# Wood in carbon efficient construction: environmental impacts assessment for the mitigation of climatic changes

**Francesco Pittau*, Enrico De Angelis**

Politecnico di Milano, B.E.S.T. Department, 20133 Milan, Italy

*francesco.pittau@mail.polimi.it

**Abstract** The building sector is responsible for a significant share of the total primary energy use and greenhouse gas emission in Europe. Although sophisticated tools for the analysis of life cycle environmental impacts of many goods and services have been developed over the last several decades, the typical life cycle assessment (LCA) methods, widely applied on industrial products, are not easily exploitable for real buildings' cases due to the complexity of the different processes in very different times that involves the buildings and the lack of specific databases to quantify the impacts of the different environmental indicators. There are several reasons for the increased complexity of the environmental analysis of wood products compared to that of most other products: a long time frame is involved, a range of useful products can be obtained at different points in time, a broad array of joint products can be obtained from a tree and the unique relationship between forest development and environmental services, including climate stability. Furthermore, the life cycle analysis of buildings is also more complex than that of many other products. Therefore, in order to achieve the goals of environmental sustainability it is essential to calibrate a complete analytic method specifically adjusted for these particular kind of materials and technological systems, able to support the choices of the different stakeholders during the various stages of the building design process, and to define a building management plan to minimize the human footprint and the final waste of the construction processes, optimizing the energy consumption for every stage of the building life.

## 1 Introduction

Concerns about local and global environmental situation are rising in the developed and developing world; global warming, ozone depletion, destruction of natural habitats, and loss of biodiversity are the cause of much debate in international forums [1]. Global warming, and its various potential effects on the Earth, is a consequence of a long-term accumulation of the so-called greenhouse gases (CO2, CH4, N2O, etc.) in the higher layer of the atmosphere [2]. The emission of these gases is the result of intensive human activities such as the burning of fossil fuels, deforestation and land-use changes. In such a prevailing global environmental scenario, sustainability is the main objective to achieve and should be given the prime importance in execution of activities in all sectors in order to keep future secure for coming generations. Forestry and wood products hold a particular position in the current political discussion on climate change and on the implementation of the "Kyoto-Protocol" [3]. On one hand, the destruction of large forest areas taking place mainly in countries of the Southern Hemisphere is a considerable source of greenhouse gas emissions; on the other hand, forestation, reforestation and forest conservation are considered valuable sinks for mitigation and storage of CO2 [4]. Due to its carbon neutrality, wood is given an important role for its carbon storing potential in applications with long service life [5] as well as for its substitution potential of non-renewable fuels and of material whose extraction and processing heavily relies on non-renewable energy carriers [6,7].

In every country, the construction industry is the major contributor to socio-economic development and also the major user of energy and natural resources. European building construction industry consumes 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases and the agents of acid rain. Therefore, in order to reduce the impacts of the buildings and to achieve sustainable development in the society it is essential to promote the use of materials and systems with low embodied energy and the development of innovative solutions to decrease the energy demand and the greenhouse emissions.

## 2 Wood as construction material

Wood is one of the oldest building materials in the world. Used as a structural element already in prehistoric times, unlike other materials finding in nature, has the benefit to be a renewable material. Today, unlike in the past, wood-based structural components have different forms, having developed over the last several decades of technological and production innovations. There are elements in the form of massive wooden panels, laminated panels, particleboards, chipboards, etc, and their uses range from structural components (massive or laminated beams, plywood boars, OSBs, etc.) cladding components, to insulation panels (mineralized wood panels, cork panels, cellulose flakes, etc).

The use of wood as building material allows now, thanks to the technology improvements and the characteristics of the material, for an almost 100% utilization of the resource. However, being a natural material, wood is inhomogeneous, also related to the imperfections of its fibrous structure, with an anisotropic mechanical behaviour, as well as a flimsy response to crack. Moreover, the physical characteristics and the mechanical properties may be very different from tree to tree and from section to section, and its flimsy mechanical behaviour has limited the use in seismic areas for several years. Today, thanks to technical and technological advancements, wood-based structural elements can be used even in highly seismic areas, with excellent structural response to the stresses induced by ground acceleration, due to its particularly low loads and the flexibility gathered by metal joints.

Among the several advantages of wood there are the relatively low price, the easy availability of the resources in nature, the workability with low power consumption, the vapour permeability, the high values of thermal and acoustic insulation and its high structural stability under fire loading. Being a biogenic material, it is subject to the biological and photochemical degradation, sometimes with a significant performance decay. This degradation is usually caused by environmental conditions under which it is subjected during the service life, but may be easily restricted in order to protect the material surface with chemical treatments (application of protective coatings, primers, etc) or physical treatments (heat treatment). Typically, external applications require specific detailed studies for each case. Among the most important aspects to consider there are the maintenance cycles, in order to guarantee the performance during the useful life based on the durability of each building components and the methods for disposal at the end of service life. The disposal may provide different scenarios for the wood: landfill, incineration with energy recovery (due to the high values characteristic of wood energy feedstock) or recycling/reuse. However, any operation to restore the original properties provides a use of non-renewable resources and/or materials [8].

## 3 Sustainable forestry for a certificated wood management

The term "sustainability", widely used and often "abused" in the current terminology, is historically linked to forest activity. Born in the 18th century, coinciding with the population explosion after the industrial revolution, today it

assumes a broader meaning. One of the most widely accepted definitions has been set up in 1993 by the "Ministerial Conference for the Conservation of Forests in Europe" in Helsinki: «The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems» [9].
In Europe, the forest cover is about 35% of the territory (about 23% in Italy), recording a continuous growth in the recent years. However, the development of the local forestry is still below a desirable levels, although the potential is actually very high. Besides, generally, the main European regions specialized in the forestry sector (mainly Scandinavia, Eastern Europe and Central Europe) are characterized by a relatively long wood-chains, with significant environmental impacts given by transportations [10]. Recent cases have highlighted that the adoption of a short wood-chain has considerable benefits both from the economic point of view, producing beneficial effects due to the generation of economies of scale, and from the environmental point of view, with a significant reduction of greenhouse gas emissions. Intensive use of certified forests at the local level, an increase of the exploitation up to 40% compared with today, would lead to an expansion of the protected areas and the natural reserves, with the possibility of protection of various animal species and the rejuvenation of the tree species, in addition to the creation of new skilled work positions, with a relative increase in local income [11].

## 4 Use of wood in the building sector

Although the intensive use of forest resources would lead to the activation of a beneficial economic mechanism, with the shift from non-renewable to renewable resources, it may lead, however, to an unacceptable pressure of the soil [12]. Therefore, based on the concept of sustainability, this pressure must be eliminated or at least minimized, with the improvement of the efficiency of the resource [13]. Even for a natural resource like wood problems related to the energy savings during the extraction/production phase, waste management and landfiling still remain. However, the wood only needs to improve efficiency by a factor of 2 compared with 3 or 8 of other materials typically used for construction, such as concrete, steel or aluminium, so that, in anticipation of a more sustainable future, certainly wood has more potential [14]. For this reason, especially in recent years, even in the areas that historically did not consider this resource as a building material, there has been a marked increase in building applications. Basically, being a very easy material to work which not requires a large amounts of energy during production, it can be used as a component in various parts of the building. Typically, there are two categories of wood-based construction technologies for the design of building envelopes: massive systems or lightweight-framed systems. Recently, the technological development of wood-based components is directed towards the use of "green" products, able to minimize the amount of chemical materials, always present in the glued components such as plywood, laminated beams or veneers, chipboard, etc.

The peculiar features of wood components, having the advantage to participate actively in the sequestration of carbon from the atmosphere, are particularly favorable for the application in the carbon neutral buildings. Therefore, the wood-based building constructions, as well as traditionally are realized in the main Northern European Countries, have considerable benefits in terms of reducing energy consumption and greenhouse gases emission [15-18] and in the latest decade they have been utilized for the realization of several Zero-carbon net and Zero-energy net buildings.

## 5 Life cycle analysis applied to the wood-based building components

Although the LCA methodology is not fully adapt for applications in the construction sector [19], it is still the only validated tool for the holistic assessment of the environmental impacts. As in other fields, the need to assess the environmental impact of wood products has emerged during the 70s of last century as a consequence of the two oil crises. Consequently, the first early research studies focused only on the problem of assessing the energy consumption during the production processes [20, 21]. In the following years the analysis are been extended to all of the environmental aspects and the whole life cycle, although many of the eco-indicators typically used in the LCA for industrial products, are difficult to measure [22, 23]. The development of LCA methodology for environmental assessment of wood products has been developed and consolidated significantly in Europe and North America over the last ten years. Thanks to this effort has become possible to model and assess the environmental impacts related to the main processes of the timber industry, as demonstrated by numerous publications in the scientific literature. From a careful analysis of the studies recently carried out it is evident, however, how the definition of a common and at the same time comprehensive methodology, easy to apply to construction cases, is still far away, as well as many of the studies and applications of LCA methodologies are not available to the scientific community [19]. Several of these studies focus on GHG emissions without taking into account other environmental aspects, other studies are documented in a rather rudimentary way. Many of them are comparative, based on the analysis of buildings or parts of buildings with different construction technologies (e.g. wood vs. concrete, masonry vs. lightweight construction, etc), and are able to offer an interpretative analysis of the results very more simple and straightforward [24]. Many of the analysis are carried out in relation to the ISO 14040 series, while latest others with the ISO 21931, specifically for the building field.

For the interpretation of the results, it should be kept in mind that buildings are indeed very complex products. Buildings differ in technical aspects, internal and external appearance, execution of the constructive works, intervals of maintenance and cleaning, behaviour and fashions of its users, etc. This implies that assessing and comparing buildings is based on many assumptions that can have a large influence on the result, e.g. the assumed life time of building elements, the specifications of the equipment for heating, cooling, air conditioning, etc. In general, particular attention should be placed on transport, critical in terms of primary energy used due to variability depending on the actual spatial distances between the various stakeholders involved in the evaluation process.

## 6 Conclusions

Over the last ten years has developed a considerable sensitivity to the environmental performance of wood products. The analysis of the state of the art shows it tend to have a favourable environmental profile compared to functionally equivalent products, although wood products impregnated tend to be more critical because of the toxicological effects. The incineration of wood products can cause a higher impact due to acidification and eutrophication, even if the heat may be recovered. Wood products such as panels composed of particles and fibres benefit from a greater share of timber than solid wood products. In addition there is a generally high consumption of fossil fuels associated with the production of fibres and particles, as well as the production of resins, additives, etc. Nevertheless, many critical issues related to the LCA still persist, such as the sensitivity of comparative analysis results to the methodological decisions, including selection of allocation procedures often used to model multi-output processes, recycling, or different assumptions scenarios associated to end of life. Furthermore, existing

methodologies do not allow to describe adequately the toxicological effects of chemical components, because the structure of an LCA model has no spatial or temporal resolution.
Finally, the issue of availability of correct data for analysis at building level, where the limits of applicability of LCA models are very wide, is still critical.

## 7 References


[1] Various, Intergovernmental Panel on Climate Change (IPCC), *International Climate Change 2007 (AR4): The Physical Science Basis*, Cambridge University Press, 2007.

[2] Özer Arnas A., On the Principles of Thermodynamics – Effects on the Environment, Global Warming and Sustainability, *International Global Worming Engineering Solutions*, Vol. XIII, p. 685.

[3] Various, Kyoto Protocol to the United Nations Framework Convention on Climate Change, *United Nations Framework Convention on Climate Change (UNFCCC)*, 1997.

[4] Various, Land-use, Land-use Change and Forestry, *Special Report of the IPCC*, Cambridge University Press, 2000.

[5] Skog K. E., Nicholson G. A., Carbon Cycling Through Wood Products: The Role of Wood and Paper Products in Carbon Sequestration, *Forest Products Journal*, Vol. 48, 1998, pp. 75-83.

[6] Sikkema R., Nabuurs G. J., Forest and Forest Products: the Challenge for a Better Carbon Balance, Life-Cycle Analysis – A Challenge for Forestry and Forest Industry, Hamburg, 1995, pp. 169-175.

[7] Matthews R. W. et al., WG3 Summary: Evaluation the Role of Forest Management and Forest Products in the Carbon Cycle, *Forest Ecosystem, Forest Management and the Global Carbon Cycle*, 1996, pp. 163-172.

[8] Fraanje P. J., Cascading of Pine Wood, *Resources, Conversation and Recycling*, 19(1), 1997, pp. 21-28.

[9] Various, General Declaration and Resolution Adopted, Ministry of Agriculture, Rural Development and Fishery of Portugal, Lisbon, 1998.

[10] Janssens I.A. et al., Europe’s terrestrial biosphere absorbs 7 to 12% of European anthropogenic CO2 emissions, *Science*, Vol. 300, 2003, pp. 1538-1542.

[11] Various, State of European forests and Forestry, Timber Section, Geneva, 1999.

[12] Agren G. I., Hyvonen R., Changes in carbon stores in Swedish forest soils due to increased biomass harvest and increased temperatures analyzed with a semi-empirical model, *Forest Ecology and Management*, Vol. 174, 2003, pp. 25-37.

[13] Fraanje P. J., Cascading of Pine Wood, *Resources, Conversation and Recycling*, 19(1), 1997, pp. 21-28.

[14] Nabuurs G. J., Pussinen A., Karjalainen T., Erhard M., Kramer K., Stemwood volume increment changes in European forests due to climate change: a simulation study, *Global Change Biology*, Vol. 8(4), 2002, pp. 304-316.

[15] Dodoo A., Gustavsson L., Sathre R., Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard, *Resources, Conversation and Recycling*, Vol. 54, No. 12, 2010, pp. 1152-1160.

[16] Gustavsson L., Joelsson A., Life cycle primary energy analysis of residential buildings, *Energy and Buildings*, Vol. 42, No. 2, 2010, pp. 210-220.

[17] Gustavsson L., Joelsson A., Sathre R., Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building, *Energy and Buildings*, Vol. 42, No. 2, 2010, pp. 230-242.

[18] Fahey T. J., Woodbury P. B., Battles J. J., Goodale C. L., Hamburg S. P., Ollinger S. V., Woodall C. W., Forest carbon storage: ecology, management and policy, *Frontiers in Ecology and the Environment*, Vol. 8, No. 5, 2010, pp. 245-252.

[19] Optis M., Wild P., Inadequate documentation in published life cycle energy reports on buildings, *International Journal of Life Cycle Assessment*, Vol. 15, No. 7, 2010, pp. 644-651.

[20] Boyd C. W., Koch P., McKean H. B., Morschauer C. R., Preston S. B., Wangaard E. F., Wood for structural and architectural purposes, *Forest Products*, Vol. 27, 1976, pp. 10–20.

[21] Ressel J., Energy analysis of the wood industry in the Federal Republic of Germany", Bundesministerium für Forschung und Technologie (BMFT), Hamburg, 1986.

[22] Asif M., Muneer T., Kelley R., Life cycle assessment: A case study of a dwelling home in Scotland, *Building and Environment*, Vol. 42, No. 3, 2007, pp. 1391-1394.

[23] Buchanan A. H., Levine S. B., Wood-based building materials and atmospheric carbon emissions, *Environmental Science & Policy*, Vol. 2, No. 6, 1999, pp. 427-437.

[24] Bowyer J., Briggs D., Lippke B., Perez-Garcia J., Wilson J., Life cycle environmental performance of renewable materials in the context of residential building construction, Consortium for Research on Renewable Industrial Materials (CORRIM), Seattle, 2004.