Dr. Pablo van der Lugt & **Dr. Joost Vogtländer**, Delft University of Technology, Faculty of Industrial Design Engineering, Design for Sustainability, the Netherlands

The Potential Role of Wood Acetylation in Climate Change Mitigation

Carbon Negative Window Frames: Fiction or Reality?

Introduction – Role of Forests and Wood on Global warming

There are various strategies for climate change mitigation either by reducing the causes of CO2 emissions (e.g. higher energy efficiency, better insulation, using renewable energy, etc) or by increasing the sinks (carbon sequestration), in which forests and forest products play a major role.

During growth, trees absorb CO2 from the atmosphere, while producing oxygen in return, and store this in their tissue and soil, and after harvest in durable wood products throughout their lifespan. As such, forests and wood products play an important role (both negative as positive) in the global carbon cycle through deforestation, forest conservation, afforestation (planting of trees on soils that have not supported forests in the recent past) and increasing application of wood in durable (construction) products.

Although afforestation in temperate regions is a positive development, for the world as a whole, carbon stocks in forest biomass still decreased by an estimated 0.5Gigatons due to deforestation in (sub)tropical regions worldwide between 2005 and 2010 (see also figure 1), where a region of over 8 million hectares was deforested (Source: FAO Global Forest Resources Assessment 2010).

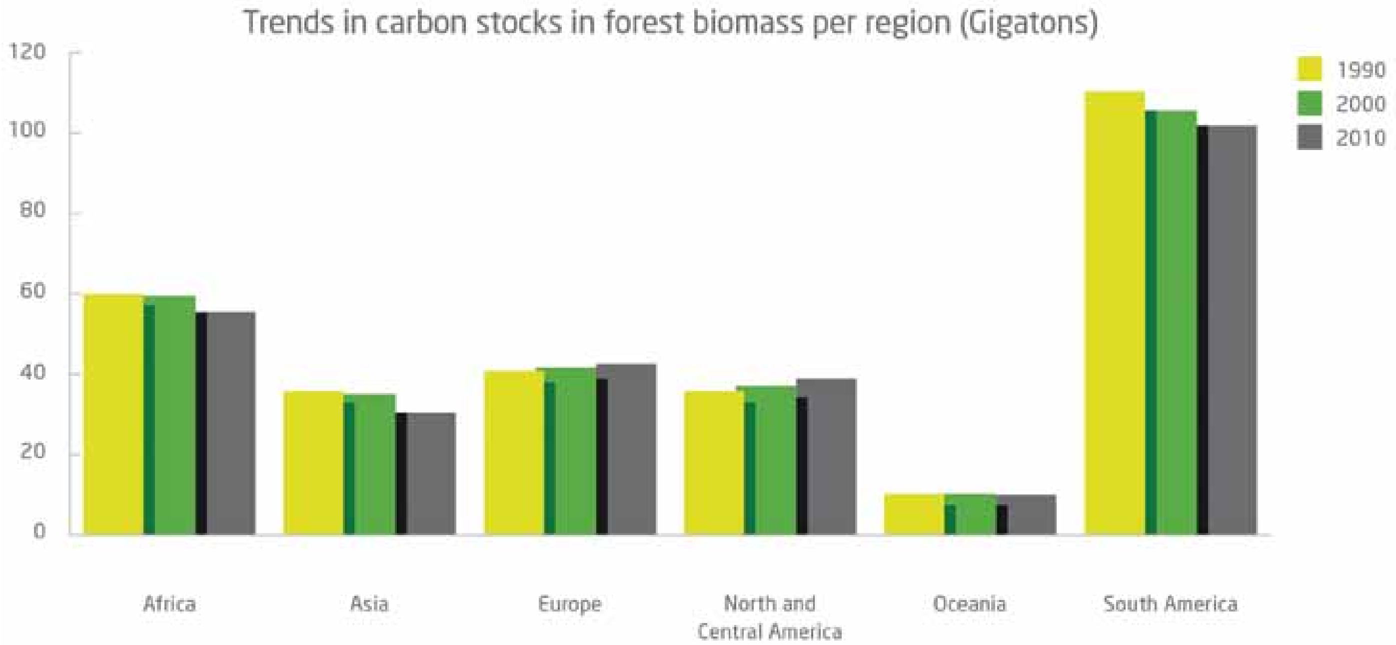


Figure 1: *Trends in carbon storage in forests from 1990-2010 (source: FAO Global Forest Resources Assessment 2010)*

Combined with 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 from rainforests, which is high in demand worldwide because of its superior performance over softwood in terms of durability, hardness and sometimes dimensional stability.

Although the amount of sustainable sourced and certified tropical hardwood on the market is increasing - due in part to new legal requirements like the European Timber Regulation becoming obligatory in March 2013 and the expanded Lacey Act in the USA - demand is still considerably higher than supply, and sustainable and durable alternatives are needed to reduce pressure on endangered sources.

Wood Modification for Improved Sustainability

A promising route enabling legally and sustainably sourced - but poor performance - temperate wood species to be used in high performance applications is through large scale non toxic wood modification. Acetylation is the leading known method. Through the acetylation process the unstable hydroxyl (OH) groups in wood are replaced by a wood's naturally occurring and more stable acetyl groups, through which the dimensional stability and durability of the treated wood species significantly increases. Acetylated wood has been developed to commercial scale by the UK based company Accsys Technologies under the brand name Accoya® wood. Through the optimized process, Accoya® is guaranteed to have an excellent performance in terms of durability (class 1 according to EN 350) and stability, making it a promising alternative in exterior applications where tropical hardwood is typically used such as joinery, decking, cladding, as well as structural applications.

Figure 2: *Accoya® wood used for cladding, decking and structural beams in boathouse in Horning, Norfolk, UK*

Carbon Footprint for Accoya® Wood

Cradle to Gate Assessment

In a carbon footprint assessment, the greenhouse gas emissions (GHG) during the life cycle of a material can be measured, and compared to alternative products in terms of kg CO2 equivalent (CO2e). Recently a carbon footprint, following the Greenhouse Gas Reporting Protocol of the World Business Council for Sustainable Development (WBCSD) and World Resource Institute (WRI) was executed by independent consulting firm Verco (2012) for Accoya® based on a cradle to gate scenario, thus until the factory gate. This includes sourcing, harvesting and processing of the input timber, as well as all energy and raw material consumption in the acetylation plant of Accsys Technologies in Arnhem, the Netherlands. Figure 3 presents the results in cubic meters Accoya® including several other material alternatives. ►

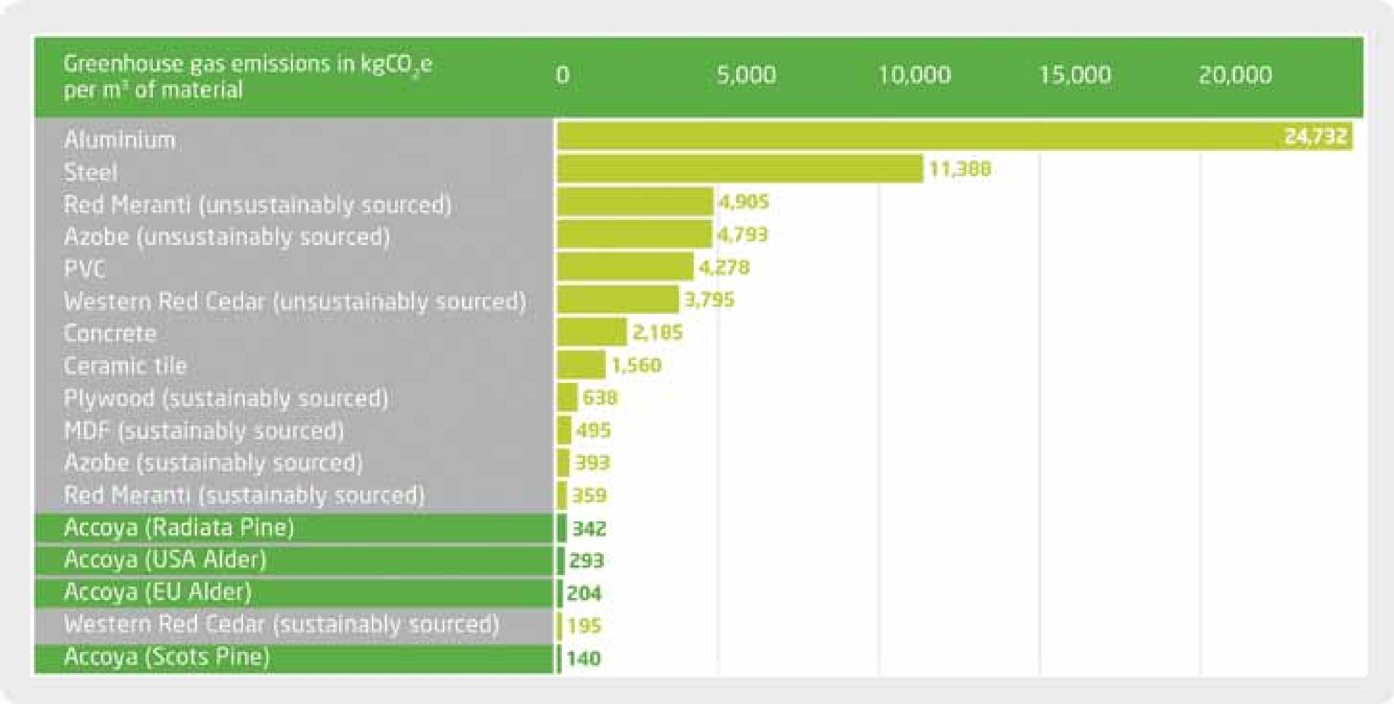


Figure 3: *the greenhouse gas emissions of several building materials per cubic meter based on a cradle to gate scenario (Verco 2012, University of Bath 2011, Ecoinvent 2012)*

on a cradle-to-gate basis, Accoya's carbon footprint significantly outperforms most other commonly used building materials

The graph above shows that, on a cradle-to-gate basis, Accoya's carbon footprint significantly outperforms most other commonly used building materials such as concrete, PVC, MDF, plywood as well as a range of tropical hardwoods such as Azobe and Red Meranti, even when sourced from sustainable managed plantations. Logically, because of the shorter transport distance, the Accoya® scenarios based on continental sourced wood perform better than the intercontinental scenarios.

However, a cradle-to-gate analysis does not cover the in-use and end of life phase of the product. For the materials illustrated above, in-use emissions are likely to be centred around i) material properties such as density or strength, which dictate the volume of material required, ii) durability of the material which influences lifespan, iii) maintenance procedures and frequency, iv) carbon sequestration properties of renewable materials, and v) Disposal and recycling routes available.

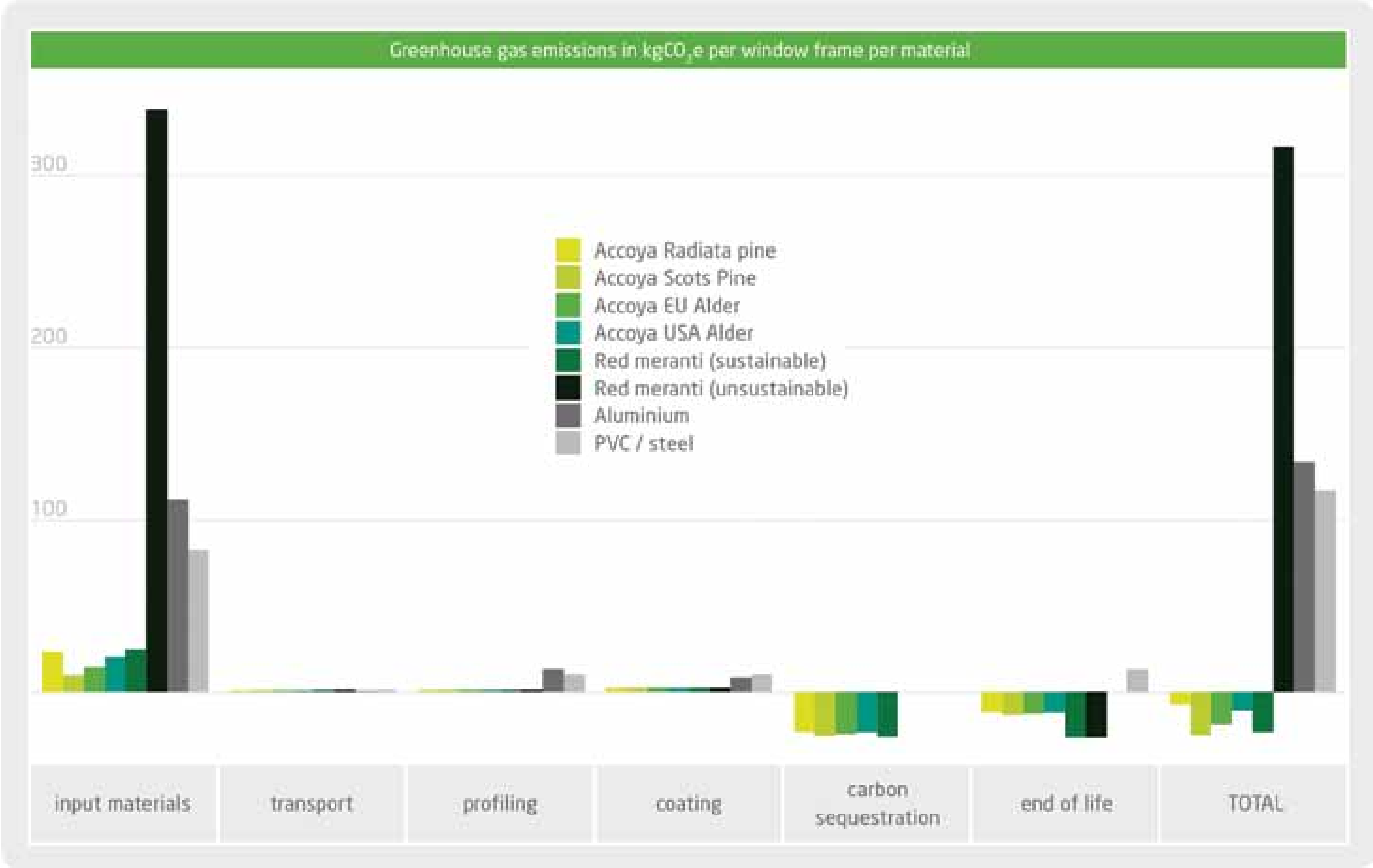
Therefore, to avoid comparing 'apples with oranges', for a complete "cradle till grave" assessment the carbon footprint results per cubic meter from the graph need to be 'translated' to an application example to include the in-use and end of life phase related aspects mentioned above. This subsequent analysis was performed by Delft University of Technology (2013), who also executed the Life Cycle Assessment (LCA) for Accoya® wood in 2010.

Cradle to Grave Assessment

Just as in the 2010 LCA study, an application, a window frame, was chosen in which Accoya® has been compared with non-renewable materials (metals, plastics). For details of the functional unit and the calculation please refer to the report itself, downloadable via http://www.accoya.com/downloads. In order for the comparison to be fair, all alternatives in this application have to meet the same functional requirements. The assessment includes End of Life considerations and the effect of carbon sequestration over a 100 year timeframe following leading standards in carbon footprint and LCA (ILCD, PAS 2050: 2011 and the EN norm under development EN16449). These methods allow for the carbon sequestered in the wood to be included as a negative CO2 value with respect to the emissions, which can be deducted from the total fossil CO2 emissions. A higher negative CO2e value is allocated if the life span of the wood in-use is longer, which is beneficial for acetylated wood due to the predicted longer useful life.

The two co-products of the product system, waste wood (from saw mills, planing, profiling, etc) and acetic acid from the acetylation process, are dealt with by the so-called "system expansion" and "credits" for "substitution" in line with ISO 14044. For acetic acid this means that the GHG emissions resulting from the "avoided acetic acid production elsewhere" is subtracted from the total GHG emissions of Accoya®. For the wood waste it is assumed that 100% is incinerated for energy production, applying the Lower Heating Value of the waste material. For the Western European situation this is a plausible assumption. This energy output from biomass substitutes heat from oil, leading to a "carbon credit" for the avoided use of oil.

The results of the cradle to grave window frame comparison are presented in the graphs as follows, first per process step (figure 4) then for the total emissions (figure 5).



Figures 4 & 5: *Greenhouse gas emissions for a window frame in various material alternatives*

From the graphs several conclusions can be made:

- Because of the limited emissions during production in case of sustainable sourcing, and credits that can be earned through carbon sequestration (especially in case of a long lifespan) and incineration for electricity in the End of Life phase, all wood products, including Accoya®, are CO2 negative over the full life cycle. The best performing alternative is Accoya® made from locally sourced species (in this case Scots Pine).

- The non renewable materials PVC, steel and aluminium perform considerably worse than sustainably sourced wood, especially because of the high embodied energy (emissions during production). Although through recycling aluminium, PVC and steel earn some credits back, this does not outweigh the high emissions during production.

- In the case of tropical hardwood from rain forests (deforestation) the picture totally shifts and wood is the worst performing alternative (see unsustainably sourced Meranti). This shows the importance of conservation of tropical rainforests as they act as important carbon sinks.

- The eco-burden of transport and maintenance (coatings) of the window frames appears to be negligible in the total context.

Note that another recent LCA study on window frames in the UK executed on behalf of the Wood Window Alliance (Menzies, 2013) provides similar results as the study executed by the Delft University of Technology, presented in this paper.

From the results it is obvious that the credit for temporary carbon sequestration has a large impact on the outcome. It is important to note here that there is still a lot of discussion going on in working groups of LCA and carbon footprint methodology (most notably PAS 2050, ILCD and WRI/WBCSD GHG protocol) on how to exactly allocate credits for temporary storage of biogenic carbon in wood products. Nevertheless, if the temporary carbon sequestration credit would be neglected and only the credit for energy production in End-of-Life would apply, the results would slightly change, with most of the wood alternatives (except Accoya® made from Radiata Pine), still carbon negative (see figure). ►

Figure 6: *Greenhouse gas emissions for a window frame in various material alternatives excluding credit for temporary carbon sequestration*

Discussion

It should be noted that several environmental issues cannot be caught by a carbon footprint. Although the scope of a LCA is a lot broader than the carbon footprint, and also includes several other eco-indicators besides GHG emissions (global warming effect), such as acidification, euthrophication, smog, dust, toxicity, depletion, land-use and waste, in both instruments the issue of social sustainability is not included. Land-use change is incorporated in LCA indicators like Recipe and eco-costs. It is strongly related to the harvesting of tropical hardwood. For example, globally FSC certified tropical hardwood is partly sourced from plantations (40%), but the rest is still coming from natural forests (harvested with Reduced Impact Harvesting), having a negative impact on biodiversity and carbon sequestration.
Yield of land is another specific aspect of sustainability, not included in a carbon footprint, which is related to the fact that land is becoming scarce, especially when current materials (metals, fossil fuels) will be replaced by renewable materials like wood and crops for biomass. The high growing speed of species suitable to produce Accoya® such as Radiata Pine is an environmental competitive advantage over regular wood species, and in particular slow growing tropical hardwood species. Therefore, the annual yield is another aspect of sustainability which should to be taken into account in addition to the carbon footprint performance results presented earlier.

This does put the results of the carbon footprint in another perspective by looking at a global level. One of the striking conclusions of the cradle to grave carbon footprint comparison is that when sourced from tropical rainforests, wood is the worst performing alternative. This shows the importance of conservation of (tropical) forests as they act as important carbon sinks, and the need to search for (rapidly) renewable alternatives from abundantly available sustainable managed sources.

	Wood Species	Annual Yield [m^3 / ha / year]
A	Radiata Pine	28
B	Western Red Cedar	15
C	Bamboo	11
D	Beech	11
E	Teak	6
F	Oak	5

Figure 7: *Annual yield for various wood species in cubic meters produced per hectare per year*

Acetylation seems to be the right solution as it enables an abundantly available resource (legally sourced timber from temperate regions) to substitute tropical hardwood, and due to the improved performance characteristics (durability, stability) even materials such as plastics, metals and concrete.

Therefore on a global level Accoya® may help in further reducing greenhouse gas emissions directly on a product level through temporary carbon sequestration in products but more importantly on a global level by substitution of carbon intensive materials such as hardwood from tropical rain forests, plastics, concrete and metals. Furthermore, it provides a powerful drive for reforestation as softwood species can now serve as input for high performance wood. ■