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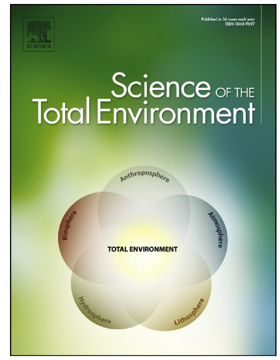

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Life cycle assessment of a novel tannin-boron association for wood protection

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Abstract: In these studies of fix boron compounds, associations between tannins and boron (TB) in the form of boric acid appear to be of interest. These TB associations allow the use of boron at very low levels (in compliance with EU restrictions, 2008/58/EC) and limit boron leaching which maintains biological resistance and fire retardant properties. As a consequence, TB wooden products present an extended service life compared to boron compounds alone and were designed to be environmentally-friendly wood protection systems. A follow up of tannin-boron use identified the environmental impacts using a life cycle assessment (LCA). This LCA was performed on tannin-boron preservative products as well as several industrial preservative-treated timbers and concrete used in the landscape. Cr-containing inorganic salt and an alkaline copper quaternary preservative formulation, as well as concrete, have been used as referential materials to compare the environmental footprint with the tannin-boron treated system. A model was created with life cycle stages used to calculate inputs and outputs during raw material extraction, supplier transportation, manufacturing process, distribution, disposal transportation and processing. Tannin production data were based on Vieira et al. in the field of condensed tannin extraction. However, the extracted tannin in the extraction yield, the inorganic salt, and the process applied are not perfectly comparable with the extraction conditions industrially applied for the Mimosa (*Acacia mearnsii*) extract which is the major constituent of the TB formulations. The latter is counter-current water extracted without any chemicals or with a limited amount of $NaHSO_3$ or Na_2SO_3 (at 0.5% to 1 %) - at a temperature of 70-90°C. Unfortunately these parameters cannot be elaborated by the LCA program because there is no data available for the production of Na bisulphite or Na bicarbonate in the LCI data used. Other input data were sourced from the ecoinvent v3.8 database. The ReCiPe midpoint method was used to assess the environmental footprint and the CED method was chosen to

analyze a general view of the energy-related environmental impacts in the life cycle. Overall, the results demonstrated that tannin-boron preservatives can be regarded as a low-environmental impact formulation. Additionally, an economic analysis of the development of a commercially-viable tannin-boron preservative would now be timely.

Keywords: LCA; Tannin-boron preservative; Landscaping materials; Low-environmental impact

List of acronyms

LCA	Life Cycle Assessment	TB	Tannins and Boron
CED	Cumulative Energy Demand	ACQ	Alkaline Copper Quaternary
CCA	Chromated CopperArsenate	TWW	Treated Waste Wood
LCI	Life Cycle Inventory	LCIA	Life Cycle Impact Assessment
CC	Climate Change	OD	Ozone Depletion
TA	Terrestrial Acidification	FEP	Freshwater Eutrophication
MEP	Marine Eutrophication	HT	Human Toxicity
POF	Photochemical Oxidant Formation	PMF	Particulate Matter Formation
TET	Terrestrial Ecotoxicity	FET	Freshwater Ecotoxicity
MET	Marine Ecotoxicity	IR	Ionizing Radiation
ALO	Agricultural Land Occupation	ULO	Urban Land Occupation
NLT	Natural Land Transformation	WD	Water Depletion
MD	Metal Depletion	FD	Fossil Depletion
LM1	refers to landscaping material of $1m^3$ ACQ treated wood (ex-AP)	LM3	refers to landscaping material of $1m^3$ Cr treated wood (ex-AP)
LM2	refers to landscaping material of $1m^3$ concrete block	LM4	refers to landscaping material of $1m^3$ TB treated wood (ex-AP)

1 Introduction

The landscaping materials market is progressively growing at manufacturers selling prices when landscape architectures are more and more popular, especially hard landscape materials. Cheap concrete and naturally occurring wood are frequently used in hard landscaping for the decorative building. While carbon-neutral performance remains the holy grail for sustainable landscapes, do-no-harm materials used in the construction are seeking until now. So very little focus on the potential negative impacts of landscape attracts people's attention (Dunnett & Clayden, 2007; O'Connor et al., 2011). Furthermore, timber's ability to sequester CO_2 keeps it generally near or at the bottom of the measures of impact comparison with other materials. While the critical review is required for comparative assertions, this study is intended to highlight the influence of wood preservatives compared to environmental impacts out of alternative products in the landscape architecture.

In sustainable production and consumption strategies, bio-based products are increasingly developed, produced, and used as a result of eco-innovation approaches aimed at reducing the use of non-renewable raw materials. Nevertheless, to comprehensively evaluate the environmental profile of bio-based products, it is paramount to carry out life-cycle based study, as being bio-based bulks is not sufficient to be considered environmentally friendly. This LCA study is limited by its geographic and temporal scales. The relevance of the results and conclusions that are drawn from this work cannot be applied unilaterally to other geographic regions, building types or time periods.

Wood is ideal for commercial or industrial application because of its renewability, strength, beauty, versatility, and workability. However, wood that is used outdoors needs to be protected against wood-destroying organisms in order to extend its service life. A pitiful resistant wood can be altered by treating with chemical preservatives, such as creosote, oilborne preservative, and waterborne preservatives. Within the wood industry sector, the preservative industry plays an important role in the protection from environmental influences, such as heat, light, moisture, oxygen, pressure, enzymes, microorganisms, dust particles, which can cause deterioration of the beverages, but it can generate potential adverse impacts to the environment over its life cycle. Due to increasing public interest in the environmental impacts of consumption, there is a growing need for environmental information in wood preservation industry. It is known that the effect of the impact assessment method on the final outcome of an LCA has previously been evaluated in wood preservation sectors. In recent years, many companies in the wood preservation sector have been utilizing LCA as a tool to analyze the environmental performance (Robertson et al., 2012; Chau et al., 2015) of their packaging systems and the number of potential applicants is increasing. The series of LCAs has covered borate-treated lumber, pentachlorophenol-treated utility poles, ACQ (alkaline copper quaternary)-treated lumber, CCA (chromated copper arsenate)-treated guardrail and creosote-treated railroad ties (Bolin & Smith, 2011a; 2011b; 2011c; 2013a; 2013b). Therefore, a relative green preservative concept was established to reflect the resource efficiency of wood industry to consider both economic and environmental impacts.

In the preservative research field which is proposed to protect wood with tannins, the technology has indicated that the activated oligomers of flavonoid in the wood is subjected to a chemical equation with a successive in-situ polymerization catalysed by heat (Thevenon et al., 2009). It should also be paid attention that tannin-boron formulations have shown very good preservation properties against biologic attacks and fire, and which have also shown improved mechanical properties (Tondi et al., 2012). Until now, it is known that the tannin-boron formulation is low-environmental, which could only rely on the vegetal tannin and anchor boron into wood without consideration of the thorough process itself to impact on the environment.

In this study a follow-up of the TB exploitation can be tentatively performed. The study is going to provide a comprehensive, scientifically-based, fair, and quantifiable perception of environmental burdens, which are associated with the entire life cycle of TB-treated wooden landscaping materials. This study is performed using LCA methodologies in a manner consistent with the principles and guidance, which are provided by the International Organization for Standardization (ISO, 2006E) in standards ISO 14040 and 14044. SimaPro was used for calculation of index values for ReCiPe and CED. The study includes the four phases of an LCA: 1) Goal and scope definition; 2) Inventory analysis; 3) Impact assessment; and 4) Interpretation.

2 Methodologies

2.1 Goal and scope definition

This study comparatively analyses the cradle-to-grave life cycle environmental impacts of TB preservative and TB-treated lumber as landscaping materials, which could use LCA to quantify such impacts. The findings of this LCA study are based on a steady-state analysis assumption. While it gives a well-defined scope for LCA from the product fabrication point of view, the raw materials production of tannin also is justified in term of the different process conditions. The environmental impacts of concrete product and treated lumber are assessed throughout their life cycles, which are considered from raw materials acquisition to recycling or disposal of the product, through the manufacture/processing stages, accounting for the production and use of water, electricity, and fossils, as well as taking into account transportation/distribution impacts at all points along the product supply chain. Namely, three sets of LCA are conducted in this research:

(1) Based on water-extraction method proposed by Vieira (Vieira et al., 2011; Aires et al., 2015; Gagi et al., 2020), comparison of three treated process: liquor/bark ratio 15:1, 12:1 and 7.5:1; respectively Na_2CO_3 concentration of liquor 8%, 7.5% and 7%.

(2) Comparison of three preservatives: inorganic salt containing Cr (Cr), ACQ and TB.

(3) Comparison of concrete product and three treated wood product with Cr, ACQ and TB serviced in the landscape for estimated 30 years.

Tannin is sourced from Italy by truck.Some chemicals of tannin-boron formulation are purchased from surrounding Montpellier, France. In the present study all various scenarios are based in Europe. SimaPro software system has been used for these series of LCA, where the inventory data are primarily extracted from the ecoinvent v3.8 LCA database (2016) (Huijbregts et al., 2017; Dekker et al., 2021) .

The study was carried out according to a static focus, so the life cycle inventories could include intermediate values of the current processes within the system analysed, without analysing their variation over time. The software tool used in the study is SimaPro.

2.1.1 Functional unit

The functional unit is the comparison unit in a life cycle inventory. One kg of material is the selected functional unit, of which the considered stages are the material manufacture, the transport from production plant to landscape site, and the final disposal of the landscaping product. In this study, 1 kg of tannin is chosen in the different process, secondly 1 kg of preservative is regarded as the functional unit to Cr-based, ACQ and TB preservatives, then successively comparing 1 m^3 of landscaping materials which are made of concrete, Cr-treated lumber, ACQ-treated timber and TB-treated wood has been considered. All inputs and outputs are consistently based to these functional units.

2.1.2 System boundaries

The cradle-to-grave life cycle stages of woody landscaping materials considered in this research are illustrated in Figure 1, meanwhile system boundaries include the following life-cycle activities. Specially, processes including inputs and outputs are apportioned per functional unit, which are related to burning wood biomass to dry lumber, use of electricity in saw mills, and transportation-involved inputs and outputs.

(1) Stage of lumber and preservatives. The dominant species is Scots pine. The production of wood grew on French forest land at average forestry intensity, milled to dimensions, kiln-dried, and shaped at the local lumber mills. Tannins are supported by an Italian factory. The boron of boric acid anchored in TB is commercial and purchased from a company in Montpellier. Some preservatives are representative of lumber shipped to European wood-preserving plants for treatment. It is noticed that cold-extraction process of tannin is referred to Vieira et al. (2011). The following amounts of electricity and transport ton-miles are calculated.

(2) Lumber treating stage.

(3) Preservative-treated lumber service life as landscaping materials. The treated products are classified C3 according to EN 335-2 (exterior exposure, above ground), then these wood landscapes can be reasonably conserved in the service life.

(4) Preservative-treated lumber disposal stage. The legislations of Commission Directive appear to reflect relating to restrictions on the treated waste wood (TWW). then these scenarios are imagined to treated wood with three preservatives involved in this study: TB preserved TWW is recycled, and ACQ preserved TWW is poured into in the landfill, then Cr preserved TWW is put into an incinerator.

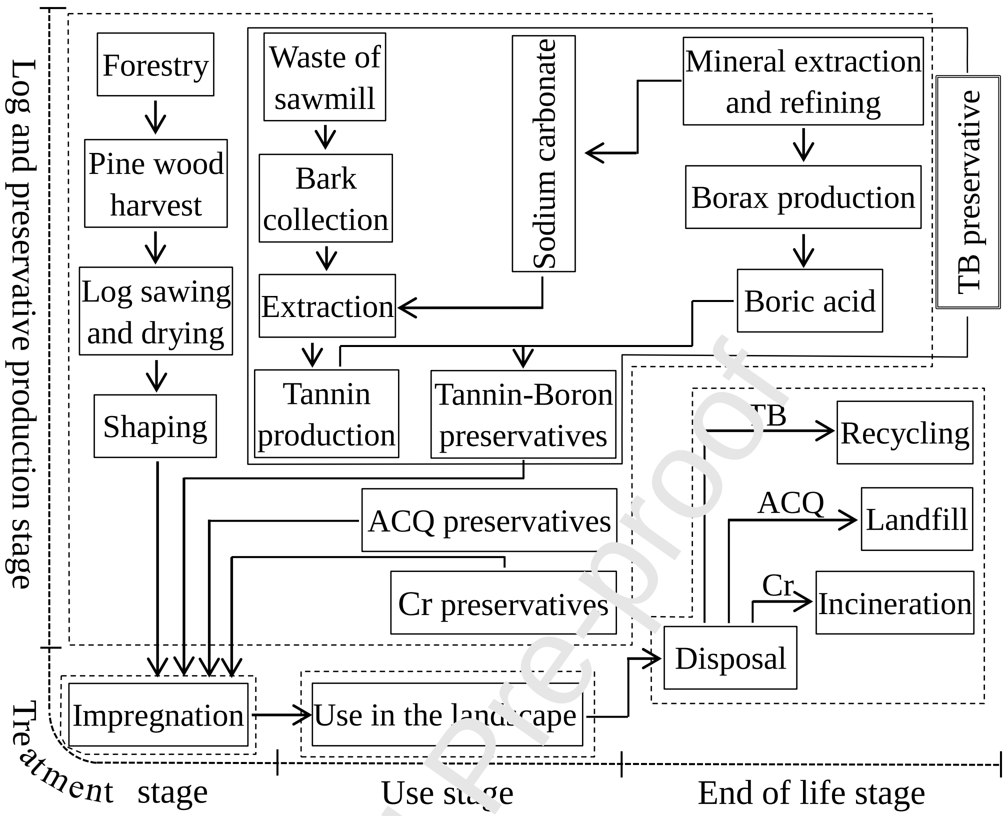

Figure 1 General flowchart for the life cycle of treated timber as landscaping material

Comparable cradle-to-grave LCA is available for concrete landscaping materials by the SimaPro software. A representative concrete design has been assumed: the concrete landscape equivalent to a C3 wooden landscape is likely to be appropriate during the service life. Concrete landscaping components include water, cement, sand, aggregate and admixture. The materials of landscape casting processes include electricity, diesel and water. Concrete landscape manufacturing components transporting to the casting plant is modeled as if by truck. Transportation of outbound precast concrete product to the use site also is modeled as if by truck. Post-use transport is assumed by truck as well. Transport distances to produced site Montpellier were assumed for each stage. This LCA models 100% of used concrete landscape as landfill disposed.

2.2 Life cycle inventory (LCI)

In accordance with the general framework provided by ISO 14040 and ISO 14044, an analysis of life cycle inventory is carried out. The data used in the present study focus on the landscaping materials of inputs from technosphere, i.e. energy, materials, emission and services. LCI has been segregated to compare the environmental impact of the various scenarios based on the results of the same boundaries. These data have been obtained by the combination of different sources, which have been also acquired under considering the functional unit previously established. Prominently, French data has been recommended to complete the LCI for the production. In other cases European data supported by Ecoinvent v38 database (2016) have been chosen, furthermore, some inventory data are connected with processes of SimaPro databases. The data which are selected from French databases have the following requirements: it is to represent a relatively new technology, data based on laboratories, industries or processes in France, data from the latest time possible. The calculations, specifically for tannin production, TB and ACQ, are based on literature reviews, whereas the majority of parameter values are derived from verifiable literature resources and statistical data on the relative production and utilization. This study adheres to the ISO standards on data quality with the purpose of help to ensure consistency and reliability.

Notably, the approach has a few limitations. In the data of tannin and TB, partial technical parameters can't be involved in the industries because of the TB formulations at experimental stage. It is assumed that the product flows included in the process-LCA are included completely. Table 1 provide details of the aspects considered within the LCI of TB. Analytical tools for testing the completeness of inventory data are required the company level data, which are unfortunately not available. However, it's known that tannin resources come from the forestry by-products, namely the rubbishy bark. Especially, since the life cycle assessment inventory is very thorough, some errors in the amounts of raw materials a re assumed to be as small as possible. Therefore the following results in this study can be considered as accurate.

Table 1 Detailed LCI of 1kg TB preservatives

Product materials	Process	Amount	Unit	Information reference
Bark	Harvest	1.07	m^3	Information references Vieira et al, 2011 and Li et al, 1998
Water	Extraction	5.91	kg	Information references Vieira et al, 2011
Sodium carbonate	Extraction	0.51	kg	Information references Vieira et al, 2011
Boric acid	Manufacture	0.02	kg	Data obtained from the experiment.
Water	Manufacture	0.83	kg	Data obtained from the experiment.
Sodium hydrate	Manufacture	0.005	kg	Data obtained from the experiment.
	Transport	0.13	tKm	The transport of chemical and tannin has been considered.

				The chemical dealer is a French company, at 100km to Montpellier. The origin of tannin is fabricated by an Italy factory, assumed the distance of 500 km. The weight of each unit component considered is affirmed in this table 1.
Electrical energy	Manufacture	0.063	kWh	Figures are based on average useage of laboratory-scale stirrer (Hopkinson et al., 2011). It is assumed that the mixture is stirred for 10 minutes to 1kg TB preservative production.

2.3 Life cycle impact assessment (LCIA)

The assessment of environmental impacts of individual emissions and resource depletion is the sum of the impact generated from each scenario. These impact categories to analyze in this study are selected considering the current energy and environmental problem in the France/Europe. This study is performed a combination with life cycle impact assessment methods, CED and ReCiPe, which are relatively innovative and have not been used in wood preservation domains.

The ReCiPe method for this LCIA, referring many other reports on LCIA similar to the Eco-indicator 99 and CML 2002 methods, provides a recipe to calculate life cycle impact category indicators (Goedkoop et al., 2009). ReCiPe comprises two sets of impact categories with associated sets of characterisation factors, which is one of the most updated methods, combining midpoint and endpoint methodologies in a consistent way (Goedkoop et al., 2009; Huijbregts et al., 2017). In this study impacts are evaluateed at the midpoint level since it has less uncertainties and value choices than the endpoint level, thereforce these eighteen impact categories are addressed at the midpoint level. Furthermore, for purpose of decline a degree of uncertainty in the knowledge of the mechanisms which lead to climate change and other environmental impacts, ReCiPe is developed three versions of individualist (I), hierarchist (H) and egalitarian (E) on the basis of the cultural perspectives theory of Thompson 1990(Goedkoop et al., 2009). Three perspectives reflect different degrees of optimism for the causality process-effect by thinking different time frames, rates of adaptation, etc. In the present study, the hierarchist perspective is chosen for the calculation of midpoint impact.

It should be noted that the applied LCIA method for energy-related issues evaluate the primary energy use through the life cycle of the product. CED method states the entire demand is assessed as the primary energy, which arises in connection with the production, use and disposal of a product or service, or which may be respectively attributed to it through cause (Zabalza Bribián et al., 2011). Thus, the CED method is chosen to analyze a general view of the energy-related environmental impacts in a life cycle, and it can also deliberate the electricity in France and distinguish between non-renewable (fossil and nuclear) and renewable primary energy use (hydraulic, biomass, wind, solar and geothermal) (Zhao et al., 2021; Grabarczyk and Grabarczyk, 2022).

2.4 Sensitivity parameters

In order to see the influence of the assumptions of tannin extract, a sensitive analysis was singularly performed on those parameters of liquor and the concentration of sodium carbonate, because of their uncertainty, were arbitrarily assumed during the inventory and that resulted in. To tannin production, the cold extractive process can be combined in the attempt to define an upper and a lower boundary of the impacts in the scenario. Change the assumption and recalculate the LCA. With this analysis there will be a better understanding of the magnitude of the effect of the assumptions. Sensitivity parameters in which they were combined for the mentioned purpose are described in Table 2.

Table 2 Three processes of cold-extraction tannin in the laboratory

Nº process	Liquor / bark ratio	Na_2CO_3 concentration
1	15:1	8.0%
2	12:1	7.5%
3	7.5:1	7.0%

3 Results and discussion

3.1 LCIA of procedure network for 1kg TB preservatives

The Kyoto protocol agreement has set binding targets for 37 industrialized countries and the European community to reduce the greenhouse greenhouse gas emissions. This was possibly conducted in response to the imminently threatening global warming problem caused by greenhouse gas emissions. The assessment of producing TB attained by ReCiPe method is shown in Figure 2, where GWP could beenseen the main contributions to the entire process. Because tannin process selected in the scenario is not performed according to the techniques of the commercial production, the assessment of producing TB attained by ReCiPe method is focused on much more attenation and firstly shown. The biggest emission sources regarded the climate change potential in the system can be found in Figure 2 which show parts of the simulations done by Simapro. The carbon dioxide of TB is regarded as the chemical of boric acid. Tannin production in this case subsequently concerns the sodium carbonate, which is performed in the form of cold process. Climate change is also mostly affected by the produce-need liquid ammonia and electricity energy. Moreover, the evaluated results of primary energy use in terms of CED method are shown in Figure 3. Noticeable in this Figure 3 is again the predominant presence of the impact from the sodium carbonate sub-process, excluding the depletion of renewable biomass. Nevertheless, it mentions here some "striking" facts from Figure 3, like the high contribution of the electricity energy to the non-renewable nuclear indicator, as well as of the bark to the renewable biomass. France derives about 75% of its electricity from nuclear energy (Finon and Romano, 2009; Zhao et al., 2021); therefore, electricity use dominates a remarkable situation in the non-renewable nuclear. The effect of fully occupied renewable biomass is bark, which probably due to the manufacturing material of only plant.

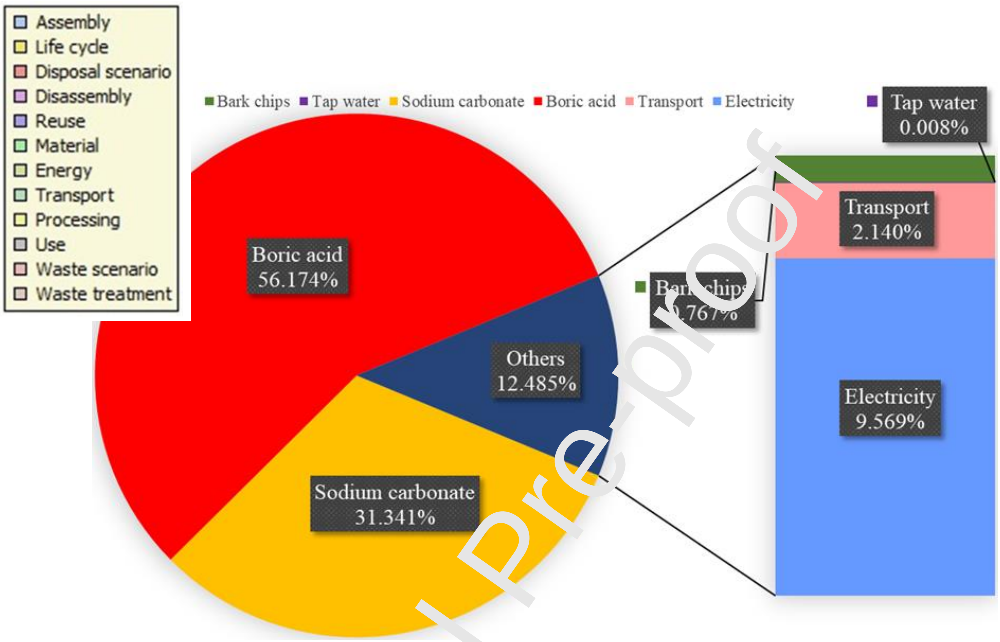

Figure 2 SimaPro exposing the main contributions of TB process to global warming potential (GWP)

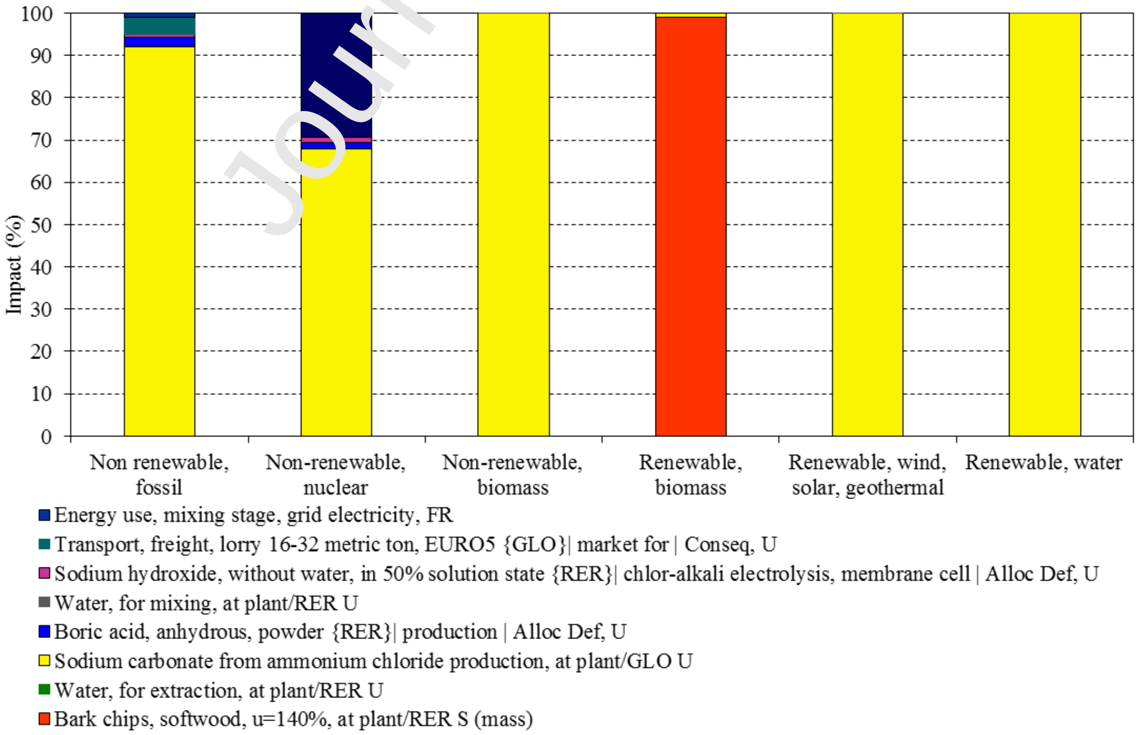

Figure 3 Contribution of impact categories to the single score for TB by CED method

3.2 Comparison of selected landscaping materials

Table 3 Impact categories for 4 landscaping materials based on ReCiPe-characterization results per m^3 material

Impact category	Unit	LM1	LM2	LM3	LM4
CC	kg CO_2 eq	$1.725\cdot10^{2}$	$5.557\cdot10^{2}$	$6.244\cdot10^{2}$	$1.998\cdot10^{2}$
OD	kg CFC-11 eq	$7.119\cdot10^{-5}$	$1.848\cdot10^{-5}$	$8.455\cdot10^{-5}$	$2.194\cdot10^{-5}$
TA	kg SO_2 eq	1.124	2.464	9.838	$9.416\cdot10^{-1}$
FEP	kg P eq	$1.601\cdot10^{-1}$	$7.509\cdot10^{-2}$	2.081	$8.088\cdot10^{-2}$
MEP	kg N eq	$5.839\cdot10^{-1}$	$1.003\cdot10^{-1}$	$5.773\cdot10^{-1}$	$3.894\cdot10^{-1}$
HT	kg 1,4-DB eq	$3.228\cdot10^{2}$	$1.065\cdot10^{2}$	$4.803\cdot10^{3}$	$8.032\cdot10^{1}$
POF	kg NMVOC	1.273	2.539	4.101	1.212
PMF	kg PM10 eq	$4.327\cdot10^{-1}$	$9.949\cdot10^{-1}$	3.357	$3.649\cdot10^{-1}$
TET	kg 1,4-DB eq	$4.248\cdot10^{-2}$	$2.618\cdot10^{-2}$	$3.452\cdot10^{-1}$	$2.541\cdot10^{-2}$
FET	kg 1,4-DB eq	5.875	2.609	$1.118\cdot10^{2}$	2.183
MET	kg 1,4-DB eq	5.989	2.637	$1.142\cdot10^{2}$	2.221
IR	kBq U235 eq	$2.105\cdot10^{2}$	$2.975\cdot10^{1}$	$6.624\cdot10^{1}$	$6.352\cdot10^{1}$
ALO	m^2a	$2.312\cdot10^{3}$	$2.357\cdot10^{1}$	$2.335\cdot10^{3}$	$2.313\cdot10^{3}$
ULO	m^2a	$2.921\cdot10^{1}$	$1.246\cdot10^{1}$	$4.095\cdot10^{1}$	$2.796\cdot10^{1}$
NLT	m^2	$2.271\cdot10^{-1}$	$-5.808\cdot10^{-3}$	$3.306\cdot10^{-1}$	$2.670\cdot10^{-1}$
WD	m^3	$1.359\cdot10^{3}$	$6.987\cdot10^{2}$	$2.533\cdot10^{3}$	$6.590\cdot10^{2}$
MD	kg Fe eq	$8.234\cdot10^{1}$	$4.346\cdot10^{1}$	$2.371\cdot10^{3}$	$1.936\cdot10^{1}$
FD	kg oil eq	$5.291\cdot10^{1}$	$1.038\cdot10^{2}$	$1.470\cdot10^{2}$	$6.539\cdot10^{1}$

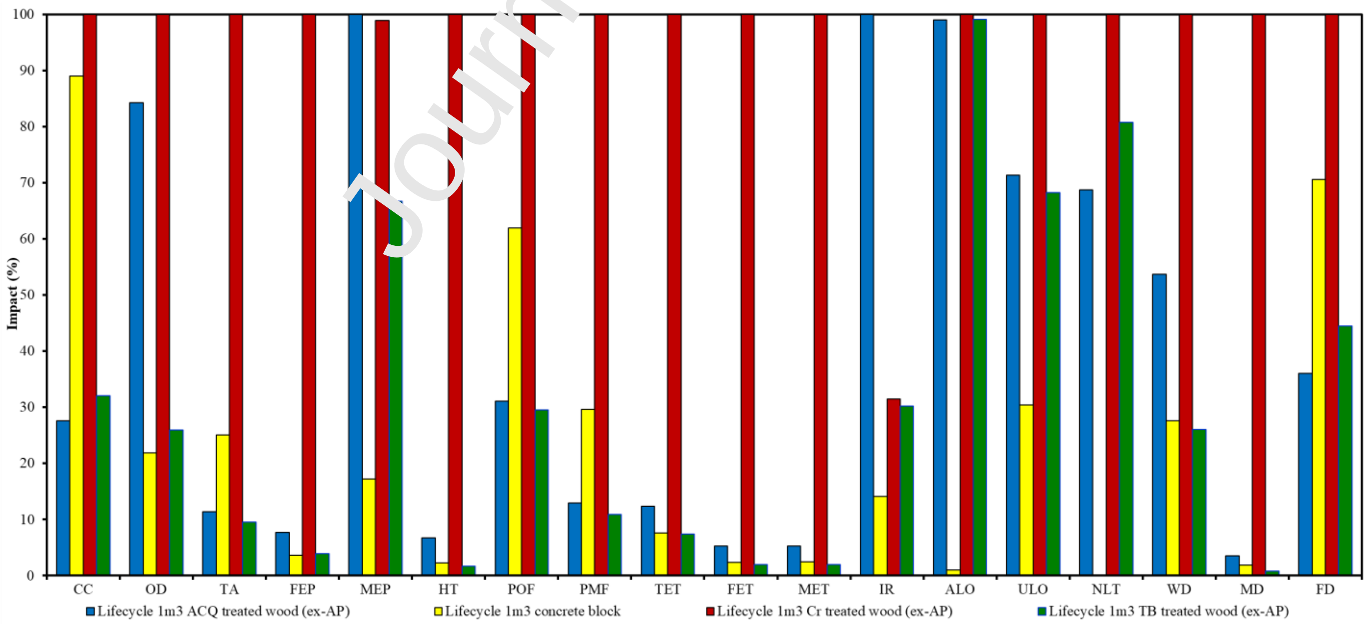

Figure 4 Contributions from impact categories of ReCiPe method toward each per m^3 material

Absolute results of impact factors are reported in Table 3. Figure 4 shows the results of environmental contributions for the characterization step. That is to say that the results for each impact category are presented on a percentage basis, with the highest scoring scenario represented as 100% and the remaining three scenarios scaled against this. This allows for comparison of relative scale across the various impact categories. In terms of climate change, the emission factor of TB-treated wood is 199.8 Kg CO_2 eq, slightly more than ACQ-treated wood (172.5Kg CO_2 eq), and much less than the case of Cr-treated wood and concrete (respectively 624.4 Kg CO_2 eq and 555.7 Kg CO_2 eq). Category most affected TB treated wood is agricultural land occupation, and it is not surprising due to raw materials input producing in the land. In total, the environmental burdens of Cr treated wood is severe, and the concrete landscaping material is general excluding resources depletion. Comparing those TB treated wood and ACQ treated wood, 2 impact categories out of 18 present some interesting, viz. climate change and fossil depletion. Foucusing on attention from global warming potential and fossil depletion, these weaknesses of TB treated wood arre indicated due to the sodium carbonate. However, the distance of contributor based these impact categories is not so great between TB treated wood and ACQ treated wood.

Table 4 Impact categories for 4 landscaping materials based on CED-characterization results per m^3 material

Impact category	Unit	LM1	LM2	LM3	LM4
Non-renewable, fossil	MJ	$2.363\cdot10^{3}$	$4.639\cdot10^{3}$	$6.613\cdot10^{3}$	$2.942\cdot10^{3}$
Non-renewable, nuclear	MJ	$2.655\cdot10^{3}$	$2.157\cdot10^{2}$	$6.988\cdot10^{2}$	$6.709\cdot10^{2}$
Non-renewable, biomass	MJ	$4.659\cdot10^{-3}$	0.000	$4.263\cdot10^{-3}$	$5.786\cdot10^{-3}$
Renewable, biomass	MJ	$9.207\cdot10^{3}$	0.000	$9.206\cdot10^{3}$	$1.119\cdot10^{4}$
Renewable, wind, solar, geothe	MJ	3.464	0.000	3.191	8.611
Renewable, water	MJ	$3.558\cdot10^{1}$	0.000	$2.432\cdot10^{1}$	$6.487\cdot10^{1}$

Regarding four landscaping materials, energy consumption is relatively high compared to other impact categories according to ReCiPe method. A CED is calculated based on the higher heating value and distinguishes renewable and non-renewable energy sources (Frischknecht et al., 2007). Non-renewable CED is very important to assess the depletion of fossil energy resources or the renewability of a system (Malça et al., 2006). As can be seen in Figure 5 and Tab. 4, there is an attention in four landscaping materials, namely consuming non-renewable energies of TB treated wood. The results show that the concrete block is the most significant due to no consummation of non-renewable energies. It can also be noted that there is a significant difference in non-renewable CED results between the various landscape scenarios, i. e. the nuclear energy of ACQ treated wood is highest because France is a country of nuclear electricity.

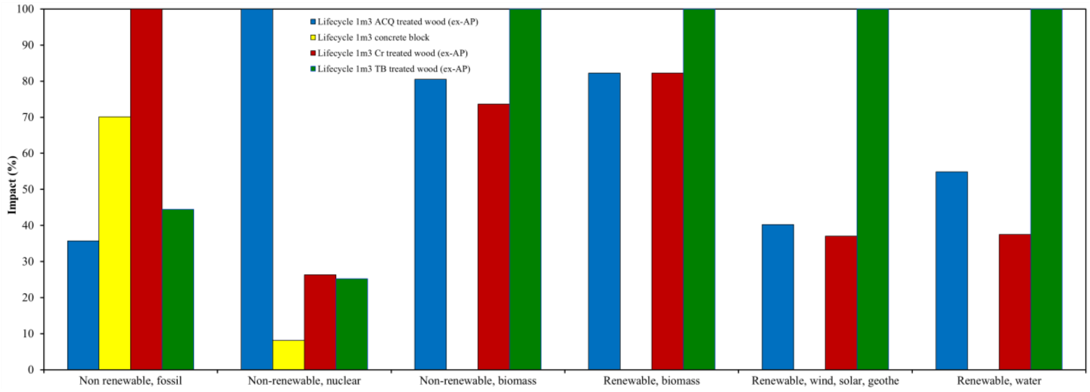

Figure 5 Contributions from impact categories of CED method toward each per m^3 material

3.3 Sensitive analysis

It is said that the outcome of the LCA can be quite heavily dependent on some of the assumptions. This does not need to be a problem as long as the conclusions of LCA are stable (Neo et al., 2021). From Figure 6 and 7, those environmental burdens and energies consummation have changed following the liquor and the concentration of sodium carbonate. The life cycle impact assessment results of tannin extraction also present significantly different, being that for the climate change the uncertainty range is between -38.14% and 13.71%, regarding the 0.451 Kg CO_2 eq used to model the process 2. Generally, the treatments with varying proportions of sodium carbonate have different values of tannin extract, however the treatment with 8% sodium carbonate has provided the higher yield of condensed tannins, underlining the importance of utilizing this specific salt concentration in the extraction process (Vieira et al., 2011). Hence, finding the most important assumptions is typically something. These results indicate that the effect of using Vieira's tannin extract process (Vieira et al., 2011) could appear a severely-environmental impact. It will be compelled to seek a environmentally-friendly tannin extract process, which is going to be perfectly filed the LCI data.

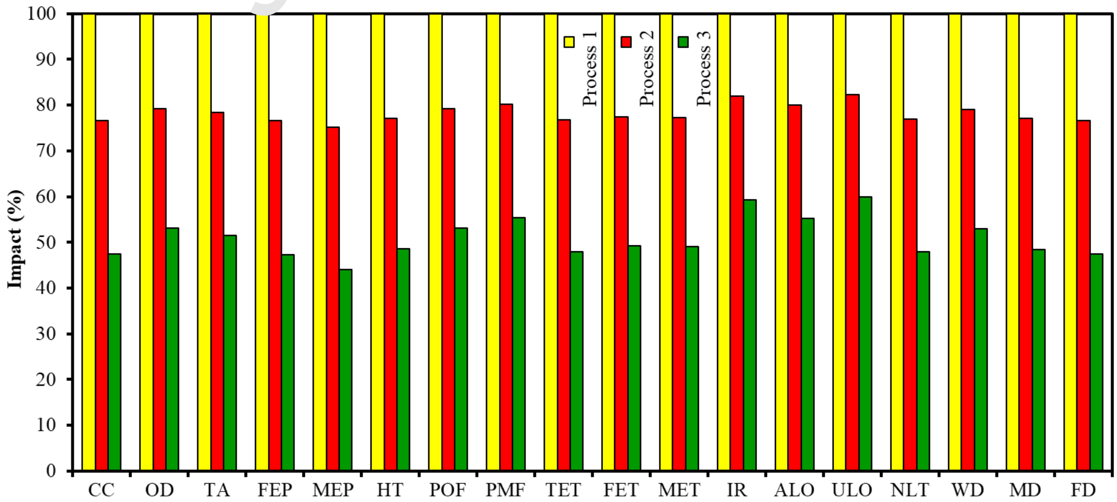

Figure 6 Comparing contributions from impact categories of ReCiPe method toward 3 processes of tannin extract

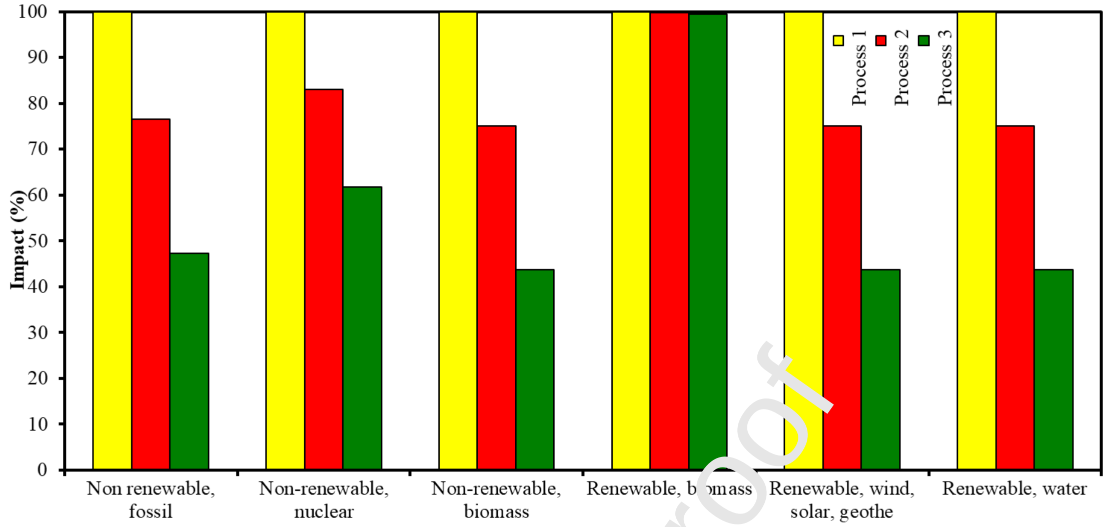

Figure 7 Comparing contributions from impact categories of CED method toward 3 processes of tannin extract

3.4 Limitation and recommendations

LCA study emphasizesonly the direct and indirect environmental impacts related to these landscaping materials by considering the potential exposure rather than the actual exposure. However, LCA lies in its ability to describe the studied system with a systematic and comprehensible LCIA method. LCA deals with the cradle-to-grave assessment of these products, which is usually not covered by other assessment tools. The environmental impacts in LCA are calculated from a set of well-defined factors, which help simplify the studied problem and accelerate the analysis.

In the future, additional research is required in order to improve the quality and comprehensiveness of the new TB preservatives and other subsequent comparative LCA studies related to wood preservation formulation. The accuracy of this study could be improved by using full-scale TB treated production manufacturing input data, along with refining the tannin production. With respect to sustainability of wood prevention, this comparison is based solely on environmental performance. Hence, in order to address the full scope of sustainable TB treated timber, life cycle costing, and life cycle sustainability assessment are some significant techniques, that could be employed in order to expand the analysis of TB formulation comparison to include a more complete sustainable treatment. Predominantly, the data referred in the life cycle inventory is laboratory-scale scenarios, which has been averaged over the entire Europe in the Ecoinvent (2016). Further research is also needed to identify and develop industry product LCI data, which would be set for other relevant environmental impact categories. It would facilitate to reveal an even clearer perspective of the comparative LCIA analysis.

LCIA conducts some analyses to present essential information from an inventory of interfered environment and energy. In LCIA, part of information is lost while the LCIA results are largely determined by a set of factor. The way to evaluate environmental performance and energy consumption of landscaping materials is schematized by ReCiPe and CED. The midpoint approach of ReCiPe is reliable, but the information of damages could not be given . CED method shows the depletion of energies and resources but do not correlate with environmental factors, climate change, acidification and eutrophication etc. There could still be additional tiers, for example, the concentration of pollutants can be derived by fate modeling between ReCiPe and CED when performed a LCA of preservative-treated timber.

4 Conclusions and recommendations

LCA evaluating the environmental impacts of 4 landscaping materials from cradle to grave has been implemented by a scenarios. TB preservative formulation determined the environmental benefits might offer over other preservatives, which has been focused by LCA in some previous literatures. The results calculated for the two LCIA methods have been elaborated: the use of ACQ-treated lumber for landscape offers lower environmental impacts than others, and TB-treated wood landscape consumes more renewable resources. In general the impact categories are limited to: non-renewable resources (with and without energy content), renewable resources (with and without energy content), global warming (CO_2 equivalents), acidification (kg SO_2 equivalents), ozone depletion (kg CFC-11 equivalents) and photochemical oxidant formation (kg ethane-equivalents), and then TB preservatives can be regarded a low-environmental impact formulation. From the results, it appears that the LCA results of the tannin-boron products are greatly impacted by the environmental factors assigned to the tannin extraction. However, the influential parameters of tannin processing at an industrial scale should be further investigated seeing as a variety of different studies and opinions currently existed on this topic. Additionally, an economic analysis of the development of a commercially-viable tannin-boron preservative would be timely.

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Authors' contributions

Conceived and designed the experiments: Jinbo Hu, Campbell Skinner; performed the experiment: Jinbo Hu; supervised the work: Marie-France Thevenon; wrote the paper: Jinbo Hu, Campbell Skinner; revised the paper: Jinbo Hu, Graham Ormondroyd, Marie-France Thevenon.

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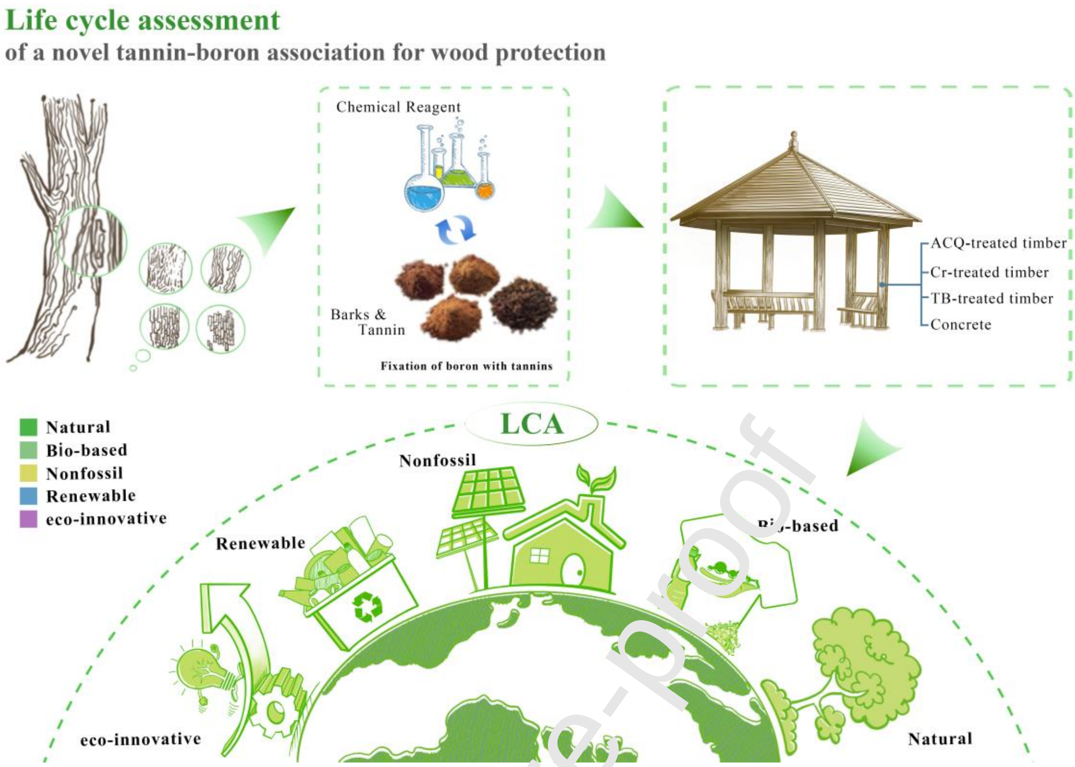
Graphical abstract



Highlights

Tannin-boron preservative pretecting the wood in outdoor scenario can be regarded as a low-environmental impact formulation.

LCA results of the tannin-boron products were greatly impacted by the environmental factors assigned to the tannin extraction, which should be further investigated by the progress of process system engineering seeing as a variety of different studies and opinions currently existed on this topic.

Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr. Jinbo HU reports financial support was provided by COST Action FP1303.

Authors’ contributions

Conceived and designed the experiments: Jinbo Hu, Campbell Skinner; performed the experiment: Jinbo Hu; supervised the work: Marie-France Thevenon; wrote the paper: Jinbo Hu, Campbell Skinner; revised the paper: Jinbo Hu, Graham Ormondroyd, Marie-France Thevenon.