Life Cycle Assessment and Carbon Sequestration; the Environmental Impact of Industrial Bamboo Products

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Abstract
Life Cycle Assessment (LCA) is the commonly accepted methodology to systematically assess the environmental impact of a product or material over the full life cycle, thus from the extraction of resources until the end phase of demolition or recycling (from cradle till grave). However, in LCA it is problematic to deal with the positive aspect of carbon sequestration in terms of environmental impact.
The objective of this study is two-fold. The first objective is to gain a better understanding about the environmental impact of industrial bamboo products and their production process in terms of CO2 equivalent (carbon footprint) and toxic emissions (LCA). The second objective is to clarify how carbon sequestration on a global scale can be defined and calculated for bamboo products, and can be incorporated in the standard LCA calculations.
The study concludes that industrial bamboo products, if based on best-practice technology (in this case production chain of Moso International), even when used in Europe can – depending on assumptions made - actually be labelled as being CO2 neutral.

Keywords: Life Cycle Assessment (LCA); Carbon footprint, Industrial Bamboo products

1. Introduction & Goal

The growing human population on our planet in combination with an increase of consumption per capita, is putting more and more pressure on global resources, which results in materials depletion, ecosystem deterioration and human health problems. Because of its rapid growth and applicability giant bamboo species such as *Phyllostachus Pubescens* are perceived as being an environmentally benign alternative that could act as a promising substitute in light of these problems. In this paper the sustainability of industrial bamboo materials is analysed using Life Cycle Assessment (LCA), coping with all environmental effects along the production chain over the full life cycle of a product.
The first objective of this study is to gain a better understanding about the environmental impact of industrial bamboo products and their production process in terms of greenhousegases (including CO2) and toxic emissions.

There is a distinction of two levels of carbon sequestration in natural renewable products (like wood, bamboo and agricultural products):
1. the level of the life cycle of a product (from cradle-to-grave), which is the domain of LCA analyses
2. the level of the global CO2 cycles and global storage of CO2, which is not the domain of a standard LCA, and which has to be analysed separately.

Discussions on carbon sequestration are often blurred, since the aforementioned distinction in system levels are often not made clear. This leads to a secondary goal of this paper:
- to clarify the LCA calculation as such, and the way “biogenic CO2” is dealt within the life cycle

- to clarify how carbon sequestration on a global scale can be defined and calculated for bamboo products, and can be incorporated in the standard LCA calculations

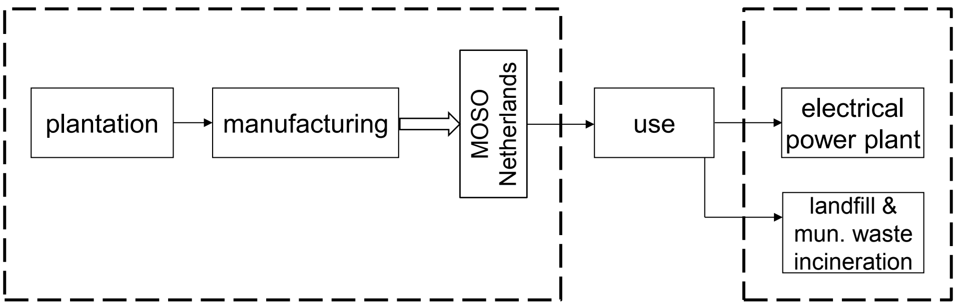
The analyses on biogenic CO2 in LCA and carbon sequestration on a global scale are according to a recent scientific book on this subject (Vogtländer 2010).

2. Scope & Methodology

This study is based on the production process of the company Moso International for all solid bamboo products of this company, i.e. bamboo flooring, panels, veneer and decking. In this paper the LCA results for one typical product, representative for most products in the portofolio is selected for analysis: carbonized 3-layer laminated bamboo board. For details about the other products is referred to Vogtländer (2011).
The analyses in this paper are fully in line with the ISO specifications (ISO 14040 and 14044) and the manual for LCA (ILCD 2010). Details on the calculations, including detailed production data, been published in peer reviewed papers (Vogtländer et al. 2010) and books (Van der Lugt et al. 2009, van der Lugt 2008).

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 Figure 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)



(figure 1)

The LCA methodology is internationally standardized in the ISO 14040 series, and measures the environmental impact in several categories, including depletion, air quality (dust, smog), toxicity and global warming potential (GWP). The environmental impact caused by a product can be caught under one number, for example expressed in eco-costs. Given the increasing attention with respect to global warming, the GWP of products is often assessed separately in a so-called carbon footprint. In this assessment all the greenhouse gas emissions during the life cycle of a product are measured in kg CO2 equivalent.

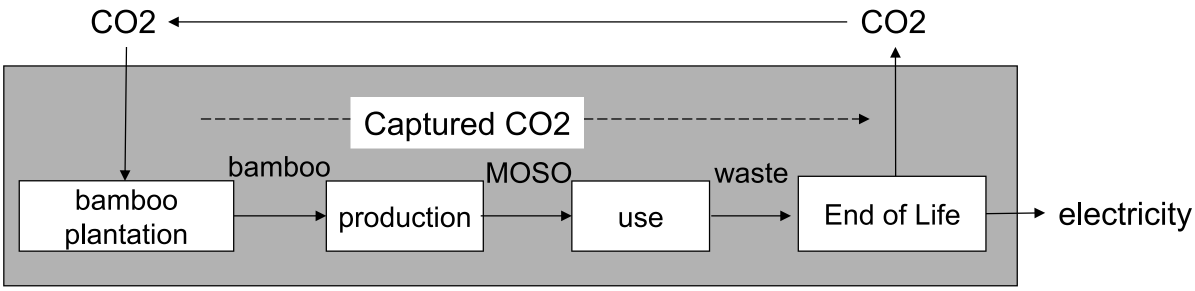
The core of the LCA method comprises two basic steps: the Life Cycle Inventory (a list of emissions and used materials) and the Life Cycle Inventory Analyses (a system to express the result of a LCI in one score, the so called "single indicator") (ISO 2006).
For this study, two single indicators are 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 more information please refer to http://en.wikipedia.org/wiki/Eco-costs

3. Scientific Background of LCA and the CO_2 cycle

Additional to the standard LCA (ISO 14040 and 14044), the sequestration (capture and storage) of CO_2 has been taken into account in this study. Sequestration (= capture and storage) of CO_2 in wood is an important issue in sustainability. However, it is also a confusing subject, leading to many discussions.

3.1. Carbon Sequestration at Product Level

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 figure.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 CO_2 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 figure 2 generates electricity. This electricity can replace electricity from fossil fuels. In other words: the use of fossil fuels is avoided, so fossil CO_2 emissions are avoided, which results in a reduction of global warming. In LCA calculations this leads to a system credit: the production of electricity from bamboo waste has a negative carbon footprint and negative eco-costs.
The conclusion is that the storage of biogenic CO_2 (carbon sequestration) in bamboo is not counted in LCA, unless the bamboo (or any other bio-product like wood) is burned for electricity or heat.



(figure 2)

The widespread confusion comes from the fact that the storage of CO_2 as such, even temporary, is good for the environment, so "it has to be incorporated in some way in the total LCA calculation". However, the positive effect of storage cannot be analysed on the level of one single product.

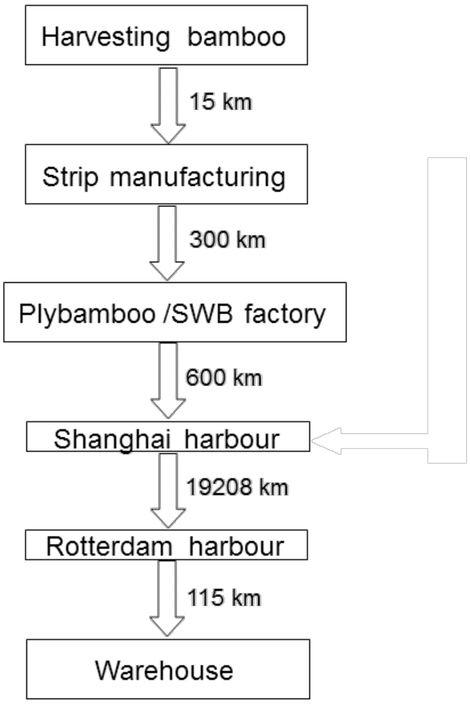
3.2. Carbon Sequestration at System Level

The effects of carbon sequestration can be understood when we look at a global system level.
On a global scale, CO_2 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 thorough description of the global CO_2 cycle, please refer to Vogtländer (2010).
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. Thus 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).

4. Cradle-to-gate Calculations

The production system of bamboo “from cradle-to-warehouse-gate” is depicted in figure 3.

The calculations have been made on the actual product chain of Moso International based on consumption in the Netherlands:
- Type of bamboo: *Phyllostachys Pubescens* (density 700 kg/m3, length up to 15 m, diameter on the ground 10-12 cm, wall thickness 9mm).
- Plantation and first processing: the Anji region, the province of Zhejiang, China
- Final processing (Laminated bamboo board, compressed bamboo, veneer): Huangzhou, the province of Zhejiang
- The product is shipped via Shanghai and Rotterdam to the warehouse of Moso International in The Netherlands (Zwaag)



(Figure 3)

The required heat for the manufacturing process is generated locally by combustion of sawdust and bamboo waste. 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, applying LCI databases of Ecoinvent v2 (2008) and Idemat 2008 (a database of the Delft University of Technology, partly based on Ecoinvent Unit data).
For this study, 3 layer carbonized laminated bamboo board was used as reference product where the LCA calculations were based on. Laminated bamboo board, a hard aesthetical material which is often used in flooring or table tops, is manufactured in various varieties: 1, 3, or 5 layers, bleached or carbonized, side pressed or plain pressed. Table 1 and 2 provide specific production data for the production of 3 layer carbonized laminated bamboo board. A comprehensive description of the production processes and Tables for the other varieties can be found in van der Lugt et al. (2009) and van der Lugt (2008).

Process step	amount	unit	Carbon fp kgCO2/unit	Carbon fp kgCO2/FU	Carbon fp kgCO2/kg	Carbon fp %
1. Cultivation and harvesting from plantation						
Gasoline consumption	0.224	litre / FU	3.895/ litre	0.873	0.0209	1.7%
2. Transport from plantation to strip manufacturing facility; eco-costs of a 5 tons truck (transport of 23.1 FUs)	30	km / truck	0.63/ km	0.818	0.0196	1.6%
3. Strip making	1.38	kWh/ FU	0.608/kWh	0.839	0.0201	1.7%
4. Transport from strip manufacturing facility to factory; eco-costs of a 10 tons truck (transport of 77.6 FUs).	600	km / truck	0.825/km	6.379	0.1530	12.7%
5. Rough planing	8.62	kWh/ FU	0.109/kWh	5.241	0.1257	10.5%
6. Strip selection						
7. Carbonization	4.73	kWh/FU	0.109/kWh	2.876	0.0690	5.7%
8. Drying carbonized strips	9.66	kWh/FU	0.109/kWh	5.873	0.1408	11.7%
9. Fine planing	5.8	kWh/FU	0.109/kWh	3.526	0.0846	7.0%
10. Strip selection						
11. Glue application (1-layer boards)	0.894	kg / FU	2.24 /kg	2.003	0.0480	4.0%
12. Pressing strips to 1-layer board	1.89	kWh/FU	0.608/kWh	1.149	0.0276	2.3%
13. Sanding 1-layer board	1.62	kWh/FU	0.608/kWh	0.985	0.0236	2.0%
14. Glue application (3-layer board)	0.983	kg / FU	2.24 /kg	2.202	0.0528	4.4%
15. Pressing three layers to one board	1.65	kWh/FU	0.608/kWh	1.003	0.0241	2.0%
16. Sawing	0.29	kWh/FU	0.608/kWh	0.176	0.0042	0.4%
17. Sanding 3-layer board	0.86	kWh/FU	0.608/kWh	0.523	0.0125	1.0%
18. Dust absorption (during all steps)	8.67	kWh/FU	0.608/kWh	5.271	0.1264	10.5%
19. Transport from factory to harbour	12.51	ton.km/FU	0.086/ton.km	1.076	0.0258	2.2%
20. Transport from harbour to harbour	800.9736	ton.km/FU	0.011/ton.km	8.811	0.2113	17.6%
21. Transport from harbour to warehouse	4.7955	ton.km/FU	0.086/ton.km	0.412	0.0099	0.8%
TOTAL carbon footprint				50.04	1.200	100.0%

Table 1: Input data and results in CO2 equivalent (carbon footprint) for the environmental impact assessment (cradle to gate) of carbonized 3-layer laminated bamboo board (consisting of two layers of 5 mm plain pressed at the outsides, and one layer of 10 mm side pressed in the core). The Functional Unit used as the base element for this assessment is one board of 2440 x 1220 x 20 mm (2.98 m2), with a weight of 41.7 kilograms (based on a density of 700 kg/m3).

Process step	amount	unit	ecocosts €/unit	ecocosts €/FU	ecocosts €/kg	ecocosts %
1. Cultivation and harvesting from plantation						
Gasoline consumption	0.224	litre / FU	1.04/ litre	0.233	0.0056	1.7%
2. Transport from plantation to strip manufacturing facility; eco-costs of a 5 tons truck (transport of 23.1 FUs)	30	km / truck	0.243/ km	0.316	0.0076	2.3%
3. Strip making	1.38	kWh/ FU	0.109/kWh	0.150	0.0036	1.1%
4. Transport from strip manufacturing facility to factory; eco-costs of a 10 tons truck (transport of 77.6 FUs).	600	km / truck	0.32/km	2.474	0.0593	18.0%
5. Rough planing	8.62	kWh/ FU	0.109/kWh	0.940	0.0225	6.8%
6. Strip selection						
7. Carbonization	4.73	kWh/FU	0.109/kWh	0.516	0.0124	3.7%

8. Drying carbonized strips	9.66	kWh/FU	0.109/kWh	1.053	0.0253	7.7%
9. Fine planing	5.8	kWh/FU	0.109/kWh	0.632	0.0152	4.6%
10. Strip selection						
11. Glue application (1-layer boards)	0.894	kg / FU	0.57/kg	0.510	0.0122	3.7%
12. Pressing strips to 1-layer board	1.89	kWh/FU	0.109/kWh	0.206	0.0049	1.5%
13. Sanding 1-layer board	1.62	kWh/FU	0.109/kWh	0.177	0.0042	1.3%
14. Glue application (3-layer board)	0.983	kg / FU	0.57/kg	0.560	0.0134	4.1%
15. Pressing three layers to one board	1.65	kWh/FU	0.109/kWh	0.180	0.0043	1.3%
16. Sawing	0.29	kWh/FU	0.109/kWh	0.032	0.0008	0.2%
17. Sanding 3-layer board	0.86	kWh/FU	0.109/kWh	0.094	0.0022	0.7%
18. Dust absorption (during all steps)	8.67	kWh/FU	0.109/kWh	0.945	0.0227	6.9%
19. Transport from factory to harbour	12.51	ton.km/ FU	0.033/ton.km	0.413	0.0099	3.0%
20. Transport from harbour to harbour	800.9736	ton.km/ FU	0.0052/ton.km	4.165	0.0999	30.3%
21. Transport from harbour to warehouse	4.7955	ton.km/ FU	0.033/ton.km	0.158	0.0038	1.2%
TOTAL eco-costs (€)				13.75	0.330	100.0%

Table 2: Input data and results in eco-costs for the environmental impact assessment (cradle to gate) of carbonized 3-layer laminated bamboo board (consisting of two layers of 5 mm plain pressed at the outsides, and one layer of 10 mm side pressed in the core). The Functional Unit used as the base element for this assessment is one board of 2440 x 1220 x 20 mm (2.98 m2), with a weight of 41.7 kilograms (based on a density of 700 kg/m3).

5. End-of-life Calculations

The end-of-life of bamboo is a combination of:
1. Combustion in an electrical power plant
2. Combustion in a municipal waste incineration plant
3. Landfill

In the Netherlands and other West European Countries, wood and bamboo is separated from other waste and ends up in an electrical power plant. Only a small proportion is combusted in a municipal waste incinerator.

The end-of-life credit for electricity production from bamboo waste is (data from the Idemat database):
- carbon footprint: 1.18 kgCO2 per kg of bamboo waste
- eco-costs: 0.21 € per kg of bamboo waste

In this study we assume that 90% of the bamboo products will be combusted for production of electricity and/or heat, leading to a credit of:
- carbon footprint: 1.18 x 0.9 = 1.062 kgCO2 per kg of bamboo product
- eco-costs: 0.21 x 0.9 = 0.189 euro eco-costs per kg of bamboo product

The overall scores for LCA ("cradle-to-warehouse-gate" + "end-of-life") of carbonized laminated bamboo board are
- carbon footprint: 1.2 – 1.062 = 0.138 kgCO2 per kg Laminated bamboo board (see Table 1)
- eco-costs: 0.33 – 0.189 = 0.141 € per kg Laminated bamboo board (see Table 2)

Although the above scores are according to the formal LCA (according to ISO 14040 and 14044, and according to the European LCA manual (ILCD 2010)), the effects of the carbon sequestration on a global level must be taken into account as well.

6. Calculation of Carbon Sequestration

As has been explained in section 3, the extra global carbon sequestration is proportional to the growth of the market for bamboo products. According to van der Lugt and Lobovikov (2008) annual growth of the market for industrial bamboo products in EU and China ranges between 17% to 25%. However, the establishment of new plantations often does not directly follow increase in market demand but is following the market growth with a delay. This phenomenon also becomes clear from the 7th Chinese National Forestry Inventory (2010) where is shown that the area of bamboo resources in China in 2004-2008 has grown from 4,84 million ha to 5,38 million ha in 2008, thus a growth of 11,18% in 5 years which refers to an annual growth of 2,24%. Note that the growth of tree forest area in China lies at a similar level (11,74%) with a growth of 174,91 million ha to 195,45 million ha in the same period (2004-2008).
For this study it is assumed that the annual growth in permanent plantations in China will increase to 5% as a result of the high domestic and international market growth of 17-25%. This can be considered a conservative approach as it may be expected that this number will turn out to be higher considering the high market growth.

It is assumed that the additional permanent plantations are established on grassland or other degraded land and do not come at the expense of natural tree forests. This is a plausible assumption as a large portion of the Moso bamboo resources comes from the industrialised provinces around Shanghai (Zhejiang, Anhui, Jiangxi) with few natural forests. Furthermore, this assumption fits well in the current policy for afforestation and natural forest protection of the Chinese Government controlled by the Chinese State Forestry. More information on this issue can be found at http://english.forestry.gov.cn/web/index.do, which shows the increasing forest area in China.

It is important to realize that one kg of a industrial bamboo product relates to many kg of bamboo in the plantation:

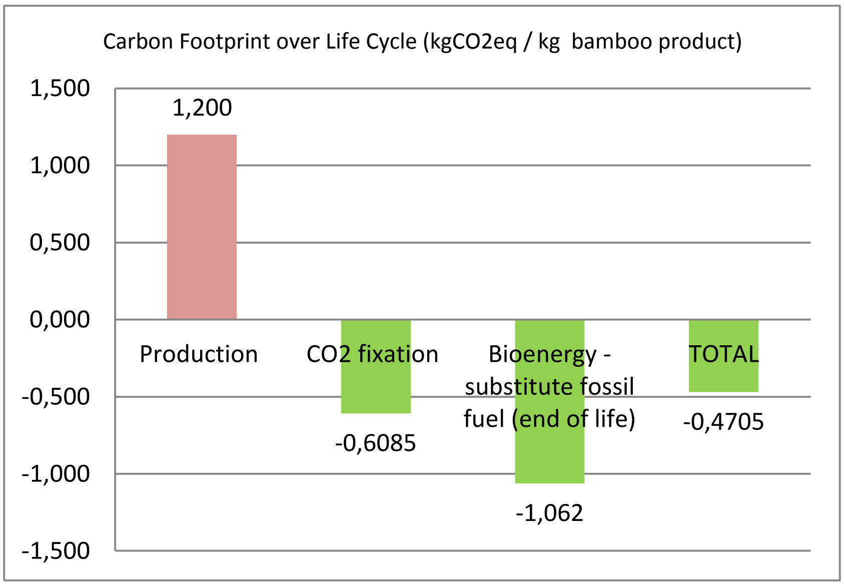
- 1 kg final industrial bamboo product (A-quality bamboo material) consists of approximately 0.9 kg bamboo strip, 0.08 kg water (at 20 degrees Celsius and a relative humidity of 50%) and 0.02 kg glue;
- 0.9 kg bamboo strip is manufactured from 2.14 kg bamboo at the plantation above the ground (production efficiency 42%, see van der Lugt (2008))
- 2.14 kg bamboo contains 2.14 kg x 1.83 kg CO2 / kg bamboo = 3.92 kg CO2
- 3.92 kg CO2 above the ground relates to 3.92/0.32 = 12.2 kg CO2 above + below the ground[1]

Concluding: 1 kg final bamboo product is related to 12.2 kg CO2 stored at the plantation.
Only 5% of this CO2 is taken out of the air, needed for the growth of the new plantation area, following the assumed market growth. According to LCA, this 5% can be allocated to the total market of bamboo in the building industry. That means that 5% of the 12,2 kg CO2 (i.e. 0,61 kg CO2) can be allocated to 1 kg final bamboo product in the building industry.
Therefore, following the scenario above, an amount of 0,61 kg CO2 per kg final bamboo product can be allocated as ‘credit’ in the LCA calculation (in addition to the end-of-life credit in the case of combustion in electrical power plants, as explained in section 5).

7. Results and Conclusions

[1] Besides in the trunks, branches and shrub, there is CO2 stored below ground in the soil and roots of a plantation. Zhou et al. (2004) found that, for a medium intensity managed Moso bamboo plantation in Lin’an, Zhejiang province, the distribution of biomass above ground versus below ground is 32.2% and 68.8% respectively.

Figures 4 and 5 below presents the total results for carbonized 3-layer laminated bamboo board based on carbon footprint and eco-costs over the full life cycle and including the effects of carbon sequestration.



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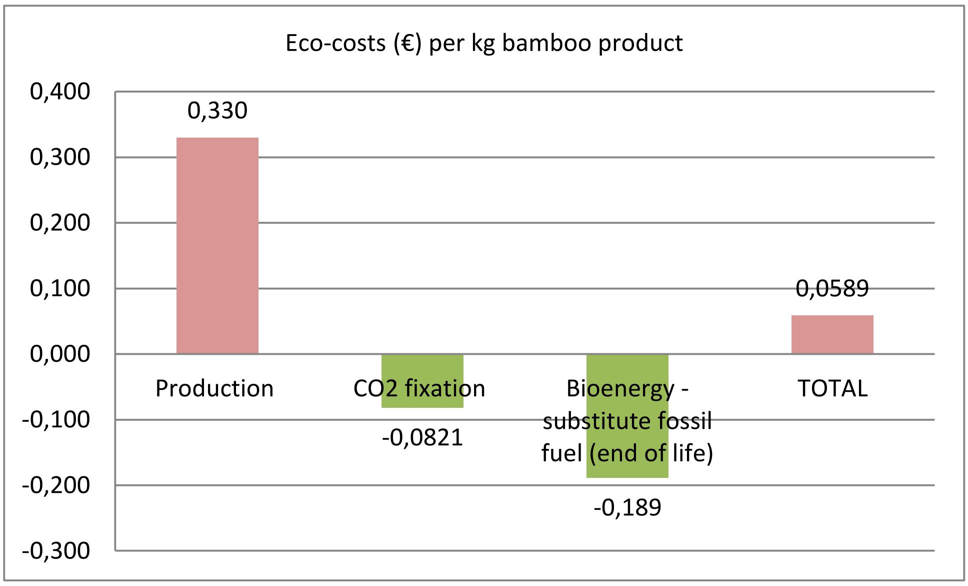
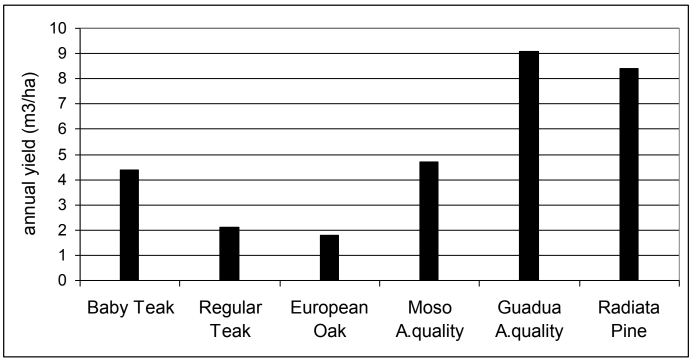


(figure 5)

From the results can be concluded that industrial bamboo products, if based on best-practice technology (in this case production chain of Moso International), even when used in Europe can actually be labelled "CO2 neutral or better". When used in the country of production (China), the results will be even more positive.

The high annual yield of bamboo (see figure 6), in combination with its durable root structure which enables growth on difficult habitats such as eroded slopes, is not included in LCA and carbon footprint and can therefore be considered as an additional environmental advantage on top of the CO2 neutrality. In terms of land-use, bamboo seems to be one of the promising solutions in the required shift towards renewable materials.



(figure 6)

Due to its good mechanical properties (hardness, dimensional stability) and aesthetical looks, the laminated and compressed industrial bamboo products compete with A-quality hardwoods. In terms of annual yield as well as eco-costs and carbon footprint industrial bamboo products score well compared to FSC hardwood (van der Lugt et al. 2009), and therefore can be an eco-friendly, highly renewable alternative for (tropical) hardwood and thus mitigate the decrease of tropical forest area including its important ecological and biological functions.

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Footnotes

1. Besides in the trunks, branches and shrub, there is CO2 stored below ground in the soil and roots of a plantation. Zhou et al. [10] found that, for a medium intensity managed Moso bamboo plantation in Lin'an, Zhejiang province, the distribution of biomass above ground versus below ground is 32.2% and 68.8% respectively

Figure captions

Figure 1: System boundary: cradle-to-gate plus end-of-life.
Figure 2:. The CO2 cycle on product level.
Figure 3: The production system of Moso International (cradle-to-warehouse-gate).
Figure 4: Carbon Footprint over Life Cycle (kgCO2eq / kg bamboo product) for carbonized 3-layer laminated bamboo board
Figure 5: Ecocosts over Life Cycle (€ / kg bamboo product) for carbonized 3-layer laminated bamboo board
Figure 6: The annual yield in m3/ha A-quality semi-finished materials, sourced from plantations (van der Lugt 2008).