Life cycle assessment of thermally treated and untreated maritime pine boards: a Portuguese case study

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ABSTRACT

The main aim of this Life Cycle Assessment (LCA) study was to assess and compare the environmental impacts of thermally treated and untreated maritime pine boards to be used as cladding. All processes were considered from forest management and resource extraction until cladding construction and its use during the next 15 years. At the end of the claddings life cycle it has been considered that the pine boards will be used as wood fuel to substitute firewood in the local heating system. The ReCiPe-V1.08 was the method selected for Life Cycle Impact Assessment of the products. The foreground data came from a Portuguese company that uses the ThermoWood method to thermally treat the pine boards and the background data came from the databases embedded in the SimaPro software. LCA results from the study have shown that the ´Ecosystems´ is the most important damage category mainly due to ´Agricultural land occupation´ by the wood in the forest. The cladding made by pine boards thermally treated can be considered more environmental friendly than the cladding made by untreated pine boards unless a very high weight (very close to 100 %) is given to impacts on ´Human health´ and ´Resources´ while a very low weight (very close to 0 %) is given to impacts on ´Ecosystems´. The study has also demonstrated an increase of potential environmental advantages of the thermally treated pine boards if wood energy is used in the heat treatment process instead Liquefied Petroleum Gas.

INTRODUCTION

Wood is a light, strong, beautiful and natural renewable material that grows in ever-increasing abundance in Europe, particularly in Portugal where maritime pine (*Pinus pinaster* Aiton.) is the third forest species with more planted area.

Pine heartwood is considered in Durability Class 4 (EN350-2, 1994) – low durability with an expected service life in ground contact of 5-10 years though can be used as cladding (IDEMAT 2012).

Wood durability can be increased through the application of wood-preservative systems or by wood modification. For environmental reasons wood modification processes have, at the moment, higher interest. Heat treatment is one of the most successful wood modification processes through which wood durability can be improved to Durability Class 2 (15-25 years). Esteves and Pereira (2009) describe several methods that have been developed in a number of countries, Thermowood® in Finland, Plato® in The Netherlands, Rectification® and Bois-Perdure® in France and OHT® in Germany. New heat treatment processes are also emerging in other countries, such as Denmark (WTT) and Austria (Huber Holz). The main changes on thermal modified timber - compared to

untreated wood – are improved dimensional stability and increased resistance to wood destroying fungi and insects such as longhorn or furniture beetles. Treated wood also has a darker colour and higher thermal insulation. On the other hand, there is a decrease in several mechanical properties, mainly bending strength.
Previous LCA studies of ThermoWood® have shown that "ThermoWood® has a potential of being a green building material if consideration is made to the production as well as the use and disposal at the end of its life cycle using best available techniques" (Thermowood 2008). In accordance to Infosheet (2008) Plato®WOOD has substantially better environmental benefits and the amount of energy used and CO_2 formed are limited compared to other materials such as preservative treated wood, meranti, PVC, aluminium and steel.
Life Cycle Assessment as described in ISO 14040 series of standards is the best Environmental System Analysis tool to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying the energy and materials used and the wastes released to the environment. LCA provides better understanding and better estimation of energy (and other environmental) aspects in the life cycle of any sort of good and can help decision makers in the selection of products or processes that result in a lesser impact to the environment.
The main aim of this LCA study was to evaluate and compare the environmental impacts of untreated and thermally treated maritime pine boards to be used as cladding. Wood was thermally modified by a Portuguese company using a process similar to ThermoWood® process.

EXPERIMENTAL

To evaluate and compare the environmental aspects and potential impacts associated with the two products a Life Cycle Assessment (LCA) study was performed based on ISO 14040 (2006 a) and ISO 14044 (2006 b) recommendations. LCA is divided into four phases: 1) goal definition – which defines the aim and scope of the study as well as the functional unit (a measure of the function of the studied system); 2) inventory analysis – which lists emissions of pollutants into air, water and soil, solid wastes and consumption of resources per functional unit; 3) impact assessment – which assesses the environmental impact of the pollutants emitted throughout the life cycle; 4) interpretation of results

Goal and scope of the study

Goal of the study

The main aim of this study was to conduct a LCA to assess and compare the potential life cycle environmental impacts associated with thermally treated and untreated maritime pine boards produced by a Portuguese company to be used as claddings over the next 15 years. The results of the study will be communicated to the company decision makers who can assess the environmental profile of the products and indicate areas where opportunities exist to improve its overall environmental impacts.

Scope of the study

Regarding the scope, the study is based on a cladding with a surface area of 55.44 m^2 made of maritime pine boards with the following dimensions: thickness = 18 mm; width = 132 mm; length = 3000 mm. Then, each cladding has 140 boards or 1 m^3 of wood.
The product "Untreated cladding" – is the cladding made with untreated pine boards - the durability complies with the requirements for Durability Class 4 (5-10 years).

The “Treated cladding” – is the cladding made with thermally treated pine boards produced in a Portuguese mill using the ThermoWood process to reach a durability level which complies with the requirements for Durability Class 2 (15-25 years).
It was assumed, like previously justified, the improvement of two durability classes for pine boards thermally treated.

Functional unit

Considering that the durability of the treated pine boards is (15 years) three times more than untreated pine boards (5 years), the functional unit is: “Treated cladding” - 1 m^3; “Untreated cladding” - 3 m^3. A sensitive analysis will be done considering that thermally treated pine boards durability is two or four times more than that of untreated pine boards.
The system boundary for the product system (cladding) is represented in a simplified way in Figure 1. The sawing, planning and thermal treatment of wood is made at the same place so no transport is considered between them. Thermo-D treatment class of ThermoWood method was considered for “Thermal treatment” process. The product system delivers a secondary raw material (wood waste) that can be used as raw material for other product system (heat production). To solve this allocation problem the system boundaries were expanded to include the firewood production and delivery to the consumer.

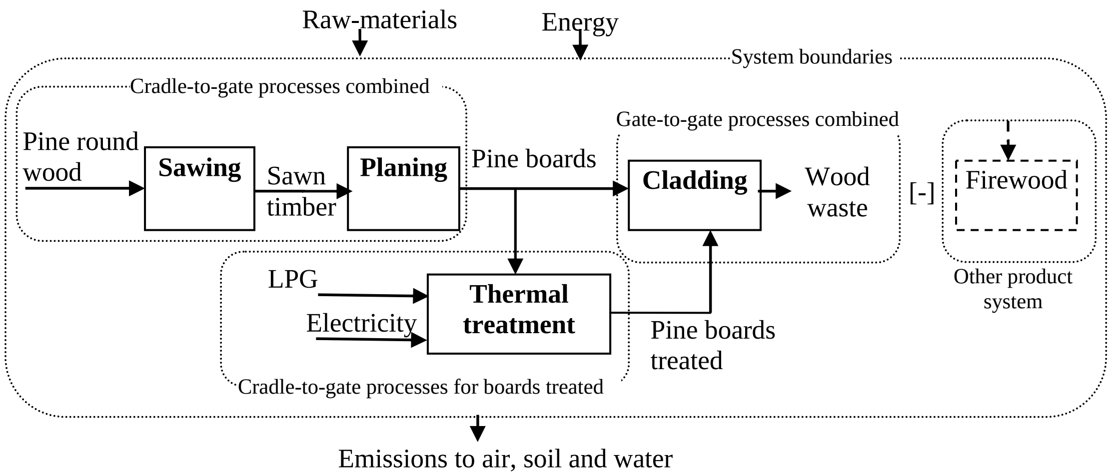

Figure 1: Life cycle assessment system boundaries for the cladding

Inventory analysis

Data type/data collection

The inventory analysis and, subsequently, the impact analysis have been performed using the LCA software SimaPro7.3.3 and embedded databases and methods (PRé Consultants 2010). The inventory datasets for the products and processes included in the system boundaries are presented in Table 1 and were calculated according to the following assumptions:
- Data for the production of pine round wood was obtained from a previous study carried out by the authors (Ferreira and Domingos 2012);
- The pine round wood with a moisture content of 70 % is transported from the forest to sawmill by a distance of 50 Km. Transport process is equivalent to ¨Transport, lorry >16 t, fleet average/RER U¨ in ecoinvent database. The pine round wood is natural (air) dried at the sawmill plant until wood moisture contents decrease to 20 %;

- The “Sawing and planing” process was adapted from the “Sawn timber, softwood, raw, air dried, u = 20%, at plant/RER U” combined with “Sawn timber, softwood, planed, air dried, at plant/RER U” in ecoinvent database. This is a multi-output process that produces two co-products: pine boards and industrial residue wood. The allocation of environmental loads to the co-products was based in the economic value of them.
- The data for the “Thermal treatment” unit process was provided from International ThermoWood Association and adapted to a Portuguese factory that uses the ThermoWood process to treat the pine boards. The LPG production and consume was considered equivalent to ¨Heat from LPG FAL¨ in Franklin USA 98 database and the electricity production equivalent to ¨Electricity, medium voltage, production PT at grid/PT U¨ in ecoinvent database.
- In the cladding construction it was considered only the pine boards (treated/untreated) and its transport. It was considered that the pine boards are transported for 100 Km by lorry from the factory to a storehouse and then by van to the final consumer. These processes were considered equivalents to ¨Transport, lorry >16t, fleet average/RER U¨ and ¨Transport, van < 3.5t/RER U¨ respectively in ecoinvent database. No environmental loads were considered in the use phase because no additional treatment will be considered.
- As the product system delivers a quantity of secondary raw material (wood waste) avoided impacts from the same quantity of firewood production and transport to consumer was considered. This is why the value of firewood at consumer is negative in Table 1. The data of the “Firewood production process” was provided from a previous study carried out by Ferreira *et al*. (2013). Manufacturer data for “Thermal treatment” equipment was not included. According to Vigon *et al*. (1992) data from manufacturing of capital goods is, generally, not included in the limits of the system because it has been shown to have a negligible effect on results.

Table 1: Material and process input data for pine cladding boards

Process Data	**Inputs**			**Outputs**		
	Name	**Value**	**Units**	**Name**	**Value**	**Units**
Sawing and Planning	Pine round wood	2.056	m^3	Pine boards	1	m^3
	Transport by lorry	50	Km	Industrial residue wood	1.056	m^3
Thermal treatment	Pine boards	1.08	m^3	Pine boards treated	1	m^3
	LPG	480	KWh			
	Electricity	150	KWh			
Cladding*	Pine boards treated	1	m^3	Wood waste	1	m^3
	Transport by lorry >16t	100	Km			
	Transport by van <3.5t	10	Km			
Firewood	Firewood production	1	m^3	Firewood at consumer	-1	m^3
	Transport by van <3.5t	10	Km			

(*) For claddings with pine boards untreated the inputs and outputs values are multiplied by 3

Life cycle impact assessment (LCIA)

ReCiPe (Goedkoop *et al*. 2013) was the method chosen for impact assessment of the products (claddings) functional unit. This method has both midpoint (problem oriented approach of CML-IA method) and endpoint (damage oriented approach of Eco-indicator 99). As the method leads to many different impact categories (18), in this study, the environmental profile (characterisation at midpoint level) will be shown in the impact categories related with the creation of Environmental Product Declarations (EPDs) (ISO

14025 c). In the normalisation step, the quantified impacts are compared to a certain reference value - the average environmental impact of a European citizen in one year.
The triangle tool (PRé Consultants 2010) was used to compare the two product systems for all possible weighting sets. Each point within the triangle represents a combination of weights that add up to 100%. The line of indifference (based on the normalised results) divides the triangle into areas of weighting sets for which treated pine boards is favorable to untreated pine boards and *vice versa*.

RESULTS AND DISCUSSION

The environmental profile comparison of the claddings to be used over the next 15 years using the method "ReCiPe Midpoint (H) V1.08 / Europe Recipe H / Characterisation" are shown in Figure 2. The impact categories shown are that related to EPDs as justified before.

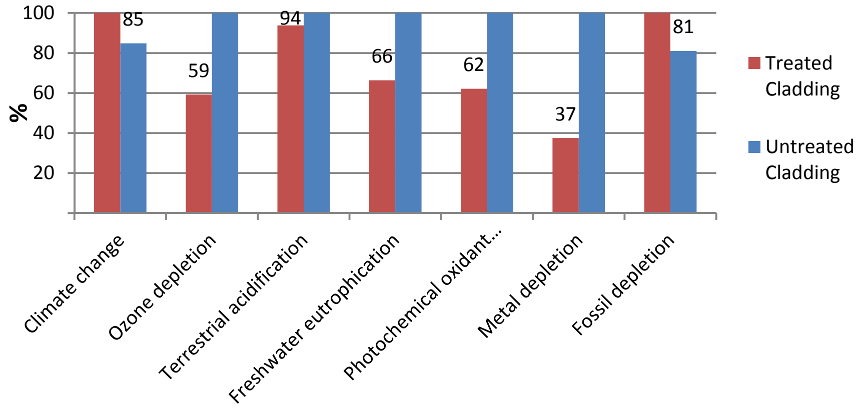

Figure 2: Environmental profile comparison of the products functional unit

From Figure 2, the "Treated cladding", using treated pine boards, presents a better environmental performance than "Untreated cladding", using untreated pine board, for ´Ozone depletion´, ´Acidification´, ´Eutrophication´, ´Photochemical oxidation formation´ and ´Metal depletion´. The opposite is true for ´Climate change Human Health´ and ´Fossil depletion´.
The environmental profile of "Treated cladding" presents the following results: the ´Climate change´ is mainly due to heat from LPG (40.2%) and electricity consumption (31.9%) in the "Thermal treatment" process; the electricity consumed in "Thermal treatment" is the process that most contributes to ´Ozone depletion´ (43.6%), ´Acidification´ (40.2%) and ´Eutrophication´ (61.9 %); the ´Photochemical oxidant formation´ is mainly (45.7%) due to "Pine round wood" production processes; the ´Metal depletion´ is mainly due to sawmill (54 %) equipment; the ´Fossil depletion´ is mainly due to heat from LPG (50.9 %) and electricity (23.1 %) consumed in the "Thermal treatment" process; the use of wood waste as firewood at the end of Claddings life cycle has a significant and positive impact for ´Metal depletion´(-40.6 %), ´Ozone depletion´ (-21.7 %) and ´Photochemical oxidant formation´ (-19 %); transport by lorry has the majority of the contribution for ´Metal depletion´ with 11.7%.
The environmental profile of "Untreated cladding" presents the following results: the "Sawing" is the process that most contributes to ´Climate change´ (49.6 %), ´Acidification´ (46.9%), ´Eutrophication´ (60.5%), ´Metal depletion´ (73.7%) and ´Fossil depletion´ (45.9%). It also contributes very much to ´Ozone depletion´ (45.2%); the "Pine round wood production" processes are the ones that contribute the most for

´Ozone depletion´ (46.5%) and ´Photochemical oxidant formation´ (88.6%). They also contribute greatly to ´Climate change´ (33.4%), ´Acidification´ (33.8%) and ´Fossil depletion´ (45.7%); the "Planning" process has an important contribution to ´Climate change´ (30.6%),´Acidification´ (31.7%), ´Eutrophication´ (44.6%) and ´Metal depletion´ (43.5%); the environmental benefits by the use of wood waste as firewood are in terms of ´Metal depletion´(-45.9%), ´Ozone depletion´ (-38.6%), ´Photochemical oxidant formation´ (-36.9%), ´Fossil depletion´ (-36.7%), ´Eutrophication´ (-23%), ´Acidification´ (-22.4%) and ´Climate change´ (-30.2%); the transport operation by lorry contributes significantly to ´Climate change´ (19.4%), ´Ozone depletion´ (32.2%), ´Photochemical oxidant formation´ (18.3%) and ´Fossil depletion´ (25.7%).
A comparison of claddings in normalized damage categories using the method "ReCiPe Endpoint (H) V1.08 / Europe Recipe H/A / Normalisation" is given in Figure 3. The ´Ecosystems´ is the most important damage category mainly due the impact on ´Agricultural land occupation´ that represents 0.42 and 0.14 European equivalents for "Untreated cladding" and "Treated cladding" respectively. From the ´Ecosystems´ point of view the "Treated cladding" is preferable to "Untreated cladding". Contrarily, the "Untreated cladding" is seen to be slight better than "Treated cladding" on ´Resources´**.** For ´Human health´ the results are almost equal.

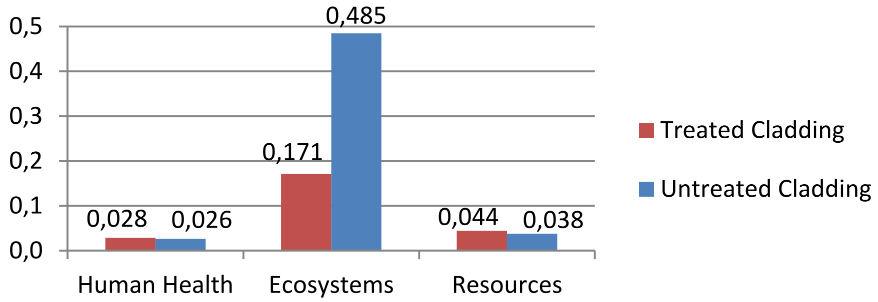

Figure 3: Environmental impact comparison of the claddings in normalised damage category

The line of indifference in the weighting triangle and the sub areas with their specific ranking orders are presented in Figure 4. The "Untreated cladding" has a lower environmental load than "Treated cladding" only if a very high weight (close to 100 %) is given to impacts on ´Human health´ and ´Resources´ while a very low weight (close to 0 %) is given to impacts on ´Ecosystems´. Otherwise the opposite is true.

Sensitive analysis

A sensitive analysis was done considering the following situations related to the base line: treated pine boards durability was two or four times more than that of untreated pine boards; the LPG in the "Thermal treatment" process was replaced by wood chips; pine boards untreated were kiln dried from u=20% to u=10% (RH=0.9%).
If durability of treated wood is four times higher than untreated pine boards the "Treated cladding" presented a better environmental performance than the "Untreated cladding" in all considered impact and damage categories. A similar result was obtained if the LPG in the "Thermal treatment" process is replaced by wood chips.
If durability of treated is two times higher than untreated pine boards the "Treated cladding" presented a better environmental performance than "Untreated cladding" for ´Ozone depletion´, ´Photochemical oxidation formation´ and ´Metal depletion´. The opposite was true for ´Climate change´, ´Acidification´, ´Eutrophication´ and ´Fossil depletion´. From the weighting triangle that includes all environmental impacts (18) the

"Untreated cladding" has a lower environmental load than "Treated cladding" only if a very high weight is given to impacts on ´Human health´ (100 %) and ´Resources´ (close to 90 %) while a very low weight (close to 10 %) is given to impacts on ´Ecosystems´. Otherwise the opposite was true.

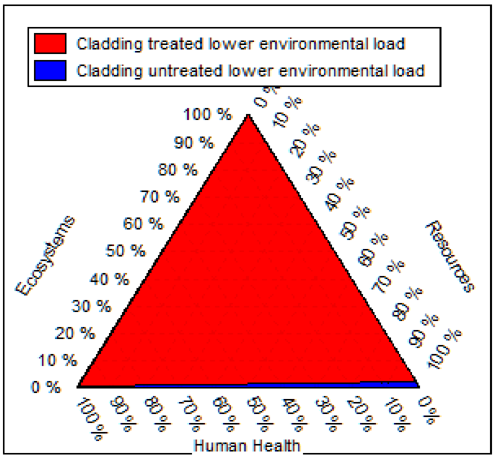

Figure 4: The weighting triangle

If the untreated pine boards were kiln dried from u=20% to u=10% the impact category results of "Untreated cladding" slightly increased but in terms of ´Global warming´ and ´Fossil depletion´ still maintained better results than "Treated cladding". However, in terms of damage categories the "Treated cladding" was now better for ´Ecosystems´ and ´Human health´ and the opposite was true only for ´Resources´ but by a very small bit.

CONCLUSIONS

The main conclusion of the study is that the "Treated cladding", made by thermally treated pine boards, presented results that can be considered more environmental friendly than the "Untreated cladding", made by pine boards without any treatment. It just will not be true if a very high weight (close to 100 %) is given to impacts on ´Human health´ and ´Resources´ while a very low weight (close to 0 %) is given to impacts on ´Ecosystems´.
If durability of treated pine boards was four times higher than untreated pine boards the "Treated cladding" presented a better environmental performance than the "Untreated cladding" in all considered impact and damage categories. A similar result was obtained if the LPG in the "Thermal treatment" process was replaced by wood chips.
Likewise the studies reported in the introduction for ThermoWood® and Plato®WOOD this study showed that thermally treated maritime pine boards has the potential of being a green building material.

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REFERENCES

Esteves, B., Pereira, H. 2009. Wood modification by heat treatment: a review. *Bioresources* **4**(1), 370-404.

European Committee for Standardization (1994). EN 350-2. Durability of wood and wood-based products – Natural durability of solid wood. Guide to natural durability and treatability of selected wood species of importance in Europe.

Ferreira, J. and Domingos, I. (2012). Life Cycle Inventory of Softwood Production in the Portuguese Forest. Proceedings IUFRO Conference, Division 5, Forest Products, Estoril Congress Centre, Lisbon, Portugal.

Ferreira, J., Viana, H., Esteves, B., Lopes, L., Domingos, I. (2013). Environmental Profile of the Firewood and Wood Chips out of the Portuguese Pine Forest "(in Portuguese)". *Proceedings of the Seventh National Forest Conference "Florestas - Conhecimento e Inovação"*, Vila Real / Bragança, Portugal.

Goedkoop, J., Heijungs, R., Huijbregts, M.., Schryver, A., Struijs, J., Van Zelm, R. (2013). ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition (version 1.08) Report I: Characterisation. (VROM), The Netherlands.

IDEMAT (2012). Ecocosts 2012, LCA data on products and services V2-2, 2012. *Delft University of Technology.*

Infosheet (2008). The Plato Technology, Green Building Solutions. *Plato International BV*, The Netherlands.

International Standard Organisation (2006 b). ISO 14044. *Environmental management – Life cycle assessment – Requirements and guidelines.*

International Standard Organisation (2006 c). ISO 14025. *Environmental labels and declarations - Type III environmental declarations - Principles and procedures*.

PRé Consultants (2010). SimaPro Database Manual-Methods library. Report version 2.4.

ThermoWood (2003). *Handbook.* International ThermoWood Association. Helsink, FL.

Thermowood (2008). Executive summary - Thermowood®: Life cycle assessment (LCA) of Finnish thermally modified wood cladding. International Thermowood Assoc.

Vigon, B., Tolle, D., Cornaby, B., Latham, H., Arrison, C., Boguski, T., Hunt, R., Sellers, J. (1992). *Life-Cycle Assessment: Inventory Guidelines and Principles*, Washington D.C. & Cincinnati: Office of Research And Development, USEPA.