Life Cycle Assessment

of Accoya® Wood

and its

applications

(full report with confidential information available on request)

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Peer reviewers:

Databases:

Contents

1. Goal

The reasons for carrying out this LCA study is twofold

a) for the management of Titan Wood[1]: to establish the strength and the weakness of their product and the production process in terms of toxic emissions
b) for external parties: to communicate the position of Accoya® Wood in relation to the alternative materials for applications in the building industry

The studied applications are:

1. window frames (as applied in The Netherlands)
2. decking (in gardens)
3. bridge construction (a pedestrian bridge)

The structure of this report is:

Part 1. LCA study according to ISO 14040:2006 and ISO 14044:2006 [Ref. 1,2] including the critical review report.

Part 2. LCA according to NEN 8006: 2004/A1:2008 [Ref. 3]

Part 3. Single indicator results (eco-costs) and conclusions (outside ISO) for company management information

Since the technology and the process of acetylation of wood is to be kept secret, it was decided to split this LCA study in two parts:

- A **cradle to gate** study for the output of the production plant in Arnhem. This part of the study is reported in Section 3 and Annex III. It is of special interest of the management of Titan Wood, however, it contains confidential information (outsiders can only have access to this confidential information after signing a Confidentiality Agreement).
  The members of the review panel have signed such a Confidentiality Agreement, and have had access to all the relevant data of the cradle to gate study.
- A **cradle to grave** study for the total chain. This part of the study is reported in Section 4 and Annex IV.
  The output of the cradle to gate study of Section 3 is input for the cradle to grave study.
  This part of the study is intended "to be used in comparative assertions intended to disclose to the public" , so section 4.4.5 of ISO 14044 is applicable, and a critical review is obligatory, as described in section 6 of ISO 14044.
  The critical review is reported in Section 5

[1] For more information on Titan Wood and its main product Accoya® Wood, see www.titanwood.com and www.accoya.com

The main parties involved in this LCA study are listed below.

Commissioner of this study:

Titan Wood, Arnhem, The Netherlands.

Practitioner and author of the report:

Dr. ir. Joost G. Vogtländer, Associate Professor, Delft University of Technology

The members of the critical review panel for the ISO study:

- Dr. Richard Murphy, Imperial College London, UK (chairman)
- Harry van Ewijk, IVAM UvA BV, University of Amsterdam, NL
- Erik Alsema, W/E consultants, Utrecht & Tilburg, NL

The reviewer for the NEN study:

- IVAM UvA BV, University of Amsterdam, NL

2. Scope

The scope of this LCA study are the following 3 product systems with various kinds of materials (for details see Annex I):

1. one window frame, size 1,65 x 1,3 m
   materials: Accoya (Scots Pine, Beech, Radiata Pine), Spruce, Meranti, Aluminium, PVC
   functional unit: good condition over a period of 75 years
   output of the calculations expressed in eco-burden per year
2. one piece of decking, size 2500 x 20 x 150 mm
   materials: Accoya (Scots Pine, Beech, Radiata Pine), Teak (old growth and new growth), and Wood-Plastic Composite
   functional unit: good condition over a period of 75 years
   output of the calculations expressed in eco-burden per year
3. The bearing structure of a passenger bridge, span 16 m, width 3 m
   materials: Accoya (Scots Pine, Beech, Radiata Pine), Azobé, Robinia, Spruce, Concrete, Galvanized Steel
   functional unit: per year in good condition

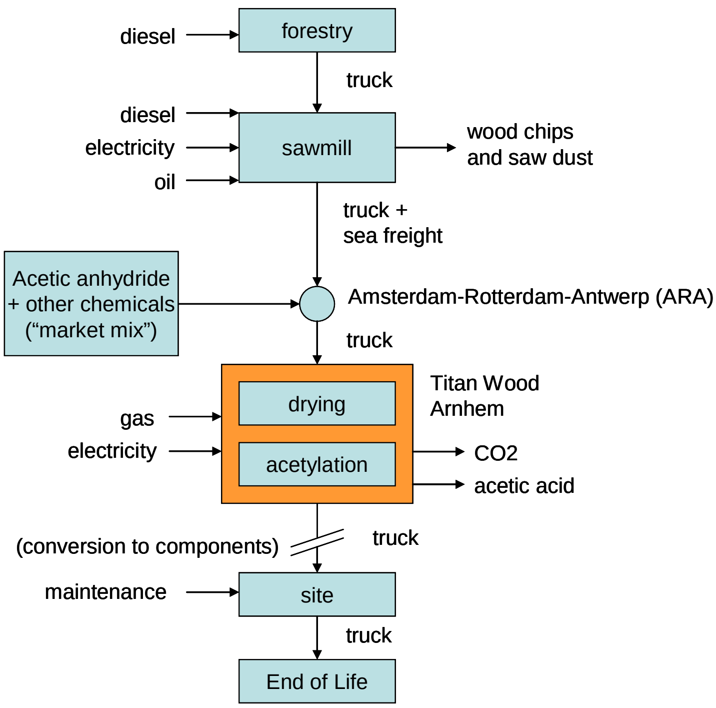

Figure 1: Process flow diagram for the LCA of Accoya Wood

The process flow diagram is depicted in Figure 1.

The system boundary is determined as follows:

- included in cradle to gate:
  wood (including stand establishment, forest management, harvesting, drying (to 12%), saw mill, transport from Forests - Rotterdam)
  energy for production plant in Arnhem
  chemicals and other materials (no single sourcing, but "market mix") for production in Arnhem
  transport of wood and chemicals Rotterdam – Arnhem
- included in use phase:
  transport Arnhem - site
  maintenance
- included in End of Life:
  transport site - EoL destination
  EoL treatment (e.g. combustion, land fill, etc.)
- excluded (since it is assumed to be the same for all materials in each product system):
  assembling of components
  marketing and distribution activities of components
  construction activities on site
- excluded (since it is partly incorporated in Ecoinvent, and since detailed data is not known):
  transport of "market mix" chemicals to Rotterdam

The LCI data, required for the calculations on the inputs, are from the Ecoinvent v2 database [Ref. 4] of the Swiss Centre for Life Cycle Inventories, and the Idemat 2008 database [Ref. 5] of the Delft University of Technology. The Idemat LCIs are based on Ecoinvent LCIs and some data of the Cambridge Engineering Selector [Ref. 6]).
The Simapro 7.1 software has been used for the LCIA calculations in this report.

The system has two co-products:

- waste wood from saw mills, planing, routing, etc
- acetic acid from acetylation of wood

Both types of co-products are dealt with by the so-called "system expansion" or "substitution" in LCA. For acetic acid this means that the eco-burden resulting from the "avoided acetic acid production elsewhere" (as "market mix") is subtracted from the total eco-burden of the Accoya Wood chain. This is according to ISO 14044, section 4.3.4.2. Step1 point 2.
Wood waste of the saw mill (bark, chips and dust) is used for pulp, wood products and combustion. In this LCA, this flow is calculated as 100% combustion, transformed into energy output, applying the Lower Heating Value of the material (i.e 20 MJ/kg dry wood). This is according to section 4.3.3.1. of ISO 14044. This energy output substitutes heat from oil (leading to a "eco-burden credit" for the avoided use of oil).
In the End of Life stage there are 3 forms of allocation where "system expansion" is applied:

- combustion of wood, applying the Lower Heating Value for the output of electricity from a municipal waste incinerator (with an overall efficiency of 25%)

- recycling of PVC, applying "system expansion" of the recycling step of PVC: the recycled PVC is substituting virgin PVC, leading to a "net benefit of recycling" (= the eco-burden from the recycling activity minus the eco-burden of virgin PVC)
- for recycling of steel and aluminium, the "net benefit of recycling" approach is used as well, however, only for the "virgin" part of the input of these materials, avoiding double counting of recycling (for the input, the "market mix" is taken, being the mix of recycled and virgin materials currently on the market).

For further explanation, see also www.ecocostsvalue.com FAQs question 2.4, 2.5, 2.6, and 2.7.
For comprehensive information on the subject of recycling and energy recovery, see General Guidance Document for Life Cycle Assessment (LCA) of the European Commission (ILCD) [17], Section 14, "consequentional modelling").

Since the goal of Titan Wood is the calculation, the comparison and the communication of the emissions of the chain, the following impact categories ("midpoints") have been selected from the CLM-2 baseline (for the ISO 14044 LCA)[2]:

- global warming (100 years)
- acidification
- eutrophication
- photochemical oxidation (respiratory organics, summer smog)
- human toxicity
- fresh water aquatic eco-toxicity
- terrestrial eco-toxicity

In addition to the above emission categories, data on abiotic depletion are provided as well (required for the NEN 8006).

The following CML-2 baseline midpoints are regarded as not relevant for the ISO 14044 study:

- ozone layer depletion (there are hardly any emissions in this category)
- marine aquatic eco-toxicity (not reliable: under heavy discussion, e.g. a factor 100 for HF [3])

For the convenience of the management of Titan Wood, the sum of the eco-costs 2007 of these selected impact categories are calculated as well. The eco-costs 2007 is a single indicator for LCA, see ANNEX VI and [Ref. 7]. In addition to the eco-costs of emissions, the eco-costs of land-use are given as well, to cope with the loss of biodiversity caused by harvesting of tropical hardwood from rain forests.
These calculations are given in Part 3 of this report.

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[2] According to ISO 14044 section 4.2.3.4 and 4.4.2.2.
[3] Ecoinvent recalculated the characterisation factor for Hydrogen Fluoride, since this substance had a unrealistic high contribution to the total score for the production of electricity. The characterisation factor appeared to be a factor 100 lower! CML didn't made a recalculation of the impact category so far.

The findings of this LCA are restricted to Western Europe. The transport scenarios which are used are specific to the manufacturing plant in Arnhem and a building site within a radius of 150 km. When the building site is at a further distance, extra transport must be added to the results as shown in this report.

Throughout the whole study, a cut-off criterion of 2% is used - according ISO 14044 section 4.2.3.3.3 - to decide that a sub-process can be excluded (declared outside the boundary limit). When a sub-process is excluded because of this cut-off criterion, it is clearly stated in the text (examples are the external pumping system for the fresh water supply in Arnhem, and the BOD of the effluent of the production plant in Arnhem). In such cases it is known that the impact on the overall LCA is negligible, so that further research on the details doesn't make sense.

It must be made clear that the overall accuracy of this LCA is not governed by this cut-off criterion, but by the fact that wood is a natural material with rather high spread of physical properties within each type of species, and high uncertainties with regard to its lifespan in certain applications (depending on construction and maintenance practice).

It must be mentioned that this LCA is characterized by the fact that most emissions are outside the production plant in Arnhem, so not in control of Titan Wood. This implies that the LCA is heavily dependant on the data quality of third parties. It was decided to apply the data of the Ecoinvent v2 database from the Swiss Centre for Life Cycle Inventories, unless stated otherwise in the text. Although the data quality of Ecoinvent v2 is far from perfect, it is the best there is at this moment[4]. For reasons of transparency, the LCIs which have been used are specified by its formal names, so the reader can check the data quality at the Swiss Centre for Life Cycle Inventories.

When processes data are not provided in the Ecoinvent database, the Idemat 2008 database of the Delft University of Technology is used. This special database has been build on Ecoinvent data of sub-processes, and is available as "open access" for organisations which have a Ecoinvent licence.

[4] Note that LCIA results are relative expressions and do not predict impacts on category endpoints.

Part 1. LCA study according to ISO 14040:2006 and ISO 14044:2006 including the critical review report.

3. LCIA of Accoya® Wood cradle to gate (finished product from Arnhem)

3.1 The production of Accoya® Wood in Arnhem

The heart of this LCA study is the production step in Arnhem. The process is depicted in Figure 2.

The transport of wood, acetic anhydride and other materials from the ARA (ARA = Amsterdam, Rotterdam, Antwerp) region is included in this production step. The soft water (x litres per m3 wood) is outside the boundary limit of the system, as well as the cooling water (x m3, x kWh, per m3 wood), because it is below the cut-off criterion of 2% of the total chain.

Figure 2 is confidential

The certified measurement of the flows for the current type of wood (Radiata Pine) is given in Annex II. Since this LCA is also for other types of wood (Scots Pine and Beech, see Annex I), the input and output flows have been calculated on the assumption that all flows are proportional to the density of the wood, except from liquid nitrogen. See Table 1.

confidential data

Table 1. Input and output from the production plant in Arnhem

For the analyses the following LCIs from Ecoinveent v2 have been applied:

- liquid nitrogen — Nitrogen, liquid, at plant/RER
- gas — Natural gas, at long distance pipeline/RER
- electricity — Electricity, medium voltage, production UCTE, at grid/UCTE
- inland transport — Operation, Lorry > 32 t, EURO 3/RER (full load, empty back)

The materials which were used for building the production facility ("the infrastructure") have been incorporated as well, for the maximum capacity of 40.000 m3 wood per year, over 20 years:

- steel x kg/m3 wood Steel, converter, unalloyed, at plant/RER
- stainless steel (316) x kg/m3 wood Idemat2008, X5CrNiMo18 (316)
- reinforced concrete x kg/m3 wood Idemat2008 Concrete (reinforced)

Note: Idemat 2008 has been used where Ecoinvent v2 data are not available.

Data on the effluent to the local sewage system (mainly acetic acid) were not available. Acid Acid in a sewer system is not toxic, however, requires O_2 for oxidation. Estimates from the material balance show that the effluent is less than x kg per m3 Accoya, so the COD is x, which is far below the 2% cut-off criterion.

3.2 Acetic Anhydride

Since acetic anhydride is not single sourced, the "market mix" has been used in the calculations. There are two ways acetic anhydride is produced:

- the ketene route, approx 36% of the global market
- carbonylation of methyl acetate, approx 64% of the global market

The Ecoinvent v2 database does not contain information on the carbonylation route, and has data on an outdated process of the ketene route. Titan Wood was able to provide manufacturer certified production data of the ketene route (2009) from an acetic anhydride supplier.

The ketene route is characterized by the following inputs:
- acetic acid (market mix), 1,22 kg/kg see Section 3.3
- gas for heat, 2,1 kWh/kg Heat, natural gas, at industrial furnace > 100kW/RER
- electricity, 0,3 kWh/kg Electricity, medium voltage, production UCTE, at grid/UCTE
- diesel, 0,1 kg/kg Diesel, low-sulphur, at regional storage/RER

The carbonylation of methyl acetate is characterized by [Ref. 8]:
- Carbon Dioxide, 0,431 kg/kg Carbon Dioxide liquid, at plant/RER
- the production facility (4E-10 part) Chemical plant, organics/RER
- electricity, 0,8 MJ Electricity, medium voltage, production UCTE, at grid/UCTE
- gas (for production), 0,55 kg Natural gas, at long distance pipeline/RER

The emissions to air are included in the calculation, however, are negligible: acetic acid 8,9E-5 kg/kg; carbon monoxide 5,5E-4 kg/kg; methane 4,7E-5 kg/kg; methanol 4,7E-8 kg/kg; NMVOC 1,1E-4 kg/kg.

3.3 Acetic Acid

Acetic acid is a co-product from the production plant in Arnhem. In LCA it substitutes the normal market mix production. As an output it has therefore negative eco-burden.
Although it is possible to make acetic acid from acetic anhydride in water (a reaction which takes place in the production plant in Arnhem as well), the production routes of acetic acid in the market are different:

- carbonylation of methanol, approx 90% of the world market
- acetic acid from butene, approx 5% of the world market
- acetic acid by fermentation of biomass, approx. 5% of the world market

The ecoinvent v2 processes which have been used are (in the same order):
- Acetic acid, 98% in H2O, at plant/RER
- Acetic acid, from butene, at plant/RER
- Ethanol, 95% in H2O, from sugar beets, at fermentation plant/RER
 (the real process not known in Ecoinvent, so the production of ethanol is used as surrogate process)

3.4 Wood

As already has been mentioned in Section 3.1, Titan Wood is planning to expand their product-portfolio with various locally produced species, such as:

- Scots Pine, e.g. sourced from Scandinavia
- Beech, e.g. sourced from Schwarzwald (in the southern part of Germany).

Apart from the impact of higher density on the production characteristics in Arnhem (see Section 3.1), the differences of the transport distances of Radiata Pine from New Zealand and European wood play an important role in the LCA calculations of the total chain.

Although the harvesting, sawing and drying operations in the exporting countries have a rather small contribution to the eco-burden of the total chain (even slightly lower than the cut-off criterion of 2%), it was decided to incorporate these activities in this LCA. Since the characteristics of wood can vary quite much (e.g. the density) and the characteristics of the operations (harvesting, sawing, drying) differ from location to location, the analyses have been done on scenario bases.

The scenario is depicted in Figure 3.
The main characteristics of the types of wood are summarized in Table 2.
The main characteristics of the scenarios of wood processing and transport are given in Table 3.

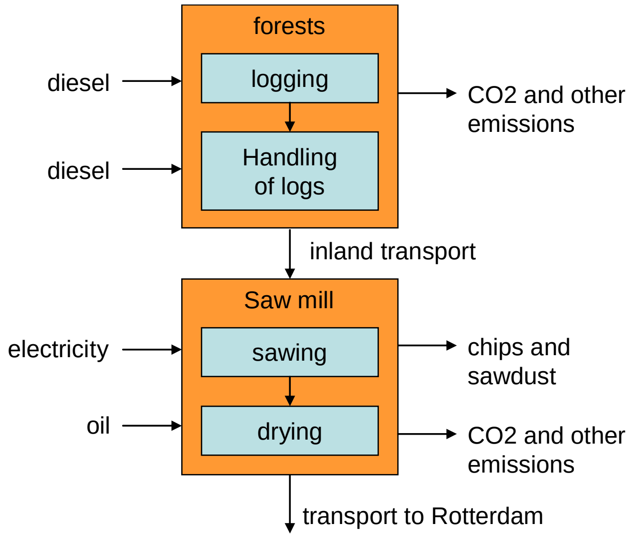

Figure 3: simplified process of timber (“4 sides sawn”)

An important issue is that the co-product, i.e. bark, chips and saw dust, is counted as feedstock for heat production (according to section 4.3.3.1. of ISO 14044), applying the Lower Heating Value of it. This implies that the LCA is not sensitive for the replacement of oil (for drying) by biomass from the saw mill.

	density 12%MC (kg/m3)	range density 12%MC (kg/m3)	density fresh (kg/m3)	density dry (kg/m3)	water out (kg/m3)	evap. heat (MJ/m3)	evap. heat (MJ/kg dry)
Scots Pine	520	320-800	670	458	150	338	0,74
Beech	710	690-750	960	625	250	564	0,90
Radiata Pine	450	360-550	850	396	400	902	2,28

Table 2. Main characteristics of wood [Ref. 9]

	heat input (MJ/kg dry)	petrol harvesting (MJ/kg dry)	electr. saw mill (kWh/kg)	sourced from	road tra (km)	sea tra (km)
Scots Pine	1,77	0,17	0,157	Scandinavia	260	2.500
Beech	2,17	0,17	0,157	Schwarzwald	630	0
Radiata Pine	5,47	0,17	0,157	Nw Zealand	80	20.811

Table 3. Processing and transport of wood

For the biomass (sawdust, chips) it is assumed in the scenario that the moisture content of the fresh wood is 50%. This results in a Lower Heating Value of 8,9 MJ per kg.
The efficiency of drying is assumed to be 41% (5,5 MJ per kg H_20 evaporated) [Ref. 10]
The transport distance from the forest to the mill is added to the distance from the mill to the seaport (for European wood directly to Rotterdam).
The following Ecoinvent v2 processes have been applied:

- petrol for harvesting — Idemat, petrol, including combustion
- oil (heat) — Heat, light fuel oil, at industrial furnace 1MW/RER
- electricity — Electricity, medium voltage, production UCTE, at grid/UCTE
- transport, land — Operation, Lorry > 32 t, EURO 3/RER (full load, empty back)
- transport, sea — Transport, transoceanic freight ship/OCE

3.5 Results of calculations and Life Cycle Interpretation

The results of the calculations in Simapro are given in Figure 4 and 5. These figures provide detailed information on the category indicators ("midpoints"), one by one, as required by the ISO 14044 section 4.4.5.

In Section 7.1 the results are presented in terms of a so called single indicator: the "eco-costs of emissions". Such a presentation has the advantage that information can be provided on the eco-burden in each step of the chain, in a clear graphical presentation. See Figure 11a and 11b.

Conclusions which can be drawn from the results of Figure 4 and 5 are:

- the eco-burden of the carbonylation process for acetic anhydride is less than the eco-burden of the market mix of acetic anhydride
- Accoya Radiata Pine has a significantly higher eco-burden than Accoya Scots Pine; the reason is the transport distance (Radiata Pine is transported from New Zealand, Scots Pine is transported from Scandinavia)

Note that the negative eco-burden scores (e.g. for photochemical oxidation) are caused by the "credits" which stem from the production of acetic acid. The market mix route to make acetic acid has apparently more emissions in the group of photochemical oxidation than the route via acetic anhydride (especially via the carbonylation process).

With regard to the quality of data, the following issues must be mentioned:

1. The certified input and output data of the production plant in Arnhem (DNV report, see Annex II) must be regarded as quite accurate (better than 1%), however it must be kept in mind that these data are linear to the density of the wood. Figure 6 (data per kg) is therefore more accurate than Figure 5 (data per m3).
2. The emissions of the production plant in Arnhem are low in comparison to the emissions elsewhere in the chain. For the consequences in terms of data quality: see the last paragraph of page 8 , Section 2.

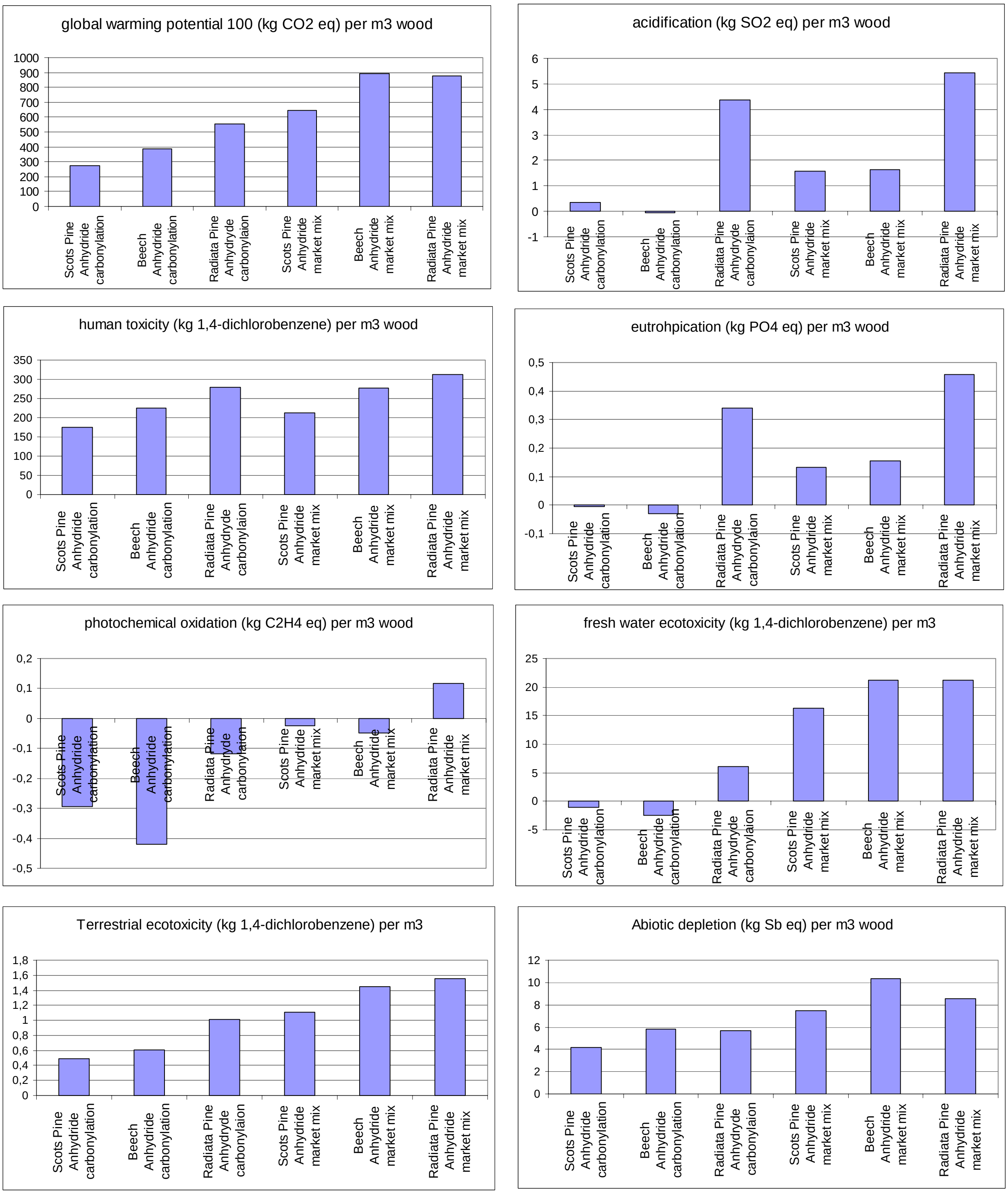

Figure 5. The category indicators for the different types of wood-anhydride combinations per m3 output

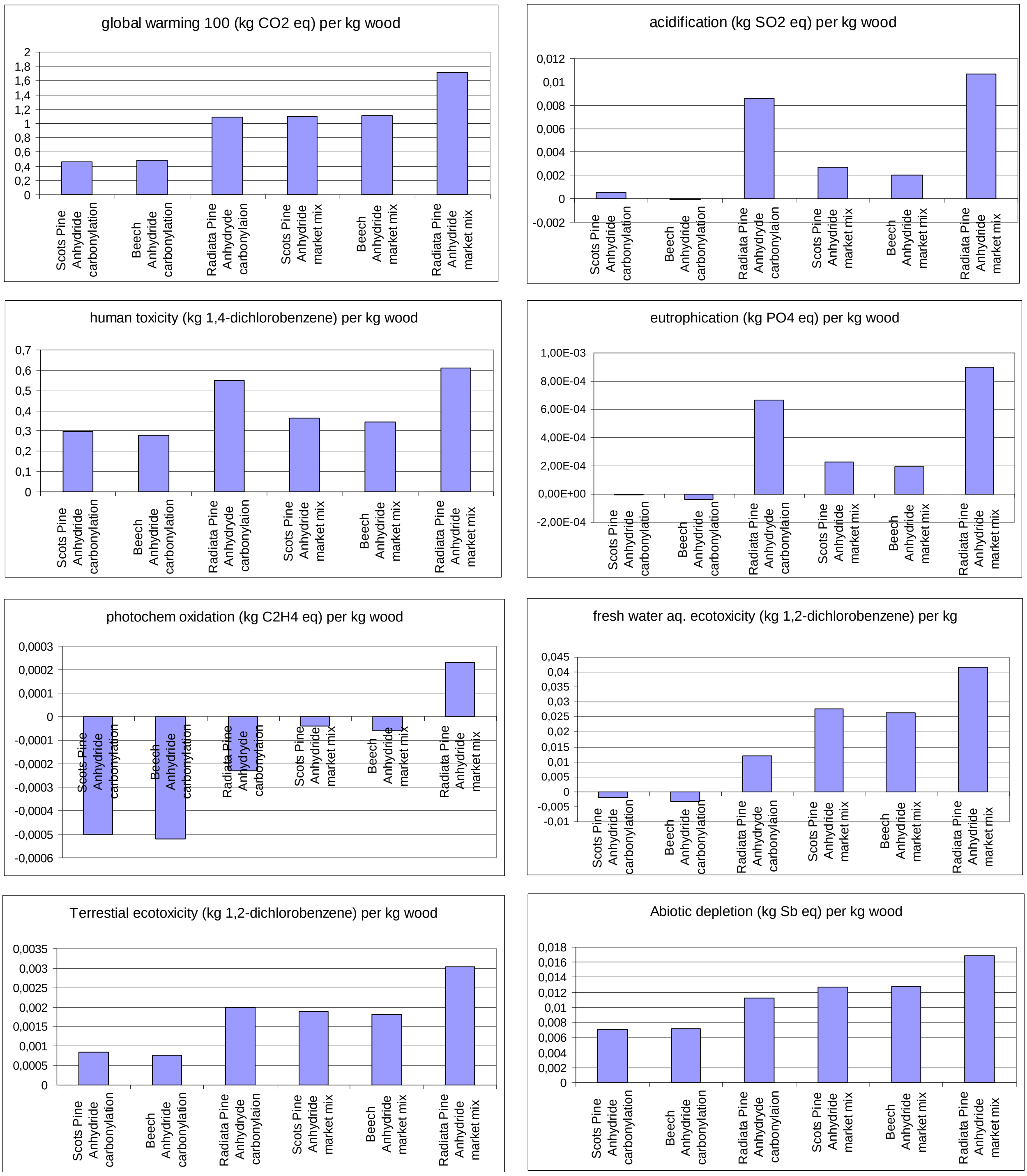

Figure 6. The category indicators for the different types of wood-anhydride combinations per kg output.

4. LCIA of Applications of Accoya® Wood from cradle to grave, ISO 14040 and 14044

4.1 The Window frame

In this section, the chain of a window frame is analysed. See Figure 7. The analysis is done according to ISO 14040 and 14044, applying scenarios in compliance with NEN 8006.

The functional unit is: 1 window frame, size 1,65 x 1,3 m
per year use,
calculated over a period of 75 years

The materials of the comparison are (with lifespan):

- Accoya wood: Scots Pine, Beech, Radiata Pine (50 years), "market mix" of Acetic Anhydride sourcing
- Spruce, untreated (25 years)
- Meranti, from plantations in South-East Asia (35 years)
- Aluminium (50 years)
- PVC, with steel (35 years)

In compliance with NEN 8006, the number of frames, required for the period of 75 years, is calculated as: 75 / lifespan.

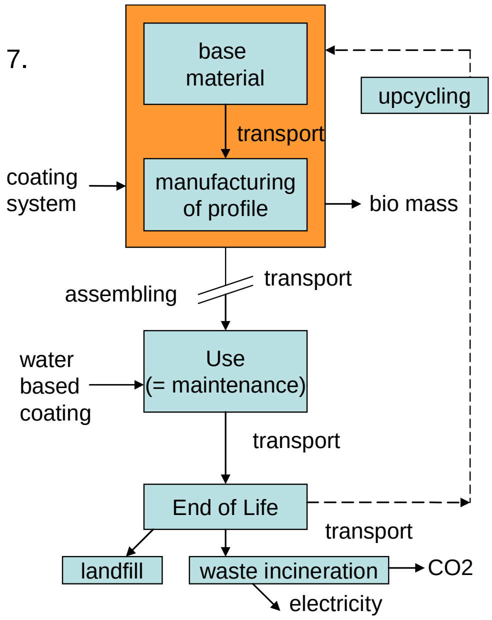

Figure 7: the chain of a window frame

The size of the wooden profile is 67 x 114 mm. This is made from timber 75 x 125 mm. With 6,5% shortening losses, the total volume of Accoya which is required is 0,059 m3. Applying the densities of Table 1, and the abovementioned life spans, the weight of the wood timber is given in Table 4. The biomass (wood chips) which stems from planning and routing is estimated as well (for 75 years).
It is assumed that 11% of the wood is removed at the last routing step to make the profile.
The weight PVC frames are from a Swiss study [Ref. 11]. The PVC frame comprises
25,6 kg PVC + 16,1 kg Steel. The weight of the Aluminium frame is calculated, applying a weight of 3 kg/m for a modern profile of good quality and low heat conductivity.

	density (kg/m3)	weight (kg)	lifespan (years)	weight 75 years (kg)	biomass waste (kg)
Accoya Scots Pine	589	34,86	50	52,29	16,84
Accoya Beech	805	47,60	50	71,40	22,99
Accoya Radiata Pine	510	30,17	50	45,26	14,57
Spruce (untreated)	460	27,21	25	81,63	26,29
Meranti	640	37,86	35	81,13	26,13
Aluminium		17,70	50	26,55	
PVC		41,70	35	89,36	

Table 4. The weight (input) of the wood which is required to make the window frame and the biomass production; results of calculations are given for a total of 75 years use of window frames.

Coating systems:

- for Accoya white acrylic 150-180 µm, plus 60 µm every 5 years[5]
- for Spruce white acrylic 150-180 µm, plus 60 µm every 5 years
- for Meranti white acrylic 150-180 µm, plus 60 µm every 6 years
- for Aluminium powder coating system, 80 µm (take total surface approx. 2,2 m2)
- for PVC (with steel) powder coating system, 80 µm (take total surface approx. 2,2 m2)

In compliance with NEN 8006, the total amount of coating is calculated for the period of 75 years, see Table 5.

	production		maintenance		total	
Accoya	0,65	kg	0,83	kg	1,48	kg
Spruce	1,31	kg	0,73	kg	2,04	kg
Meranti	0,93	kg	0,79	kg	1,72	kg

Table 5 Coating during 75 years, for production, maintenance and total

The transport distances are (in compliance with NEN 8006):

- base material to manufacturing site of the frame 50 km
- manufacturing site to building site 150 km
- building site to disassembling&sorting site 50 km
- disassembling&sorting site to landfill 50 km
- disassembling&sorting site to waste incinerator 100 km
- transport for recycling 150 km

	weight timber (kg)	weight frame (kg)	to manufacturing (tkm)	to site and EoL (tkm)
Accoya Scots Pine	52,29	35,45	2,61	10,63
Accoya Beech	71,40	48,41	3,57	14,52
Accoya Radiata Pine	45,26	30,68	2,26	9,20
Spruce (untreated)	81,63	55,34	4,08	16,60
Meranti	81,13	48,13	4,06	14,44
Aluminium		26,55	1,33	7,97
PVC		89,36	4,47	26,81

Table 6. Transport of wood to manufacturing plant (50 km) and window frames to building site and End of Life (150 + 50 + 100 = 300 km), for a total period of 75 years use

The standard scenario of NEN 8006 for recycling of building materials has been applied, see Table 7. However, the recycling percentage op PVC of 80% seems to be unrealistic and not in line with the Dutch product declaration on window frames (MRPI), so a percentage of 60% has been applied (PVC is

[5] Note that Titan Wood has a different maintenance advice for Accoya: 35 µm every 8 years. On request of the peer reviewers, however, the same painting system was applied to all wooden frames. Note that this difference in approach hardly effects the output of the total LCA, since the maintenance part is negligible, see Figure 12.

then 2x recycled, as given in the product declaration, but note that this is still not reached in practice). This issue is dealt with in more detail in de sensitivity analysis in Section 7.2.

	land fill	waste incineration	recycling
Wood	10%	90%	0%
Aluminium	5%	5%	90%
PVC	10%	10%	80%

Table 7. Standard End of Life Scenarios for the building industry in The Netherlands, NEN 8006.

It is assumed that the domestic waste is incinerated in general waste incineration plants with electrical power generation, 25% overall efficiency (55% of the efficiency of electrical power plants). The Lower Heating Value has been applied of wood 12% MC (17,3 MJ/kg).

For the calculation, the following LCIs of Ecoinvent and Idemat have been applied:

- wood — see Section 2
- energy — Electricity, medium voltage, Production UCTE, at grid/UCTE (0,2 kWh/kg)
- aluminium — 65% Aluminium, primary, at plant/RER
  35% Aluminium, secondary, from old scrap, at plant/RER
- PVC — Polyvinylchloride, at regional storage/RER
- PVC extrusion — Idemat2008 Extrusion PVC
- Steel — Steel, converter, unalloyed, at plant/RER (21% iron scrap)
- Coating wood — Acrylic varnish, 87,5% in H2O, at plant/RER
- Coating Al — Powder coating, aluminium sheet /RER
- Coating PVC — Powder coating, steel /RER
- Transport — Operation, Lorry > 32 t, EURO 3/RER (full load, empty back)
- EoL combust. — Idemat2008 Softwood 12%MC, waste incineration with electricity
- EoL combust. — Idemat2008 Hardwood 12%MC, waste incineration with electricity
- EoL combust. — Idemat2008 Polyvinylchloride, waste incineration with electricity
- EoL recycling — Idemat2008 Polyvinylchloride, recycling benefit
- EoL recycling — Idemat2008 Aluminium, recycling benefit
- EoL recycling — Idemat2008 Steel, recycling benefit

The results of the calculations in Simapro are given in Figure 8 a, b, and c.
Figures 8 provides detailed information on the category indicators (“midpoints”, one by one, as required by the ISO 14044 section 4.4.5.

Figure 8a is for the base case lifespan assumptions: Accoya 50 years, Meranti 35 years, Spruce 25 years, Aluminium 50 years and PVC 35 years. These lifespan assumptions must be regarded as scenarios in LCA.

Since actual the lifespan of a window frame depends heavily on construction details, maintenance and location, calculations have been made for different scenarios:

- Figure 8b for a 20 % shorter life span, i.e. Accoya 40 years, Meranti 28 years, Spruce 20 years, Aluminium 40 years and PVC 28 years
- Figure 8c for a 20 % longer life span, i.e. Accoya 60 years, Meranti 42 years, Spruce 30 years, Aluminium 60 years and PVC 42 years.

Comparison of data in the three Figures gives the reader a sense of the sensibility of the output for changes in assumptions in lifespan.

Data in terms of eco-costs are provided in Section 7.2, with a split-up of the total eco-burden in the eco-burden of production, transport, maintenance and end of life. This Section provides also data for other assumptions for the recycling rate of PVC (80%, 60%, 40% and 10%).

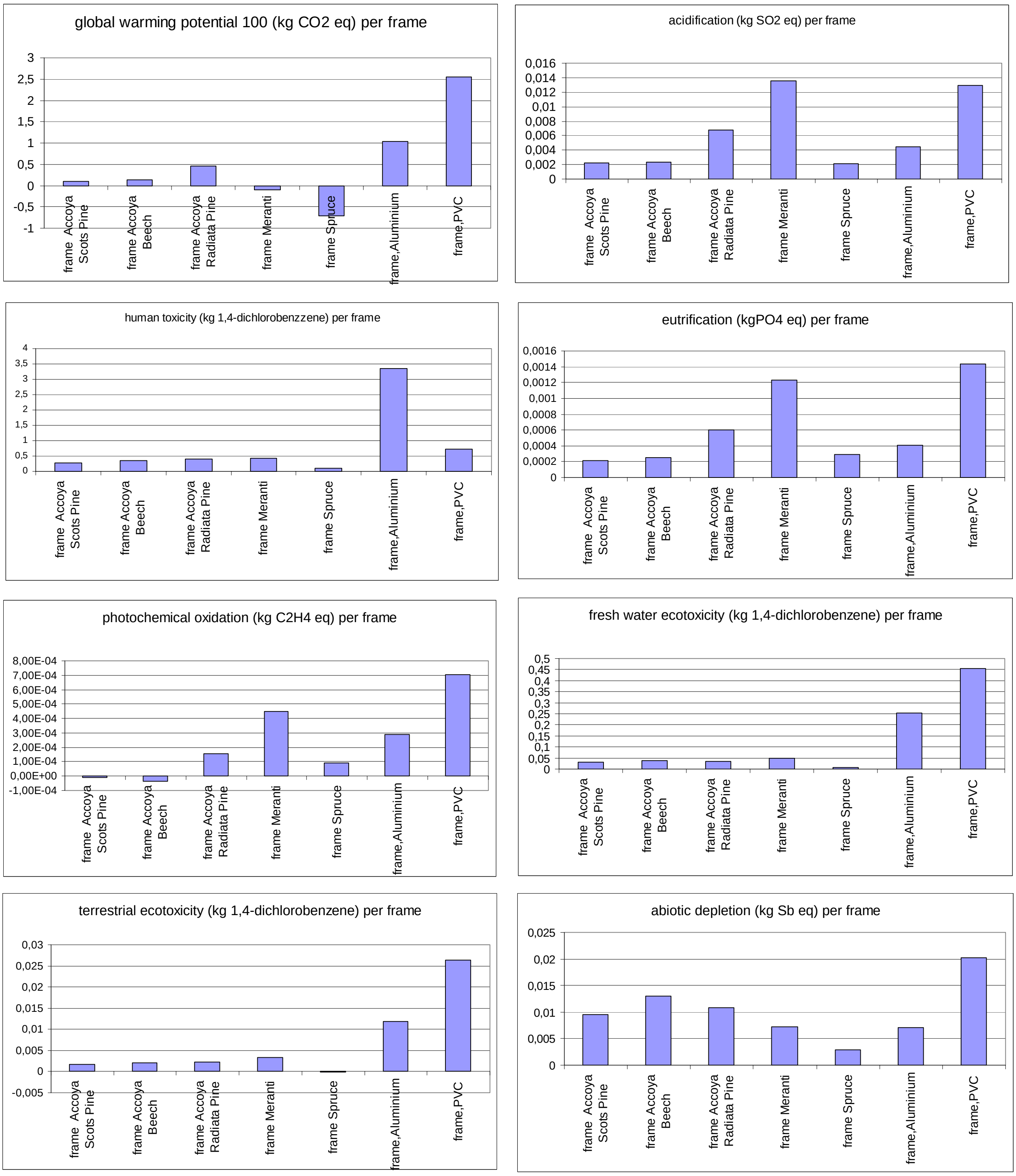

Figure 8a. The category indicators for the different types of materials for a window frame, 1,65 m x 1,3 m, per year use. Lifespan assumptions (the base case): Accoya 50 years, Meranti 35 years, Spruce 25 years, Aluminium 50 years, PVC 35 years.

Note: For Accoya the “market mix” of Acetic Anhydride sourcing has been applied.

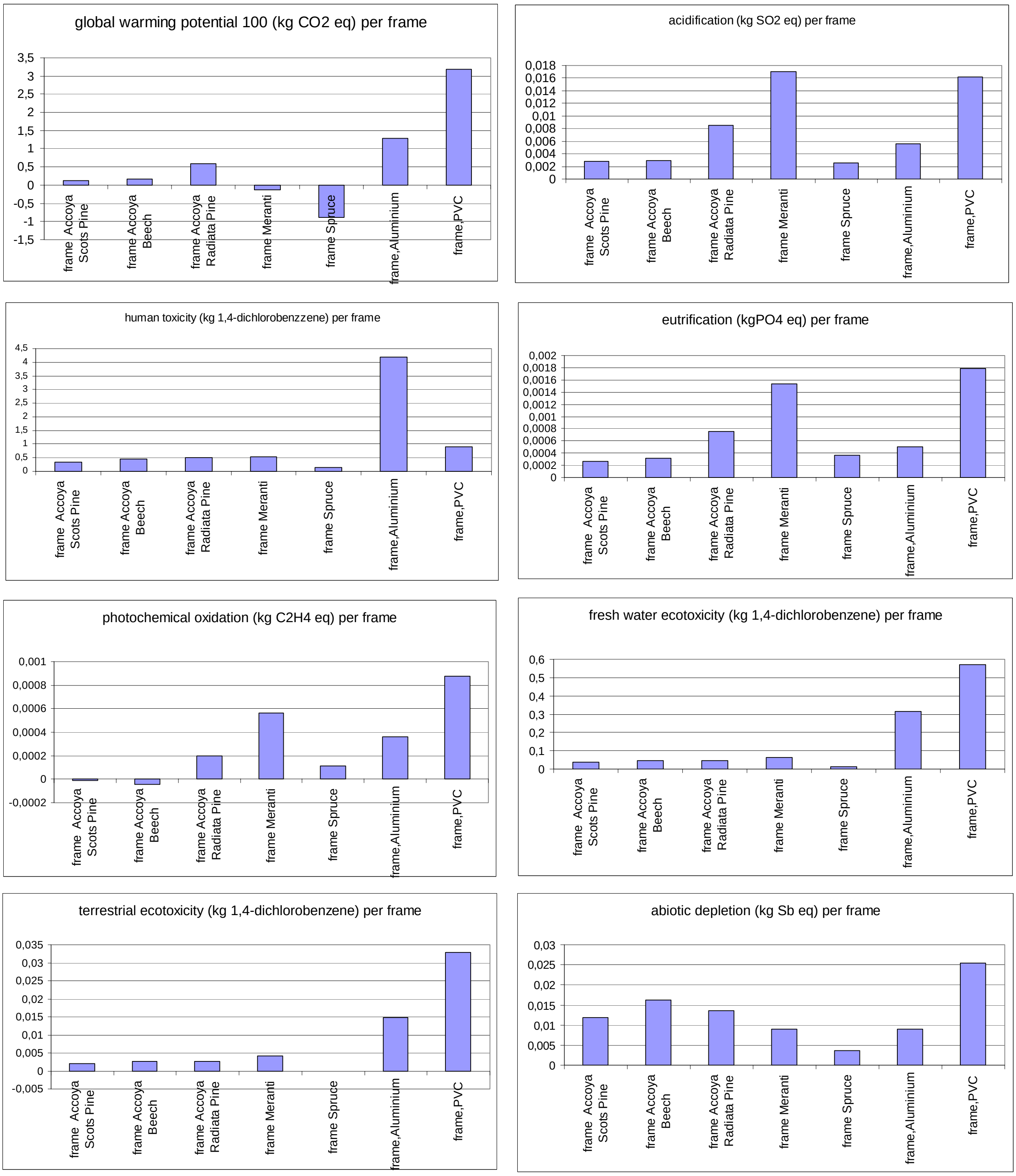

Figure 8b. The category indicators for the different types of materials for a window frame, 1,65 m x 1,3 m, per year use. Lifespan assumptions (20% shorter than the base case): Accoya 40 years, Meranti 28 years, Spruce 20 years, Aluminium 40 years and PVC 28 years

Note: For Accoya the “market mix” of Acetic Anhydride sourcing has been applied.

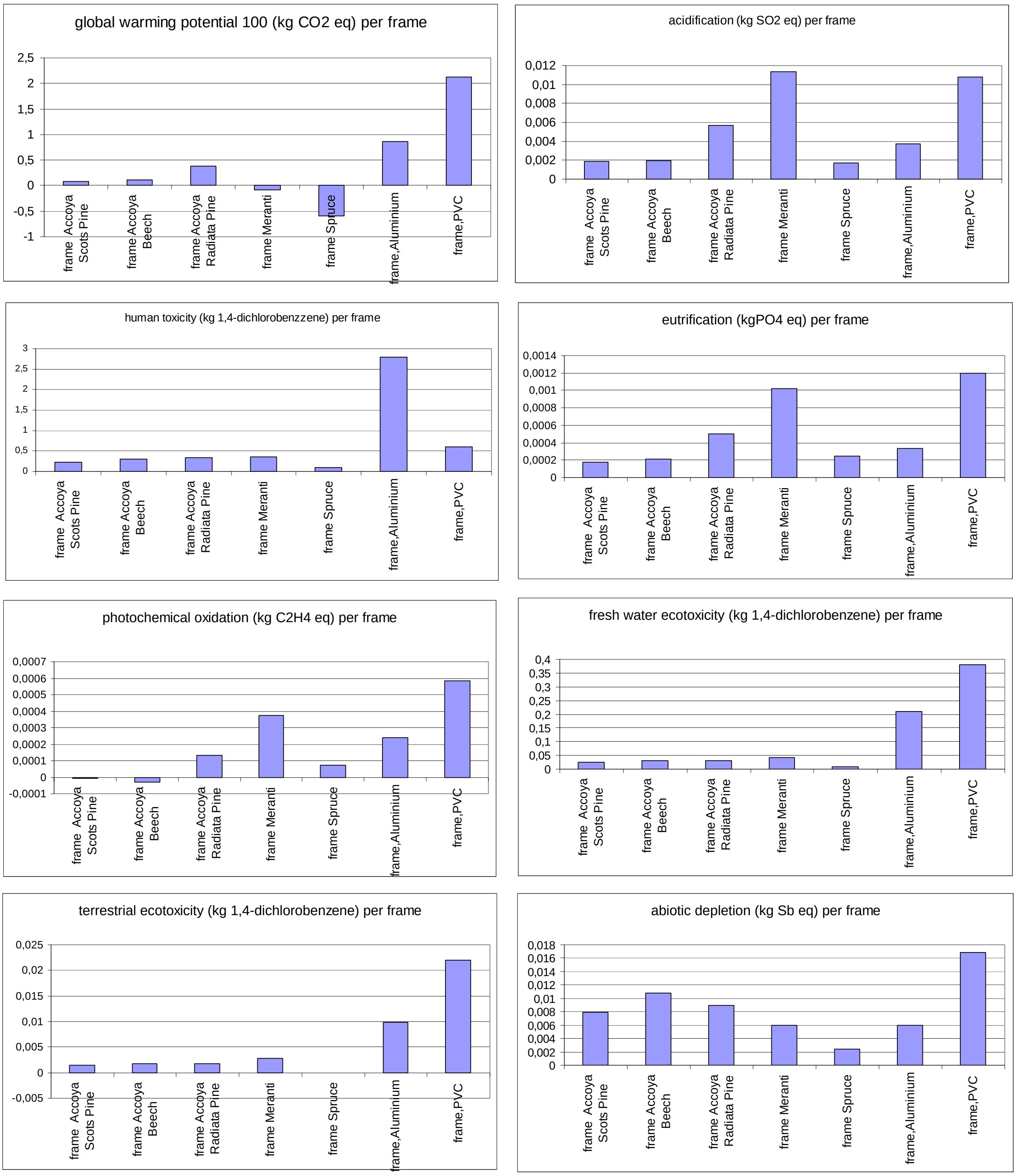

Figure 8c. The category indicators for the different types of materials for a window frame, 1,65 m x 1,3 m, per year use. Lifespan assumptions (20% longer than the base case): Accoya 60 years, Meranti 42 years, Spruce 30 years, Aluminium 60 years and PVC 42 years.

Note: For Accoya the “market mix” of Acetic Anhydride sourcing has been applied.

4.2 The Decking

In this section, the chain of a decking is analysed. The life cycle chain is similar to the chain of Figure 7. The analysis is done according to ISO 14040 and 14044, applying scenarios in compliance with NEN 8006.

The functional unit is: 1 piece of decking, size 2500 x 20 x 150 mm
per year use, calculated for a period of 75 years

The materials of the comparison are (with lifespan):

- Accoya Wood: Scots Pine (25 years), Beech (37,5 years), Radiata Pine (25 years)
  "market mix" of Acetic Anhydride sourcing
- Teak, Old Growth from plantations in Myanmar and Thailand (25 years),and New Growth from plantations in Brazil (15 years)
- Wood Plastic Composite (25 years), 60% Spruce, 40% HDPE.
  Note that a WPC plank is 30 mm thick, but hollow with inside support bars, with a net (solid) cross section of 3000 mm^2.

The yield to plane the decking from the Accoya from Arnhem is assumed at 90%.

	density (kg/m3)	weight gross (kg)	lifespan (years)	weight 75 years (kg)	biomass (kg)	weight net (kg)
Accoya Scots Pine	589	5,20	25	15,60	2,34	13,26
Accoya Beech	805	7,10	37,5	14,20	2,13	12,07
Accoya Radiata Pine	510	4,50	25	13,50	2,03	11,48
Teak Old Growth	660	5,82	25	17,47	2,62	14,85
Teak New Growth	660	5,82	15	29,12	4,37	24,75
Wood Plastic Composite	688	6,07	25	18,21		18,21

Table 8. The weight (input) of the wood which is required to make the piece of decking, the biomass production, and the weight net (after planning), all for a 75 year period

The transport distances are (in compliance with NEN 8006):

- base material to manufacturing site 50 km
- manufacturing site to building site 150 km
- building site to disassembling&sorting site 50 km
- disassembling&sorting site to landfill 50 km
- disassembling&sorting site to waste incinerator 100 km
- transport for recycling 150 km

	weight gross (kg)	weight net (kg)	to manufacturing (tkm)	to site and EoL (tkm)
Accoya Scots Pine	15,60	13,26	0,78	3,98
Accoya Beech	14,20	12,07	0,71	3,62
Accoya Radiata Pine	13,50	11,48	0,68	3,44
Teak Old Growth	17,47	14,85	0,87	4,46
Teak New Growth	29,12	24,75	1,46	7,43
Wood Plastic Composite		18,21	0,91	5,46

Table 9. Transport of wood to manufacturing site (50 km) and decking to building site and End of Life (150 + 50 + 100 = 300 km), for a 75 years period of decking

Recycling of old decking is not likely. Therefore, we apply in our scenario the following percentages for End of Life: landfill 10%, combustion in waste incineration plants 90%.
It is assumed that the domestic waste is incinerated in general waste incineration plants with electrical power generation, which have 25% overall efficiency (55% of the efficiency of electrical power plants).
The Lower Heating Value has been applied.
The eco-burden of landfill is below the cut-off criterion of 2%.

The LCIs which have been applied are the same LCIs of Section 3.1.
For HDPE, the following LCI of Ecoinvent has been applied: Polyethylene, HDPE, granulate, at plant/RER

The output of the Simapro calculations are given in Figure 9.

Data in terms of eco-costs are provided in Section 7.3, with a split-up of the total eco-burden in the eco-burden of production, transport, and end of life.

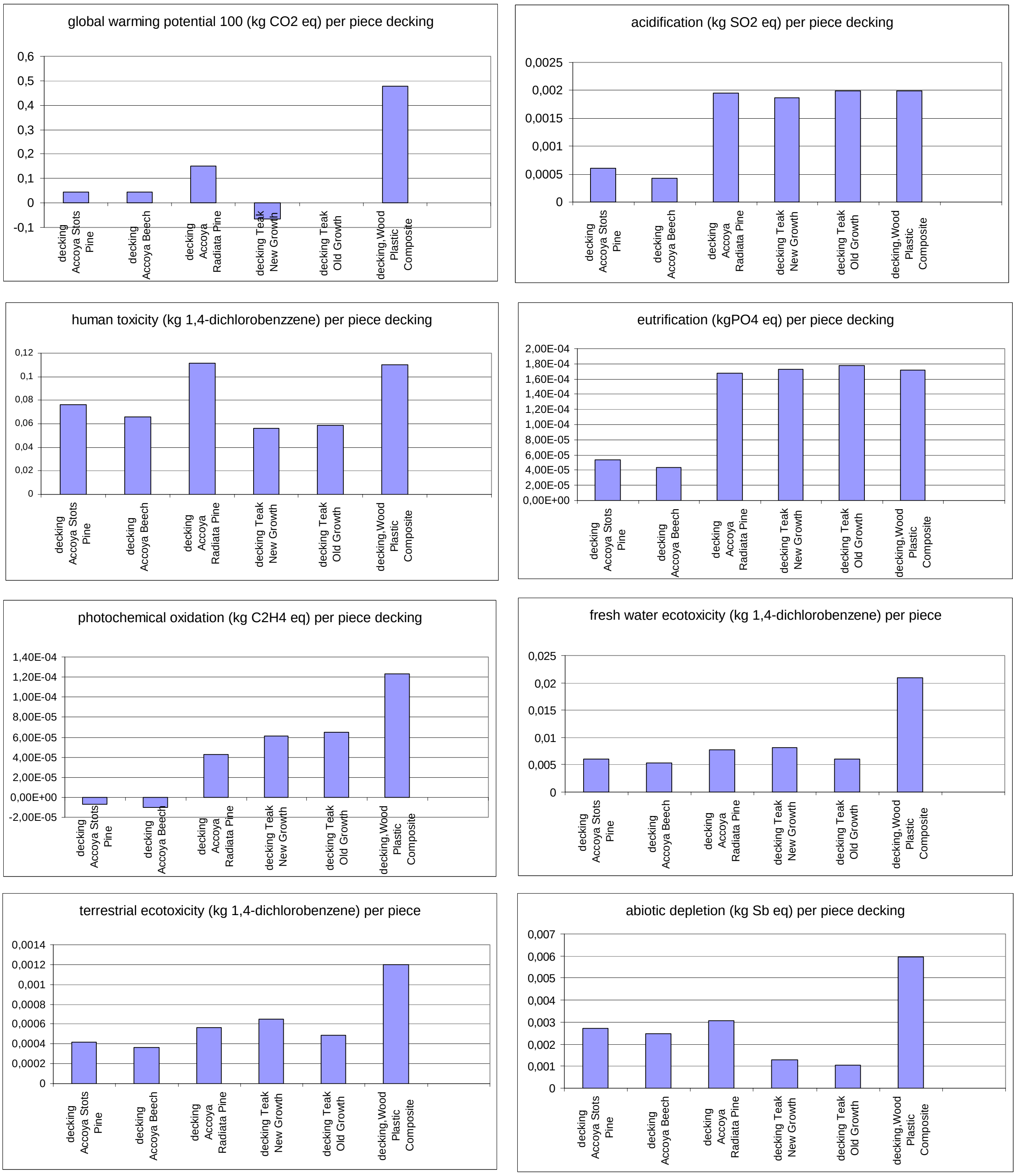

Figure 9. The category indicators for the different types of materials for a piece of decking, 2500 x 20 x 150 mm, per year use.

Note: For Accoya the “market mix” of Acetic Anhydride sourcing has been applied.

4.3 The bearing structure of the Pedestrian Bridge

In this section, the chain of a pedestrian bridge is analysed. The life cycle chain is similar to the chain of Figure 7.

The analysis is done according to ISO 14040 and 14044, applying scenarios in compliance with NEN 8006.

The functional unit is: the bearing structure of 1 pedestrian bridge, size 16 x 3 m over a period of 1 year

The materials of the comparison are (with lifespan):

- Accoya wood: Scots Pine, Beech, Radiata Pine (80 years)
  “market mix” of Acetic Anhydride sourcing
- Azobé, from plantations in tropical West Africa (50 years)
- Robinia, from plantations in Europe (35 years)
- Laminated Spruce (25 years)
- Reinforced Concrete (90 years)
- Galvanized Steel (55 years)

The yield to plane the Accoya planks from Arnhem is assumed at 90%.

	density (kg/m3)	volume net (m3)	weight gross (kg)	waste 12%MC (kg)	weight net (kg)
Accoya Scots Pine	589	6,41	4197	420	3778
Accoya Beech	805	6,41	5731	573	5158
Accoya Radiata Pine	510	6,41	3632	363	3269
Azobe	1060	5,94	6996	700	6296
Robinia	740	6,51	5353	535	4817
Spruce	460	5,92	3026	303	2723
Concrete, reinforced	2400	11,43	27432		27432

Table 10. The weight of wood and concrete required for the bridge.

The glue which is required, and the pre-stressing steel, are given in the Table below.

The zinc layer on the steel is 50,7 micrometer at a surface of 56,43 m2.

	density glue (kg/m3)	volume glue (m3)	weight glue (kg)	weight steel (kg)
Accoya Scots Pine	1050	0,096	100,8	
Accoya Beech	1050	0,096	100,8	
Accoya Radiata Pine	1050	0,096	100,8	
Azobe				297
Robinia	1050	0,098	102,9	
Spruce	1050	0,089	93,45	
Concrete, reinforced				803
Steel, gavanized				4437

Table 11. The weight of glue (polyurethane) and steel required for the bridge.

The transport distances are (in compliance with NEN 8006):

- base material to manufacturing site 50 km
- manufacturing site to building site 150 km
- building site to disassembling&sorting site 50 km
- disassembling&sorting site to landfill 50 km
- disassembling&sorting site to waste incinerator 100 km
- transport for recycling 150 km

	weight gross (kg)	weight net (kg)	transport to man. site (tkm)	transport EoL (tkm)
Accoya Scots Pine	4298	3878	215	1164
Accoya Beech	5832	5259	292	1578
Accoya Radiata Pine	3733	3370	187	1011
Azobe	7293	6593	365	1978
Robinia	5456	4920	273	1476
Spruce	3119	2817	156	845
Concrete, reinforced	27432	27432	1372	8230
Steel, gavanized	4437	4437	222	1331

Table 12. Transport of wood to the manufacturing plant (50 km) and materials to building site and End of Life (150 + 50 + 100 = 300 km), for 1 bridge.

It is assumed that the waste is incinerated in general waste incineration plants with electrical power generation, which have 25% overall efficiency (55% of the efficiency of electrical power plants). The Lower Heating Value has been applied.

The LCIs which have been applied are the same LCIs of Section 3.1, and in addition to that:

- Azobe Idemat 2008 Azobe, plantation
- Robinia Idemat 2008 Robinia
- Glue Polyurethane, rigid foam, at plant/RER
- Concrete Idemat 2008 Concrete
- Steel Steel, converter, unalloyed, at plant/RER (21% iron scrap)
- Galvanizing Idemat 2008 Electroplating Zinc, excluding use phase

  Note: the Zinc is assumed to end up in nature during the use phase; this is calculated in End of Life stage

The output of the calculations in Simapro are given in Figure 10.

Data in terms of eco-costs are provided in Section 7.4, with a split-up of the total eco-burden in the eco-burden of production, transport, and end of life.

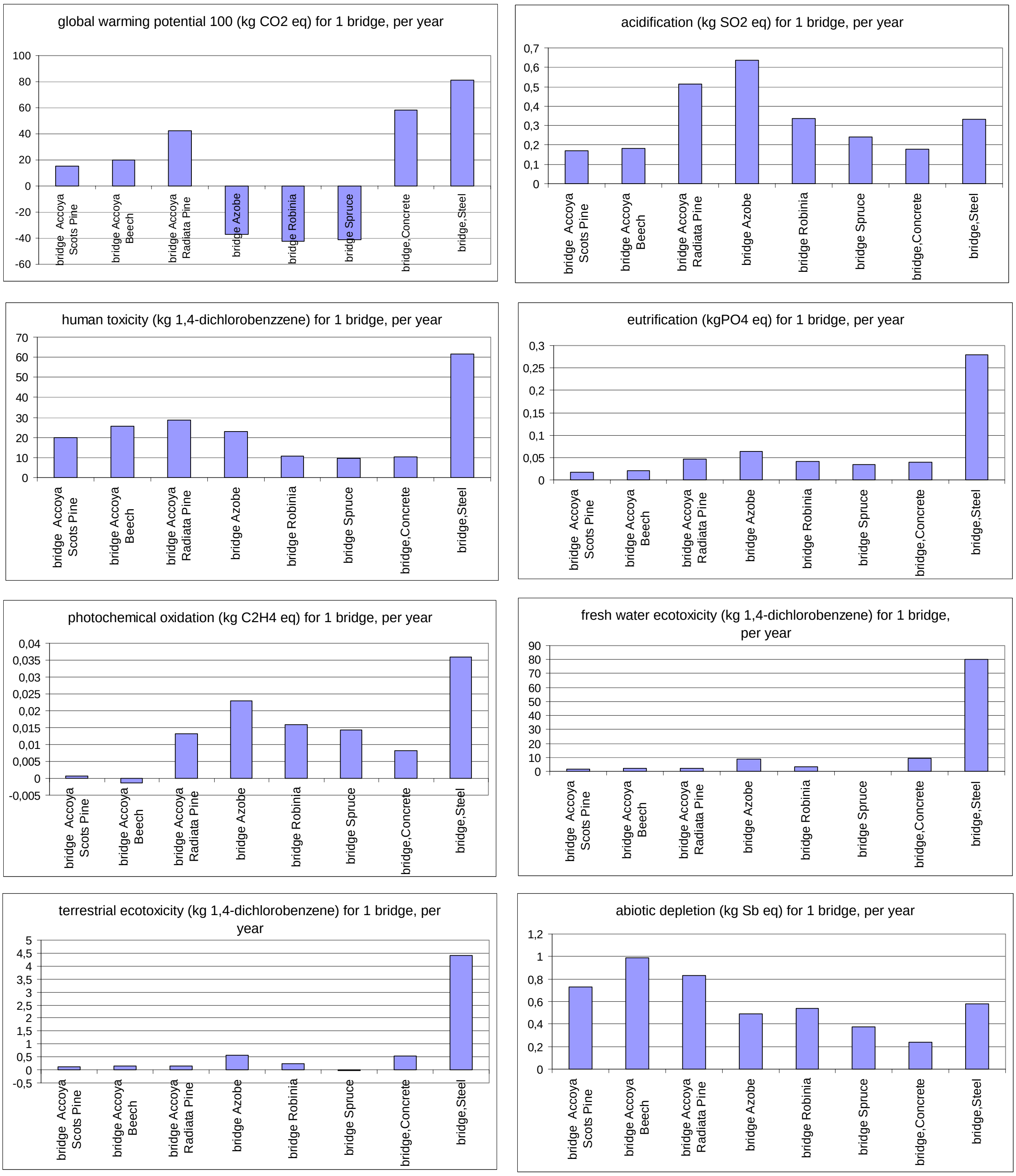

Figure 10. The category indicators for the different types of materials for the bearing structure of a bridge, 16 x 3 m, per year use.

Note: For Accoya the “market mix” of Acetic Anhydride sourcing has been applied.

5. Report Critical Review: LCA of Accoya® Wood and its applications, Part 1

Review panel: **Dr Richard Murphy** (Chairman of Review Panel), Imperial College London Consultants Ltd, Imperial College London, UK
Ir. Harry van Ewijk, IVAM UvA BV, University of Amsterdam, NL
Ir. Erik Alsema, W/E Consultants, Utrecht & Tilburg, NL

Practitioner: Dr. ir. J.G.Vogtländer, Delft University of Technology, NL

Commissioner: Titan Wood, Arnhem, NL

LCA Report Version: rev 1, January 2010

Review completion: XXX March 2010

5.1 Introduction

This critical review was conducted on the LCA report (rev. 1, January 2010) of Dr Vogtländer in accordance with ISO 14040 and 14044[6]. Interaction between the review panel and with Dr Vogtlander on the structure of the report during the review process led to some minor restructuring and this critical review report is based on the content of the LCA report (rev. 1) re-organised into a 3 part report:-

Part 1 – LCA according to ISO 14040/44
Part 2 – LCA according to NEN 8006
Part 3 – single indicator results and conclusions (outside ISO) – for company management information

The ISO critical review has been conducted only on Part 1 of the LCA report and the review report will be included within this Part 1 of the LCA Report which is intended to form a Third Party Report in accordance with ISO 14040/44.
[Note: a separate review of the LCA report in accordance with NEN 8006/MRPI is also conducted by Ir. Harry van Ewijk – this will contribute to Part 2 of the LCA report].

Summary of the critical review scope and structure (received from the practitioner):-

1. the critical review is based only on the written report
2. the critical review report will be integrated into the LCA report

It was further agreed that the review content should include 3 elements:-

- Critical review ***Comments***, for potential incorporation into Part 1 of the LCA report
- Critical review ***Recommendations*** for new calculation(s) and/or changes, for potential incorporation into Part 1 of the LCA report
- ***Errata,*** editorial in nature and communicated separately to the practitioner(not itemised in the critical review report)

5.2 Critical Review

This critical review report is a consolidated presentation of input received from each reviewer independently and agreed in telephone conferencing and via e-mail communication.

5.2.1 Critical review - *Comments*

General, structural comments

- The report sets out a clear goal, description of exemplar products to address the comparative environmental impacts of Accoya® wood in relation to alternative materials on a cradle-to-grave basis

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[6] BS EN ISO 14044 (2006) and BS EN ISO 14040 (2006) were used as the basis for this review. In these standards the term 'critical review' is used for the independent review process.

and states that the assertions are intended for disclosure to the public. A general impression of the LCA report is that it seeks to present a well-balanced and fair comparison of Accoya® products against alternatives.

- A number of requirements for ISO 14044 third party and public disclosure are not met fully in the rev1 LCA report. Specifically, details the following should be addressed:
  - any missing data, description and discussion

    Comment Practitioner: This issue is dealt with in next Section "specific comments".
  - data quality assessment for the inventory data

    Comment Practitioner: This issue is dealt with in next Section "specific comments".
  - compliance with ISO 14044 (2006) Sections 5.2 for third-party reports and 5.3 further requirements for comparative assertions intended to be disclosed to the public (for example inclusion of a statement that LCIA results are relative expressions and do not predict impacts on category endpoints (ISO 14044 (2006) section 5.2e8)

    Action Practitioner: Statement added in footer page 8.

  and a statement about whether or not international acceptance exists for the selected category indicators and justification for their use (ISO 14044 (2006) section 5.3f).

    Comment Practitioner: The category indicators of CML-2 have been applied in Part 1. CML-2 is considered as a well known and internationally accepted data set. A statement 5.3f about CML-2 seems to be superfluous. The exclusion of MAETP is argued in footer 3 page 7
    Note that the eco-costs 2007 system, applied in Part 3, is the leading international "damage based" indicator, introduced in 3 articles in the Int. J. of LCA (one of these articles was in the top 5 downloads) and 2 articles in the J. of Cleaner Production (period 2000 – 2003). It is now used at several Universities all over the world. Data is available at the website (open access), in the Cambridge Engineering Selector of Prof. Ashby, and in ArchiCAD (international design software for architects).

- Overall, there is some lack of sensitivity analysis as a check on the effects of several of the methodological choices, uncertainties and assumptions in the study.

    Comment Practitioner: This issue is dealt with in next Section "specific comments".

- The Life Cycle Interpretation element of the report does not go into sufficient detail in interpreting the life cycle. This is the part of the report where the reader (interested party or public) may expect to find a *'readily understandable, complete and consistent presentation of the results of an LCA …'* (ISO 14040 (2006).

    Comment Practitioner: This issue is dealt with in Sections 3.5, see "specific comments".

Specific comments – from front to back of rev 1 LCA report

- Goal – is this only to focus on 'toxic emissions' (see also Scope section)? If so, why is this the case and why, for example, are GWP and abiotic depletion included as impact categories?

    Action practitioner: text adapted on page 7, second paragraph.
- Scope – it should be made clear that statements 1), 2) and 3) are definitions of the Functional Unit for the LCA and, ideally, some description given of the function(s) for the three product systems.

    Action practitioner: text adapted, functional units have been added page 5.
- Scope – it must be made clear what geographic coverage the findings of this LCA report are intended to represent (e.g. is this for applications of Accoya® in Europe or wider afield?). The present review comments are relevant to a European application of the study.

    Action practitioner: text added, page 8, first paragraph.
- Scope (and Annex I) - it is not clear why a period of 1 year is chosen for the bearing structure of the pedestrian bridge when 75 years are used for window and decking.

    Comment Practitioner: The reason is the requirement in NEN 8006.
    Action practitioner: All calculations have been changed to a period of 1 year.
- Scope Fig 1 - is the full forestry system(s) for all the different wood species included within the system boundary (from planting through the rotation to harvesting, all co-products etc)? This is not apparent from the Life Cycle Inventory analysis or from Annex I.

    Comment Practitioner: Yes, establishment of standing and management is included, Since it is

included in Ecoinvent v2 LCIs.
Action practitioner: text added at page 6, first paragraph.

- Scope - the statement about the 2% cut-off criterion and the overall accuracy of the LCA would benefit from further clarification. The statement appears to infer that variation is only significant with the wood elements but there are also substantial uncertainties with overall service life prediction and with accuracy in representing the impacts associated with other materials.
  Action practitioner: text added at page 8, second paragraph, in order to explain this issue in more depth.
- Scope statement - *'Wood waste (chips as well as dust) is used for pulp, wood products and combustion. This flow is calculated as 100% combustion, transformed into energy output, applying the Lower Heating Value of the material (i.e 20 MJ/kg dry wood …'.* It is not clear what this 'energy output' substitutes for (if anything) - is it grid electricity (with an avoided burden credit), is any heat energy accounted for, is it only allocated to internal heat or power within the Accoya® treatment process etc?. This question also applies to energy derived from the EoL of wood.
  Action practitioner: text added at page 6, third paragraph, to explain the issue for the sawmill and End of Life.
- Scope – Global warming, how id biogenic CO2 dealt with in the inventory and characterisation? Is it excluded from the cradle to grave inventory or is it included?
  Comment Practitioner: In the Ecoinvent database, "Carbon Dioxide, biogenic" and "Carbon Dioxide, fossil" are kept separate. This is the reason that combustion of wood doesn't has "fossil CO2" emissions at the end of life. Since it has the credits of production of heat or electricity, the overall CO2 score is negative (no emissions, however, avoided emissions). This issue is explained in the reference given at page 7 (www.ecocostsvalue.com tab FAQ).
  Action practitioner: An extra reference has been added [17], for people who want to know more about the issue of recycling and energy recovery in LCA.
- Scope - Exclusion of MAETP is justified and acceptable (also ODP)
- LCIA, Section 3 of rev. 1 LCA report – this presents a Life Cycle Impact Assessment as results but a formal, discrete Life Cycle Inventory (LCI) analysis should precede the impact assessment. This provides opportunity to set out all inventory data used and for cross-checks for data validity, relevance, allocation procedures and sensitivity analyses (see Recommendations). The inventory presentation should include the inventory data for all products - Accoya® and the comparison materials.
  Comment Practitioner: Unfortunately it is not allowed to include LCI data of Ecoinvent in the report (infringement of copyright). It is assumed that experts, who want to check the LCIs in detail, have a licence. It is for those people that the exact LCI names are provided throughout the whole report. Idemat is open source, however, restricted to the copy right of Ecoinvent where applicable (most of the Idemat LCI are assemblies of Ecoinvent LCIs).
  The measurements of input and output data of the production facility in Arnhem are provided in Annex II.
- Section 3 – The assumption that all flows are proportional to wood density for the various species requires justification/referencing. What is the evidence for this – especially when comparing very readily treatable, high sapwood species like Radiata pine with Scots pine (with differing sapwood/heartwood ratios) or Beech? It does not seem likely, from a wood impregnation perspective and void volume considerations, that a relatively high density species like Beech will absorb 695 kg/m3 of acetic anhydride during a treatment when Radiata pine only absorbs 440 kg/m3 – see Table 1.
  Comment Titan Wood research:
  When considering the role wood density plays in acetylation, it is important consider that the Accoya® process is dominated by the requirement to use sapwood and is sourced as such. Additionally, the species chosen for acetylation and subsequent commercialization must be amenable to the process for impregnation and chemical recovery, amongst other considerations. As part of the qualification program for acetylation, intra- and inter-board uniformity are decisive variables. Through Titan Wood's extensive research on threshold durability testing, we can confidently say that the target acetyl content for the many wood species tested to-date to give Class I durability is in the range of (confidential)%. This weight percent ratio for acetyl content is thusly tied to the density of the wood, regardless of species. Certainly, other wood-related factors are important for native durability (i.e. resins, pit aspiration, minerals, etc), and treatability as discussed above, but the acetylation of wood dominates the durability 'equation', such that acetylated wood is the definitive bench mark for

exceptional durability and dimensional stability as demonstrated by 80 years worth of peer reviewed research.
Further to the point, regarding density's contribution to usage rates, the mass of wood contained in a cubic meter of beech is greater than the mass contained in a cubic meter of radiata. As we have demonstrated empirically,(confidential) % acetyl substitution is the target for Class I durability, and a higher mass per cubic meter wood would consume more acetic anhydride than the lower mass per cubic meter sample. This is further compounded when we account for the residual water that enters the process. For example, if you were to assume x weight % of water were to enter the process, then in the case of the beech versus radiata pine example the radiata pine would contribute x kg/m^3 *of water, while the beech would provide x kg/m*^{3}*. It is also critical to consider that the number of molar 'free-hydroxyl' equivalents in radiata pine is far less than the equivalents found in water, thus water is a significant contributor to the consumption of acetic anhydride, and acetic acid by-product. Finally, it is important to take into account that the water provides two equivalents of acetic acid per mole of water reacted, whereas the wood only provides one mole of acetic acid, the other acetyl is covalently bound to the wood.*

It stands to reason that the other flows from natural gas and electricity are directly related to the mass of wood or chemicals present in the process at any given time. A high density wood will require more energy to raise the temperature one degree than a lower density wood, and a greater volume of by-product acetic acid will require more energy to be vaporized either from the wood or purified by distillation.

Since the nitrogen usage is solely for the purpose of providing an inert atmosphere with which to work with flammable materials, its usage is only related to the volume of wood used.

- Section 3 – use of Idemat 2008 data is stated to occur where Ecoinvent v2 data is not available. Is this fully the case or has Idemat data sometimes been selected in preference over Ecoinvent data?
  Comment Practitioner: Idemat LCIs were only selected when Ecoinvent LCIs were not available in a direct form. Note that the are no basic system differences between Ecoinvent and Idemat, however note also that boundary limits are not the same over the total Ecoinvent database (where possible, the required infrastructure is included in the LCI, however, this could not always de done because of lack of data).
  Some discussion on the implications of relative differences between these databases is warranted (e.g. any differences in system boundaries for Idemat and Ecoinvent datasets).
  Comment Practitioner: There are no such fundamental differences between Idemat and Ecoinvent.
- Section 3 - under 'carbonylation of methyl acetate …'it seems that the input of methyl acetate itself is forgotten. Is this only omitted in the text or also in the analysis?
  Comment Practitioner: The input is <u>CO2, methane and steam</u> for the production of methanol (synthesis gas process) and CO. Methanol + acetic acid -> methyl acetate.
  CO + methyl acetate -> acetic anhydride (and acetic acid).
  Also is the quality of acetic acid byproduct as high as that from standard chemical production routes, or does the output need an additional cleaning/upgrading step before it can be sold on the market? If so, this process should be included.
  Comment Practitioner: The effluent from the wood process is distilled by Titan Wood, to arrive at a marketable Acetic Acid. This process is included in the data of Annex II.
- Section 3 - it should be noted that ethanol from sugar beet is a 'surrogate' process for an acetic acid fermentation (which may use different feedstocks and different organisms)
  Action practitioner: text added, page 11, second paragraph, to make the reader aware of that.
- Section 3 - If whole forestry and primary sawmilling process is included then bark is a co-product of sawmilling. What levels of energy self-sufficiency are assumed for the sawmilling processes – these vary considerably between EU mills and tropical mills for example, as do overall wood recovery rates.
  Comment Practitioner: Oil and electricity are input of the saw mill, bark, chips and sawdust are output. Note that the "credits" of the output are derived from a theoretical approach (according to ISO) regardless of what the actual situation is (that is the essence of the rule in ISO).
- Section 3 - the point about the sensitivity of the LCA to the replacement of oil for heating by biomass (presumably wood 'waste'?) is unclear (close to Table 2).

Comment Practitioner: See the remark above: when you replace oil by sawdust, chips and bark, the LCI stays the same.

- Section 3 - Diesel is not used in chainsaws.
  Comment Practitioner: Right (sorry). Meant was "equipment" (as was given in Table 3).
  Action practitioner: text adapted and LCI changed (Idemat LCI, since "petrol, including combustion" doesn't exist in Ecoinvent).
- Section 3 - Version of SimaPro used should be stated.
  Action practitioner: text added (Version 7.1) , page 6, second paragraph.
- Section 3 – there needs to be further explanation of, or a consistency check for, the scenarios used for presenting the effects of using the adapted chemical manufacturing process(es) for acetic anhydride production and for the consequences for using an avoided, non-adapted acetic acid production for the on-plant generated acetic acid derived from an adapted acetic anhydride.
  Comment Practitioner: The question is not fully clear. The actual processes of the production of acetic anhydride were not available in Ecoinvent: that is the reason for the "intervention" in Ecoinvent. For acetic acid the processes were available in Ecoinvent, apart from the fermentation process (hence the surrogate process).
- Section 3 – Category indicator graphs for wood anhydride combinations are not supported by marginal analysis - either tabulated or graphical. This means that it is not possible for reviewers to comment on the likely representativeness or completeness of the overall scores based on previous experience or knowledge of published studies in the literature. There is no discussion for example on how negative scores are derived for POCP, FAETP via the carbonylation route. It will be useful here to identify a 'base case' e.g. 'market matrix' for acetic anhydride that is used for comparisons later on but to explore the carbonylation route via sensitivity analysis.
  Comment Practitioner: The reviewers should be aware of the fact that negative scores result from co-products in LCA (in this case acetic acid). <u>Not</u> from the LCIs of input (as acetic anhydride). Emissions of processes are always positive, but can become negative as a "credit". See also reference [17].
  Action practitioner: A short explanation has been added to the new Chapter 3.5, second paragraph.
- Section 4 Window frame – the high weight of the aluminium window frame (39.65 kg for a 1.65 x 1.3 m window) seems excessively high. (In other building assessment tools values of 2.5 kg for a 1 m2 aluminium window frame are used). This assumption should be reconsidered with a view to defining a more realistic value for the aluminium frames
  Comment Practitioner: We agree that the weight of an Aluminium frame of ref [11] is too much. However a frame of 2.5 kg per m2 (approx. 0.78 kg/m at 3.22 m frame per m2) is extremely low for a modern frame with low conductivity of heat. A Dutch database, based on empirical value (<u>www.winket.nl</u>) uses 3 kg/m, which results in 17.70 kg for the 1.65x1.3 frame.
  Action practitioner: the data on the Aluminium frame have been adapted to the new weight.
- Section 4 Window frame - Specify what is meant by 'last routing step' - 11% wood removed
  Comment Practitioner: The last routing step is to create the profile of the window frame.
  Action practitioner: text added, Section 4.1, page 16, third paragraph.
- Section 4 Window frame – does the 75 year lifetime mean that a 'part lifetime' is applied for any replacement window frames or is the full impact of the replacement operation, use and eventual disposal assigned to the 75year lifetime?
  Comment Practitioner: The new calculations are based on the cradle to grave eco-burden, divided by the lifespan, and multiplied by 75 years where that is specified.
  Action practitioner: the output has been changed in eco-burden per year.
- Section 4 Window frame - what is the basis for assigning a 35µm thickness of paint for redecoration of Accoya® frames but a 60µm thickness for spruce or Meranti? Is paint renewal due primarily to erosion of the coating and would this not be equivalent between all frames? (it is agreed that because Accoya® is a more 'stable' substrate then redecoration intervals can be longer because paint coating adhesion will be much better and film damage reduced – but a longer redecoration schedule may well imply a need for a thicker coating at each interval to accommodate film erosion).
  Comment Practitioner: Technically, Accoya frames can have a lighter coating system. However, one might argue that that technical advantage will not be applied in practice.
  Action practitioner: Therefore, it was decided to base the LCA on the same coating system for all wood frames, see Section 4.1, page 17, first paragraph.

- Section 4 Window frame - is transport for ongoing maintenance for coatings over 75 years -included?
  Comment Practitioner: No (less than 1 kg over 150 km is far below the 2% cut-off criterion!).
- Section 4 Window frame - what is the justification for departing from the NEN 8006 'standard' End of Life scenarios for the building industry in the Netherlands (Table 7) when considering the recycling rate for PVC frames, especially when these are deemed acceptable for other framing materials? Has any sensitivity analysis been conducted on this change to a 60% PVC recycling rate assumption? (see Recommendations).
  Action practitioner: A sensitivity analysis has been added to the text in the new revision, Section 7.2, page 41 - 42.
  Comment Practitioner: The reason, to deviate from the table in the NEN, was simple: a product declaration for PVC window frames (MRPI for the VKG), 2006, according to the NEN, assumes 2x recycling. So less than the 80% recycled in the NEN Table. Note that we did not apply a "depreciation factor" to account for the fact that the recycling is in the future ("delayed recycling"), as required in the EU Manual, ref [17]).
- Section 4 Window frame – what acetic anhydride production process is modelled here and later for the Accoya®?
  Comment Practitioner: "Market mix", as it is stated in the beginning of Section 4.1, second paragraph.
- Section 4 Window frame – PVC data (Polyvinylchloride, at regional storehouse/RER) does not contain stabilisers - is this included in the inventory, if not, this needs to be included or recognised as missing data?
  Action practitioner: 3% lead added as stabilizer (although the effect is far less than the 2% cut-off criterion).
- Section 4 Window frame - data PVC, is any extrusion data included for PVC profiles?
  Action practitioner: Has been included in the new calculation.
- Section 4 Window frame - EoL, data choice, why is Idemat 2008 used for EoL – such data is available in Ecoinvent ?
  Comment Practitioner: Plastic recycling data are not available in Ecoinvent (be aware that Ecoinvent provides only data on transport and sorting, but not on the recycling of the material as such: it has "metals, secondary" but no "plastics, secondary".
- Section 4 Window frame - Plantation Meranti is referred to. What is the source of this wood, is it true 'plantations' or managed forest - what is the evidence for the availability of plantation Meranti?
  Comment Practitioner: The question is not fully understood. Please be aware that these cases are scenarios (there is no responsibility, nor involvement of Titan Wood in the manufacturing of Meranti frames). Maranti from plantations is available from Malyasia and Indonesia.
- Section 4 Decking - CCA wood, Table 8 and elsewhere, it is highly unlikely that CCA wood would be available for decking due to withdrawal of this preservative from the EU market except for some specialist applications. Its replacement will be copper-organic biocide formulations or possibly copper-chrome. A service lifetime of 20 years for such treated wood is also more realistic.
  Action practitioner: We removed CCA wood.
- Section 4 Decking - any disposal of preservative treated wood is likely to be confined to landfill or incineration with disposal of ash to chemical landfill.
  Action practitioner: We removed CCA wood.
- Section Life Cycle Interpretation - Some general points are made in this section about 'quality aspects' in LCA with suggestion about functionality per year. It is not clear how this addresses the issue of 'variable quality'.
  Comment Practitioner: Question is not clear. The answer is perhaps at www.ecocostsvalue.com tab EVR.
  Action practitioner: Text moved from Part 1 to Part 3.
- Section Life Cycle Interpretation – what is meant by a 'super green' result? (see comments below also)
  Comment Practitioner: The meaning of "super green" is "very low environmental burden".
  Action practitioner: this issue is moved from Part 1 of the report to Part 3.
- Section Life Cycle Interpretation - it is agreed that durability is, to an extent, arbitrary but there are ISO methodologies available for estimating service life of construction products (e.g. ISO 15686-8 (2006). '*Buildings and constructed assets - Service-life planning Part 8: Reference service life and service-life estimation*') and it is stated in the scope that the technical service life is the basis of the assessments in this LCA (rather than fashion or consumer preference rationales for replacements).
  Comment Practitioner: Estimating the lifespan according to this ISO is outside the scope of

this study.
Action practitioner: Data of laboratory experiments on the lifespan of Accoya is added in Annex V.

- Section Life Cycle Interpretation - this section seems not to focus enough on the specific outcomes of the LCIA and to consider these in relation to the limitations of the study and its original goal and scope.
  Action practitioner: New text on Life cycle interpretation is provided in Section 3.5.
  The commentary on wood/bamboo biomass growth rates in this section does not connect well with the LCIA and should be placed in a separate section to do with 'additional' or 'wider' considerations as long as is it is complementary with the ISO 14040/44 compliant Part 1 of the LCA report (if it is not, then it is best removed from the ISO third party part of the report and placed elsewhere).
  Action practitioner: this issue is moved from Part 1 of the report to Part 3.

5.2.2 Critical review - *Recommendations*

General, structural recommendations to support compliance with ISO

- a detailed Life Cycle Inventory (LCI) analysis should be presented (including data quality checks, completeness checks, system boundary checks, checks on undefined substances (is characterisation correct, are there any naming discrepancies between substances and characterisation in the LCIA meaning that can give faults in this step ?) and justification and/or sensitivity analysis of allocation procedures etc. This should precede presentation of the Life Cycle Impact Assessment (LCIA) and then the Interpretation.
  Comment Practitioner: There are no naming discrepancies in the relevant LCIs (i.e. the production process in the Arnhem facility). The ifs and buts of each Eco-invent LCI are provided by the Swiss Centre for Life Cycle Inventories (copy right information).

- Some revision of the overall LCA report structure from rev. 1 to more closely follow the framework of ISO 14040/14044 is recommended (*some of this has been achieved in discussion with the practitioner during the review process as noted in the Introduction to this critical review report*)
  Action practitioner: The report structure has been adapted accordingly (Part 1, 2, and 3).

- A more detailed discussion of the assumptions and derivation of the service lives used for all the materials used in the products is needed. For the Dutch situation the SBR report "Levensduur van bouwproducten" ("Life time of Building Products", SBR, 1998) specifies respectively 50 years, 35 yr and 50 yr for Aluminium, PVC and Meranti frames. It is understood that a conservative approach has been used for the alternative products in the LCA report but this issue warrants some more detailed discussion ideally giving also other estimates found in literature. Supporting evidence or arguments should be provided for the assumed life span of Accoya wood e.g. has this been shown by accelerated ageing tests or is it just an expected value?
  Comment Practitioner: The above lifespan of Aluminium and PVC window frames are OK. However the case in this LCA report is about "new growth" (from plantations and high turnover Reduced Impact Lodging), durability Class 2 thru 4, on average Class 3 (EN 350-2).
  The assumption in the above mentioned report was 50 years for "old growth" Meranti (Class 2), however this is wood from natural forests.
  The assumption of 50 years for Accoya, Class 1, is safe side (in practice more than 50 years are expected). A reasonable assumption for new growth Meranti, Class 3, is 35 years.
  Action practitioner: the following lifespans have been applied in the new revision: Aluminium: 50 years, PVC 35 years, Meranti 35 years. The results of tests to prove that Accoya wood is Class 1 has been added to the new revision in Annex V.

- Marginal analysis – it is recommended that a breakdown of the contribution of various phases of the life cycle and of key emissions and consumptions in those phases to the impact scores in each of the category indicators is presented in the LCIA and is discussed in the Interpretation. This will support transparency and completeness in the report.
  Comment Practitioner: In general this comment is right. However, the reviewers should realise what they ask. Would it really be a good idea to have 10 x the information in Figure 5 and 6; 5 x Figure 8a, b and c; 4 x Figure 9; and 4 x Figure 10 ??? German people call this "data

cemetery" ('Datenfriedhof').
That is the reason that we provide, for the management of Titan Wood, the data on the phases, and data on alternative systems, in terms of a single indicator.

- Sensitivity analysis – it is recommended that additional sensitivity analysis should be undertaken to examine the following aspects :-
- Effect of differing assumptions on service life e.g. window frames
  Action practitioner: data are provided for shorter and longer lifespans of the window frames (25% shorter and 25% longer) in Figure 8b and 8c.
- Effect of differing assumptions on paint coating thickness between Accoya® and other woods in windows.
  Action practitioner: in the new revision, we take <u>the same</u> coating system for all types of wood.
- Effect of using 60% rather than 80% recycle rate for PVC frames.
  Action practitioner: This issue is dealt with in Section 7.2, page 41 - 42.
- Effect of using Ecoinvent data for EoL instead of Idemat 2008 data.
  Comment Practitioner: For metals, Idemat is based on the difference of the Ecoinvent data on the "primary" and the "secondary" metals (= the "credits" of recycling). Ecoinvent doesn't have data for secondary plastics, so that Idemat has been applied here. Concluding: the Ecoinvent data have been used were possible (there is no "instead of").
  Note that the LCIs of Ecoinvent in the files "waste scenario" and "waste treatment" are for transport and materials handling only. Therefore, the recycling calculations must be completed with the credits of recycling according to ref [17].

Part 2. LCA according to NEN 8006: 2004/A1:2008 [Ref. 3]

6. LCIA of Accoya® Wood from cradle to gate and its Applications, NEN 8006

6.1 Accoya® Wood from cradle to gate

The LCIA of Accoya® Wood from cradle to gate according to the principles of ISO 14040 and 14044 is given in Section 3.

The NEN 8006, however, has additional requirements in terms of obligatory use of specific LCI data (see Bijlage 4 of the NEN). The problem with these LCI data is, that they are outdated (NEN 8006 requires ETH LCIs, which data are from 1996).
An update of these obligatory requirements in NEN 8006 is expected in due course [Ref. 12].

The impact of applying the obligatory ETH data is very limited:

- for inland transport ETH data differ even more than 50%, however, inland transport has a minor role in the total LCA (see Fig. 5)
- for gas and oil production ETH data differ approximately 20%, however, the eco-burden of the production of these products is less than 1/3 of the eco-burden of the combustion of it. The share of gas in the LCA of Accoya Wood is less than 10%. The resulting overall effect is less than 1%
- for electricity the difference is 18%, with a share of 20% in the LCA of Accoya Wood, resulting in an overall effect of less than 4%

So it is argued that additional calculations for the NEN 8006 are not required to get an environmental declaration for Accoya Wood.

6.2 Applications of Accoya® Wood

The calculations in Section 4.1 and 4.2 are proposed to serve for a environmental declaration on window frames and decking.
A environmental declaration for the bearing structure of the pedestrian bridge seems to be superfluous.

Part 3. Single indicator results (eco-costs) and conclusions (outside ISO) for management information

7. Single indicator results (eco-costs) of Accoya® Wood and its Applications

7.1 Accoya® Wood from cradle to gate

Figure 11a and 11b show management information on the total results in terms of eco-costs of emissions (€/m3) for the production of Accoya Wood, from cradle to gate (of the production facility in Arnhem), as calculated in Section 3.

The columns are:

1. Total eco-costs of emissions for the chain from cradle to gate (€/m3)
2. eco-costs of CO2 emissions of the production plant in Arnhem (€/m3)
3. eco-costs of emissions of the wood type, including transport to Rotterdam (€/m3)
4. eco-costs of emissions to produce the liquid Nitrogen
5. eco-costs of emissions of the Acetic Anhydride production
6. eco-costs of emissions related to the infrastructure (=construction of the production plant)
7. eco-costs of emissions of the production of Natural gas
8. eco-costs of emissions of the production of Electricity
9. eco-costs of emissions of the transport from Rotterdam to Arnhem
10. eco-costs (negative) of emissions related to (the avoidance of) the production of acetic acid

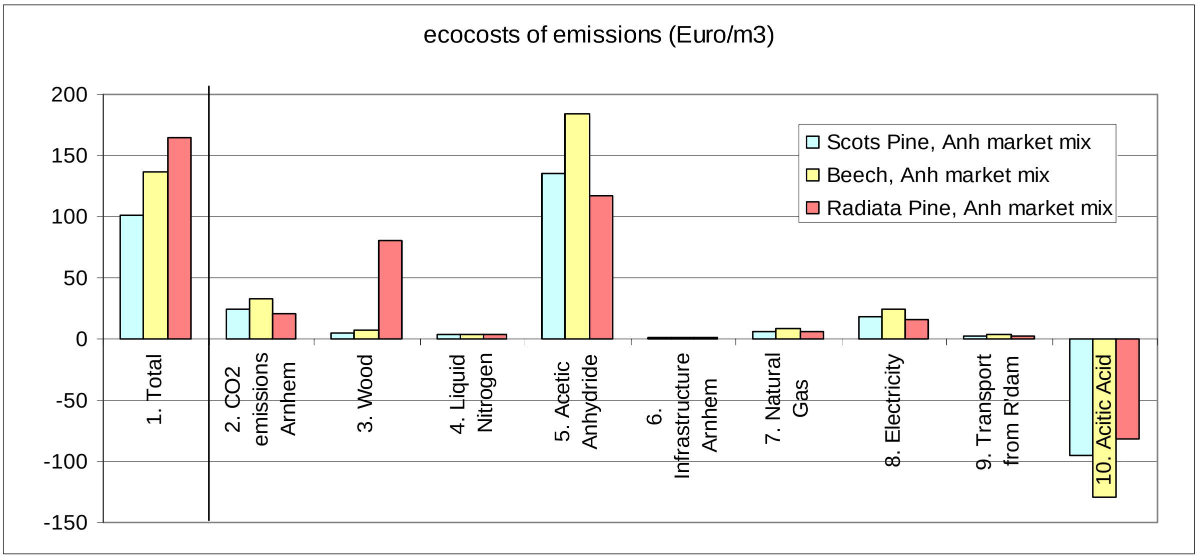


Figure 11a. The eco-costs of emissions (€/m3) of the chain from cradle to gate (column 1) and its components (column 2 trough 10) for Accoya Wood from Acetic Anhydride “market mix”.

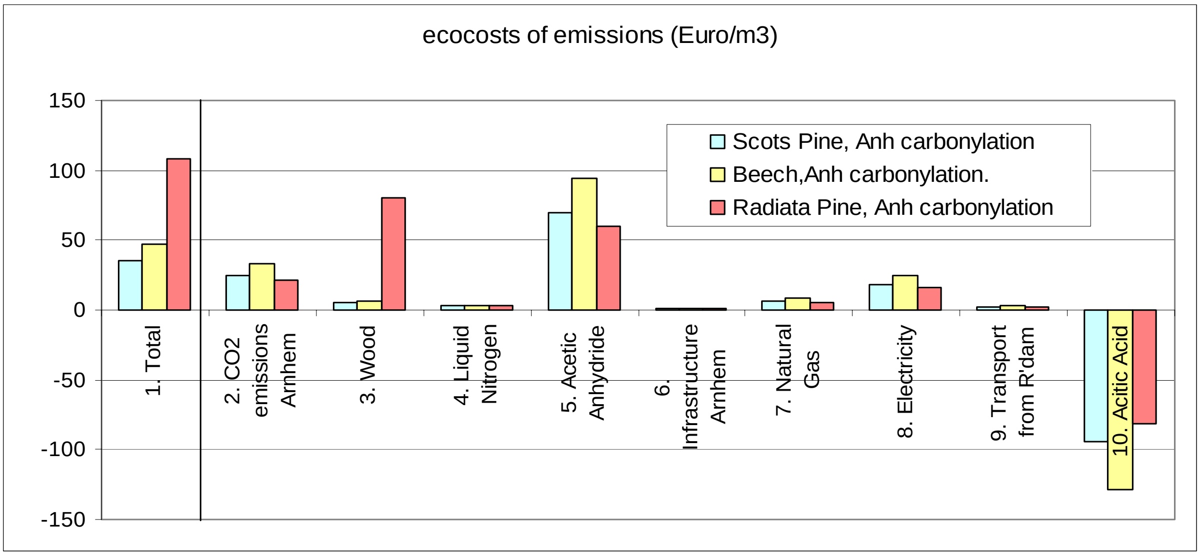


Figure 11b. The eco-costs of emissions (€/m3) of the chain from cradle to gate (column 1) and its components (column 2 trough 10) for Accoya Wood from Acetic Anhydride “carbonylation process”

7.2 Window frames

Figure 12 shows management information on the total results in terms of eco-costs of emissions (€/frame)

The negative eco-costs data for EoL stem from the fact that:

- wood is burned at the EoL in a waste incineration facility.
- Aluminium, Steel and PVC are recycled at the end of life, leading to “avoidance of use of virgin materials”

The eco-burden of transport (from Arnhem to the site and to EoL) and maintenance (the maintenance part of coating system) appear to be negligible in the total context.
The fact that the Aluminium is light explains the relative good score of the Aluminium frame.

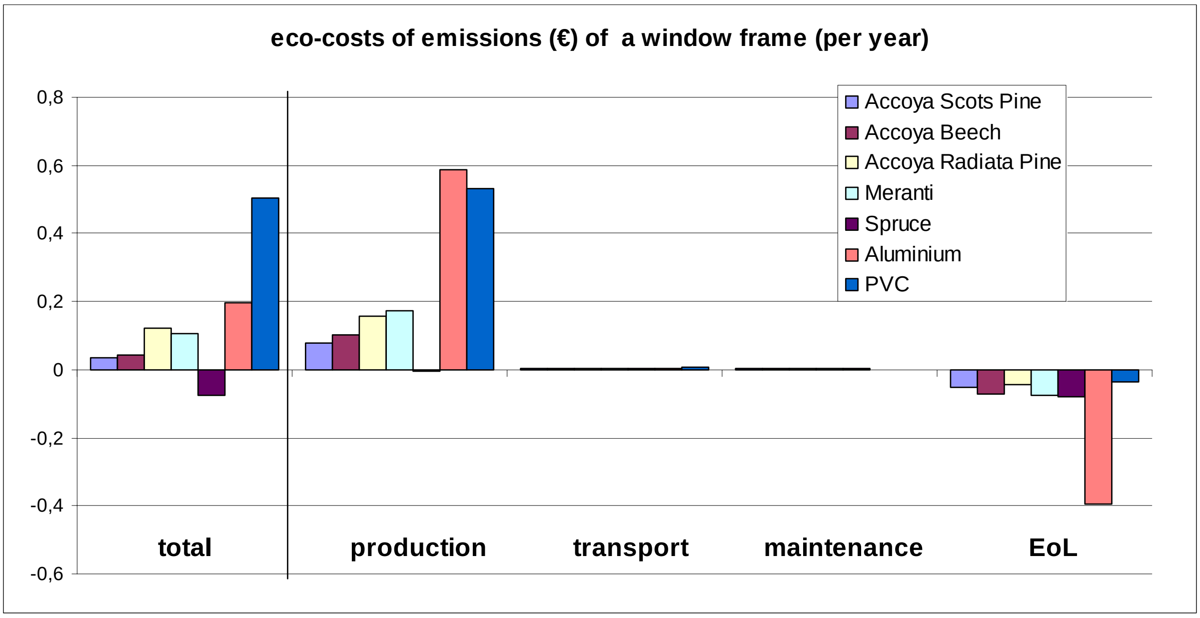


Figure 12. The eco-costs of emissions (€) of window frames per year use, 1,65 m x 1,3 m, made from Accoya "market mix", Meranti, Spruce , Aluminium and PVC.

An important issue is the recycling rate of the PVC window frames.
The issue is, that the volume of PVC recycled frames is very low in comparison with the total volume of PVC window frames which are sold today at the market. The reason is that PVC frames are not long in the market compared to its lifespan. In combination with a growth in the market, this results in a volume which is still to be recycled (the same situation applies to the PVC pipes for the building industry, stainless steel, copper, etc.).
Common practice in LCA is to take the "market mix" of virgin and recycled materials at the input of the production process. This is a 'safe side' as well as a realistic approach, since it describes the current emissions and "nobody knows what will happen in the far future".
The current 'market mix' of recycled PVC in the building industry is estimated is an range from 6-12 %. There is not much transparency in the window frame industry (the PVC pipe industry, in contrast, is quite transparent in what they recycle, see the annual report 2008 at www.wavin.com).

The common argument of the industry is that this common practice in LCA is not fair for product innovations which have success in the market. When the industry creates a recycling system for that purpose, common practice in LCA is then to accept the current percentage of recycling as standard for the future. Ref [17] proposes in such situations, however, a linear discounting system: *"future recycling is to be modelled by lowering the credit given for recyclability of products linearly down to 0 over a period of 100 years product-life-time…… This gives the following reduction factor r, calculated as r = 1 - RY/100 with RY being the number of years from the time of the study to the time of recycling."*

Given these facts, there are 2 reasons to deviate from the 80% recycling, given by the NEN 8006:

1. The Dutch product declaration on PVC window frames claims that there is no measurement in place to prove that the 80% is a realistic percentage (a recent report of TNO on the issue states that there is no good collection system in place)
2. With a lifespan of 35 years, it should make sense to apply the factor r in the system, resulting in a reduction factor of 0.65 to be applied at the estimated recycling percentage in the future, resulting in 0,65 x 80% = 52% (or, perhaps more realistic 0,65 x 60% = 39%)

The Table below shows the sensitivity of the eco-costs of EoL of the PVC window frame. The effect of the choice on the recycling rate appears to be small in terms of the overall picture of Figure 12.

recycling (percentage)	eco-costs (€/75 years)	eco-costs (€/year)
80%	-3,74	-0,04985
60%	-2,78	-0,03703
40%	-1,91	-0,02549
10%	-0,68	-0,00906

Table 13. The eco-costs of the EoL of the PVC window frame as a function of its recycling rate.

7.3 Decking

Figure 13 shows management information on the total results in terms of eco-costs of emissions (€/frame)

The negative eco-costs data for EoL stem from the fact that wood and plastic is burned at the EoL in a waste incineration facility.

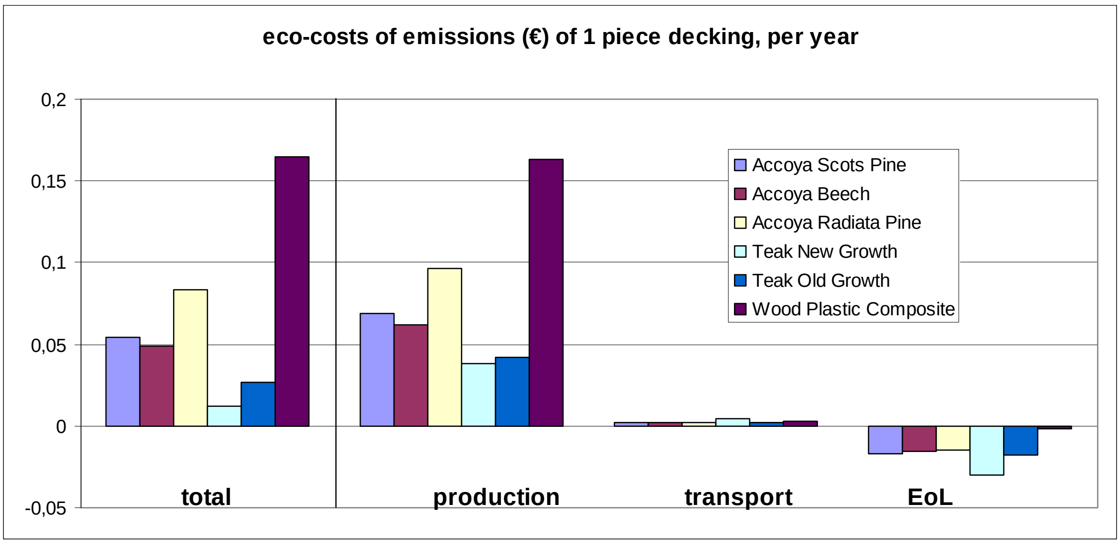


Figure 13. The eco-costs of emissions (€) of 1 piece of decking, per year use, 2500 x 20 x 150 mm, made from Accoya “market mix”, Teak and WPC.

7.4 Bearing structure of the Pedestrian Bridge

Figure 13a and 13b show management information on the total results in terms of eco-costs of emissions (€/frame).

The negative eco-costs data for EoL stem from the fact that wood is burned at the EoL in a waste incineration facility. The emissions of Zn during the year is added to the EoL score, resulting in a high score in eco-costs (because of the high eco-toxicity of Zn).

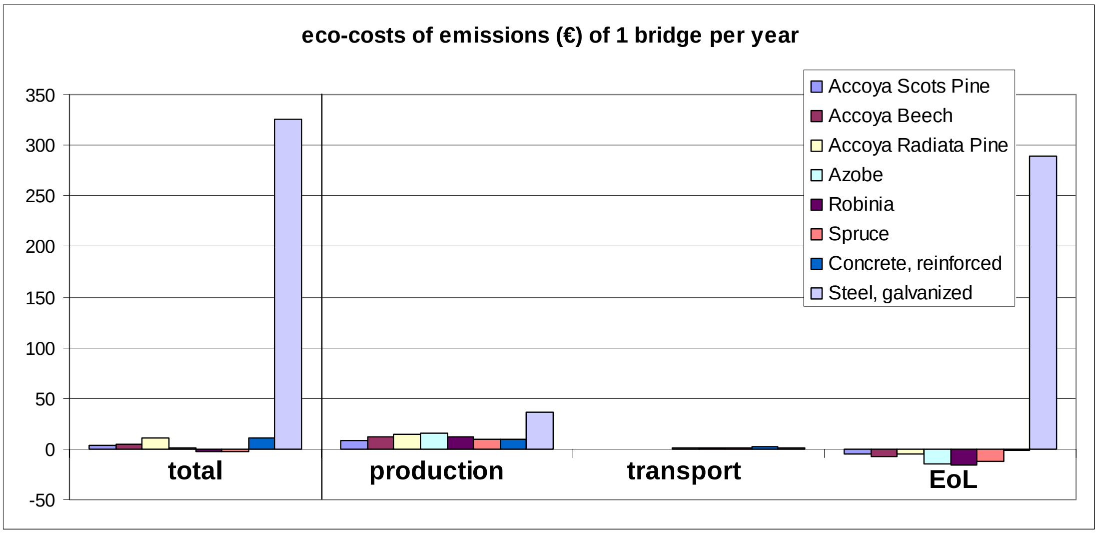


Figure 14a. The eco-costs of emissions (€) of the bearing structure of 1 pedestrian bridge, per year, 16m x 3 m, made from several types of wood, reinforced concrete and galvanized steel.

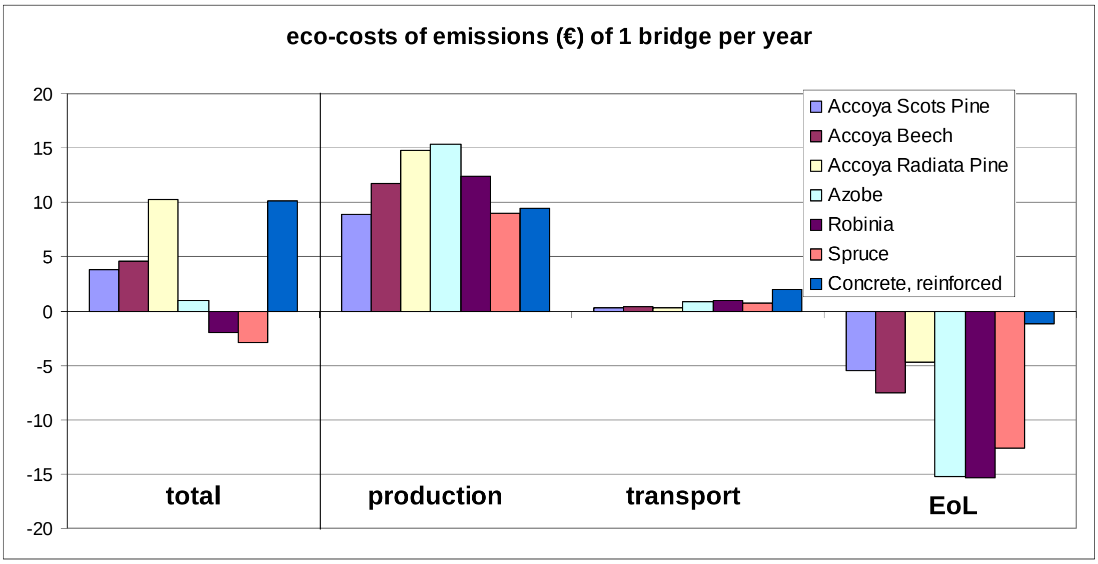


Figure 14b. The eco-costs of emissions (€) of the bearing structure of 1 pedestrian bridge, per year, 16m x 3 m, made from several types of wood and reinforced concrete (excluding galvanized steel).

8. Further conclusions on Accoya® Wood and its Applications

8.1 Accoya® Wood as an alternative for tropical hardwood

From the results of the calculations can be concluded that the toxic emissions of Accoya® Wood (especially Accoya Radiata Pine) are generally higher than of tropical hardwood. That is logical, since the Acetic Anhydride is a chemical substance made from fossil oil, and has therefore some toxic emissions.

A shift from Acetic Anhydride "market mix" to Acetic Anhydride "carbonylation process" will reduce the toxic emissions by approximately 65% for Scots Pine and Beech (see Fig. 5). Such a step would bring the eco-costs of Accoya Scots Pine nearly down to the level of Spruce, at a durability level of tropical hardwood: a "super green" result. See Table 13 and Figure 14, 15 and 16

See Table 13.

	eco-costs of emissions	
	(€/m3)	(€/kg)
Accoya Scots Pine, "market mix"	101	0,171
Accoya Scots Pine, Ahn carbonylation	35,5	0,060
Spruce	25,3	0,055

Table 13. The eco-costs of emissions for Spruce and Accoya Scots Pine "from cradle to gate (Arnhem)"

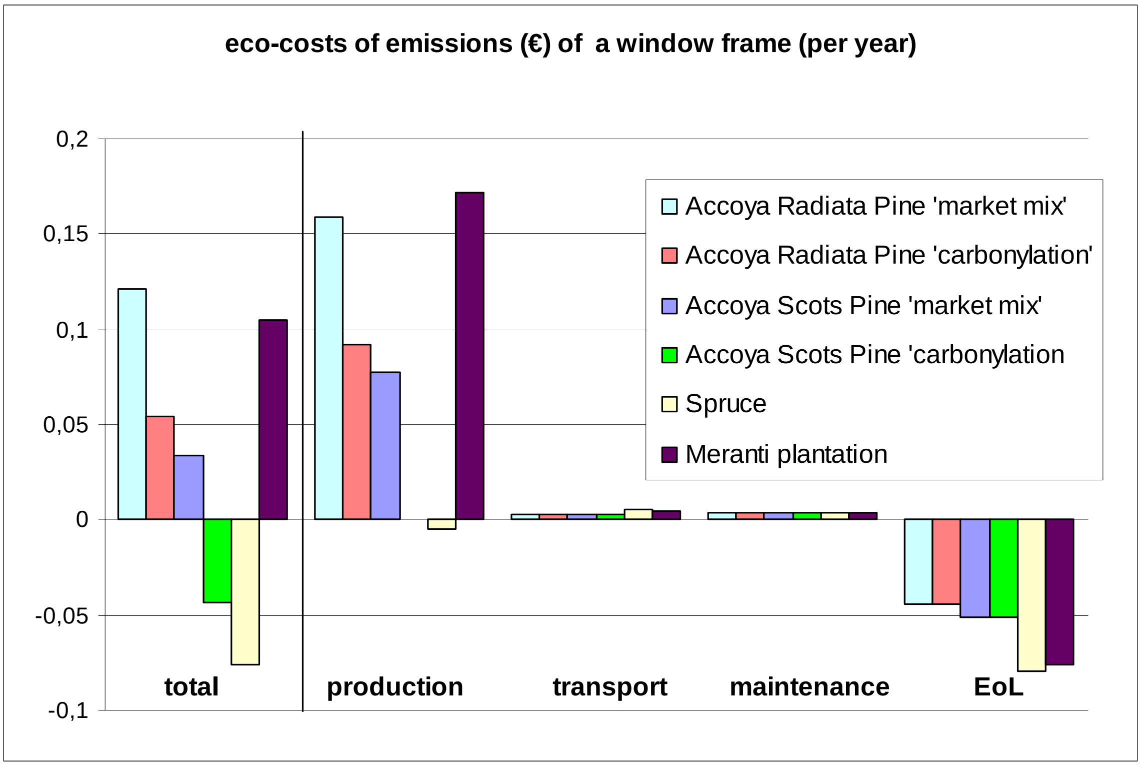


Figure 14. The eco-costs of emissions for Accoya Radiata Pine, Accoya Scots Pine (both 'market mix' and 'carbonylation', Spruce and Meranti for a window frame, 1,65 x 1,3 m, per year

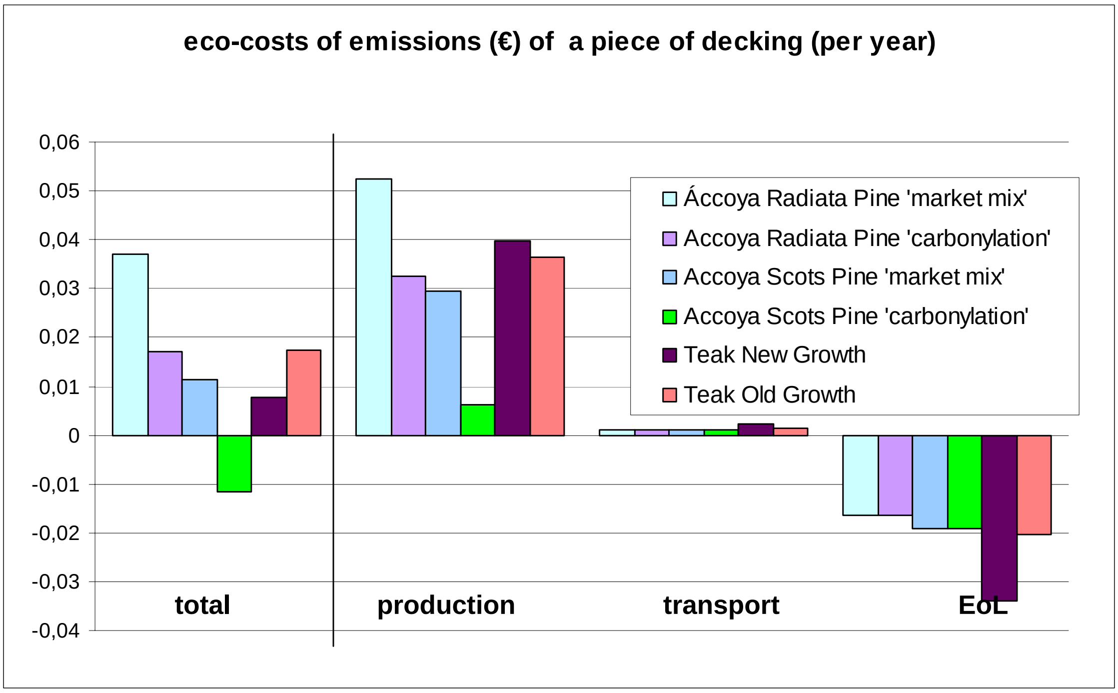


Figure 15. The eco-costs of emissions for Accoya Radiata Pine and Accoya Scots Pine (both 'market mix' and 'carbonylation'), and Teak (Old and New Growth) for a piece of decking, per year

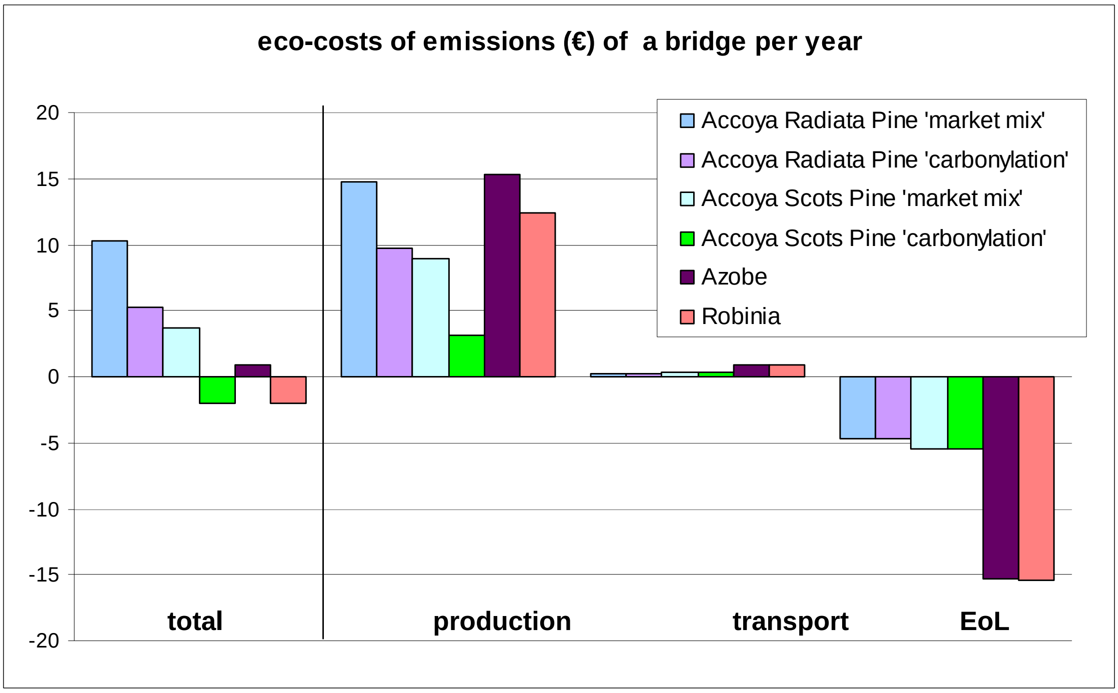


Figure 16. The eco-costs of emissions for Accoya Radiata Pine, Accoya Scots Pine (both 'market mix' and 'carbonylation'), and Azobe for a bearing structure of a pedestrian bridge, 16 x 3 m, per year

8.2 Tropical hardwood and the deterioration of biodiversity

An important issue which has to be mentioned here, is that the classical LCIA (applying CML-2 characterisation, or other category lists) does not cope with the main issue of tropical hardwood: the loss of biodiversity which is a result of harvesting.

For example, FSC certified wood is partly sourced from plantations (40%), but the rest is still coming from natural forests (harvested with Reduced Impact Harvesting, RIL, techniques).

The Delft University of Technology developed an indicator for the change (loss) of biodiversity, based on measurements of biodiversity of land by the University of Bonn. This indicator is the “eco-costs of land-use”. These eco-costs are considerable, see Table 14, and Figure 17, 18 and 19

	FSC certified		natural forests (RIL)	
	eco-costs of land-use		eco-costs of land-use	
	(€/m3)	(€/kg)	(€/m3)	(€/kg)
Azobé	806	0,76	4030	3,80
Meranti	940	1,47	4700	7,34
Teak Old Growth	940	1,42	4700	7,12

Table 14. The eco-costs of land-use (change of biodiversity) for FSC wood.

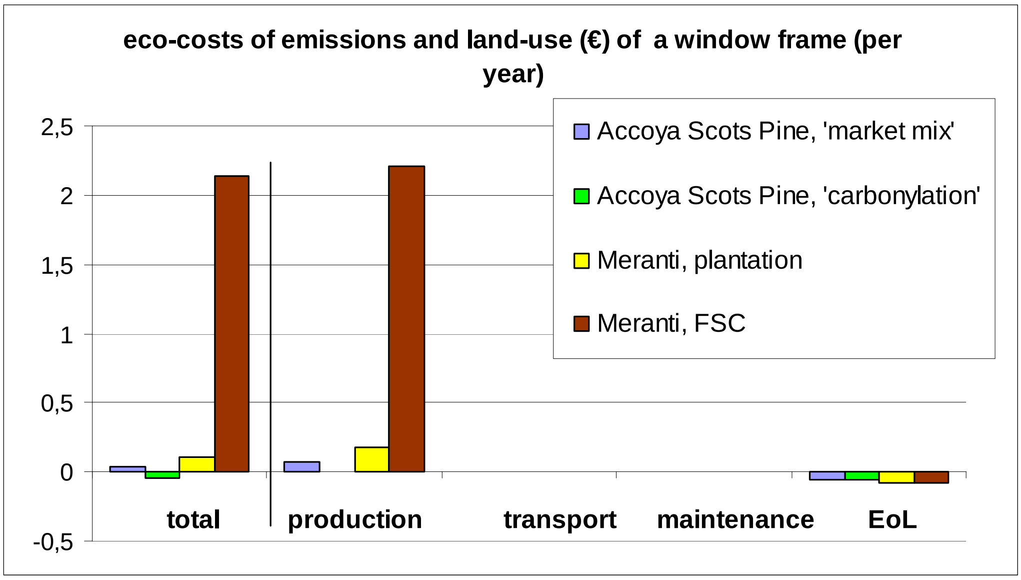


Figure 17. The eco-costs of emissions and land-use for Accoya Scots Pine, Meranti “plantation” and Meranti “FSC” for a window frame, 1,65 x 1,3 m, per year

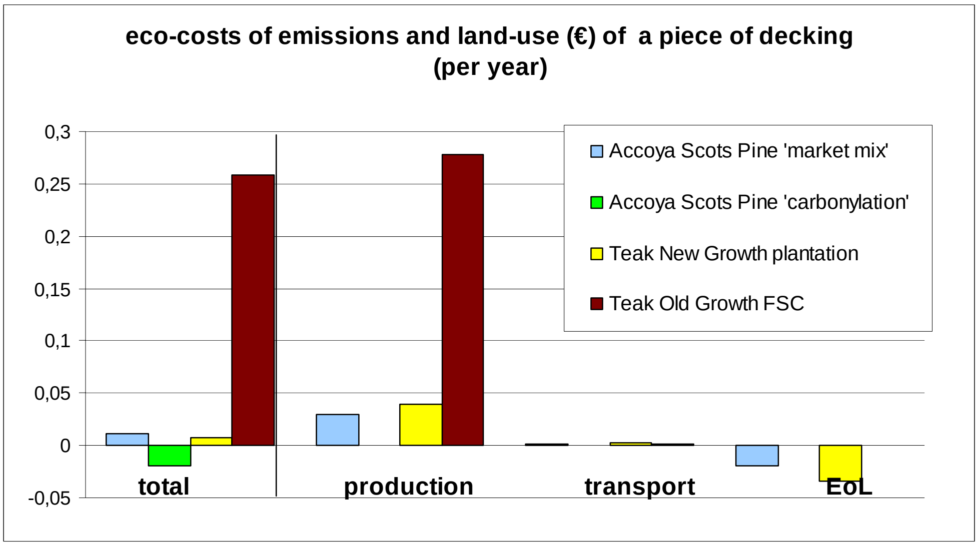


Figure 18. The eco-costs of emissions and land-use for Accoya Scots Pine, Teak (Old Growth) “plantation” and Teak (Old Growth) “FSC” for a piece of decking, 2500 x 20 x 150 mm, 75 years

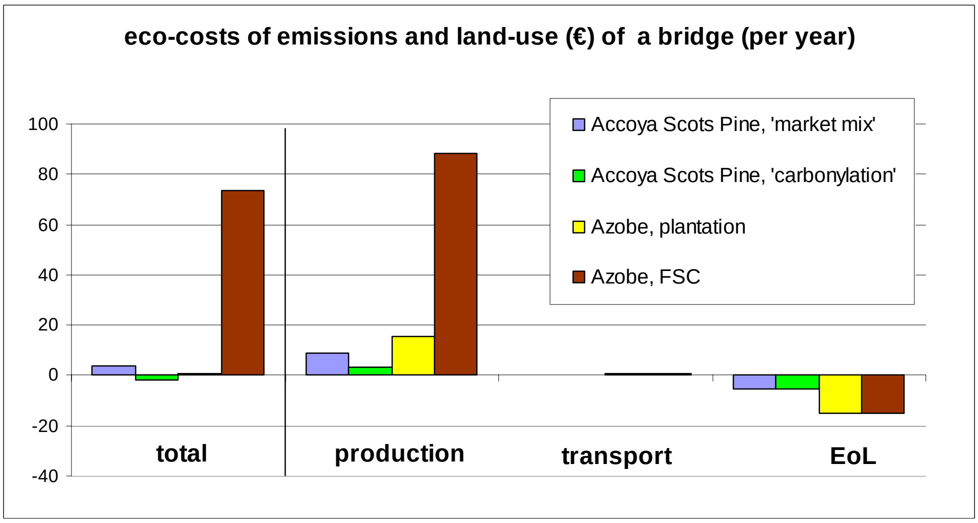


Figure 19. The eco-costs of emissions and land-use for Accoya Scots Pine, Azobe “plantation” and Azobe “FSC” for a bearing structure of a bridge, 16 x 3m, per year

8.3 Durability (lifespan) and other quality aspects

General quality aspects are not very well dealt with in the classical LCA. The issue is that in LCA the functional unit must be the same for the systems to be compared, however, quality in the broad sense is always an issue in comparisons. In the strict sense, the quality must be equal of all the systems, but in practice this is often not the case.

The generally accepted method of taking the functionality per year might be an acceptable solution in simple cases, but here it seems to fail. For the decking it might be acceptable: replacement is simple. But for the window frame and the bridge it is clear that replacement is less simple. A formal solution would be to bring the eco-burden of the construction activities into the LCIA, however, that requires to

introduce a lot of extra assumptions which are often arbitrary. Moreover, note that the durability estimates are often quite arbitrary as well (durability is often heavily affected by the type of use).
In the examples of the window frames and the bridge it is clear that systems which have to be replaced earlier (systems with less durability, such as Spruce) are less attractive.
There is an LCA based method[7] which provides a solution for this kind of flaws in the classical LCA method, however, this method goes far beyond the application of the ISO 14040 and 14044.

8.4 The issue of yield of land

Yield of land is a specific aspect of sustainability, related with the fact that land is becoming scarce, especially when current materials (metals, fossil fuels) will be replaced by renewable materials like wood and crops for biomass.
The high growing speed of Radiata Pine is a "green" competitive advantage over regular wood species, and in particular slow growing tropical hardwood species. Radiata Pine even outperforms giant bamboo – known to be an incredibly fast grower – in terms of annual yield, see Figure 20.
Therefore, the annual yield is another aspect of sustainability which might to be taken into account in addition to the LCA and Carbon Footprint performance.

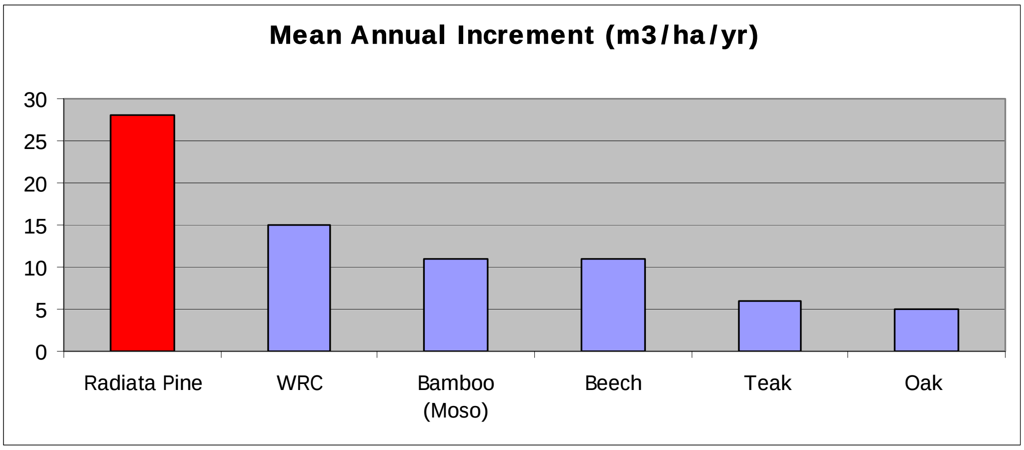


Figure 20. The Mean Annual Increment of various renewable materials. [Ref. 13, 14, 15, 16]

[7] The method of the Ecocosts/Value Ratio, EVR. See Wikipedia http://en.wikipedia.org/wiki/Eco-costs_value_ratio and www.ecocostvalue.com

ANNEX I
Cases to be analyzed (specified by Titan Wood)

PRODUCTION Phase

Timber sourcing

The following scenarios are to be analysed

Timber sourcing scenario	Scenario rationale	Forest to sawmill (truck km)	Sawmill to port (truck km)	Port to port (vessel km)	Port to acetylation facility (truck km)
Continental	Scots Pine (520 kg/m^3 at 12%MC) sourced from Scandinavia, with the acetylation facility at Arhnem, the Netherlands.	30	200	2,500	100
Locally sourced	Beech (710 kg/m^3 at 12% MC) from Schwarzwald, Southern Germany. No sea transport is required, truck carries timber 600 km from sawmill directly to acetylation facility, at Arhnem, the Netherlands.	30	600		
Intercontinental	Radiata Pine (450 kg/m^3 at 12% MC) sourced from New Zealand (Northern Island, coastal region), acetylated at Arnhem, the Netherlands.	30	50	20,811	100

ANH sourcing

Market Mix

Tons material used to construct acetylation facility

A	Civil proces part	kg	remark

confidential data

B	Civil logistic part	kg	remark

confidential data

C	Piping	kg	remark

confidential data

In addition to the abovementioned list, **x tons** of steel are used in the installation of which **y% is stainless-316 and 1-y% is ordinary steel.**

The totals are:

- Concrete: *(confidential)* kg
- stainless steel 316: *(confidential)* kg
- steel: *(confidential)* kg

Per 40.000 m3 wood per year (production capacity acetylation facility) for 20 years:

- concrete: *(confidential)* kg/m3
- stainless steel 316: *(confidential)* kg/m3
- steel: *(confidential)* kg/m3

USE phase

The use phase will be calculated for three functional units:

1. Window frame - Netherlands

For the window frame material use the comparative study executed by Richter et al (1996) is used as point of departure, based on a 1650 x 1300 mm window frame.

This study by Richter et al (1996) was commissioned by the Swiss Association for Window and Cladding Manufacturers to assess different materials used in comparable window framing systems. The study, which was conducted by Empa in 1996 in cooperation with the industry, defined a commonly accepted set of framing systems with comparable functionality across the different materials employed.

Table: Overview over the compared systems in Richter [Ref. 11].

Material specification	Wood - spruce	Aluminium: Extruded profiles	PVC - steel: Extruded profiles
Framing area (gross)	0.917 m2	0.644 m2	0.887 m2
Framing area (net)	0.489 m2	0.644 m2	0.488 m2
Framing surface	4.38 m2	4.42 m2	n.a.
Weight (net)	26.43 kg	39.65 kg	43.73 kg consisting of: 25.6 kg PVC and 16.1 kg steel

It should be noted that besides the technical lifespan of a window frame, many other factors determine the actual lifespan, such as the lifespan of the building in which the window frame is located, the maintenance policy of the building owner, adjustment of building legislation over the years (e.g. burglary proof), trends (passive house concept), etc. However, for this LCA study is assumed that the lifespan of the window frame is solely determined by the durability of the frame.

It should also be noted that the risks of the project and product are usually not included in the lifespan which makes it very difficult to make valid assumptions. For example, if a Spruce window is perfectly designed, constructed, placed in the construction and regularly coated in a sound manner, then the lifespan in theory could be unlimited. However, in practice this never happens; which results in the Spruce wood being exposed to the outdoor environment and the consequent (fast) degradation of the window, because of the low durability class (class 4).

The lifespan assumption for this LCA study is made by window frame expert Mr Jan de Jong of TNO Bouw en Ondergrond, and is based on a typical Dutch window frame, well executed and maintained. Maintenance figures (coatings) were provided by Mr Jan Huizer of Weijman Vastgoed. Efficiency and profiling figures provided by Mr Victor Vos (current European sales manager Titan Wood, former commercial director joinery factory).

Material alternatives with life span	**Material Use (m3 or kg)**	**Additives / coatings** (including frequency)
Accoya **50 years** (40-60 years)	M3 of Accoya® used may be derived from the Richter et al study: 26.43 kg / 460 kg/m3 (density spruce, see www.houtinfo.nl) = **0,057m3** efficiency Accoya® is mostly sold as 75 x 125 in order to produce a 67x114 profile	Opaque (white) acrylic coating system (37% solid compounds) on water basis (chosen because most used system in joinery industry in Netherlands), based on concept III system (totally prefabricated in joinery factory) with a 150 - 180 µm layer and a 35 µm layer for periodic coating (1 ½ > sanding,

	(81.4% yield), the most commonly used frame in the Netherlands. During selection also a 5-8% shortening loss ("kortverlies") may occur. Note that due to timber quality selection / grading at TW, quality of Accoya® wood is high, resulting in lower losses than for spruce	refining primer layer, full new layer), every 8 years.
Spruce **25 years** **(**15-35 years)	**0,057m3** Losses in profiling & processing most likely 5-10% higher than for Accoya® due to lower quality of the wood	Opaque (white) acrylic coating system (37% solid compounds) on water basis (colour and system chosen because most used system in joinery industry in Netherlands), based on concept III system (totally prefabricated in joinery factory) with a 150 - 180 µm layer and a 60 µm layer for periodic coating (2 ½ > sanding, fully new primer layer + full new lacquer layer), every 5 years.
Meranti **35 years** (25-45 years)	**0,057m3** Efficiency / Losses in profiling are the same as for Accoya®	Opaque (white) acrylic coating system (37% solid compounds) on water basis (colour and system chosen because most used system in joinery industry in Netherlands), based on concept III system (totally prefabricated in joinery factory) with a 150 - 180 µm layer and a 60 µm layer for periodic coating (2 ½ > sanding, fully new primer layer + full new lacquer layer), every 5 years.
PVC **35 years** (25-45 years)	43.73 kg consisting of: **25.6 kg PVC** and **16.1 kg steel**	Powder coated Annual cleaning and every 6 years small repairs
Aluminium **50 years** (35-60 years)	**17,70 kg (=3 kg/m frame), according to www.winket.nl** **Not 39.65 kg, according to [11]**	Powder coated Annual cleaning and every 6 years small repairs

2. Decking

Assumptions:

- FU = 1 piece of decking
- Piece is bought by consumer in DIY market
- Standard size in DIY market is assumed: 2500 x 20 x 150 mm = 0,0075m3
- No maintenance
- Completely exposed to outdoor circumstances
- For the Wood Plastic Composite (WPC) a material reduction is assumed to account for hollow extrusions.

According to Boke Tjeerdsma of SHR (Stichting Hout Research), the main selection criteria for decking are:

- durability (both aesthetical, biological and mechanical)
- dimensional stability
- strength

However, strength is in most cases not the determining factor; In practice the average consumer for a decking project does not execute precise structural calculations on decking but buys the standard size available through wholesale or DIY outlets.

Life spans in table below are a rough estimate by Mr Tjeerdsma of SHR. Mr Tjeerdsma mentioned that the actual lifespan is very situation- and consumer specific. For example, some consumers will accept colour change as a result of UV degradation and others will not. Some consumers may accept this for wood but not for plastic (WPCs), etc.

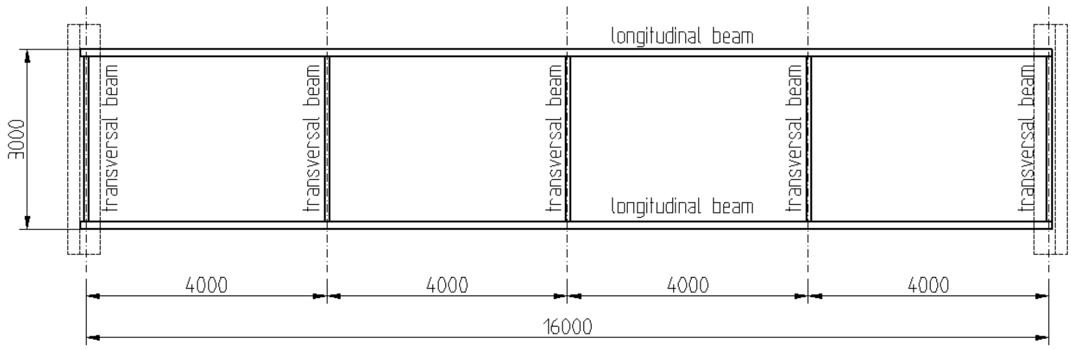
Material alternatives	**Material Use (m3 or kg)**	**Expected lifespan** (no maintenance)	**Expected critical factor / cause for end of lifespan**
Accoya	0,0075m3	25 years	Mechanical durability; because of the low hardness of Radiata Pine some mechanical wearing down is expected. In the case of Accoya® made from Beech the expected lifespan is 35 years.
Teak - **old growth** - **new growth**	0,0075m3	Old growth (durability class 1): 25 years New growth (durability class 2): 15 years	Biological durability

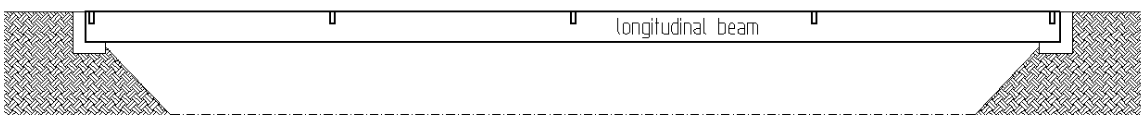
Impregnated Scots pine – toxic preservative (Copper-organic compound or Copper-Chrome – CC)	0,0075m3	15 years	Biological durability
Wood Plastic Composite (e.g. Tech-Wood)	0,00375m3	20-25 years	Aesthetical durability, WPCs prone to UV degradation which might be accepted better for wood than for plastics.

3. Bridge construction - pedestrian bridge

Structural dimensioning calculations and durability / maintenance assessment was executed by Luning Adviesbureau voor technische houtconstructies BV.

To be able to make a fair comparison of the structural dimensions of the bearing structure in various material alternatives a simple reference pedestrian bridge was designed which, based on the constructional plan, could be either executed in timber, steel or concrete.
The pedestrian bridge was assumed to be located in a non marine situation in the centre of the Netherlands (province of Utrecht), and had to comply with all relevant Dutch building legislation for a pedestrian bridge. Below the constructional plan of the bearing structure of the bridge is depicted.





L_{span} = 16.000m B = 3.000m

Table: The dimensions of the reference bridge in the various material alternatives

	LONGITUDINAL BEAM	TRANSVERSAL BEAM	TOTAL MATERIAL CONSUMPTION (full construction)
Material	**Dimensions in mm (lxbxh)**	**Dimensions in mm (lxbxh)**	
Accoya® wood	2 beams of 16000x160x1134 0,015 m3 glue / m3 wood PU or PRF glue	5 beams of 3000x100x405 0,015 m3 glue / m3 wood PU or PRF glue	6,41 m3 Accoya® 0,096 m3 glue
Tropical hardwood: Azobé	2 beams of 16000x160x1080 with 50 kg/m³ steel (dowelling and lengthening)	5 beams of 3000x100x270	5,94m3 wood 297kg steel
European hardwood: Robinia	2 beams of 16000x160x1161 0,015 m3 glue / m3 wood PU or PRF glue	5 beams of 3000x100x378 0,015 m3 glue / m3 wood PU or PRF glue	6,51m3 wood 0,098m3 glue
Laminated European softwood: Spruce	2 beams of 16000x160x1053 0,015 m3 glue / m3 wood PU or PRF glue	5 beams of 3000x100x351 0,015 m3 glue / m3 wood PU or PRF glue	5,92m3 wood 0,089m3 glue
Reinforced concrete	2 beams of 16000x300x1100 with 20.4kg steel per m1	5 beams of 3000x200x290 with 10.0 kg steel per m1	11,43m3 concrete (density 2400 kg / m3) 803 kg steel
Steel (hot dip galvanized, with a zinc layer of 50.7 µm	2 beams of 16000 - IPE600 (S235)	5 beams of 3000 - HEA160 (S235)	4437 kg steel

Assumptions & remarks with respect to lifespan (text derived from Luning report):

Prior to installation the wood beams are to be coated with an appropriate system (see below). The steel beams are galvanized and sometimes coated before installation. For the durability assessment was assumed that the bearing structure will be covered by non permeable decking which largely prevents water uptake by the structure.

Compared to the steel and concrete alternatives, the wood alternatives require more intensive maintenance. If executed in a technical sound manner, through coating, the lifespan of wood members may be increased. However, in the case of the bearing structure of a bridge, the parts which will be inflicted with biological degradation first (upper part of the beams), in practice are impossible to preserve since they are usually hard to reach. Therefore, from practical perspective, it is advised not to preserve these kinds of structures in wood. In case of durable wood species, such as Accoya® and Azobé, not applying coatings does not result in technical degradation but only in esthetical degradation ('greying' of the surface of the wood). If this is preferable depends on the eye of the beholder.

Table: The maintenance requirements and lifespan of the reference bridge in the various material alternatives

Material	Maintenance requirements	Expected lifespan
Accoya® wood	None, see remarks in main text	80 years
Tropical hardwood: Azobé	None, see remarks in main text	50 years
European hardwood: Robinia	None, see remarks in main text	35 years
Laminated European softwood: Spruce	None, see remarks in main text	25 years
Reinforced concrete	If designed and executed following appropriate guidelines, then only after 45 years some small maintenance (repair of small damages) needs to be executed.	90 years
Steel (hot dip galvanized), with a zinc layer of 50.7 µm (calculated via http://www.galvinfo.com:8080/zclp/)	During execution and use some local damages may occur to the zinc layer requiring updating of the zinc layer every 30 years.	50-60 years

ANNEX II
Certified Input and Output data of the Accoya® Wood plant in Arnhem

(confidential information)

ANNEX III
CML-2 Tables for the cradle to gate study of Accoya® Wood, Simapro 7.1 output per kg Accoya

Title:	Comparing processes
Method:	CML 2 baseline 2000 V2.04 / West Europe, 1995
Indicator:	Characterisation
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	I a Accoya, anhydride "carbonylation", Scots Pine	I b Accoya, anhydride "carbonylation", Beech	I c Accoya, anhydride "carbonylation", Radiata Pine	Ia Accoya, anhydride market mix, Scots Pine	Ib Accoya, anhydride market mix, Beech	Ic Accoya, anhydride market mix, Radiata Pine
Abiotic depletion	kg Sb eq	0,007087707	0,0071956	0,011194924	0,012707626	0,012813128	0,016816579
Acidification	kg SO2 eq	0,000574454	-7,47E-05	0,008568081	0,00266201	0,002011972	0,010656281
Eutrophication	kg PO4--- eq	-7,83E-06	-3,88E-05	0,000666376	0,000225053	0,000194012	0,000899334
Global warming (GWP100)	kg CO2 eq	0,46289551	0,47956293	1,0845972	1,0938927	1,1102916	1,7157892
Human toxicity	kg 1,4-DB eq	0,29768318	0,27910451	0,54809769	0,36204751	0,34344146	0,6124819
Fresh water aquatic ecotox.	kg 1,4-DB eq	-0,001935468	-0,003147035	0,011899431	0,027606996	0,026382858	0,041451017
Terrestrial ecotoxicity	kg 1,4-DB eq	0,000837441	0,000755309	0,001990452	0,001885502	0,001802924	0,003038836
Photochemical oxidation	kg C2H4	-0,000501497	-0,000520718	-0,000231408	-4,05E-05	-5,99E-05	0,000229751

ANNEX IV
CML-2 Tables for LCA cradle to grave ISO 14040 and 14044

Title:	Comparing processes
Method:	CML 2 baseline 2000 V2.04 / West Europe, 1995
Indicator:	Characterisation
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	frame Accoya Scots Pine	frame Accoya Beech	frame Accoya Radiata Pine	frame Meranti	frame Spruce	frame,Aluminium	frame,PVC
Abiotic depletion	kg Sb eq	0,009535	0,012976	0,010794	0,007176	0,002915	0,007115	0,020292
Acidification	kg SO2 eq	0,002218	0,002348	0,006772	0,013615	0,002084	0,00445	0,012967
Eutrophication	kg PO4--- eq	0,000216	0,000253	0,000599	0,001228	0,000292	0,000406	0,001432
Global warming (GWP100)	kg CO2 eq	0,098274	0,135853	0,465725	-0,10241	-0,7164	1,035825	2,546132
Ozone layer depletion (ODP)	kg CFC-11 eq	1,26E-07	1,74E-07	1,54E-07	1,00E-07	7,32E-08	8,35E-08	1,22E-07
Human toxicity	kg 1,4-DB eq	0,277796	0,354564	0,394452	0,418092	0,10602	3,355748	0,722357
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,03014	0,036775	0,035651	0,049065	0,00845	0,253158	0,455076
Marine aquatic ecotoxicity	kg 1,4-DB eq	97,28142	126,7581	124,1711	140,7614	29,75532	333,8389	540,3329
Terrestrial ecotoxicity	kg 1,4-DB eq	0,001663	0,002119	0,002164	0,003368	-6,23E-05	0,011859	0,026324
Photochemical oxidation	kg C2H4	-8,90E-06	-3,52E-05	0,000157	0,00045	8,93E-05	0,000288	0,000702

Eco-burden of window frames, base case, per year use.

Title:	Comparing processes
Method:	CML 2 baseline 2000 V2.04 / West Europe, 1995
Indicator:	Characterisation
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	decking Accoya Stots Pine	decking Accoya Beech	decking Accoya Radiata Pine	decking Teak New Growth	decking Teak Old Growth	decking,Wood Plastic Composite
Abiotic depletion	kg Sb eq	0,002705	0,002482	0,003081	0,001295	0,001043	0,005961
Acidification	kg SO2 eq	0,000598	0,000421	0,001957	0,001861	0,001994	0,001991
Eutrophication	kg PO4--- eq	5,40E-05	4,33E-05	0,000168	0,000173	0,000178	0,000171
Global warming (GWP100)	kg CO2 eq	0,044631	0,04372	0,150394	-0,06586	0,000403	0,476154
Ozone layer depletion (ODP)	kg CFC-11 eq	3,59E-08	3,35E-08	4,41E-08	1,66E-08	1,44E-08	1,55E-07
Human toxicity	kg 1,4-DB eq	0,076491	0,066103	0,111273	0,055939	0,058806	0,110356
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,006071	0,005294	0,007746	0,008096	0,005999	0,020907
Marine aquatic ecotoxicity	kg 1,4-DB eq	24,83865	22,25342	32,91892	25,02759	19,65464	48,04989
Terrestrial ecotoxicity	kg 1,4-DB eq	0,000416	0,000363	0,000567	0,000646	0,000487	0,001198
Photochemical oxidation	kg C2H4	-7,00E-06	-1,00E-05	4,26E-05	6,14E-05	6,48E-05	0,000123

Eco-burden of decking, per year use.

Title: Comparing processes
Method: CML 2 baseline 2000 V2.04 / West Europe, 1995
Indicator: Characterisation
Skip categories: Never
Relative mode: Non

Impact category	Unit	bridge Accoya Scots Pine	bridge Accoya Beech	bridge Accoya Radiata Pine	bridge Azobe	bridge Robinia	bridge Spruce	bridge,Concrete	bridge,Steel
Abiotic depletion	kg Sb eq	0,732371	0,991572	0,830138	0,487655	0,539846	0,377886	0,236304	0,582463
Acidification	kg SO2 eq	0,171823	0,180638	0,515179	0,635602	0,334815	0,239382	0,17951	0,333948
Eutrophication	kg PO4--- eq	0,017084	0,01989	0,045913	0,063176	0,041417	0,034879	0,040107	0,279015
Global warming (GWP100)	kg CO2 eq	15,34546	20,06186	42,63197	-37,2276	-42,617	-40,8871	58,1586	81,302
Ozone layer depletion (ODP)	kg CFC-11 eq	9,04E-06	1,27E-05	1,12E-05	5,80E-06	5,02E-06	6,57E-06	3,89E-06	4,43E-06
Human toxicity	kg 1,4-DB eq	19,86945	25,65156	28,72986	22,9927	10,53138	9,421995	10,32777	61,54265
Fresh water aquatic ecotox.	kg 1,4-DB eq	1,74329	2,213486	2,174755	8,717506	3,312355	0,0538	9,277072	80,23331
Marine aquatic ecotoxicity	kg 1,4-DB eq	6426,569	8589,036	8496,685	14358,64	8501,868	1396,234	9811,494	75937,82
Terrestrial ecotoxicity	kg 1,4-DB eq	0,113392	0,145651	0,152268	0,551513	0,239536	-0,02313	0,543007	4,420332
Photochemical oxidation	kg C2H4	0,000792	-0,00127	0,013295	0,022921	0,015824	0,014304	0,008176	0,035814

Eco-burden of a bearing structure of a pedestrian bridge, per year use.

ANNEX V
Durability Class of Accoya Wood

SKH

KOMO® product certificate

Semi-manufac-tured product

Stichting Keuringsbureau Hout SKH
Visiting address:
'Het Cambium', Nieuwe Kanaal 9c, 6709 PA Wageningen
Mailing address:
P.O Box 159, 6700 AD Wageningen, The Netherlands
Telephone: +31 (0) 317 45 34 25 E-mail: mail@skh.org
Fax: +31 (0) 317 41 26 10 Website: http://www.skh.org

MODIFIED TIMBER ACCOYA™

Number: 33058/07 PDF
Issued: 01-05-2007
Replaces:

Producer	Factory at
Titan Wood B.V. Postbus 2147 6802 CC ARNHEM THE NETHERLANDS E-mail: info@titanwood.com Website: http://www.titanwood.com	Westervoortsedijk 71 6827 AV ARNHEM THE NETHERLANDS Tel. +31 (0)26 366 41 22 Fax +31 (0)26 366 59 36

SKH declaration

This product certificate has been issued by SKH on the basis of BRL 0605 'Modified timber' in accordance with the SKH Regulations for Certification.

SKH declares that there is a legitimate confidence that the modified timber manufactured by the producer continuously complies with the technical specifications laid down in this product certificate, provided that the modified timber has been marked with the KOMO®-mark depicted hereunder, in a way as indicated in this product certificate.

For SKH R. Wigboldus, director

Users of this product certificate are advised to enquire at SKH whether this document is still valid.

This product certificate consists of 3 pages.

The Dutch version shall be consulted in case of doubt.

KOMO®

The following has been assessed:
quality system
product
Periodic control

MODIFIED TIMBER ACCOYA™

1 PRODUCT SPECIFICATION

1.1 Description of product

Accoya™ wood is based on wood acetylation of Radiata pine (*Pinus radiata D. Don)*.
Compared to untreated material the dimensional stability, the UV-stability and the natural durability is improved without addition of toxic material.

The performances in respect of the properties laid down in BRL 0605 "Modified timber" are laid down in section 2.1 "Technical specification".

2 TECHNICAL SPECIFICATION

2.1 Durability

The durability of Accoya™ wood complies at least with the requirements for durability *class 1*, tested in accordance with EN 350-1. Accoya™ wood can be used in use classes 1, 2, 3 and 4 as defined in EN 335-1.

2.2 Timber moisture content

Accoya™ is supplied with a moisture content of 3 to 6% mm.

2.3 Equilibrium moisture content

The average equilibrium moisture content of Accoya™ at a relative humidity of 65%, 80% and 90% and a temperature of 20°C is respectively 3.3%, 4.1 and 7.5% in absorption.

2.4 Dimensional stability

The average swelling from bone dry condition to water saturation in radial and tangential direction of Accoya™, when absorbing moisture, is respectively 0.7% and 1.5%.

2.5 Glue ability

In case of glueing Accoya™ it shall be done according to the instructions laid down in the manufacturers "Information Sheets".

2.6 Finishing

In case of finishing Accoya™ it shall be done according to the instructions laid down in the manufacturers "Information Sheets".

2.7 Mechanical properties

The average bending strength (MOR) and average modulus of elasticity (MOE) are not negatively effected by the modification process compared with untreated Radiata pine.

2.8 Janka Hardness

The average Janka Hardness of Accoya™ wood is radial and tangential increased by 50% compared to untreated Radiata pine. The end grain Janka Hardness is increased by 80%.

2.9 Impact bending strength

The average impact bending strength of Accoya™ wood is equal compared to untreated Radiata pine.

2.10 Fire behaviour

The quality declaration does not express an opinion about the fire behaviour.

2.11 Emission of harmful materials

Waste wood can be processed as untreated timber.

KOMO® product certificate

Page 3 of 3
Number: 33058/07 PDF
Issued: 01-05-2007

MODIFIED TIMBER ACCOYA™

3 **MARKING**

Accoya™ shall be marked per package with the KOMO®-mark.
The execution of this mark is as follows:
- KOMO® trademark or logo;
- no. **33058**;
- durability class 1 according to EN 350-1;
- unique production number;
- suitable for ground and fresh water contact, use class 4, colour Green, code "W".

Location of the mark: clearly visible on each package.

4 **SUGGESTIONS FOR THE USER**

4.1 **On delivery of the Accoya™ inspect whether:**
- the products comply with the contract of sale;
- the mark and the manner of marking are correct;
- the products do not show any visible defects due to transport or similar causes.

If the products are rejected on the basis of the above, the user should contact:

Titan Wood B.V.
Factory at Arnhem, The Netherlands
Westervoortsedijk 71
6827 AV ARNHEM
Telephone: +31 (0)26 366 41 22 E-mail: info@titanwood.com
Fax: +31 (0)26 366 59 36 Website: http://www.titanwood.com

and if desirable:

The certification-body Stichting Keuringsbureau Hout SKH
Office building 'Het Cambium',
Nieuwe Kanaal 9c, 6709 PA Wageningen
P.O. Box 159, 6700 AD Wageningen, the Netherlands
Telephone: +31 (0) 317 45 34 25 E-mail: mail@skh.org
Fax: +31 (0) 317 41 26 10 Website: http://www.skh.org

4.2 **Processing**
The use of Accoya™ wood shall be done according to the instructions and technical advice laid down in the manufacturers "Information Sheets".

4.3 **Product certificate**
It is the duty of the producer to make sure that the buyer receives a copy of the complete product certificate.

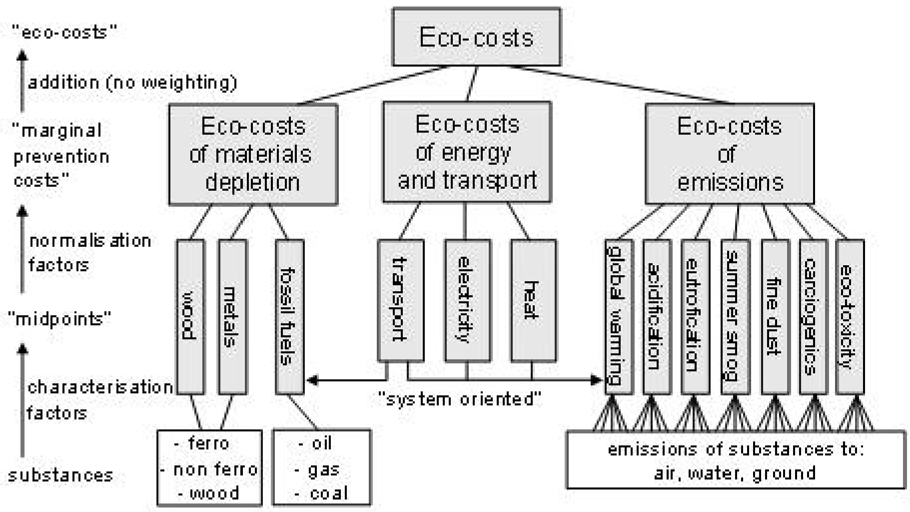
4.4 **Applications and use**
Transport, storage and deployment shall be effected in accordance with the working instructions included in this product certificate.

4.5 **Period of validity**
Consult the SKH website http://www.skh.org to verify whether the product certificate is still valid.

ANNEX VI
Short description of the Eco-costs 2007 system

From Wikipedia (http://en.wikipedia.org/wiki/Eco-costs#cite_note-1#cite_note-1**)**

Eco-costs is a measure to express the amount of environmental burden of a product on the basis of prevention of that burden. They are the costs which should be made to reduce the environmental pollution and materials depletion in our world to a level which is in line with the carrying capacity of our earth.
For example: for each 1000 kg CO2 emission, one should invest € 135,- in offshore windmill parks (or other CO2 reduction systems at that price or less). When this is done consequently, the total CO2 emissions in the world will be reduced by 65% compared to the emissions in 2008. As a result global warming will stabilize. In short: "the eco-costs of 1000kg CO2 are € 135,-".
Similar calculations can be made on the environmental burden of acidification, eutrification, summer smog, fine dust, eco-toxicity, and the use of metals, fossil fuels and land (nature). As such, the eco-costs are virtual costs, since they are not yet integrated in the real life costs of current production chains (Life Cycle Costs). The eco-costs should be regarded as hidden obligations.
The eco-costs of a product are the sum of all eco-costs of emissions and use of materials and energy during the life cycle "from cradle to cradle". The widely accepted method to make such a calculation is called Life Cycle Assessment (LCA), which is basically a mass and energy balance, defined in the 14040 and ISO 14044.



The practical use of eco-costs is to compare the sustainability of several product types with the same functionality. The advantage of eco-costs is that they are expressed in a standardized monetary value (€) which appears to be easily understood 'by instinct'. Also the calculation is transparent and relatively easy, compared to damage based models which have the disadvantage of extremely complex calculations with subjective weighting of the various aspects contributing to the overall environmental burden [1][2].

For emissions of toxic substances, the following set of multipliers is used in the eco-costs 2007 system:

• prevention of acidification	7.55 €/kg SOx equivalent
• prevention of eutrophication	3.60 €/kg phosphate equivalent
• prevention of ecotoxicity	802 €/kg Zn equivalent
• prevention of carciogens	33 €/kg PAH equivalent
• prevention of summer smog (respiratory diseases)	8.90 €/kg C2H4 equivalent
• prevention of fine dust	27.4 €/kg fine dust PM2.5
• prevention of global warming (GWP 100)	0.135 €/kg CO2 equivalent

The eco-costs of abiotic depletion is 0.7 €/kg for fossil fuels. The eco-costs of material depletion of tropical hardwood are based on the change of biodiversity before and after harvesting.

The characterization tables which are applied in the eco-costs 2007 system, are quite similar to the CML-2 tables:

- IPPC 2007, 100 years, for greenhouse gasses
- CML-2, for acidification, eutrification and summer smog (respiratory diseases)
- IMPACT 2002+, for aquatic eco-toxicity (inc. heavy metals), fine dust and carcinogens

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