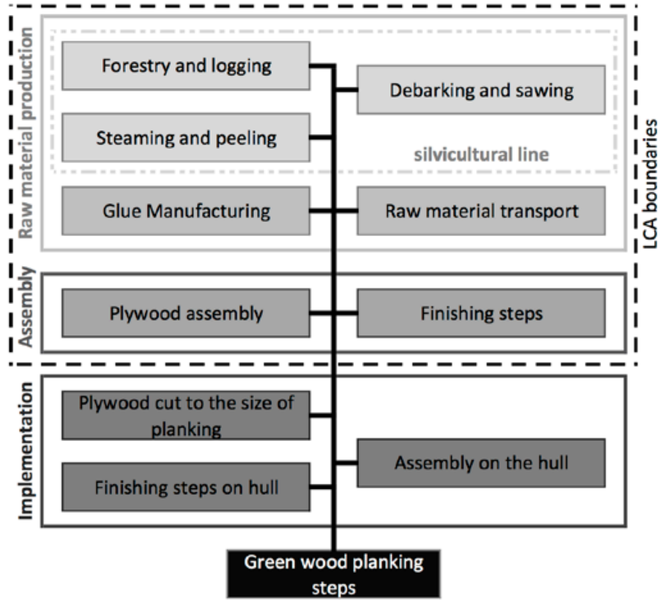

Fig. 2 Green wood planking steps and LCA boundaries

2.2. Presentation of the scenarios studied

We chose to compare 5 solutions that are shown in Table 1. Solutions 1 to 4 are already available commercially and have been selected to serve as a reference for the environmental evaluation of vacuum process.

Tab. 1 Presentation of the characteristics of 5 solutions studied

Solution	Adhesive type	Wood variety	Gluing	Temperature	Place	Source for modelling
1	Phenolic resin	Hardwood	Under press	120 °C	Europe	BDD Ecoinvent
2	Polyurethane	Hardwood	Under press	120 °C	France	BDD Ecoinvent + modifications
3	Phenolic resin	Okoume	Under press	120 °C	France	From LCA (FCBA 2012a)
4	Phenolic resin	Pinus pinaster	Under press	120 °C	France	From LCA (FCBA 2012b)
5	Polyurethane	Pinus pinaster	Vacuum	20 °C	France	New modelling

2.2.1. General points about the manufacture of solutions 1 to 4

Making plywood under pressure takes place in six stages: peeling, sorting, gluing, pressing, sanding and sawing. Logs are first debarked and sawed into widths for the peeling. The next stage is steaming followed by the peeling of the logs. Peeling is necessary to obtain thin veneers of wood, between 0.6 to 4 mm thick. These layers are first dried then cut up in the right dimensions before they are sorted according to their aspect. The best ones will be used as the face ply, while the others will serve for interior plies that are not visible and are less called upon mechanically.

After this sorting stage the planks are first glued with phenolic or polyurethane glues. For best results, the planks are pressed hot (about 120°C). This operation helps to activate the polymerisation of the glue and bring about a purifying action by destroying living organisms still present in wood at this stage.

Once the plywood planks are cold and the polymerization of bond lines are empty, they can go through the finishing stages of sanding and sawing. After cutting into the dimensions required for commercial products, the sanding gives a flat, homogenous aspect to the surface.

2.2.2. Procedure for solution 5.

The procedure for solution 5 follows the same steps as the previous solutions leading to peeling. The veneers are then directly used as in figure 1 describing the vacuum moulding. The plywood can be made on a flat surface or in the desired. Absorbent felt is applied to protect the surface. The felt will be reused several times. A peel ply is used to be easily lifted off the absorbent surface and this often cannot be used more than twice.

Concerning the process, veneers are end glued. The absorbent felt is folded back over the top of the plywood. The airtightness between the vacuum bag and the support is ensured by mastic which surrounds the plywood. One or several vacuum ports are installed above the plywood.

2.2.2. The different methods of modelling

For each of these material solutions (Table 1) we are using different modelling. Thus in the case of solutions 1 and 2 we used the unitary material sheet available in the Ecoinvent data base. We have preferred this dB which provides representative values for a study in Europe and is also one of the best documented data bases. The only difference between solutions 1 and 2 lies in the choice of glue. The first one is unchanged; using phenolic resin for the gluing and the second uses polyurethane glue.

Solutions 3 and 4 were modelled starting from the analyses of the life cycle already carried out on the plywood by the FCBA. Solution 3 concerns the Okoumé plywoods glued under pressure with the phenolic resin. These are plywoods which up to the present have been used in boat building for the hulls of wooden boats. Solution 4 models the plywood in maritime pine, still glued under pressure with phenolic resin. This plywood is sold commercially by the firm RolPIN SA. These two modelling were carried out as inventories.

The fifth solution presents the modelling of the vacuum moulding technique. This modelling comes from measurements and statements made in the Dubourdieu 1800 boatyard during different operations carried out for the building of the Greencanot®. This is the functional prototype of an 8m open motor boat that was finished in January 2014. All the figures obtained before the building of it came from studies carried out by the FIBA (FIBA 2011) on the forestry exploitation and transformation.

2.3. Hypotheses

In this study we have specified the following variable propositions which are valid for all the solutions examined. Transport is done as directly as possible. The means of transport used are based on reality (loading ratio, type of vehicle, etc.). The place for the transformation of the raw materials is chosen for being the closest to the assembly site. The assembly site is identical to the forest products transformation site so no transport is taken into account between the place where peeling takes place and the location of the gluing.

Despite exhaustive searching, some elements which are difficult to quantify or are supposedly insignificant, have been excluded from this study: lighting, heating and the cleaning of the production unit, all small supplies (gloves, masks ...), the administrative department of firms, the transport of employee and clients to the companies.

The proportion of non-modelled elements respects the rule whereby less than 2% of the total mass of the products is out. All the input for which the life cycle inventory (LCI) data are available and included in the LCI of the product. They represent over 99.8% of the inventory of the study. The proportion of non-considered input is inferior by 0.2% to the whole of the data.

2.4. Choice of the characterisation model

2.4.1. Choice of the calculation method

The aggregate of data is obtained from the calculations of the LCA software. Unless stated to the contrary, the results given in the rest of the report are the result of the ReCiPe Europe MidPoint Hierarchist (H) V1.06 (Ministry of Housing Spacial Planning and the Environnement 2009) calculation method.

In order to give an account of the impacts of each solution and not the consequences determined from the weighting , we chose to use the MidPoint of ReCiPe (Bare et al. 2000) method as well as the USEtox method (Huijbregts et al. 2010) to refine our data on ecotoxicity (Rosenbaum et al. 2008) and human toxicity. Each time, the results were calculated using the European method and not the world one.

For the duration to be taken into account for the calculations made with the help of ReCiPe, we chose to use hierarchical scale (H), which covers a period of 100 - 200 years. This offers a good compromise between an egalitarian scale (E) and a short term scale (I). The egalitarian scale looks at impacts after 500 years by amplifying the indicators for the depletion of resources but does not consider ecotoxicity. On the other hand, the short term scale examines the infinite resources but definitely increases the ecotoxicity. (Curran 2012).

2.4.2. Choice of indicators

Some methods of calculation allow us to visualize the results for over fifty impact indicators. The reading of these is a delicate exercise even though it's very thorough. The ReCiPe Midpoint method supplies results for 18 environmental impact indicators but they are not all meaningful.

Sometimes the product has no impact on one or another of them while it may have a major impact on yet another.

In order to help our interpretations, to use the representative data and to make our diagrams clearer, we have selected 8 indicators which are the most representative of global trends. The choice of indicators was made after studying the results obtained in the form of normalised graphs and according to three lines of research. (Tukker 2002)

Firstly we chose two emblematic indicators: climate change and human toxicity which seem to resume easily the global impact of solutions. These two indicators are easy to interpret and give the general trend for the solutions studied. Besides these, in order to highlight the solutions the most viable over time and the most serious, we have included the indicators for the depletion of mineral and fossil resources. These are powerful, emblematic indicators for the comparative LCAs of manufactured products. (Curran 2012).

Finally, we took the context of the study into account, that is to say the marine use of manufactured plywood. We chose to highlight the indicators linked to the marine area: marine eutrophication and marine ecotoxicity, although these are the subject of critical uncertainties (European Commission 2010).

In order to assess the ecodesign approach aiming at preferring the use of local wood, we integrated into our set of indicators two indicators which have a link with the cultivation of wood: the transformation of natural land, the acidification of the soil.

After reading the normalized graphs we were able to validate or modify the choices of indicators and thus retain a set of indicators which were pertinent and readable within the environmental evaluation framework. We can cite two indicators that, despite their pertinence, only appear in the solutions of Ecoinvent DB on the normalized histograms: toxicity of the land and exhaustion of water resources. We chose to leave these to one side in order to not disadvantage the generic solutions.

3. Results

3.1. Presentation of the results obtained for the comparison of 5 solutions

3.1.1. Comparison with the ReCiPe method

Fig. 3 shows the characterized results of the comparison of 5 solutions of plywood with the ReCiPe characterization method.

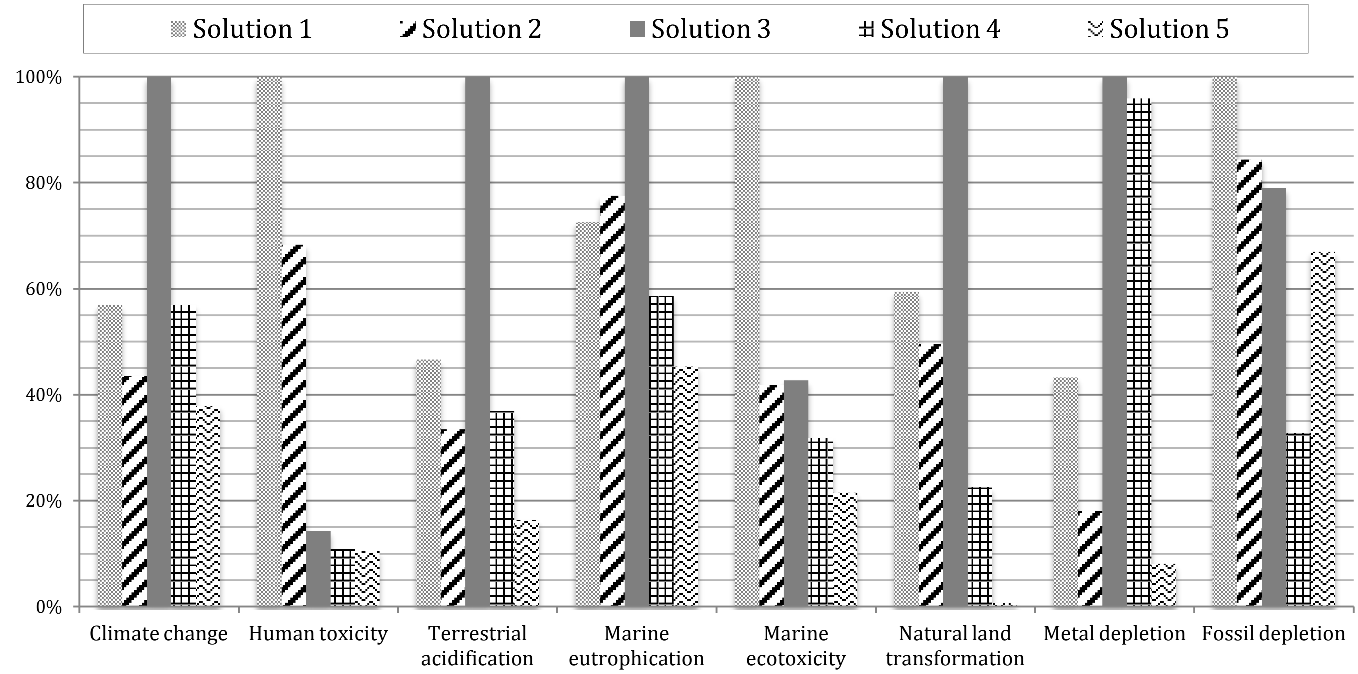

Fig. 3 Characterization of 5 plywoods, ReCiPe Midpoint (H) method

Generally, the solutions of green gluing of maritime pine veneers using vacuum process (solution 5) has the least impact from an environmental point of view in comparison with traditional gluing solutions. These results prove the interest in using maritime pine in the manufacture of plywood as opposed to deciduous species especially Okoumé. In fact Okoumé and generic plywood glued with phenolic resin are the two most damaging solutions compared with the other three.

Compared with maritime pine plywood glued under pressure, the vacuum process has a greater impact on an indicator. The depletion of fossil resources indicator is directly linked to the use of consumables (vacuum bag, absorbent felt, etc...) produced by the petrochemical industry for using in vacuum process. This study enables us to show the environmental interest of vacuum moulding process with green maritime pine.

3.1.2. Comparison with the USEtox method

As explained in section 2.4.1, we used the USEtox method of characterization to put our results on the indicators of human toxicity and ecotoxicity into perspective. These results are shown on fig. 4.

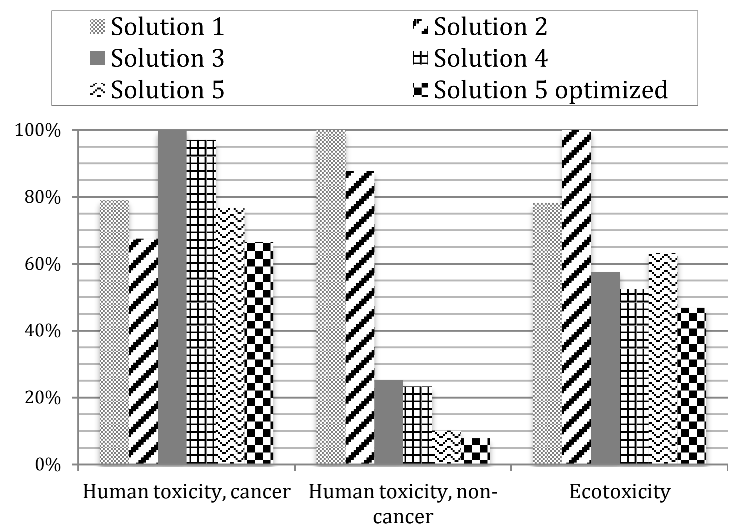

Fig. 4 Characterization of 6 plywoods, USEtox method

For this comparison we integrated the optimized solution 5, whose characterizations using the ReCiPe method are shown in Fig. 7.

The results shown on the graph below, slightly modify those obtained from the ReCiPe method. Thus the difference between the vacuum plywoods (solutions 5 and 5 optimized) compared to the solutions present in the Ecoinvent dB is less marked on the human toxicity/carcinogen indicator than on the human toxicity indicator. This gap is also weaker for the ecotoxicity indicator. Nevertheless, the hierarchy for all of the indicators is unchanged in relation to the results given in Fig. 3 (ReCiPe method).

3.2. Evaluation of solution 5

The study of the characterization of solution 5 has allowed us to determine the influence of each procedure implemented in the manufacturing of plywood glued in a vacuum. We have noticed the dominating influence (between 20 % and 50% impact according to the indicators) of the PU glue in the impact of solution 5. The consumables necessary for the vacuum gluing are responsible for 20 % to 40 % of the impacts.

This analysis has allowed us to determine the actions to be carried out in priority in order to reduce this impact. To increment the ecodesign approach, Polyurethane adhesive seems to be the priority choice for optimising the gluing of green wood. The number of paths that could be followed are for example the weight of glue and the percentage of bio sourced element in the formula of the adhesive.

The study of the network of solution 5 has allowed us to better understand which components are the most damaging for the environment. For example, for the fossil resource depletion indicator, the contribution of Polyurethane is close to 70%. These are the components of the Polyurethane and not the transformations or the transport that bring about this strong impact. On this same indicator of fossil resource depletion, the consumables contribute at around 25% with first the absorbent fabric (polyester, 8%) then the peel ply (polyamide, 4 %).

If we consider the human toxicity indicator, the Polyurethane and the consumables are still responsible for the greater part of the impact. These are the steps in the transformations of these products and particularly the fossil fuels that are the most harmful to human health.

Finally, concerning the transformation of the natural land, we still find Polyurethanes and consumables in the list of the most destructive elements for the natural land. And as in the case for human toxicity, the transformation of composites into finished or semi-finished products brings about the greatest impact on this indicator. The hierarchy of networks of the other indicators remains similar to that shown by means of these 3 indicators.

3.3. Sensitivity analysis

In the sensitivity analysis we will explain the reasons for these environmental gains based on two comparisons - the wood species and the type of adhesive used.

3.3.1. Comparison of vacuum process, according to the type of wood

We have compared coniferous and deciduous trees and their impacts are not the same. Thus we wanted to know what would be the advantages of vacuum gluing with other types of wood. In order to do this, we integrated generic modelling of hardwood and softwood species to compare with the modelling of maritime pine (solution 5). The results are given in Fig. 5 and show an advantage for maritime pine to a softwood or to a hardwood specie.

Fig. 5 shows the results of modelling of generic plywood that is vacuum glued. We studied hardwood and softwood. The comparison shows little difference between these two categories of wood, from averaged models from the Ecoinvent dB.

Nevertheless, the comparison with maritime pine proves its environmental interest is much stronger. We noticed that, besides the proximity of maritime pine resources, the environmental study tends to prove the advantages of changing the choice of wood, which is motivated by factors that are logistical but also environmental.

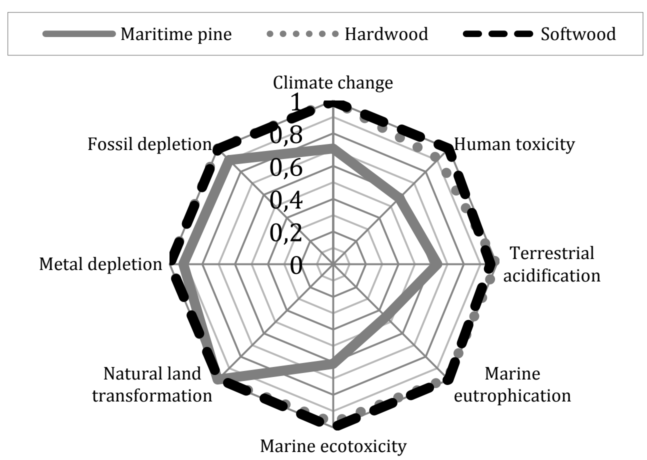

Fig. 5 Characterisation of wood types vacuum glued, ReCiPe Midpoint (H) method

3.3.2. Comparison of polyurethane glue and phenolic resin

Historically speaking, phenolic glue is the commonest on the wood glue market. The first reason is economic: Polyurethane is about 60% more expensive per kilogramme than phenolic glue. The other advantage is technical as phenolic glue is a low reactivity glue. It therefore has an open time of 4 hours at room temperature. This time is reduced thanks to heat applied when under pressure.

Nevertheless, Polyurethane requires a weight up to180 to 250 g/m^2 when phenolic resin needs 250 to 300 g/m^2. The weight of glue used should be further reduced in the case of green wood where the module is below 20%. (Wood Adhesives, 2010)

Whatever the glue used, the finished product possesses the same mechanical properties and the same finishing. Gluing green wood requires a Polyurethane, which explains the choice of this adhesive for solution 5. Fig.6 show the comparison between the two glues used in the manufacturing of plywoods. This figure allows us to validate the environmental interest of polyurethane glue in relation to phenolic glue for gluing of wood plies in the manufacture of plywoods. Changing from phenolic resin to polyurethane glue for gluing wood plies (solutions 1 and 2) allows the reduction of the impact on the whole of the selection of indicators except for marine eutrophication.

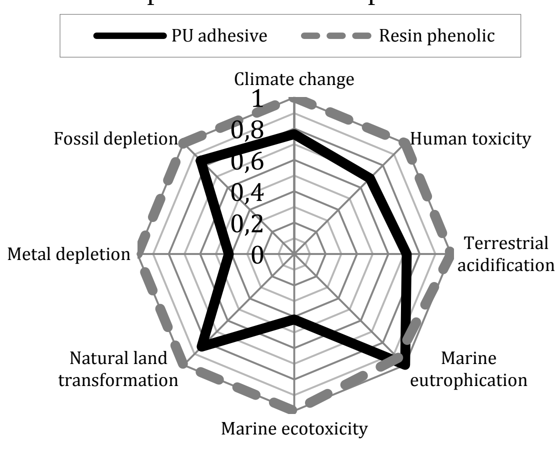

Fig. 6 Characterisation of 2 glues used for gluing plywood ReCiPe Midpoint (H) method

3.4. Validation of the choice made

Even if vacuum gluing is still only in an experimental phase it still already demonstrates the environmental gains that can be envisaged. Vacuum glued plywoods put to use have not as yet been optimised, that is to say that the drying time and the amounts of glue used have been overvalued. Below, we present a modelling which takes certain recommendations into account. These are to do with possible improvements with a view to make progress in research and do not yet correspond to the industrialisation of the process.

The first optimisation aims at reducing the amount of adhesive. We have modelled the weight decreasing from 300 g/m^2 to 200 g/m^2 which correspond to a loss of weight from 1.2 kg to 800 g of Polyurethane for the plywood measured. The second optimisation limits the vacuum drying time to 1 h 30 instead of 2 h. Finally, the last optimisation concerns the reuse of consumables, increased from 4 times to 5.

In Fig 7., the vacuum process with no particular optimization (solution 5) and the same with optimizations (solution 5, with optimization) are compared. The foreseeable gains are close to 30% for all of the indicators. These improvements help to accentuate furthermore the gap with the solution where maritime plywood is glued under pressure with phenolic glue. Among other things, the optimizations allow the improvement of the impact on the operators (human toxicity) and it also reduce the stress on fossil resources and come close to solution 4 for this indicator.

The results prove that with realistic, minor adjustments the environmental gains made with the green wood gluing can be improved by almost 30%.

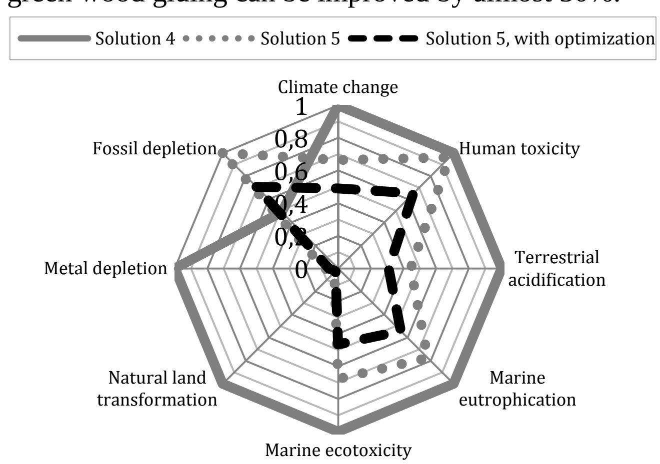

Fig. 7 Characterization of solution 5 before and after optimization in relation to solution 4, ReCiPe Midpoint (H) method

4. Discussion; perspectives and ways of improvement

During the data collection and at the end of the impacts study we identified three priorities to optimize the manufacturing of plywood with green veneers and vacuum technology.

These three topics are just as valid for boat building and particularly for the construction of wooden boats at the Dubourdieu boatyards, and also in a wider perspective. These topics are as follows: a reflexion on the raw material used, an improvement of the stages in the plywood construction and an optimization of the manufacturing process in order to anticipate the industrialisation of the procedure.

The so-called 3 RV approach (reduce, re-use, recycle, valorise) guided some of the recommendations suggested. The technology for vacuum gluing green wood allows a better adaptability of something that used to be a standard product and that offers new prospects for its use. Nevertheless, this new technology must reduce its reliance on non-renewable fossil and mineral resources and instead prefer re-using consumables. This also requires planning for the sorting of different materials at the end of their life cycle. Competitive recycling systems need to be set up.

4.1. Thematic areas for the raw materials used

4.1.1. Innovative wood materials

Wood quality needs to be improved in order to get a more homogenous result and to reduce losses before the assembling of veneers. In this study, these losses are around 40% and they consist of clean, unglued wood, reused for heating (wood as energy source).

We observed that Polyurethane is more eco friendly than phenolic glue. Moreover, besides its interesting environmental performances it allows a reduction in energy requirements. It is not necessary to heat the panel during the end pressure. Nevertheless, its role in the global impact in the solution of vacuum gluing is particularly high. The reduction in the quantity of glue used offers the chance of effectively reducing the impact of plywood, while retaining its mechanical properties. The other path of improvement concerning the glue, aims at finding bio based material to avoid putting a strain on fossil resources.

However, the consumables are also responsible for a large percentage of the total impact. The consumables are mainly in plastic and constitute a significant proportion of the waste. Reusing them more than 5 times seems difficult when considering their quality and their endurance after 4 to 5 uses. The way to explore relies above all on alternative solutions which will replace plastic materials or even the consumables themselves.

4.1.2. Prefer local resources

We have seen that vacuum moulding allows the manufacture of products adjusted to the final dimensions with a finish of very good quality. In this context, manufacturers have more flexibility in what they make and in their products. The technology described in this article is still in the research stage and work needs to be carried out to adapt the technique to other woods than coniferous or deciduous species.

At the Dubourdieu 1800 boatyard and in its search for ecodesign the use of maritime pine is extremely popular since the construction is located on the Arcachon Basin. This geographical situation means that for the boat building here, the logistics and the demand for raw materials are reduced and so therefore are the environmental and social impacts. In fact, the stocks of wood in the Landes forest mean there can be a local answer when it comes to supplying the boatyard with its prime raw material.

4.2. Optimisation of the stages for implementation

4.2.1. Reduce the impact of the transformations

The exploitation of wood, the raw material, is a good thing for the environment but the transformations necessary and the logistics involved have the greatest impact in the solutions under study. Energy sources that are more eco-friendly must be studied in order to guarantee at least a carbon neutral solution.

4.2.2. Optimise the logistic of wood plies

Vacuum gluing is penalized by the losses in wood that occur when the process is carried out. In our study, losses are around 40%, so we need to find solutions which will allow gluing to be optimized in order to reduce these losses; for example, reusing the offcuts from internal plies or else finds parallel activities to valorise these offcuts.

4.2.3. Improve the management of manufacturing waste

For the moment, the inconvenience of the solution of gluing green wood is that it produces large quantities of waste (wood and plastic) when this is done. We therefore need to find and put in place the best solutions for reusing, recycling or valorising each type of waster. The priority during the gluing operation must be to reduce the amount of waste produced as well as to set up a sorting programme for downstream recycling or revalorization.

4.2.4. The health of operators and users

The health of operators and users must be safeguarded by limiting emissions of hazardous substances and their exposure. This begins by reducing or even eliminating toxic products. Changing from phenolic resin to polyurethane glue is a step in the right direction and there have already been good results for operators' health with the elimination of formaldehyde emissions.

4.3. Preparing the industrialisation of the procedure

The guiding strategy behind the implementation of vacuum gluing of green wood was to propose this to industrial manufacturers of innovative wood products. The next stage in the research is to find techniques for industrializing the solution and thereby open up commercial prospects for this innovative solution.

This industrialisation has to answer two criteria: maintain the environmental gains made by the proof in vacuum gluing and offer manufacturers a machine able to produce moulded plywood at the best price possible. In the first case, the technical installations would have to function autonomously at a rate close to that traditional.

The technological solution will be both simple to minimise the costs but flexible in order to answer to particularities in the shapes of plywood to be made with vacuum.

5. Conclusion

The use of LCA tools is a recent step in the field of wood materials as well as in boat building, but they seem to be the ideal method to help advance applied research in the fields of wood gluing. The LCA carried out had allowed the creation of the first reference in the environmental evaluation on wood based boat building. So, the results obtained made possible the first extrapolation for other products in gluing on green wood.

The aim is to succeed in further integrating these tools in the upstream phase of the design, as a driver for eco-innovation. In fact the LCA has allowed the identification the environmental hot points in the procedure and given ideas for its improvement.

The LCA has allowed us to highlight the pollution transfers. Moreover, the margin of error in the LCA remains high. That’s why the results must be used with caution and be cared in regard with inaccuracies.

The LCA is based on measurements for a technology at a given moment and for solutions currently only implemented in the laboratory. A follow-up needs to be done on methods of industrialisation in order to guarantee the durability of the environmental gains.

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