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Life Cycle Assessment and Carbon Sequestration**

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Environmental Assessment of Industrial Bamboo Products - Life Cycle Assessment and Carbon Sequestration



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Abstract

Life Cycle Assessment (LCA) is the commonly accepted methodology to systematically assess the environmental impact of a material over the full life cycle, from the extraction of resources until the end phase of demolition or recycling (from cradle till grave).

The first objective of this study is to gain a better understanding of the environmental impact of industrial bamboo products and its production process in terms of their CO₂ equivalent (carbon footprint), toxic emissions, and materials depletion (LCA). The LCA in this paper is based on latest (2015) production and bamboo land-use change figures.

The second objective of this paper is to clarify how carbon sequestration on a global scale can be defined and calculated for industrial bamboo products, and how they can be incorporated in the standard LCA calculations.

The study concludes that industrial bamboo products, if based on best-practice technology (production chain of MOSO International BV), even when used in Europe, are CO₂ negative over their full life cycle.

Keywords: Life Cycle Assessment (LCA); carbon footprint, carbon sequestration, industrial bamboo products

1. Introduction & Goal

The growing human population in combination with an increase of consumption per capita, is increasingly putting pressure on global resources, which results in materials depletion, ecosystem deterioration, human health problems and climate change. Because of its rapid growth and wide applicability, giant bamboo species such as *Phyllostachys pubescens* are increasingly perceived as environmentally benign renewable material alternative. However, compared to wood the relatively long production process and transport distance could disturb this environmental profile and should be assessed further.

In this paper the environmental impact of industrial bamboo materials is analysed using Life Cycle Assessment (LCA), analysing a range of environmental effects over the full life cycle.

The 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 Greenhouse gas balance (carbon footprint), toxic emissions, and materials depletion.

In addition to the standard LCA (ISO 14040 and 14044), the sequestration (capture and storage) of CO₂ has been taken into account in this study. This paper provides a comprehensive explanation how such a calculation on carbon sequestration must be made on a global scale within the general logic of LCA methodology, based on recent publications on this subject (Vogtländer et al. 2014, Vogtländer 2010).

This paper builds on the 2008 LCA study performed by Van der Lugt (van der Lugt 2008), and subsequent publications by the authors (van der Lugt et al. 2009, Vogtländer et al. 2010, Vogtländer et al. 2014) which is updated following more recent (2014) production figures. Whereas sections 3 and 6 in this paper are largely similar to Vogtländer et al. 2014, it is a recalculation based on new production data, new bamboo afforestation and land conversion figures (2015), as well as the latest Eco-Invent v3.1 (allocation, recycling content, 2014) and Idemat (2015) LCIs for the background processes.

2. Scope & Methodology

This study is based on the production process of the company MOSO International BV for all solid bamboo products in its product portfolio, i.e. bamboo flooring, panels, veneer and decking based on three different production technologies. The analyses in this report are fully in line with the ISO specifications (ISO 14040 and 14044) and the ILCD manual for LCA (EC-JRC 2010).

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 excluded from the analyses, because the emissions in this step are less than 1% (in comparison to the first and the last step).

Note: This LCA has been performed for the specific case of the MOSO International BV production chain following best practice and can therefore not be perceived as being typical for the production chain of other industrial bamboo material manufacturers.

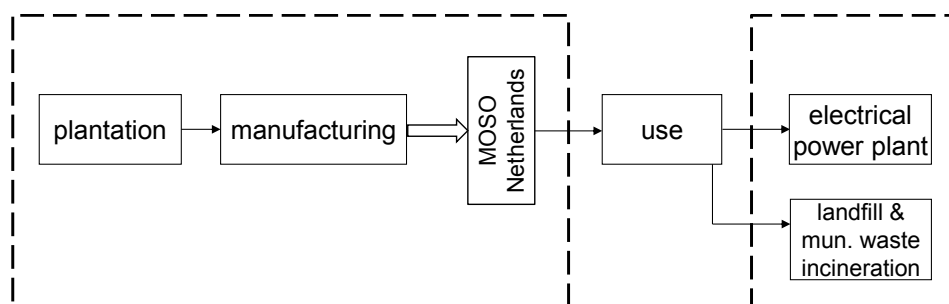


Figure 1: System boundary: cradle-to-gate plus end-of-life.

The calculations for the LCAs have been made with the computer program Simapro version 8.04, applying LCI databases of Ecoinvent v3.1 (allocation, recycled content, 2014) and Idemat 2015 (a database of the Delft University of Technology, partly based on Ecoinvent data).

The LCA methodology is internationally standardized in the ISO 14040 series, and measures the environmental impact in several categories, including resource depletion, air quality (dust, smog), toxicity and Global Warming Potential (GWP). In some life-cycle impact assessment methodologies the environmental impact caused by a product can be aggregated and expressed under one number, for example expressed in eco-costs 2012 (Vogtländer et al. 2010) which incorporates 3000 polluting substances, as well as materials depletion. 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 and expressed as kg CO₂ equivalent (in short CO₂e), which often provides a good indication of the outcome in eco-costs in processes where toxicity and materials depletion do not play a significant role. In this paper the carbon footprint is chosen as environmental indicator.

3. Scientific Background of LCA and the CO₂ cycle

3.1. Carbon Sequestration at Product Level

There is consensus in science on the way “biogenic CO₂” (=CO₂ which is captured in wood during the growth of a tree) is to be handled in LCA, see Fig.2. Biogenic CO₂ is first taken out of the air at the bamboo plantation, and then released back to the atmosphere at the end-of-life stage. So biogenic CO₂ is recycled, and its net effect on global warming is zero. However, when the bamboo product 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 calculations this leads to a system credit: the production of heat or electricity from bamboo waste has a negative carbon footprint (and eco-costs). This is the so called substitution approach in system expansion, see Section 14.5 of the ILCD Handbook (ECJRC 2010). The conclusion is that the temporary storage of biogenic CO₂ (carbon sequestration) in bamboo products is not counted in LCA, unless the bamboo (or any other bio-product like wood) is burnt for electricity or heat. A better efficiency of the production of electricity results in a higher credit.

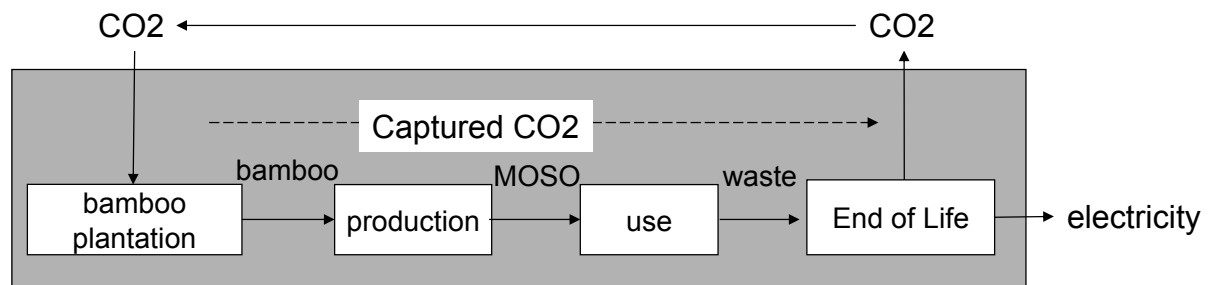


Figure 2: The CO₂ cycle on a product level.

The ILCD Handbook (EC-JRC 2010) and the PAS 2050:2011 Specification (BSI 2011) both state that, per default, temporary carbon storage shall not be considered quantitatively within the first 100 years (ILCD Handbook Section 7.4.3.7.3). ISO 14067 specifies as well that the calculation has to be done ‘without the effect of timing’ (i.e. without the temporary carbon storage in products). Such an effect should be calculated in a separate report (i.e. not in the LCA).

A comprehensive analysis of the issue of temporary carbon storage is provided in Vogtlander et al. (2014), showing that the credit for the production of heat or electricity at the end-of-life (as given in section 5) is the correct way in LCA to deal with carbon storage in durable products. However, there is a carbon sequestration effect on global level which might be allocated to wood and bamboo based products, which is explained in the next section.

3.2. Carbon Sequestration at Global Level

On a global scale, CO₂ is stored in forests (and other vegetation), in the ocean, and in products (e.g. buildings and furniture) and can be understood by looking at the highest possible aggregation level (“Tier 1” and “Tier 2”) of the Intergovernmental Panel on Climate Change (IPCC). Fig. 3 provides a simplified schematic overview of the highest aggregation level of the global carbon cycle.

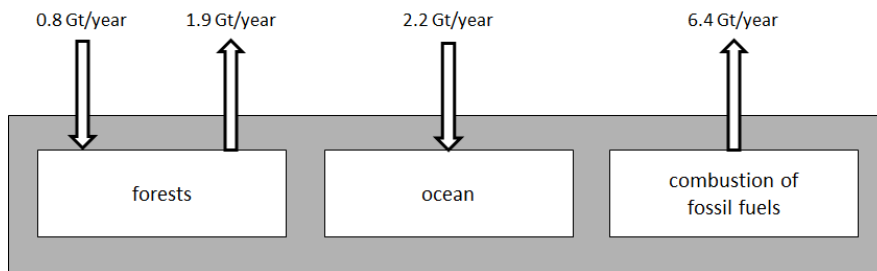


Figure 3: Global anthropogenic fluxes of CO₂ (Gt/year) over the period 2000–2010 (Vogtländer et al. 2014)

The figure shows that anthropogenic CO₂ emissions on a global scale can be characterised by three main flows:

- Carbon emissions caused by burning of fossil fuels: 6,4 Gt/year (Solomon et al. 2007)
- Carbon emissions caused by deforestation in tropical and sub-tropical areas (Africa, Central America, South America and Southeast Asia): 1,93 Gt/year (FAO 2010)
- Carbon sequestration by re-growth of forests on the Northern Hemisphere (Europe, North America, China): 0,85 Gt/year (FAO 2010)

It can be concluded that the global carbon cycle can significantly be improved in the short term by: i) less burning of fossil fuels, ii) stopping deforestation, iii) forest conservation by better management and wood production in plantations, iv) afforestation (planting of trees on soils that have not supported forests in the recent past) and v) increased application of wood/bamboo as durable products in the building industry.

However, it is far too simple to claim that application of wood/bamboo in design and construction will lead to carbon sequestration, and consequently will counteract global warming. It depends on the origin of the wood and the growth of the wood markets; if there is *no* change in the area of forests and *no* change in the volume of wood in buildings there is *no* change in sequestered carbon on a global level and hence no effect on carbon emissions. This means that only when more carbon is being stored in forests (either by area expansion with an increase of net carbon storage on that land, or by increased productivity in existing forests by improved management), and when the total volume of wood in buildings is increasing, there will be extra carbon sequestration. In boreal and temperate regions such as in Europe and North America, the forest area is increasing steadily for several decades due to afforestation and reforestation, which results in increased carbon storage over the last decennia (see Fig. 4).

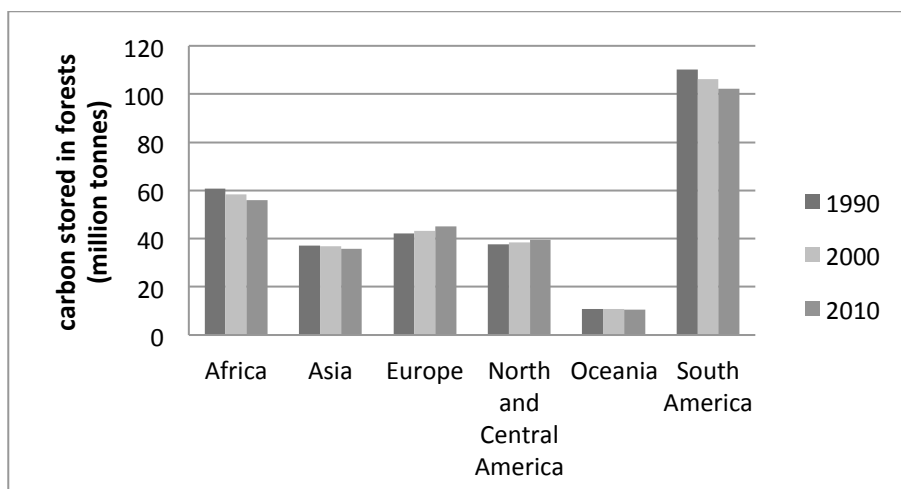


Figure 4: Trends in carbon storage in forests from 1990–2010 (Source: FAO 2010)

Fig. 4 also shows that carbon storage in tropical areas is decreasing. This is caused by the conversion of forests to agricultural or cattle land, for development of infrastructure, and illegal logging of tropical hardwood (as a result of the high market demand because of its good performance, in particular durability). Reduced Impact Logging, RIL, is a better way to fulfil the market demand for tropical hardwood in a more sustainable way (e.g. van Dam and Savenije 2011, Hodgdon et al. 2015, Putz et al. 2012). However, it still reduces the carbon sequestration capacity and the biodiversity of natural forests.

Concluding:

- Extra demand of boreal and temperate softwood from Europe and North America leads to a better forest management and an increase in forest area, so more sequestered carbon (Fig. 4).
- (Extra) demand of unsustainably sourced tropical hardwood leads to a decrease in forest area, so less sequestered carbon.

Translating this to the case for bamboo provides the following conclusion:

- Extra demand of bamboo in China has an effect on carbon sequestration which is similar to that of European and North American wood: it leads to a better forest management and an increase in bamboo forest area (Lou Yiping et al. 2010).

The carbon sequestration in wood in houses and offices is slowly rising on a global scale (because of increasing population), which is positive in terms of extra carbon sequestration. This volume of carbon sequestration, however, is low in comparison with the volume of standing trees in the forests: less than 30% of the carbon above the ground (= less than 24% of the carbon above plus under the ground) ends up in housing (see Section 5, step 1 and step 4 in Vogtländer et al. (2014)) and for bamboo this difference is even greater, see also section 6 of this paper.

The conclusion is that from a global perspective, carbon sequestration is enhanced when more boreal or temperate softwood from Europe and North America and/or bamboo is applied in buildings, since more carbon is sequestered in the forests as well as in buildings.

The consequence for bamboo 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. In section 6 it is explained that 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 in buildings).

4. Cradle-to-gate Calculations

The production system of industrial bamboo “from cradle-to-warehouse-gate” is depicted in Fig. 5. The calculations have been made on the actual product chain of MOSO International BV 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: 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 warehouse of MOSO International in The Netherlands (Zwaag)

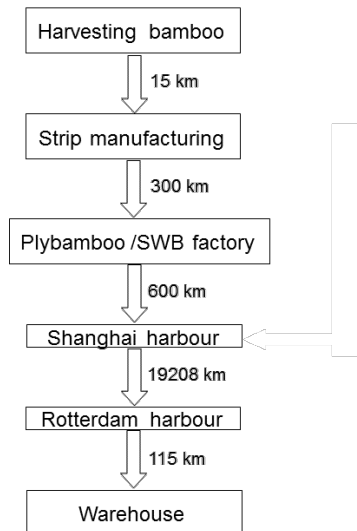


Figure 5: The production system of bamboo products of MOSO International BV (cradle-to-warehouse-gate).

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.

The cradle-to-gate calculations have been made for 3 main production technologies that are currently used for industrial bamboo products:

- 1) flattening longitudinally cut bamboo culms with vapour treatment (flattened bamboo - 850 kg/m³), mainly used for the production of flooring.
- 2) lamination of strips (Plybamboo - 700 kg/m³) to produce panels, beams and flooring boards is the most commonly used technology to develop industrial bamboo products.
- 3) compression moulding of rough bamboo strips with resin to extremely hard and dense (1100-1200 kg/m³) boards and panels (Strand Woven Bamboo - SWB), optionally with thermal treatment for outdoor application (cladding & decking).

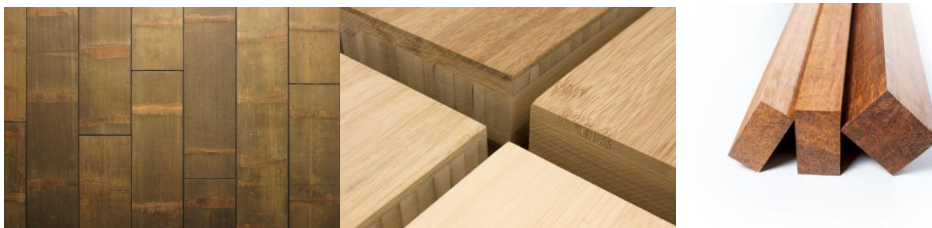


Figure 6: flattened bamboo flooring boards, Plybamboo panels, Strand Woven bamboo beams (pictures: MOSO International BV)

Based on these three main production techniques the carbon footprint of various derived products can be calculated. For example, a 1 ply Plybamboo panel or 5 ply Plybamboo panel are produced in a similar way and per kilogram product will only have a slightly lower (1 ply - less resin content, less pressing) or slightly higher (5ply - more resin, more pressing) carbon footprint.

In figure 7 an example of the carbon footprint over the production process of an industrial bamboo product (in this case flattened bamboo) is provided. The total scores (carbon footprint) of the various variations for the industrial bamboo products are provided in section 7.

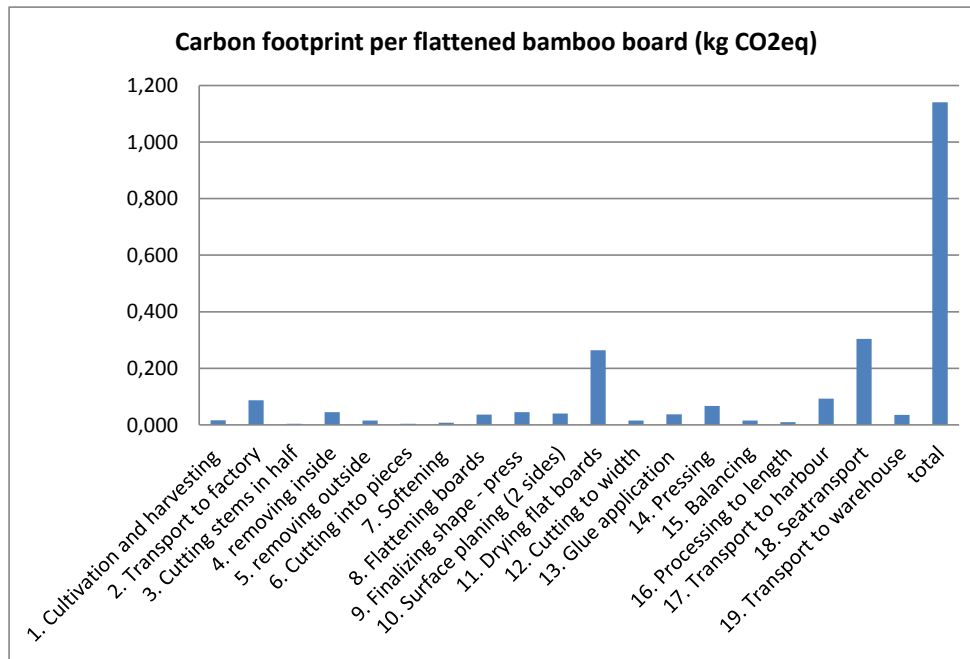


Figure 7: Carbon footprint per flattened bamboo board (kg CO2eq)

5. End-of-life Calculations

In the Netherlands and most other mainland West European Countries, wood and bamboo is separated from other waste and ends up in an electrical power plant. Although the efficiency of a modern coal fired electrical power plant is highest, i.e. 45% (IEA 2007), current practice in Western Europe is that biomass is bought by energy providers and combusted in smaller electrical power plants specialized in biomass with an approx. 30% lower efficiency than the large coal plants.

The end-of-life credit for electricity production from bamboo waste is (data from the Idemat database: "Idemat2015 Hardwood 12% MC, Bamboo, Cork, combustion in small elec. power plant"): 0,778 kgCO₂ per kg of bamboo waste. In this report we assume that 90% of the bamboo products will be combusted for production of electricity and/or heat, leading to a credit of $0,778 \times 0,9 = 0,70$ kgCO₂ per kg of bamboo product (MC 12%).

Although the above scores are according to the formal LCA (ISO 14040 and 14044, and the European LCA manual (EC-JRC 2010)), the effects of the carbon sequestration on a global level must be taken into account as well before the final result can be calculated.

6. Calculation of Carbon Sequestration

As has been explained in section 3.2, the extra global carbon sequestration is proportional to the growth of the market for bamboo products. The calculation of carbon sequestration caused by land-use change and additional application of bamboo products in the building industry is done in 5 steps and explained in detail in Vogtländer & van der Lugt (2014). In this paper we give a brief explanation how this is performed for flattened bamboo as an example, including the latest land-use change figures in China.

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 (State Forestry Administration of P.R. China 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, 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).

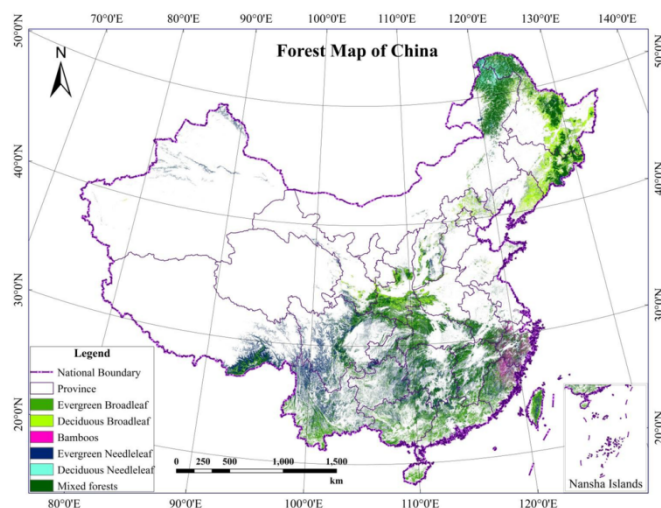


Figure 8: Recent forestry map of China (2010), showing that bamboo forest (>60% bamboo) is a marginal part of the total Chinese forest, which has a lot of mixed forests.

More recent figures (2013) from the State Forestry Administration in China show that the growth of bamboo forests and plantations in China has accelerated past years, with a growth from 5,38 million ha in 2008 to 6,73 million ha in 2011, which corresponds with an annual growth of 8,36%. In our calculation we have based ourselves on the average bamboo coverage growth from 2004 – 2011 which corresponds with an annual growth of 5,54%. Given the high GDP of the Chinese economy (approximately 7.5%), a 5,5% increase of bamboo production seems to be a fair estimation for the calculation of the extra stored carbon in bamboo plantations.

The related growth of yearly extra carbon storage in the plantation is to be allocated to the total production of bamboo products: of every kg bamboo, **0,055 kg** is related to the extra plantations which are required to cope with the market growth, and add to the global carbon sequestration.

Furthermore, it is important to realize that one kg of an industrial bamboo product relates to many kg of bamboo in the plantation:

- 1 kg biomass, dry matter (d.m.) above the ground in the bamboo plantation, on average is equivalent to 0,42 kg of bamboo in the end-product, see also van der Lugt (2008).
 - 0,42 kg d.m. of bamboo, is used in 0,425 kg d.m. flattened bamboo (the resin content is on average approx 1,3 % of the weight of flattened bamboo).
 - 1 kg biomass above the ground in the bamboo plantation is equivalent to 3,1 kg d.m. biomass above + below the ground, since bamboo has a vast root system; this number is in line with various recent studies bundled in Lou Yiping et al. (2010).
 - 1 kg d.m. of flattened bamboo originates from $3,1/0,425=7,29$ kg d.m. biomass in the bamboo plantation.
 - The carbon content is 0,5 kg C per 1 kg bamboo (Aalde et al. 2006, Verchot et al. 2006)
- Therefore, 1 kg d.m. flattened bamboo is equivalent to the storage of $7,29 \times 0,5 \times 3,67$ (molar weight ratio CO₂ vs C) = **13,37 kg CO₂** in the plantation.

We also have to take into account the land-use change factor; before the afforestation, the land had also stored biomass. There are 3 situations (cases) with regard to the carbon sequestration of land before the afforestation with bamboo:

1. The area was (barren) grassland or poor farming ground
2. The area was scrubland, bush land and wild forests (not used for any economic activity)
3. The area was a forest used for wood production

For case 1 and 2, the carbon sequestration guidelines of the IPPC have to be applied.

For case 3, the situation is a bit more complex, since the area which is replaced by bamboo will be planted in another area (to cope with the market demand). Cutting trees and replanting in another area is basically relocation of the forest area. The stored biomass of the other area (normally grassland or poor farming ground) before the relocation has to be allocated then to the bamboo. However, case 3 is not common, so will not be applied to our calculation.

In the publication Vogtländer and van der Lugt (2014) was assumed that the additional permanent plantations are established on grassland (case 1) and do not come at the expense of natural tree forests (case 2). However, consultation with INBAR bamboo forestry expert Lou Yiping (2015) revealed a more diverse situation regarding the current land conversion situation for bamboo in China, which is included in the calculation in this paper.

As mentioned above, there has been a large growth of the bamboo area (mainly *Phyllostachus Pubescens* - moso bamboo species) in the past decades, especially through natural expansion of existing moso bamboo forests either on farmland but also on secondary / wild forests (not used for any economic activity) with no or low biomass- and biodiversity change as a result. Through the expanding rhizome network, the moso bamboo species (*Phyllostachus Pubescens*), which is mainly used in the bamboo industry, has the capacity to expand in area by 1-3% every year (which can be even higher if this process is facilitated by right agricultural practices). These secondary natural bamboo forests provide a large portion of the bamboo used in industry¹.

Another reason for the expanded bamboo area is the reforestation of barren waste land or poor farming grounds (see example in figure 9) with bamboo plantations amongst others through the ‘Grain for Green’ programme of the Chinese government.



Figure 9: typical barren grassland which has been rehabilitated with bamboo in the past years (Photo: Lou Yiping)

¹ Note that despite the fast growth, in less than 5% of the plantations / managed bamboo forests used for industrial bamboo production pesticide and / or fertilizer is used as prescribed in the Chinese standard for high yield Moso plantations (GB/T 20391-2006); in a well-managed bamboo plantation / forest the fallen branches and leaves should provide sufficient nutrition for new shoots (this choice is also often made for economic reasons).

For the calculation of the land-use correction factor the following assumptions have been made.

- 30% increase in bamboo area through establishment of plantations on grassland defined in the IPCC guidelines (Verchot et al. 2006) as “Total above-ground and below-ground non-woody biomass”: 7,5 tonnes d.m./ha (it ranges from 6,5 to 8,5) with a carbon content of 47%.
- 70% increase in bamboo area as a result of natural expansion either on grassland (35%, see IPCC figures above) or by expansion in secondary / wild forests with no biomass change assumed (which is line with the figures mentioned in Yiping et al 2010). The biomass of bamboo plantations is $35,8 \times 3,1 = 111$ tonnes d.m./ha for biomass above + below the ground (Van der Lugt 2009, Zhou and Jiang 2004), and a carbon content of 50%.

The land-use change correction factor for afforestation is therefore:

$\{(111 \times 0,50) - (7,5 \times 0,47)\} / (111 \times 0,50) = \mathbf{0,936}$ for the plantation establishment and natural expansion on grassland, and **0** for the expansion in wild / secondary forests, which leads to an overall land-use change factor of **0,608**.

At a market growth of 5,5%, the sequestered carbon at the plantation per kg flattened bamboo production is therefore 5,5% of 8,16 ($0,608 \times 13,37$) kg CO₂, i.e. **0,45 kg CO₂**.

On top of this figure the carbon sequestration in industrial bamboo applied in buildings needs to be taken into account minus “application losses”, which we estimate at 10%. Including the resin content in the end-product (1,3% for flattened bamboo), this results in $0,987 \times 0,9 \times 0,5 \times 3,67 = 1,63$ kg biogenic CO₂ storage in the buildings per 1 kg d.m. flattened bamboo. The extra storage, related to the 5,5% market growth, results in the extra carbon sequestration of $1,63 \times 0,055 = \mathbf{0,09}$ kg CO₂ per kg d.m. flattened bamboo.

In total this means that **0,54 kg CO₂** can be allocated to 1 kg final bamboo product (flattened bamboo) applied in the building industry. For the other production technologies the carbon sequestration figure related to increased demand and land-use change would be **0,53** kg CO₂ per kg d.m. plybamboo, **0,53** kg CO₂ per kg d.m. SWB indoor and **0,51** kg CO₂ per kg d.m. SWB outdoor. For detailed calculations please refer to Vogtländer and van der Lugt (2014).

The amounts mentioned above 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).

Note that these carbon sequestration credits for bamboo as a result of land change are higher than for wood: European softwood acquires a credit for carbon sequestration as a result of land change of 0,19 kg CO₂ per kg softwood d.m., for detailed calculations is referred to Vogtländer and van der Lugt (2014).

There are two main reasons why Chinese bamboo acquires a higher credit for carbon sequestration as a result of land use compared to European softwood:

- the root - shoot ratio of bamboo is a lot higher than for wood; as a result of the extensive root (rhizome) system, bamboo stores considerably more CO₂ under the ground in the rhizomes as well as the surrounding soil.
- The higher reforestation rate in China with bamboo than in Europe with softwood. This is the result of the quicker market growth of bamboo products compared to wood products.

7. Conclusions & Discussion

In this paper, a carbon footprint calculation was executed for industrial bamboo products following a best-case scenario, in which the effect of carbon sequestration was included. From the final results, presented in figure 10, it can be concluded that all industrial 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.

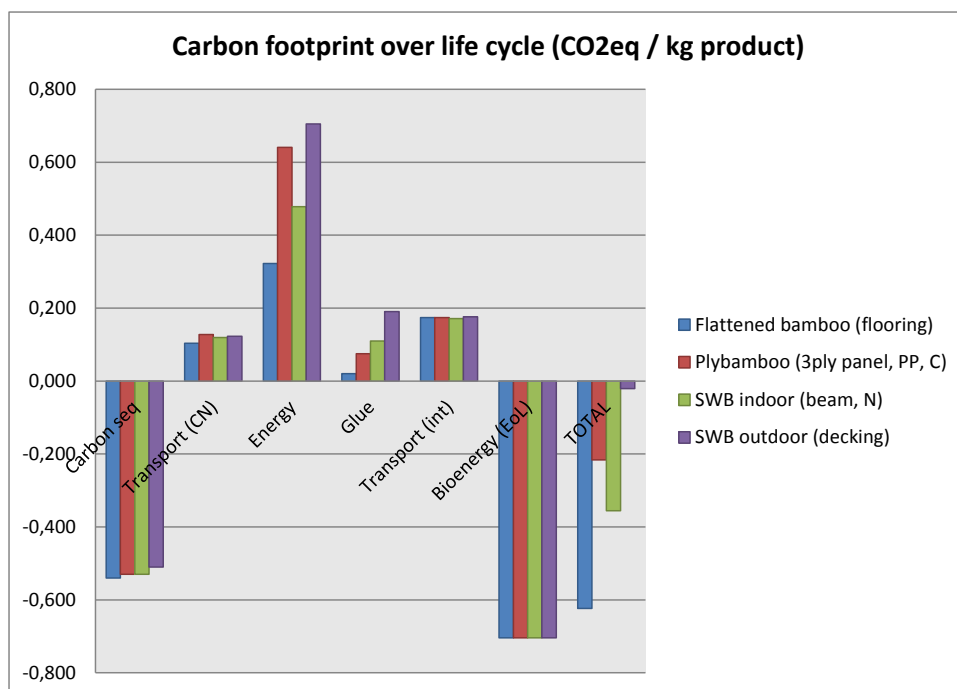


Figure 10: Carbon Footprint over Life Cycle (kgCO₂eq / kg product), for various industrial bamboo products based on different production technologies.

From figure 10 the main components in the carbon footprint of industrial bamboo products can be identified (range depending on the product assessed):

- Energy consumption for processing: 52-63%. Since the bamboo processing facilities in general use biomass (bamboo waste) for heat, the energy is only electricity from the local grid. This electricity from the Chinese grid (dominated by coal) might be replaced by electricity from a combined power generator (bamboo waste is abundantly available) at the production facility, or on-site production of solar energy.
- International sea transport: 15-25%. In case of local consumption (China) this additional eco-burden can be directly subtracted from the total. For the European market this is of course not a possibility, but closer sourcing (e.g. from Ethiopia with its large bamboo resource) could be an option for the near future improving the environmental impact (the electricity mix of Ethiopia is largely focussed on hydro).
- local transport: 10%. Reductions could be possible by opting for larger, more efficient trucks in the first steps of the production chain (28 tons instead of 5 tons) and/or using more efficient trucks (EURO 5 instead of EURO 3).
- use of resin: 3% (flattened bamboo) to 16% (outdoor SWB). Although it is clear that in absolute numbers the contribution of the glue is low compared to the other components mentioned above, in the perception of the conscious Western consumer the glue content is the main environmental 'problem' with industrial bamboo products, and therefore requires attention. Scenarios for improvement could be to increase the amount of formaldehyde free resins such as EPI (Emulsion Poly Isocyanate), because of the relatively low environmental impact or better even: switching to a fully biobased resin (EPI is a synthetic resin), with the additional benefit that the industrial bamboo product in that case would be 100% biobased content (important 'green' Unique Selling Point).

It is interesting to mention here that the bamboo stem is potentially the most eco-friendly building material available, as it has the unique property that it can be used in construction in its natural form without further processing. However, as shown in for example van der Lugt (2008) the eco-burden of sea transport is calculated with a volume based eco-indicator when the weight/volume ratio is low, which is the case for the bamboo stems, resulting in a carbon footprint for production (cradle to gate) of 1,45 kg CO₂eq/kg stem. However, when the bamboo stem is used locally, the sea transport is eradicated and the cradle to gate carbon footprint is only 0,19 kg CO₂eq/kg stem.

However, due to the irregularities of the material and the distinct appearance, the market adoption in Western markets of the bamboo stem will be marginal, so it is advised (also for eco-burden reasons) to only use it locally (where it grows).

Another 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 figure 11 the environmental performance is provided for several commonly used materials, including the main bamboo industrial production technologies.

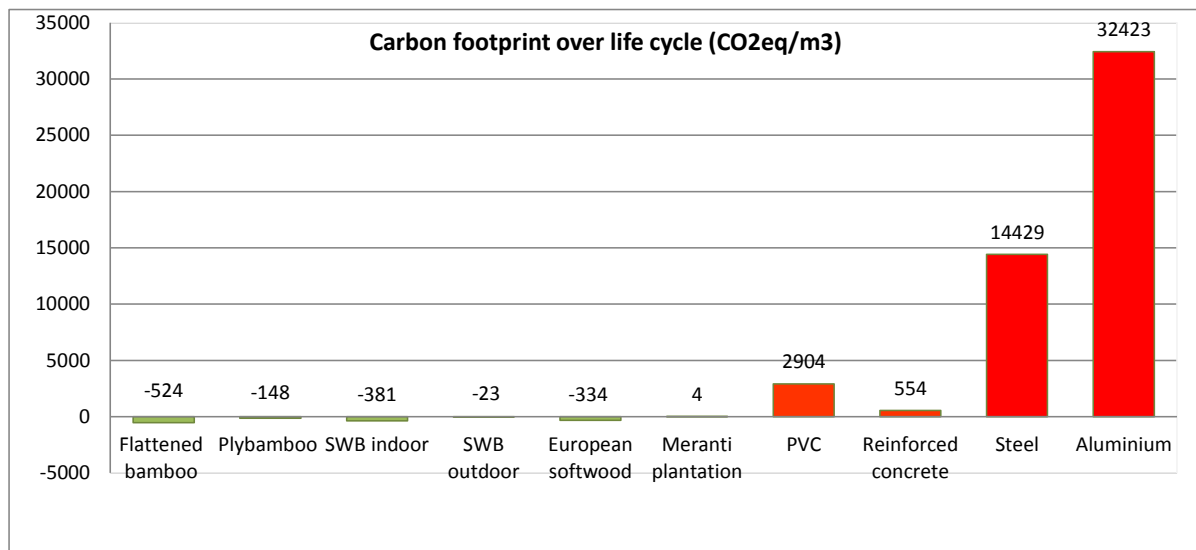


Figure 11: Carbon Footprint over Life Cycle (kgCO₂eq / m³ building material) for various common building materials.

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. The results also show that industrial bamboo is one of the best performing materials from environmental point of view, even taking into account the intercontinental transport and resin use.

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 fundamental different way of growing and harvesting than trees (crop like harvesting scheme with annual thinning with high annual yield, see figure 12), it is less susceptible for clear-cutting / deforestation (no short term economic gain as with wood) and very suitable for reforestation even in areas where farming is not feasible, e.g. by rehabilitating degraded land - including eroded slopes.

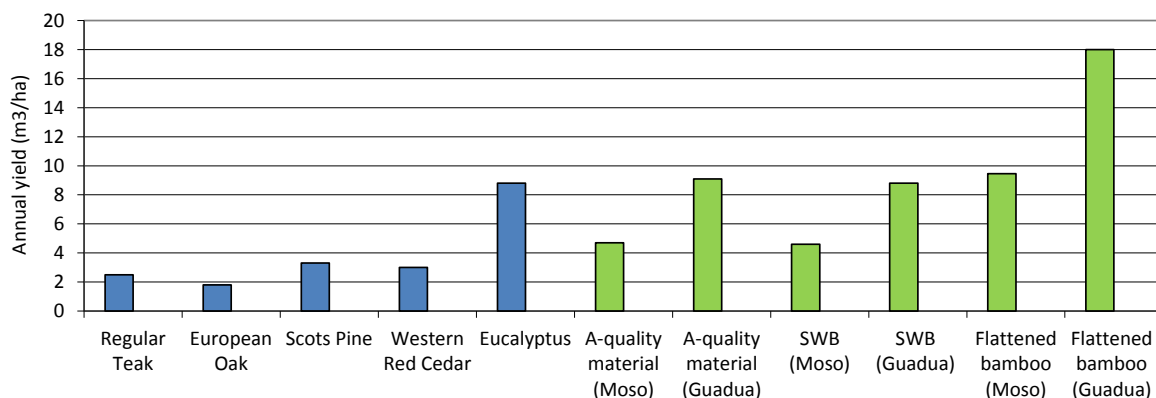


Figure 12.: Annual yield for various wood and bamboo species in cubic meters produced per hectare per year (FAO 2006, MAF 2008, van der Lugt 2008, USDA 2013)

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 as well as non-renewable materials such as PVC, steel and aluminium;
- 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;
- carbon sequestration through reforestation of degraded grassland and slopes with bamboo forests.

Given the positive impact bamboo can have in carbon storage on land, but also in durable products, it is of crucial importance that (giant) bamboo is more specifically included in the next IPCC Guidelines for National Greenhouse Gas Inventories, in particular Volume 4 AFOLU: Agriculture, Forestry and Other Land Use, chapters 4 Forest Land and 12 Harvested Wood Products. In this way bamboo reforestation and housing plans can be specified in (and thus financially supported by) National Plans for reaching objectives as agreed in the Kyoto Protocol.

References

Aalde, H., Gonzalez, P., Gytarsky, M., Krug, T., Kurz, W.A., Ogle, S., Raison, J., Schoene, D., Ravindranath, N.H., Elhassan, N.G., Heath, L.S., Higuchi, N., Kainja, S., Matsumoto, M., Sánchez, M.J.S., Somogyi, Z. (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 4 Forest Land. Available at www.ipcc.ch

BSI, British Standards Institution (2011) PAS 2050: 2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. BSI, London.

EC-JRC, European Commission - Joint Research Centre and Institute for Environment and Sustainability (2010). International reference life cycle data system (ILCD) handbook – General guide for life cycle assessment – Detailed guidance. Publications Office of the European Union, Luxembourg.

FAO (2006). Global Planted forests thematic study: results and analysis, by A. Del Lungo, J. Ball and J. Carle. Planted Forests and Trees Working Paper 38, Rome.

FAO (2010). Global Forests Resources Assessment, Forestry Paper 163. Food and Agriculture Organisation of the United Nations, FAO. Available at www.fao.org/forestry

Hodgdon, B.D., Hughell, D., Ramos, V.H., Balas McNab, R. (2015). Deforestation Trends in the Maya Biosphere Reserve, Guatemala (2000 - 2013). Rainforest Alliance, CONAP, Wildlife Conservation Society.

ISO (2006). ISO 14044 Life cycle assessment – Requirements and Guidelines. ISO/FDIS, Geneva, Switzerland.

Lou Yiping, Li Yanxia, Kathleen Buckingham, Giles Henley, Zhou Guomo (2010). Bamboo and Climate Change Mitigation. INBAR Technical Report no. 32. International Network for Bamboo and Rattan, Beijing, China.

Lou Yiping (2015). Personal communication. INBAR, Beijing, China.

MAF - New Zealand Ministry of Agriculture and Forestry (2008). Afforestation Grant Scheme Guidelines.

Putz, F.E., P.A. Zuidema, T. Synnott, M. Peña-Claros, M.A. Pinard, D. Sheil, J.K. Vancley, P. Sist, S. Gourlet-Fleury, B. Griscom, J. Palmer & R. Zagt. (2012). Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conservation Letters* 5 (2012) 296–303.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (2007). IPCC Fourth Assessment Report: Climate Change (AR4), The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge. Available at www.ipcc.ch

State Forestry Administration of P.R. China (2010). China's Forest Resources Status and Dynamic Change. *Forestry Economics*. (2): 66-72.

State Forestry Administration of P.R. China (2013). China National Bamboo Master Plan for 2013 to 2020. Beijing.

USDA Forest Service (2013), Silvics manuals, available online via http://www.na.fs.fed.us/pubs/silvics_manual/Volume_1/thuja/plicata.htm

van Dam, J. and Savenije, H. (2011). Enhancing the trade of legally produced timber - A guide to initiatives. Tropenbos International, Wageningen, the Netherlands.

Van der Lugt, P. (2008). Design interventions for stimulating bamboo commercialization. PhD thesis. Delft University of Technology. ISBN 978-90-5155-047-4, VSSD, Delft, the Netherlands.

Van der Lugt, P., Lobovikov, M. (2008). Markets for bamboo products in the West. *Bois et forêts des tropiques*, 295(1): pp 81-90. CIRAD, Paris, France.

Van der Lugt, P., Vogtländer, J.G, Brezet J.C. (2009). Bamboo, a sustainable Solution for Western Europe. Design cases, LCAs and Land-use. ISBN 978-90-6562-196-2, VSSD, Delft, the Netherlands.

Van der Lugt, P., J.G. Vogtländer, J.H. van der Vegte, J.C. Brezet (2012). Life Cycle Assessment and Carbon Sequestration; the Environmental Impact of Industrial Bamboo Products. *Proceedings 9th World Bamboo Congress*, Antwerp, Belgium.

Verchot, L., Krug, T., Lasco, R.D., Ogle, S., Raison, J., Yue Li, Martino, D.L., McConkey, B.G., Smith, P. (2006) IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 6 Grass Land. Available at www.ipcc.ch

Vogtländer, J.G., Van der Lugt, P., Brezet, J.C. (2010). The sustainability of bamboo products for local and Western European applications. LCAs and land-use. *Journal of Cleaner Production* 18 (2010) 1260-1269.

Vogtländer, J.G. (2010). A practical guide to LCA for students, designers and business managers, cradle-to-grave and cradle-to-cradle. ISBN 978-90-6562-253-2, VSSD, Delft, the Netherlands.

Vogtländer, J.G. et al. (2010). LCA-based assessment of sustainability: The Eco-costs/Value Ratio (EVR). ISBN 978-90-6562-233-4, ISBN 978-90-6562-234-1 (e-book), VSSD, Delft, the Netherlands.

Vogtländer, J.G. (2011). Life Cycle Assessment and Carbon Sequestration - Bamboo products of MOSO International. Delft University of Technology

Vogtländer, J.G., van der Velden N.M., Van der Lugt, P. (2014). Carbon sequestration in LCA, a proposal for a new approach based on the global carbon cycle; cases on wood and on bamboo. *Int J Life Cycle Assessment* (2014) 19:13-23.

Vogtländer J.G., Mestre A., Van der Helm R., Scheepens A., Wever R. (2014). Eco-efficient Value Creation, sustainable strategies for the circular economy. 2nd edition, Delft Academic Press.

Zhou, G. M., Jiang, P. K. (2004). Density, storage and spatial distribution of carbon in *Phyllostachys pubescens* forest. *Scientia Silvae Sinicae*, 6: 20-24. (In Chinese with English summary).