Life Cycle Assessment

and

Carbon Sequestration

Bamboo products

of

MOSO International

Update 2014

SUMMARY REPORT

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1. Goal, Scope and Methodology

This summary report presents the main outcomes from the Life Cycle Assessment of the product portfolio of MOSO International. The full report is available upon request.

The reasons for carrying out this LCA study is twofold

a) for the management of MOSO International[1]: to establish the strengths and the weaknesses of the MOSO bamboo products and the production process in terms of CO2 and toxic emissions, in order to further improve the sustainability of these products.
b) for external parties: to communicate the relative position of MOSO Bamboo products in terms of environmental impact and carbon footprint throughout the life time.

The scope of this LCA study is the full range of MOSO bamboo products:

- Flooring & Floor covering (Solid strip – MOSO Purebamboo, Solid wide board – MOSO Bamboo Elite, 2-Ply flooring – MOSO Bamboo Supreme, On-edge / Industrial floor – MOSO Bamboo Industriale)
- Thermally modified decking and cladding – MOSO Bamboo X-treme
- Panels & Beams (Solid panel, 1-ply panel, Veneer, Solid joist)

Excluded from the scope are engineered products by MOSO such as Topbamboo (HDF carrier) and Unibamboo (latex backing).
Note: This LCA has been performed for the specific case of the MOSO production chain following best practice and can therefore **not** be perceived as being typical for the production chain of other industrial bamboo material manufacturers.

The system boundary of this LCA is “cradle-to-warehouse-gate” plus “end-of-life” as depicted in Fig. 1. The Use-Phase has been kept out of the analyses, because the emissions in this step are negligible (in comparison to the first and the last step) and often based on user preferences (e.g. application of oil on a floor or leaving it untreated).

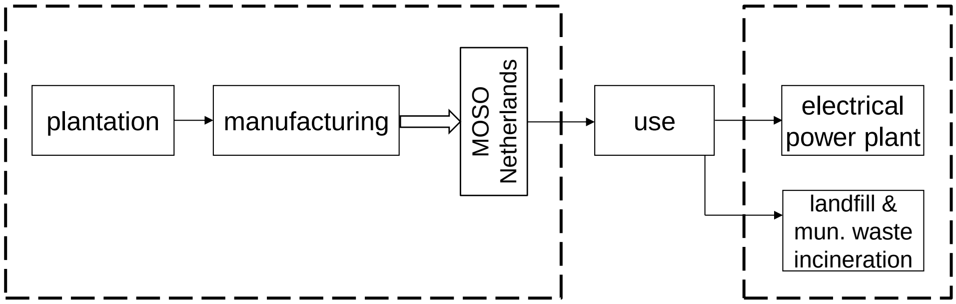

Figure 1: System boundary: cradle-to-gate plus end-of-life.

[1] For more information on MOSO International and its bamboo products, see www.moso.eu

The LCIA (Life Cycle Impact Analysis) is not done at the level of so called “midpoints” (environmental impact indicators for specific environmental themes such as toxicity, acidification, etc), since a set of midpoints is not meaningful for the average reader (even specialist often struggle with a meaningful interpretation of midpoints). In this report, so called “single indicators” are used. The advantage of a single indicator is that the environmental burden of the product life cycle is expressed in <u>one</u> number.
Two single indicators are used:

- the “CO2 equivalent” (“carbon footprint”) , which can easily be understood and explained, but is lacking other polluting emissions (like SOx, NOx, carcinogens, fine dust, etc.)
- the “eco-costs” system which incorporates 3000 polluting substances (as well as materials depletion).

For end-of-life it is assumed that 90% of the bamboo products are incinerated in an electrical power plant, and 10% will end-up in landfill, which is considered to be a realistic scenario for the Netherlands (NEN 8006) and Western Europe.

The analyses in this report are fully in line with the ISO specifications (ISO 14040 and 14044) and the LCA manual (EC-JRC 2010). Details on the calculations have been published in peer reviewed papers (Vogtländer et al. 2014, Vogtländer et al. 2010) and –books (van der Lugt et al. 2009a, van der Lugt et al. 2009b, van der Lugt 2008).

2. LCA and the CO2 cycle

Additional to the standard LCA (ISO 14040 and 14044), the sequestration (capture and storage) of CO2 has been taken into account. Carbon sequestration in biological materials is an important issue in sustainability. However, it is also a confusing subject, leading to many discussions. This chapter provides a summary of this complex issue, which is related to the “delayed pulse” issue and the issue of “system expansion” in LCA. For a scientific analysis see Vogtländer at al. (2014).

<u>Carbon sequestration in LCA on the level of a product</u>.
There is consensus in science on the way “biogenic CO_2” (=CO_2 which is captured in wood during the growth of a tree) is to be handled in LCA. See Fig.2.
Biogenic CO_2 is first taken out of the air at the bamboo plantation, and then released back to the atmosphere at the End of Life. So biogenic CO2 is recycled, and its net effect on global warming is zero.
When the bamboo product, however, is burnt at end-of life in an electrical power plant, the total system of Fig. 2 generates electricity. This electricity can replace electricity from fossil fuels. In other words: the use of fossil fuels is avoided, so fossil CO2 emissions are avoided, which results in a reduction of global warming. In LCI (Life Cycle Inventory, i.e., analysis of all input and output flows in the product system) calculations this leads to a system credit: the production of heat or electricity from bamboo waste has a negative carbon footprint and negative eco-costs (ECJRC 2010).

The conclusion is that the storage of biogenic CO2 (carbon sequestration) in bamboo is not counted in LCA, unless the bamboo (or any other bio-product like wood) is burnt for electricity or heat.

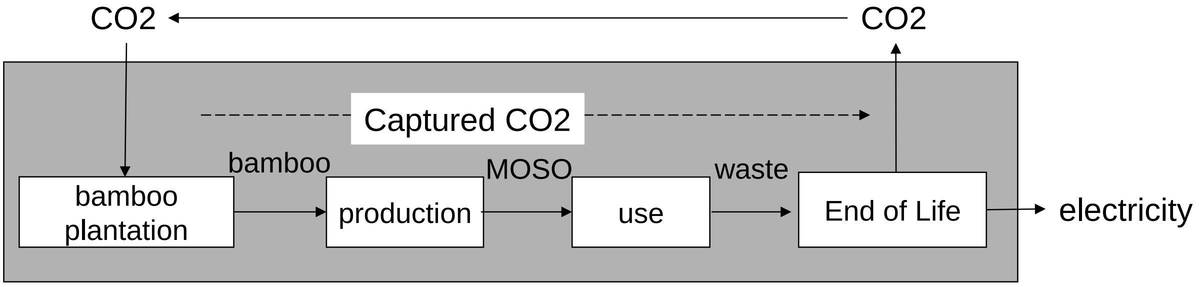

Figure 2: The CO2 cycle on product level.

The widespread confusion comes from the fact that the storage of CO2 as such, even temporary, is good for the environment, so “it has to be incorporated in some way in the total LCA calculation”. Compared to the temporary storage credit as specified as “optional” in PAS 2050 (BSI 2011) and the ILCD manual (ECJRC 2010), this report adopts an alternative, more realistic approach on how to cope with carbon sequestration in renewable products, see section below.

<u>The effects of carbon sequestration at global system level</u>

The effects of carbon sequestration can be understood when we look at a global system level.
On a global scale, CO2 is stored in forests (and other vegetation), in the ocean, and in products (buildings, furniture, etc). One should realise that, when there is *no change* in the area of forests and *no change* in the total volume of wood in products (houses, furniture, etc.), there is *no change* in sequestered carbon. For a description of the global CO2 cycle, please refer to the full report.
The consequence is that there is only extra carbon storage on a global scale, when there is market growth of the application of bamboo. This market growth leads to more plantations and more volume of bamboo in the building industry. The positive major effect on global warming is mainly caused by the increase of bamboo plantations, rather than by the increase of bamboo products (e.g. bamboo products applied in the building industry). On the contrary, the application of tropical hardwood is damaging global carbon sequestration, since the decrease of carbon in the tropical forests (deforestation) is more than the increase of carbon in the wood products.

This report adopts the more realistic allocation for carbon sequestration credits based on the *extra global carbon sequestration in forests / plantations related to the total global production of bamboo products*. The full report of this LCA provides detailed information about assumptions and calculations regarding this matter.

3. Cradle-to-gate calculations on bamboo products

The production system of bamboo "from cradle-to-warehouse-gate" is depicted in Fig. 3.
The calculations have been made on the actual product chain of bamboo products of MOSO International based on consumption in the Netherlands:

- Collection production data: October 2013 – January 2014
- Type of bamboo: *Phyllostachys Pubescens* (density 700 kg/m3, length up to 15 m, diameter on the ground 10-12 cm, wall thickness 9mm), also called "Moso bamboo" by the native population.
- Plantation and first processing: the Anji region, the province of Zhejiang, China
- Final processing in Huangzhou, the province of Zhejiang, and Jianyang, Nanping county, the province of Fujian, both in China
- The product is shipped via Shanghai and Rotterdam to the MOSO warehouse in The Netherlands (Zwaag)

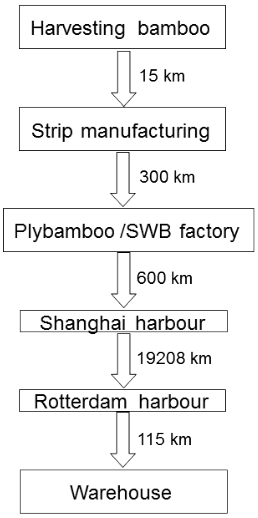

Figure 3: The production system of MOSO bamboo products (cradle-to-warehouse-gate).

The required heat for the manufacturing process is generated locally by combustion of sawdust and bamboo waste produced during the manufacturing process. Electricity is from the local grid.
Note: a cogeneration plant for electricity and heat is an opportunity for the future, to reduce the carbon footprint even further.

The calculations for the LCAs have been made with the computer program Simapro version 8.01, applying LCI databases of Ecoinvent v3 (2014) and Idemat 2014 (a database of the Delft University of Technology, partly based on Ecoinvent Unit data). The eco-costs of construction materials (from cradle to gate) and transport can be found in the open access tables provided at www.ecocostsvalue.com or can be calculated with the Idemat databases for Simapro.

This report is based on current production data of the MOSO facilities, and therefore an update of previous LCA studies about MOSO bamboo products published (Vogtländer 2011, van der Lugt et al. 2009a, van der Lugt et al. 2009b, van der Lugt 2008) which can be perceived as outdated.
In general, there are three main production techniques used for the development of MOSO bamboo products:

- Plybamboo: lamination of strips (700 kg/m3)
- Strand Woven Bamboo (SWB) / High Density: compression of rough strips / fibers (1100-1200 kg/m3)
- Flattened bamboo (850 kg/m3)

Figure 4: Plybamboo boards are available in various colours, sizes and styles (photo MOSO International).

Figure 5: High Density beams are made by compressing rough bamboo fibres in moulds under very high pressure (photo MOSO International)

Figure 6: Flattened bamboo features the original bark of the bamboo stem as toplayer (photo MOSO International).

A comprehensive description of the production processes can be found in the full report. The total scores (carbon footprint as well as eco-costs) of the various variations for the MOSO bamboo products are given in the next chapter. Full calculations are available only after signing an NDA.

4. Results: Tables on combined cradle-to-grave calculations, including Carbon Sequestration

The tables below show the combined results of the calculations of the LCA and the CO2 storage for the product portfolio of MOSO International.

Note: SP = Side Pressed, PP = Plain Pressed, D = Density / Compressed, N = Natural (bleached), C = Caramel (Carbonized), E0 = produced with glues with No Added Formaldehyde (Formaldehyde emission: Class E0, <0,025 mg/m3)

Flooring					Carbon Footprint (CO2eq) per kg final product					Eco-costs (€) per kg final product			
					PRODUCTION cradle to gate	EoL CO2 credit	CO2 storage	CO2 total	CO2 Neutral	PRODUCTION cradle to gate	EoL Eco-costs	eco-costs CO2 storage	eco-costs Total
	Thickness(mm)	type	Style	Color	CO2equ/kg	CO2equ/kg	CO2equ/kg	CO2equ/kg	Yes / No	Euro/kg	Euro/kg	Euro/kg	Euro/kg
Solid strip													
(MOSO Purebamboo)	15		SP	N	0,925	-0,704	-0,629	-0,4084	Yes	0,257	-0,132	-0,085	0,040
	15	E0	SP	N	0,911	-0,704	-0,629	-0,4217	Yes	0,253	-0,132	-0,085	0,036
	15		PP	N	0,951	-0,704	-0,629	-0,3822	Yes	0,268	-0,132	-0,085	0,051
	15	E0	PP	N	0,945	-0,704	-0,629	-0,3884	Yes	0,266	-0,132	-0,085	0,049
	15		SP	C	0,964	-0,704	-0,629	-0,3690	Yes	0,265	-0,132	-0,085	0,048
	15	E0	SP	C	0,951	-0,704	-0,629	-0,3824	Yes	0,262	-0,132	-0,085	0,045
	15		PP	C	0,990	-0,704	-0,629	-0,3429	Yes	0,276	-0,132	-0,085	0,059
	15	E0	PP	C	0,984	-0,704	-0,629	-0,3491	Yes	0,275	-0,132	-0,085	0,058
	15		DT	C	1,048	-0,704	-0,623	-0,2795	Yes	0,301	-0,132	-0,084	0,085
	15		DT	N	1,008	-0,704	-0,623	-0,3194	Yes	0,292	-0,132	-0,084	0,076
Solid wide board (3 ply)													
(MOSO Bamboo Elite)	15		SP	N	1,015	-0,704	-0,629	-0,3176	Yes	0,286	-0,132	-0,085	0,069
	15	E0	SP	N	0,957	-0,704	-0,629	-0,3764	Yes	0,271	-0,132	-0,085	0,054
	15		PP	N	1,006	-0,704	-0,629	-0,3266	Yes	0,283	-0,132	-0,085	0,066
	15	E0	PP	N	0,952	-0,704	-0,629	-0,3807	Yes	0,269	-0,132	-0,085	0,053
	15		SP	C	1,055	-0,704	-0,629	-0,2783	Yes	0,294	-0,132	-0,085	0,077
	15	E0	SP	C	0,996	-0,704	-0,629	-0,3371	Yes	0,280	-0,132	-0,085	0,063
	15		PP	C	1,046	-0,704	-0,629	-0,2873	Yes	0,291	-0,132	-0,085	0,074
	15	E0	PP	C	0,992	-0,704	-0,629	-0,3414	Yes	0,278	-0,132	-0,085	0,061
	13		DT	N	1,004	-0,704	-0,623	-0,3227	Yes	0,288	-0,132	-0,084	0,071
	13		DT	C	1,042	-0,704	-0,623	-0,2846	Yes	0,296	-0,132	-0,084	0,080
2-Ply flooring													
(MOSO Bamboo Supreme)	10		SP	N	0,876	-0,704	-0,629	-0,4573	Yes	0,248	-0,132	-0,085	0,031
	10	E0	SP	N	0,870	-0,704	-0,629	-0,4626	Yes	0,247	-0,132	-0,085	0,030
	10		PP	N	0,871	-0,704	-0,629	-0,4620	Yes	0,246	-0,132	-0,085	0,029
	10	E0	PP	N	0,868	-0,704	-0,629	-0,4653	Yes	0,246	-0,132	-0,085	0,029
	10		SP	C	0,915	-0,704	-0,629	-0,4183	Yes	0,256	-0,132	-0,085	0,039
	10	E0	SP	C	0,909	-0,704	-0,629	-0,4237	Yes	0,248	-0,132	-0,085	0,031
	10		PP	C	0,910	-0,704	-0,629	-0,4232	Yes	0,255	-0,132	-0,085	0,038
	10	E0	PP	C	0,907	-0,704	-0,629	-0,4265	Yes	0,247	-0,132	-0,085	0,030
	10		DT	N	0,939	-0,704	-0,623	-0,3883	Yes	0,270	-0,132	-0,084	0,054
	10		DT	C	0,978	-0,704	-0,623	-0,3491	Yes	0,279	-0,132	-0,084	0,062
On-edge / Industrial floor													
(MOSO Bamboo Industriale)	10, 15		SP	N	0,816	-0,704	-0,629	-0,5168	Yes	0,229	-0,132	-0,085	0,012
	10, 15		SP	C	0,856	-0,704	-0,629	-0,4775	Yes	0,238	-0,132	-0,085	0,021
	10		DT	N	0,971	-0,704	-0,623	-0,3556	Yes	0,283	-0,132	-0,084	0,067
	10		DT	C	1,010	-0,704	-0,623	-0,3170	Yes	0,291	-0,132	-0,084	0,075
Flattened bamboo (3 ply)													
(MOSO Bamboo Forest)	18	E0			0,620	-0,704	-0,637	-0,7208	Yes	0,208	-0,132	-0,086	-0,010

Panels & Beams					Carbon Footprint (CO2eq) per kg final product					Eco-costs (€) per kg final product			
					PRODUCTION cradle to gate	EoL CO2 credit	CO2 storage	CO2 total	CO2 Neutral	PRODUCTION cradle to gate	EoL Eco-costs	eco-costs CO2 storage	eco-costs Total
	Thickness(mm)	type	Style	Color	CO2equ/kg	CO2equ/kg	CO2equ/kg	CO2equ/kg	Yes / No	Euro/kg	Euro/kg	Euro/kg	Euro/kg
Panels													
1 ply panel	3, 5		SP	N	0,925	-0,704	-0,629	-0,4084	Yes	0,257	-0,132	-0,085	0,040
	3, 5	E0	SP	N	0,911	-0,704	-0,629	-0,4217	Yes	0,253	-0,132	-0,085	0,036
	3, 5		PP	N	0,915	-0,704	-0,629	-0,4180	Yes	0,253	-0,132	-0,085	0,036
	3, 5	E0	PP	N	0,907	-0,704	-0,629	-0,4263	Yes	0,251	-0,132	-0,085	0,034
	3, 5		SP	C	0,964	-0,704	-0,629	-0,3690	Yes	0,265	-0,132	-0,085	0,048
	3, 5	E0	SP	C	0,951	-0,704	-0,629	-0,3824	Yes	0,262	-0,132	-0,085	0,045
	3, 5		PP	C	0,954	-0,704	-0,629	-0,3786	Yes	0,262	-0,132	-0,085	0,045
	3, 5	E0	PP	C	0,946	-0,704	-0,629	-0,3869	Yes	0,260	-0,132	-0,085	0,043
	4		DT	N	1,008	-0,704	-0,623	-0,3194	Yes	0,292	-0,132	-0,084	0,076
	4		DT	C	1,048	-0,704	-0,623	-0,2795	Yes	0,301	-0,132	-0,084	0,085
multi-layer panel	16, 20, 30, 40		SP	N	0,995	-0,704	-0,629	-0,3383	Yes	0,282	-0,132	-0,085	0,065
	16, 20, 30, 40	E0	SP	N	0,965	-0,704	-0,629	-0,3676	Yes	0,275	-0,132	-0,085	0,058
	16, 20, 30, 40		PP	N	0,979	-0,704	-0,629	-0,3543	Yes	0,277	-0,132	-0,085	0,060
	16, 20, 30, 40	E0	PP	N	0,958	-0,704	-0,629	-0,3752	Yes	0,272	-0,132	-0,085	0,055
	16, 20, 30, 40		SP	C	1,034	-0,704	-0,629	-0,2990	Yes	0,291	-0,132	-0,085	0,074
	16, 20, 30, 40	E0	SP	C	1,005	-0,704	-0,629	-0,3283	Yes	0,284	-0,132	-0,085	0,067
	16, 20, 30, 40		PP	C	1,018	-0,704	-0,629	-0,3150	Yes	0,285	-0,132	-0,085	0,069
	16, 20, 30, 40	E0	PP	C	0,997	-0,704	-0,629	-0,3359	Yes	0,280	-0,132	-0,085	0,063
	20, 38		DT	N	0,976	-0,704	-0,623	-0,3513	Yes	0,289	-0,132	-0,084	0,073
	20, 38		DT	C	1,015	-0,704	-0,623	-0,3123	Yes	0,297	-0,132	-0,084	0,081
Veneer	0,6		SP	N	1,110	-0,704	-0,629	-0,2231	Yes	0,300	-0,132	-0,085	0,083
	0,6	E0	SP	N	1,106	-0,704	-0,629	-0,2271	Yes	0,292	-0,132	-0,085	0,075
	0,6		PP	N	1,330	-0,704	-0,629	-0,0032	Yes	0,352	-0,132	-0,085	0,135
	0,6	E0	PP	N	1,325	-0,704	-0,629	-0,0079	Yes	0,335	-0,132	-0,085	0,118
	0,6		SP	C	1,153	-0,704	-0,629	-0,1799	Yes	0,310	-0,132	-0,085	0,093
	0,6	E0	SP	C	1,149	-0,704	-0,629	-0,1839	Yes	0,301	-0,132	-0,085	0,084
	0,6		PP	C	1,381	-0,704	-0,629	0,0478	No	0,300	-0,132	-0,085	0,083
	0,6	E0	PP	C	1,376	-0,704	-0,629	0,0431	No	0,346	-0,132	-0,085	0,129
Solid joist	55, 60, 72, 100		SP	N	1,020	-0,704	-0,629	-0,3130	Yes	0,266	-0,132	-0,085	0,049
	55, 60, 72, 100	E0	SP	N	0,991	-0,704	-0,629	-0,3423	Yes	0,266	-0,132	-0,085	0,049
	55, 60, 72, 100		SP	C	1,059	-0,704	-0,629	-0,2737	Yes	0,2742	-0,132	-0,085	0,057
	55, 60, 72, 100	E0	SP	C	1,030	-0,704	-0,629	-0,3031	Yes	0,2742	-0,132	-0,085	0,057
	60, 72, 100		DT	N	0,878	-0,704	-0,623	-0,4485	Yes	0,261	-0,132	-0,084	0,045
	60, 72, 100		DT	C	0,916	-0,704	-0,623	-0,4111	Yes	0,269	-0,132	-0,084	0,053

Outdoor					Carbon Footprint (CO2eq) per kg final product					Eco-costs (€) per kg final product			
					PRODUCTION cradle to gate	EoL CO2 credit	CO2 storage	CO2 total	CO2 Neutral	PRODUCTION cradle to gate	EoL Eco-costs	eco-costs CO2 storage	eco-costs Total
	Thickness(mm)	type	Style	Color	CO2equ/kg	CO2equ/kg	CO2equ/kg	CO2equ/kg	Yes / No	Euro/kg	Euro/kg	Euro/kg	Euro/kg
Decking & cladding													
(MOSO Bamboo X-treme)	20		DT	C	1,193	-0,704	-0,607	-0,1176	Yes	0,356	-0,132	-0,082	0,142

5. Conclusion & Discussion

In this study, a Life Cycle Assessment and carbon footprint was executed for the bamboo products of MOSO International, in which the effect of carbon sequestration was included. From the results, shown in chapter 7, it can be concluded that almost all MOSO bamboo products, based on use in Europe, are “CO2 neutral or better” i.e. CO2 negative. Apparently the credits for bio-energy production during the End of Life (EoL) phase and carbon sequestration as a result of land change, outweigh the emissions during production in China and shipping the bamboo products to Europe, see figure 7. Note that in the case eco-costs (all environmental indicators combined) the outcomes are similar, with slight differences as the impact of sea transport is more significant as well as the impact of some resins, see figure 8 below.

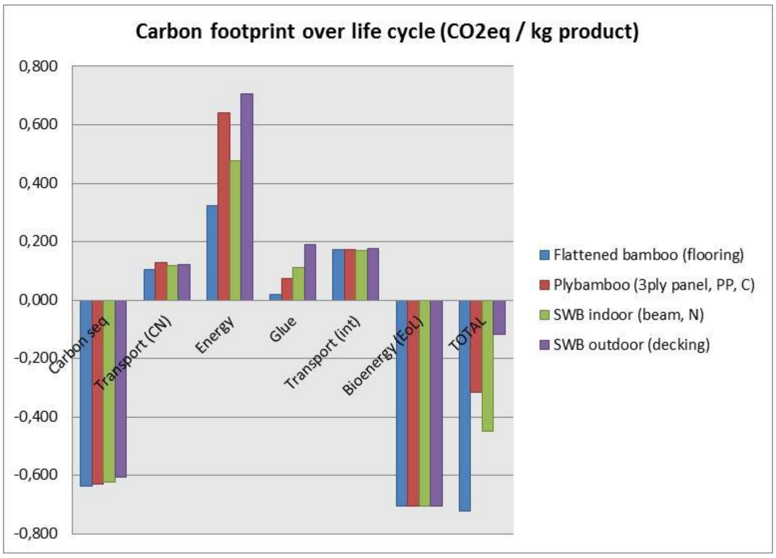

Figure 7: Carbon Footprint over Life Cycle (kgCO2eq / kg MOSO product), for various MOSO products based on different production technologies.

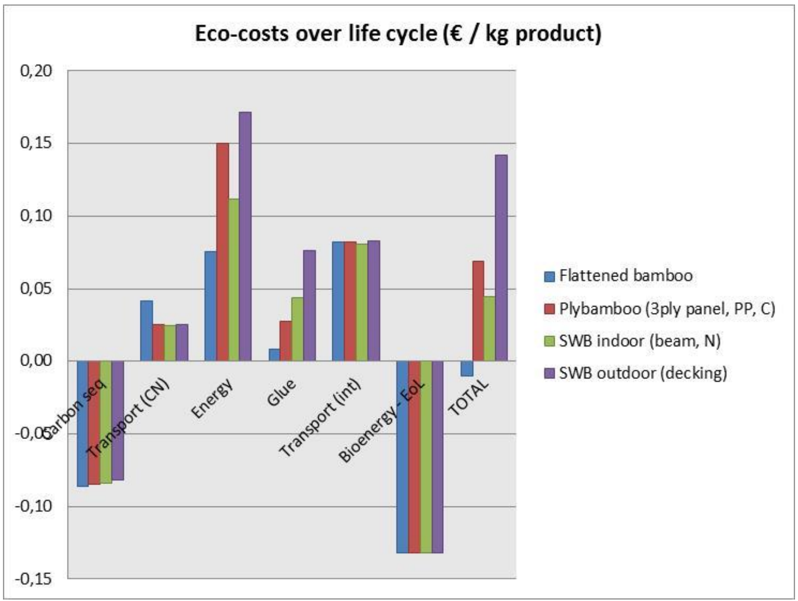

Figure 8: Eco-costs over Life Cycle (kgCO2eq / kg MOSO product), for various MOSO products based on different production technologies.

A further question is how industrial bamboo materials compare to other commonly used materials, and especially the materials it tries to substitute: tropical hardwood and non-renewable carbon intensive materials such as plastics (e.g. PVC) and metals (e.g. aluminium, steel). In table 1 and figure 9 the environmental performance is provided for several commonly used materials, including the main bamboo industrial production technologies.

Table 1: Carbon Footprint over Life Cycle (kgCO2eq / kg or m3 building material) for various common building materials (this report, Idemat 2014 database and Vogtländer et al. 2014)

Carbon footprint (CO2eq per kg product)	Density (kg/m3)	Production cradle to gate	End of Life small elect. power plant (32% efficiency)	Carbon seq based on land use change	Total / kg	Total / m3
Flattened bamboo (d.m. 90%)	850	0,620	-0,704	-0,6370	-0,721	-613
Plybamboo (Caramel) (d.m. 90%)	700	1,018	-0,704	-0,6290	-0,315	-220
SWB indoor (Natural) (d.m. 90%)	1080	0,878	-0,704	-0,6230	-0,449	-484
SWB outdoor (d.m. 90%)	1200	1,193	-0,704	-0,6070	-0,118	-141
Sawn timber, softwood, planed, kiln dried, at plant/RER S (d.m. 90%)	460	0,260	-0,817	-0,1700	-0,727	-334
Idemat2014 Meranti plantation	640	0,710	-0,704	0,000	0,006	4
Idemat2014 PVC (Polyvinylchloride, market mix)	1380	2,104			2,104	2904
Idemat2014 Steel (21% sec = market mix average)	7850	1,838			1,838	14429
Idemat2014 Aluminium trade mix (66% prim 33% sec)	2800	11,580			11,580	32423
Idemat2014 Concrete (reinforced, 40 kg steel per 1000 kg)	2400	0,231			0,231	554

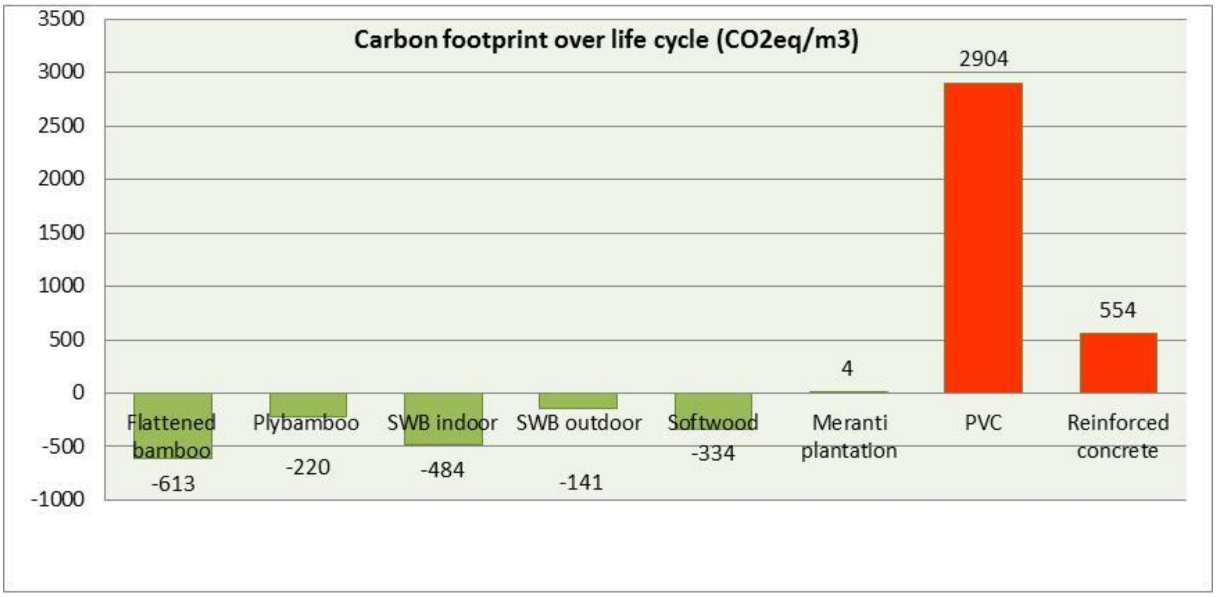

Figure 9: Carbon Footprint over Life Cycle (kgCO2eq / m3 building material) for various common building materials (this report, Idemat 2014 database and Vogtländer et al. 2014). Note: aluminium and steel are not shown because of the high carbon footprint (see table) therefore not fitting in the graph.

Note that tropical hardwood, like Meranti, does not have a carbon sequestration credit. In the best scenario, the carbon sequestration credit is zero, which is the case for plantation wood (currently 35 – 40% of the FSC wood on the market). For other tropical hardwood, the situation in worse: the deforestation of natural rain forests leads to a debit of carbon sequestration. The major disadvantage of hardwood from rain forests, however, is not the carbon sequestration debit, but the negative effect on biodiversity, which is taken into account in the eco-costs for production (cradle to gate) of these materials, see the three scenarios for Meranti (plantation, FSC, natural forest) in the table and graph below.

Table 2: Eco-costs over Life Cycle (€ / kg or m3 building material) for various common building materials (this report, Idemat 2014 database and Vogtländer et al. 2014)

LCA | Eco-costs (€ per kg product)	**Density (kg/m3)**	**Production** cradle to gate	**End of Life** small elect. power plant (32% efficiency)	**Carbon seq** based on land use change	**Total / kg**	**Total / m3**
Flattened bamboo (d.m. 90%)	850	0,208	-0,132	-0,086	-0,01	-8,7
Plybamboo (Caramel) (d.m. 90%)	700	0,285	-0,132	-0,085	0,07	48,0
SWB indoor (Natural) (d.m. 90%)	1080	0,261	-0,132	-0,084	0,04	48,1
SWB outdoor (d.m. 90%)	1200	0,356	-0,132	-0,082	0,14	171
Sawn timber, softwood, planed, kiln dried, at plant/RER S (d.m. 90%)	460	0,035	-0,154	-0,023	-0,14	-65,3
Idemat2014 Meranti plantation	640	0,211	-0,132	0,000	0,08	50
Idemat2014 Meranti FSC	640	2,090	-0,132	0,000	1,96	1253
Idemat2014 Meranti natural forest	640	9,611	-0,132	0,000	9,48	6066
Idemat2014 PVC (Polyvinylchloride, market mix)	1380	0,735			0,73	1014
Idemat2014 Steel (21% sec = market mix average)	7850	0,679			0,68	5329
Idemat2014 Aluminium trade mix (66% prim 33% sec)	2800	4,353			4,35	12190
Idemat2014 Concrete (reinforced, 40 kg steel per 1000 kg)	2400	0,059			0,06	142

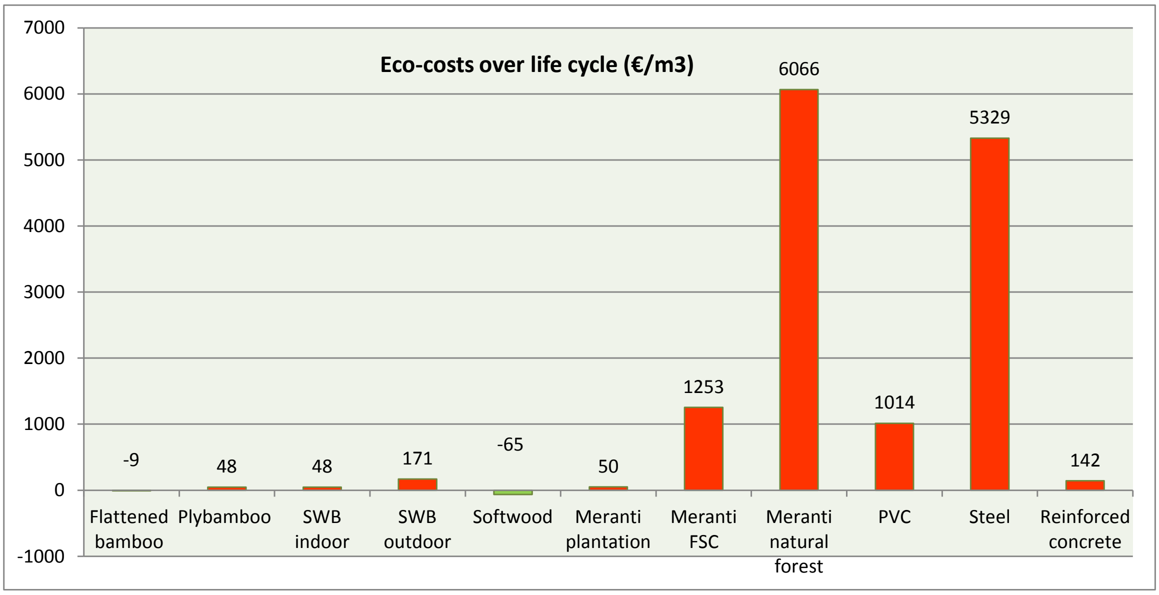

Figure 10: Eco-costs over Life Cycle (€/ m3 building material) for various common building materials (this report, Idemat 2014 database and Vogtländer et al. 2014). Note: aluminium is not shown because of the high eco-costs (see table 2) therefore not fitting in the graph.

Although the numbers are per m3 material, and not for a specific application - in which also maintenance and material use based on required mechanical and functional properties are included (functional unit) - these figures do give a good indication how the various materials compare from environmental point of view and can be used as basis for more specific calculations for several applications (functional units).

With respect to their environmental impact, the graphs show that the various industrial bamboo materials are competitive (especially in terms of carbon footprint) with sustainably sourced European softwood, and score slightly better than tropical hardwood from sustainably managed plantations. However, when taking into account that a large portion of tropical hardwood, including FSC certified hardwood[2], still comes from natural forests the differences become larger in the favour of industrial bamboo materials due to loss of biodiversity (included in the eco-costs figures) as well as the carbon sequestration debit (not yet included in the figures above).
In contrast to (tropical) hardwood, one of the main environmental benefits of bamboo, lies at the resource side. As bamboo is a giant grass species, with a fundamentally different way of growing and harvesting than trees, it is less susceptible for clear-cutting / deforestation and very suitable for reforestation for several reasons:

- the mother plant consists of many stems, connected through a vast root (rhizome) system under ground, with new stalks coming up each year. Note that in case of sustainable harvesting, the mother plant remains alive and the root structure stays intact, from which the bamboo stems grow from new shoots;
- it is harvested like an agricultural crop: annual harvest of the 4-5 year old culms provides steady annual income to farmers and even stimulates the bamboo plant to reproduce stems even faster. Note that this is an important difference from wood production where rotation cycles of trees of over 30 years makes forests vulnerable for illegal logging / clear-cutting for the short term gain. As giant bamboo can be harvested annually, it is for this (economic) reason that in practice there is no clear-cutting of giant bamboo forests, as it would mean a waste of capital for the farmer. In fact, much of the bamboo production in the past comes from better forest management[3] (Lou Yiping et al. 2010);
- due to the extensive root system bamboo can be planted in areas where farming is not feasible, e.g. by rehabilitating degraded land - including eroded slopes - and re-establishing functioning and productive ecosystems by improving soil quality and restoring the water table (Kuehl and Lou Yiping 2011).
- another important advantage of the bamboo resource is the fast growth resulting in a high annual yield (m3 semi-finished material). This aspect is related to the fact that land might become scarce

[2] Globally FSC certified tropical hardwood is partly sourced from plantations and semi-natural forests, but the lions share (64%) is still coming from natural forests (harvested with Reduced Impact Harvesting).

[3] Although FSC certification is now available for bamboo, the above explains that in reality it is not really required (only increases costs because of increased documentation requirements), as bamboo forests and plantations are managed sustainably for economic reasons.

in the future. Figure 11 shows that industrial bamboo materials have a larger annual yield than hardwoods (where they compete with in terms of material properties), especially in the case of production of SWB and/or flattened bamboo because of the higher processing efficiency, and even more so in the case of giant bamboo species such as “Guadua” (annual yield almost twice as high as “Moso”). Compared to one of the fastest growing wood species worldwide, eucalyptus, the industrial bamboo products are competitive or even outperform eucalyptus depending on the production scenario.

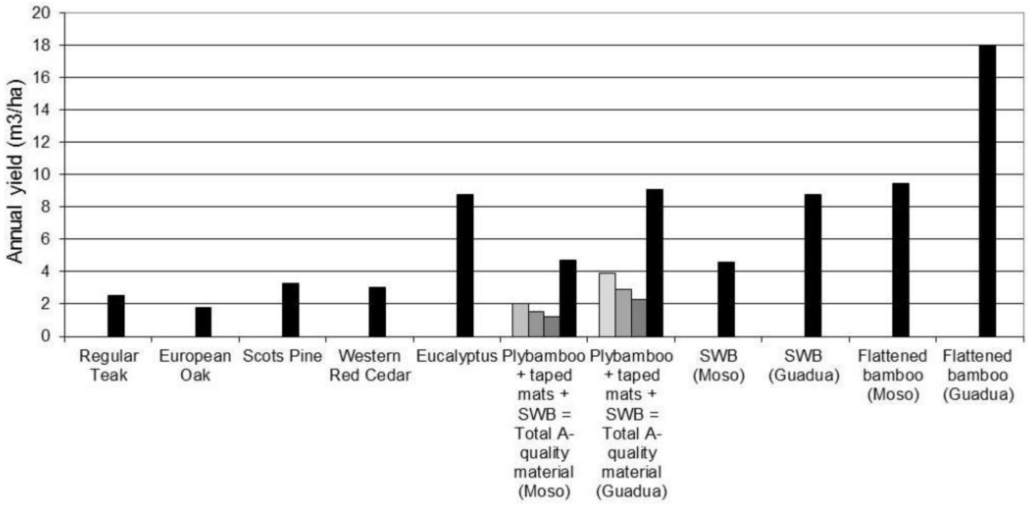

Figure 11: Annual yield for various wood and bamboo species in cubic meters produced per hectare per year (FAO 2006, MAF 2008, van der Lugt 2008, USDA 2013)

- A final general benefit of bamboo as a reforesting crop compared to wood, is the short establishment time of a bamboo plantation. While the establishment time of a plantation of tropical giant bamboo species such as Moso and Guadua to come to maturity will not take longer than 10 years, the establishment time of a wood plantation to maturity may range from 15 years (eucalyptus), 30 years (plantation teak), 70 years (regular teak) to 80 years (European oak). This means that a bamboo plantation will be able to deliver the annual yield of a mature plantation faster than any wood species can.

Concluding we can state that at *product level* the various MOSO bamboo products, due to their good mechanical properties (hardness, dimensional stability) and aesthetical looks, compare to A-quality (FSC certified) hardwoods it might substitute, both in terms of carbon footprint as well as eco-costs. When looking from a *global perspective* at the global carbon cycle, taking into account the benefits of bamboo at the resource side mentioned above (high yield, annual harvesting, reforestation on degraded land, short establishment time, etc), it becomes clear that bamboo can be one of the promising solutions in the required shift to a more sustainable, bio-based economy based on renewable resources:

- reducing emissions (and biodiversity loss) caused by deforestation in tropical and sub-tropical areas by providing a viable low emission alternative for tropical hardwood;

- carbon sequestration through reforestation of degraded grassland and slopes with bamboo forests;
- reducing emissions caused by burning of fossil fuels by combustion with heat recovery (production of electricity) at the end-of-life of the increased amount of bamboo products, based on the expected market growth.

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