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CARBON SEQUESTRATION THROUGH APPLICATION OF INDUSTRIAL BAMBOO MATERIALS

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ABSTRACT

This study assesses the carbon sequestration potential through the increased use of industrial bamboo materials in the Western building industry, to better understand how engineered bamboo compares with commonly used building materials such as tropical hardwood. The first objective of this study is to measure the environmental impact of industrial bamboo products and its production process in terms of their CO_2 equivalent (carbon footprint). The second objective of this paper is to clarify how carbon sequestration on a global scale, including in bamboo forests and plantations, can be defined and calculated for industrial bamboo products, and how they can be incorporated in the standard carbon footprint 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, can be CO_2 negative over their full life cycle.

Keywords: Carbon footprint, LCA, climate change mitigation, carbon sequestration, industrial bamboo products, Moso bamboo

INTRODUCTION AND GOAL

Climate change is increasingly being acknowledged as a threat to our environment and human society. As such binding agreements have been made during COP 21 at Paris to prevent a temperature rise of 1.5 degrees Celsius as a result of global warming. There are various strategies for climate change mitigation either by reducing the causes of CO_2 emissions (e.g. higher energy efficiency, better insulation of buildings, increasing the use of renewable energy, etc) or by increasing the sinks (carbon sequestration), in which forests and bamboo/wood products can play a major role.

Through the photosynthesis process, plants absorb CO_2 from the atmosphere, while producing oxygen in return, and store carbon in their tissue and soil. After harvest this carbon remains stored in bamboo/wood products until they are discarded or burnt. As a result, forests and bamboo/wood products play an important role in the global carbon cycle through deforestation, forest conservation, afforestation and increasing application of bamboo/wood in durable (construction) products.

Besides the conversion of forests to agricultural land or for development of infrastructure, one of the main causes of deforestation in tropical regions is (illegal) logging of tropical hardwood.

Because of its rapid growth and wide applicability, giant bamboo species such as *Phyllostachus Pubescens* are increasingly perceived as environmentally benign tropical hardwood alternative. However, compared to wood the relatively long production process and transport distance could disturb this environmental profile and should be investigated further.

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). In addition to the standard LCA (ISO 14040 and 14044), the sequestration (capture and storage) of CO_2 has been taken into account in this paper. This paper builds on the LCA study performed by Van der Lugt (2008), and subsequent publications (van der Lugt et al. 2009, Vogtländer et al. 2010, Vogtländer et al. 2014) updated following more recent (2014) production figures, and extensively reported in the INBAR Technical Report 35 (van der Lugt and Vogtländer 2015), presented during the international Climate Conference COP 21 in Paris.

MATERIALS AND METHODS

Carbon footprint

In a carbon footprint assessment, the greenhouse gas emissions (GHG) during the life cycle of a material are measured, and compared to alternative materials in terms of kg CO_2 equivalent (CO_2e). Although not as comprehensive as the Life Cycle Assessment (LCA) methodology as defined in the ISO 14040/44 series, which besides the carbon footprint (Global Warming Potential) also includes environmental indicators such as acidification, euthrophication, smog, dust, toxicity, depletion, land-use and waste, a carbon footprint assessment is an easily understandable and commonly used tool to assess a material’s environmental impact.

Scope

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 using various production technologies in China, and based on consumption in the Netherlands. The use phase has been excluded from the analyses, because the emissions in this step are less than 1% (in comparison to production and waste phase).

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).

Cradle to gate (production)

The cradle-to-gate calculations have been made for 3 main production technologies that are currently used for industrial bamboo products, based on the *Phyllostachus Pubescens* species (locally known as “moso bamboo”), sourced and produced in Zhejiang province, China:

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 1: Flattened bamboo flooring boards, laminated bamboo panels, Strand Woven Bamboo beams (pictures: MOSO International BV).

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 Fig.2. Biogenic CO2 is first taken out of the air at the bamboo plantation, and released back to the atmosphere in the end-of-life stage. So biogenic CO_2 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 CO_2 emissions are avoided, which results in a reduction of global warming, and a credit in carbon footprint methodology.

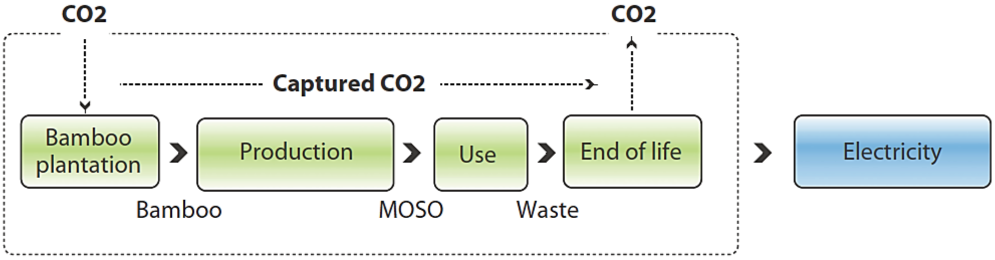

Figure 2: The CO2 cycle on a product level.

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), 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 kg CO_2 per kg of bamboo waste. In this paper 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 × 0,9 = **0,70** kg CO_2 per kg of bamboo product (MC 12%).

However, there is an additional carbon sequestration effect on global level which might be allocated to wood and bamboo based products, which is explained in the next section, and more elaborately in INBAR Technical Report 35 (van der Lugt and Vogtländer 2015).

Carbon sequestration at global level

On a global scale, CO_2 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.

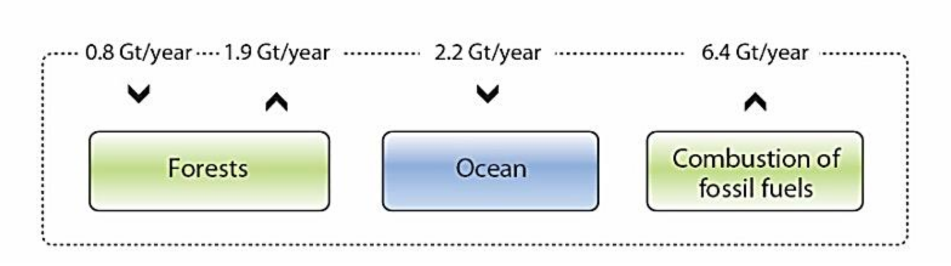

Figure 3: Global anthropogenic fluxes of CO_2 (Gt/year) over the period 2000–2010 (Vogtländer et al. 2014).

The figure shows that anthropogenic CO_2 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)

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). 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.

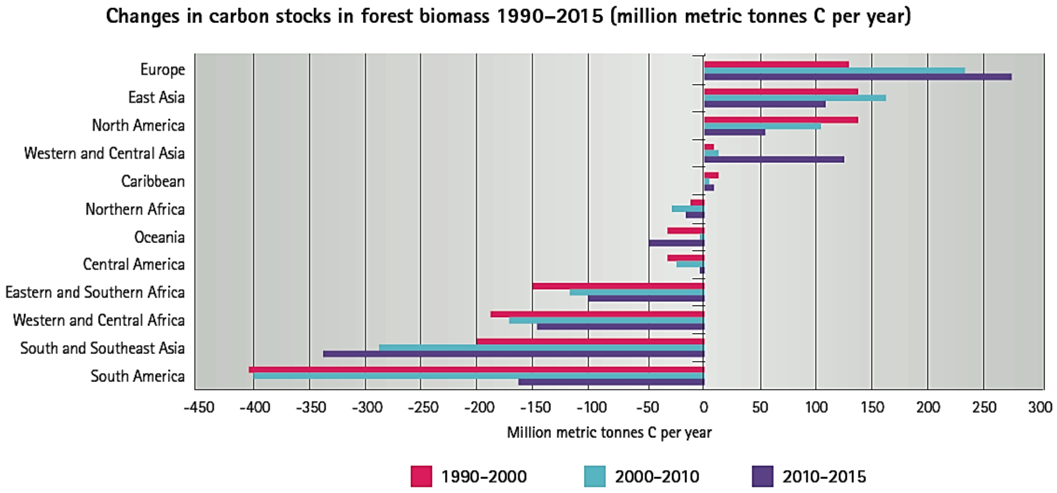

Figure 4: Trends in carbon stocks in forests from 1990–2015 (FAO 2015).

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).

This extra carbon storage on a global scale only applies when there is market growth of industrial bamboo products. This market growth leads to more plantations and more volume of bamboo in the building industry. How this additional carbon storage can be allocated to industrial bamboo products is explained in the following section.

Calculation of carbon sequestration

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 et al. (2014). In this paper we give a brief explanation how this is performed for flattened bamboo as an example.

Recent figures from the State Forestry Administration in China (2013) 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% 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, **0,05 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 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 × 0,5 × 3,67 (molar weight ratio CO_2 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. The Tier 2 Gain-Loss Method (Verchot et al. 2006) of the IPCC was used to compare the steady state before and after the land use change.

As mentioned above, in China there has been a large growth of the bamboo area in the past decades, especially through natural expansion of existing moso bamboo forests on farmland. Through the expanding rhizome network, the moso bamboo species, 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 industry.

Another reason for the expanded bamboo area is the reforestation of barren waste land or poor farming grounds (see example in figure 5) with bamboo plantations amongst others through the ‘Grain for Green” programme of the Chinese government.

Figure 5: Typical barren grassland which has been rehabilitated with bamboo in the past years (Photo: Lou Yiping).

For the purposes of this paper, it is assumed that the new bamboo plantations / forests are established on grassland and do not come at the expense of natural forests. This is a plausible assumption since a large portion of the Moso bamboo resources comes from the industrialized provinces around Shanghai (Zhejiang, Fujian, Anhui, Jiangxi). Furthermore, this assumption is in line with the current policy for afforestation and natural forest protection of the Chinese State Forestry Administration (SFA 2013).

The land-use change factor is then calculated as follows:

Grassland: Total above-ground and below-ground non-woody biomass is 7,5 tonnes d.m./ ha (it ranges from 6,5 to 8,5) with a carbon content of 47% (Verchot et al. 2006).

The biomass on bamboo plantations is 35,8 × 3,1 = 111 tonnes d.m./ ha for biomass above and below the ground (Van der Lugt 2009, Zhou and Jiang 2004) with a carbon content of 50%. The land-use change correction factor for afforestation is therefore:

[(111 × 0,50) – (7,5 × 0,47)] / (111 × 0,50) = **0,936**

Much of the additional Chinese bamboo production in the past has resulted from better management of existing bamboo forests (Lou Yiping et al. 2010). In that case, the land-use change correction factor is **1** for additional bamboo production.

Note that in the case of converted shrubland (according to Aalde et al. 2006, the above ground biomass is 60 tons d.m. for tropical shrubland in continental Asia with root-shoot ratio of 0,4 and carbon content of 46%) to bamboo plantation the land-use change correction factor is [(111 × 0,50) – (84 × 0,46)] / (111 × 0,50)] = **0,30**

At a market growth of 5%, the sequestered carbon at the plantation per kg flattened bamboo production is therefore 5% of 12,51 (0,936 × 13,37) kg CO_2, i.e. **0,62 kg CO_2**.

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 × 0,9 × 0,5 × 3,67 = 1,63 kg biogenic CO_2 storage in the buildings per 1 kg d.m. flattened bamboo. The extra storage, related to the 5% market growth, results in the extra carbon sequestration of 1,63 × 0,05 = **0,082** kg CO2 per kg d.m. flattened bamboo.

Taking into account 10% moisture content this leads to a total carbon sequestration of 0,9 x (0,62 + 0,082) = **0,64 kg CO_2** per 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 **0,63** kg CO_2 per kg plybamboo (10% MC), **0,62** kg CO_2 per kg SWB indoor (10%MC) and **0,61** kg CO_2 per kg SWB outdoor (10% MC). For detailed calculations please refer to van der Lugt and Vogtländer (2015).

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 above).

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 CO_2 per kg softwood d.m., for detailed calculations is referred to Vogtländer et al. (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 CO_2 under the ground in the rhizomes as well as in 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.

RESULTS AND 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 6, it can be concluded that all industrial bamboo products, based on use in Europe, are "CO_2 neutral or better" i.e. CO_2 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.

From figure 6 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%.
- International sea transport: 15-25%
- Local transport (truck): 10%.
- Use of resin: 3% (flattened bamboo) to 16% (outdoor SWB).

From the above becomes clear that unlike commonly expected, not the glue use nor the relatively long transport distance to Western markets, but the energy consumption in China (energy mix dominated by coal energy plants) has the highest portion in the carbon footprint of industrial bamboo products. For a more detailed analysis including points for improvements please refer to van der Lugt and Vogtländer (2015).

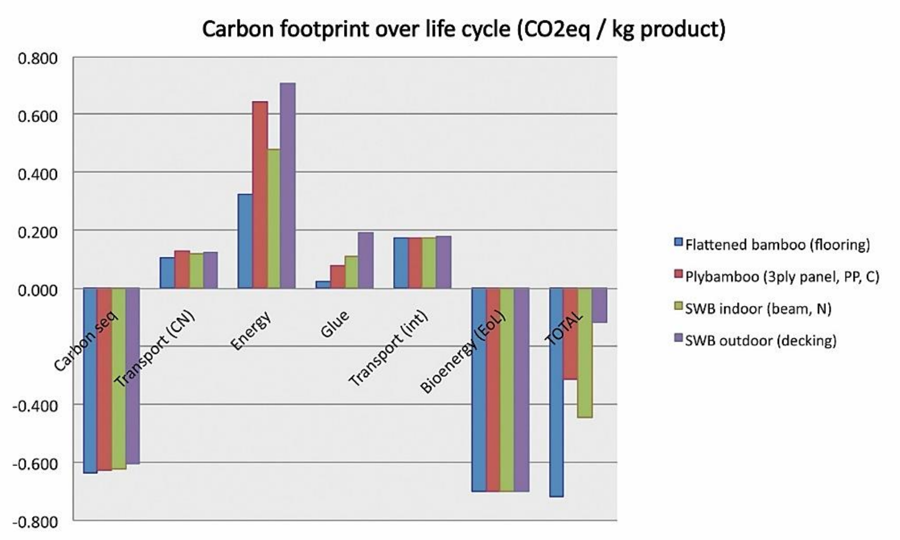

Figure 6: Carbon Footprint over Life Cycle (kgCO2eq / kg product), for various industrial bamboo products based on different production technologies.

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 CO_2eq/kg stem based on use in the Netherlands. However, when the bamboo stem is used locally (China), the sea transport is eradicated and the cradle to gate carbon footprint is only 0,19 kg CO_2eq/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 the bamboo stem locally in the bamboo growing countries.

Another question is how industrial bamboo materials compare to other commonly used building 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 7 the carbon footprint is provided for several commonly used materials, including the main bamboo industrial production technologies.

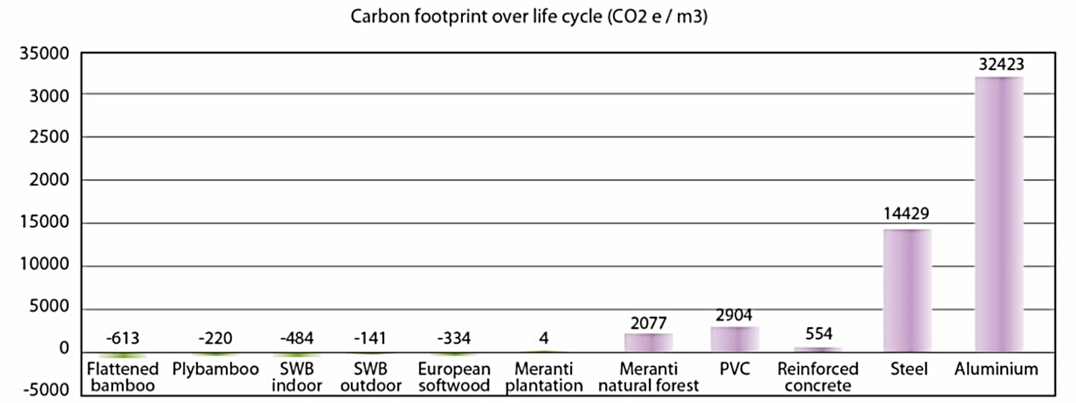

Figure 7: Carbon footprint over life cycle (kg CO_2eq / m3 building material) for various common building materials.

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 based on annual thinning with high annual yield, see figure 8), it is less susceptible for clear-cutting / deforestation (no threat of going for short term economic gain as with wood with its long rotation cycles). Furthermore, bamboo is very good reforestation crop, even in areas where farming is not feasible, e.g. rehabilitating degraded land on eroded slopes.

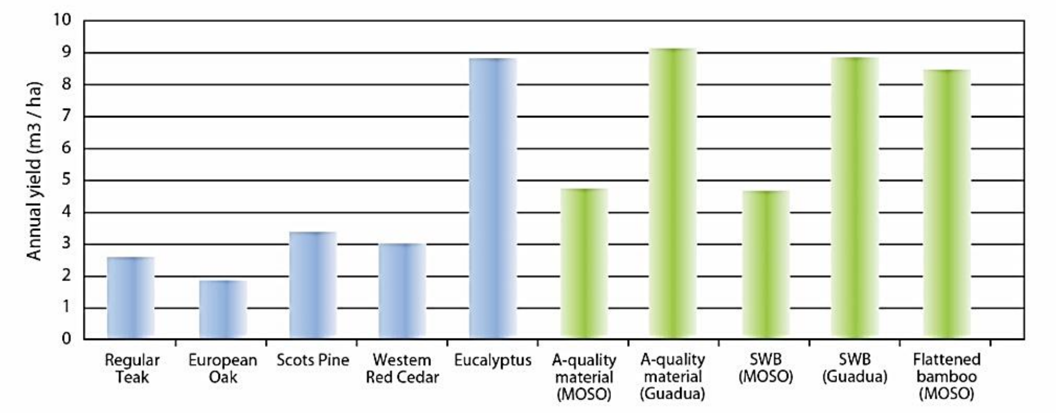

Figure 8: Annual yield for various wood and bamboo species in cubic meters produced per hectare per year (FAO 2006, MAF 2008, van der Lugt 2008, USDA, 2013).

CONCLUSION

In conclusion, it seems clear that industrial bamboo products, due to their hardness, dimensional stability and aesthetic appearance, could be a favourable substitute for hardwood and other non-renewable building materials.

From a global perspective, taking into account the resource-side benefits of bamboo (high yield, annual harvesting, reforestation on degraded land, short establishment time, etc.), it becomes clear that bamboo could be a promising contributor to a more sustainable, biobased economy through:

- Reducing emissions (and biodiversity loss) caused by deforestation in tropical and sub-tropical areas by providing a viable low emission alternative to tropical hardwood;
- Reducing emissions from burning fossil fuels by generating electricity at the end-of-life of a growing number of industrial bamboo products on the market;
- Carbon sequestration through reforestation of degraded grassland and slopes with bamboo forests.

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