Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe – Timber Committee
October 11-14, 2010, Geneva, Switzerland

Embodied Energy and Carbon Footprint of Norwegian Roundwood

Per Otto Flæte
Norsk Treteknisk Institutt
PO Box 113 Blindern, NO-0314 Oslo, Norway

Gry Alfredsen
Norwegian Forest and Landscape Institute
PO Box 115, NO-1431 Ås, Norway

Kristian Bysheim
Norsk Treteknisk Institutt
PO Box 113 Blindern, NO-0314 Oslo, Norway

Øyvind Eriksen
Paper and Fibre Research Institute
Høgskoleringen 6b, NO-7491 Trondheim, Norway

Anders Q. Nyrud
Norsk Treteknisk Institutt
PO Box 113 Blindern, NO-0314 Oslo, Norway

Birger Vennesland
Norwegian Forest and Landscape Institute
PO Box 115, NO-1431 Ås, Norway

Abstract

Roundwood timber is raw material for numerous products. Wood based products are generally recognised as favourable regarding energy consumption and greenhouse gas (GHG) emissions. Several studies have shown that the net CO^2 emissions can be reduced by using biofuels harvested from forests to substitute fossil fuels, and by using wood for building materials.

Energy use and GHG emissions associated with producing roundwood can be influenced by a broad range of factors, such as silvicultural practice, topography, applied technology, forestland ownership, industrial structure, etc. This emphasizes the importance of using representative data for energy use and GHG emissions when calculating environmental impacts.

The aim of this study was to investigate the embodied energy and life cycle GHG emissions of industrial softwood sawlogs in Norway, covering the production chain from tree seed to log yard. Analyses were based on activity data for the Norwegian forest sector for the year 2007.

The results showed that the embodied energy and GHG emissions were low compared with the energy and CO^2-equivalents stored in the roundwood (about 2%). The findings from this study can be used to inform future decisions on processes in forestry that should be focused on when planning actions to reduce energy consumption and GHG emissions. Additionally, as roundwood timber is raw material for numerous products the results can be useful when preparing documentation of environmental impacts, such as environmental product declarations, which are increasingly demanded by the market.

Keywords Embodied energy, greenhouse gas emissions, carbon footprint, roundwood

Introduction

Forests play an important role as carbon sinks. Productive forest area covers 24% of the total land area in Norway and the forests have a growing stock of 765 million m^3. Annual increment is approximately 25 million m^3, and annual commercial roundwood removal is approximately 8 million m^3 (SSB 2009). In 2005 the net sequestration was calculated at 27.2 million metric tons of CO^2, which would offset 50% of the total greenhouse gas (GHG) emissions in Norway that year (SFT 2007).

Wood based products are generally recognized as favorable regarding energy consumption and GHG emissions. Several studies have shown that the net CO^2 emissions can be reduced by using biofuels harvested from forests to substitute fossil fuels (Schlamadinger *et al*. 1997, Gustavsson & Karlsson 2006), and by using wood for building materials (Börjesson & Gustavsson 2000, Petersen & Solberg 2002a, b, c, 2003, 2004, 2005, Lippke *et al*. 2004, Perez-Garcia *et al*. 2005, Gustavsson & Sathre 2006, Gustavsson *et al*. 2006a, b, Eriksson *et al.* 2007, Upton *et al*. 2008, Sathre & Gustavsson 2009) A comprehensive overview of scientifically studies are given in Alfredsen *et al*. (2008) and Wærp *et al*. (2008).

The global GHG and carbon profile of the forest products industry value chain consists of emissions, sequestration and avoided emissions. Wood can significantly reduce GHGs in atmosphere through:
- storing carbon in forests (increased carbon sink in next rotation) and products.
- product substitution (substituting fossil fuel-intensive products).
- using wood byproducts as fuel instead of fossil fuels.

Important differences in energy use and GHG balance of forest products exist between countries. They can be explained by a range of factors such as product mix, typical processes used, plant size, technology, plant age, feedstock quality, fuel prices and management attention for energy efficiency. This means that calculated figures for the environmental performance of a product should be handled with care when it comes to general validity.

Additionally, energy use and GHG emissions associated with producing roundwood can be influenced by a broad range of factors, such as silvicultural practice, topography, applied technology, forestland ownership, industrial structure, etc. This emphasizes the importance of using representative data for energy use and GHG emissions when calculating environmental impacts.

The objective of the reported study was to estimate energy consumption and GHG emissions associated with production of softwood sawlogs in Norway.

Material and methods

LCA (Life Cycle Assessment) is an objective method to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material uses and releases to the environment, and to evaluate and implement opportunities to influence environmental improvements. The method assesses the entire life cycle (cradle to grave) of the product, process or activities, encompassing extracting and processing material; manufacturing, transporting and distribution; use, reuse and maintenance; recycling and final disposal. The present work focus on energy and GHG emissions and not all the environmental impacts and resources consumed estimated in a full LCA specified in the 14000 series of the ISO Standards (ISO 2006). Functional unit is 1 m^3 sawlogs under bark. The studied system is illustrated in Figure 1. The study did not include upstream processes, such as the production of energy carriers or capital goods.

In principle the energy consumption and GHG emissions for a sawlog should be based on specific data for that sawlog. In Norwegian forestry it can take more than 100 years from a tree seed germinates to the logs from that tree are delivered to the industry. To avoid uncertainties associated with the long time span, and for reasons discussed later in this paper, the estimated energy consumption and GHG emissions of the sawlog production chain were based on overall activity data for different sub-processes in Norwegian forestry for the year 2007.

Data for annual industrial roundwood harvest (8,2 mill m^3) and activity data for different sub-processes in Norwegian forestry in 2007 were mainly based on reports from Statistics Norway and productivity analyses of various forest operations performed at the Norwegian Forest and Landscape Institute.

Emission factors and data for energy content and density of fuels were based on “The Norwegian Emission Inventory 2008” (Aasestad 2008). The report serves as a part of the National Inventory Report submitted by Norway to the United Nations Framework Convention on Climate Change (UNFCCC).

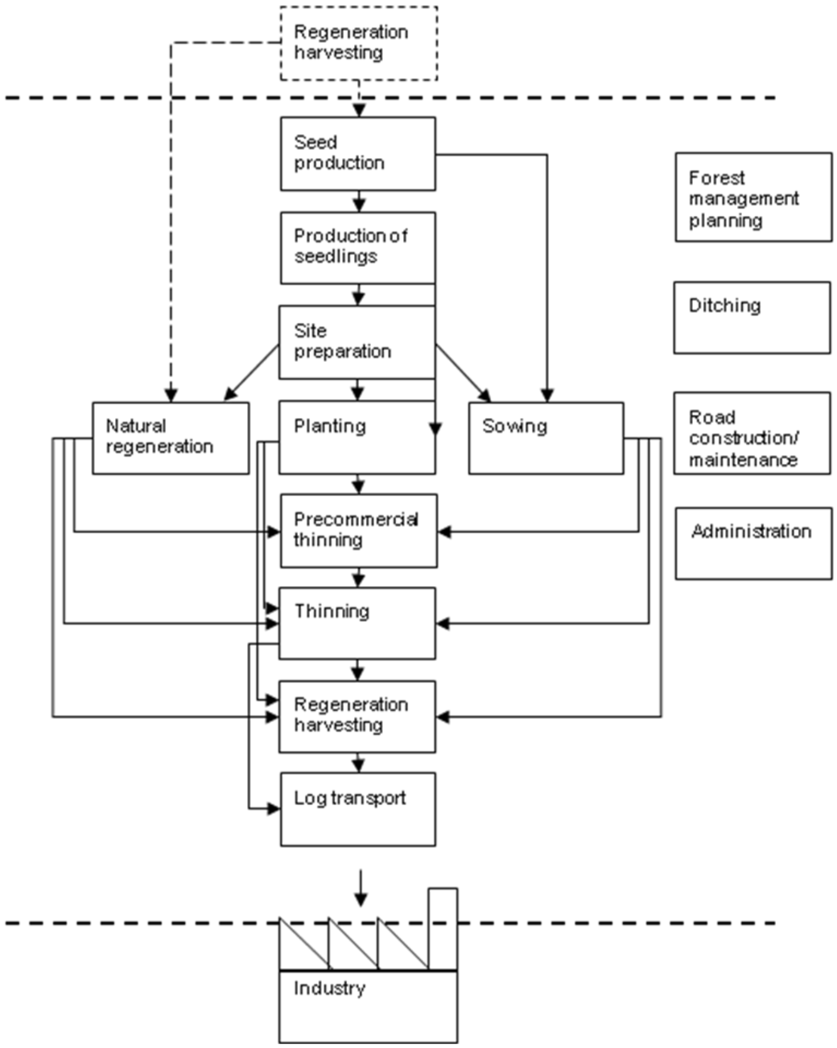

Figure 1. System flow chart illustrating sub-processes in the sawlog production chain.

Estimated GHG emissions were converted to Global Warming Potential (GWP). As defined by the Intergovernmental Panel on Climate Change (IPCC), a GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time period, such as 100 years (GWP_{100}). The GWPs for different emissions can then be added together to give one single indicator that expresses the overall contribution to climate change of these emissions expressed as kg CO_2 equivalents. According to IPCC Fourth Assessment Report: "Climate Change 2007" the GWP_{100} for carbon dioxide (CO_2) is 1, methane (CH_4) is 25, and nitrous oxide (N_2O) is 298.

Results

Embodied energy

The estimated energy consumption was 153 MJ/m^3 sawlogs. Figure 2 shows the energy consumption for different sub-processes in the production chain.

GHG emissions

The estimated GHG emissions were 12.1 kg CO_2 equivalents/m^3 sawlogs. Figure 3 shows the GHG emissions for different sub-processes in the production chain.

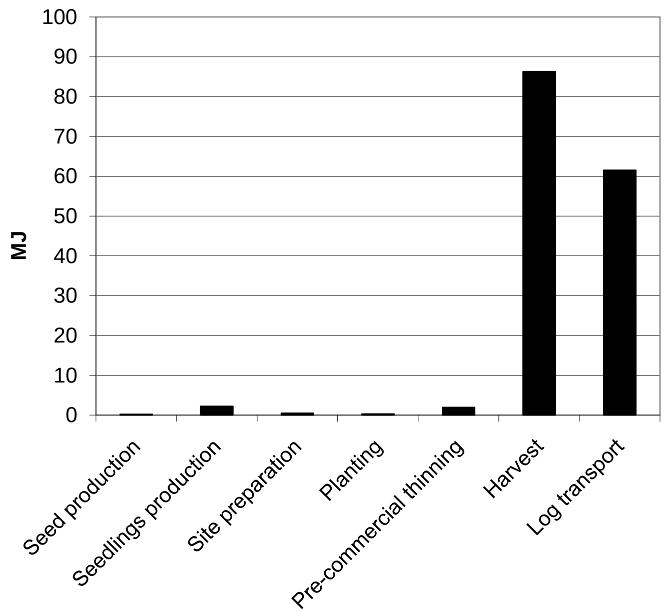

Figure 2. Energy consumption for different sub-processes in the sawlog production chain.

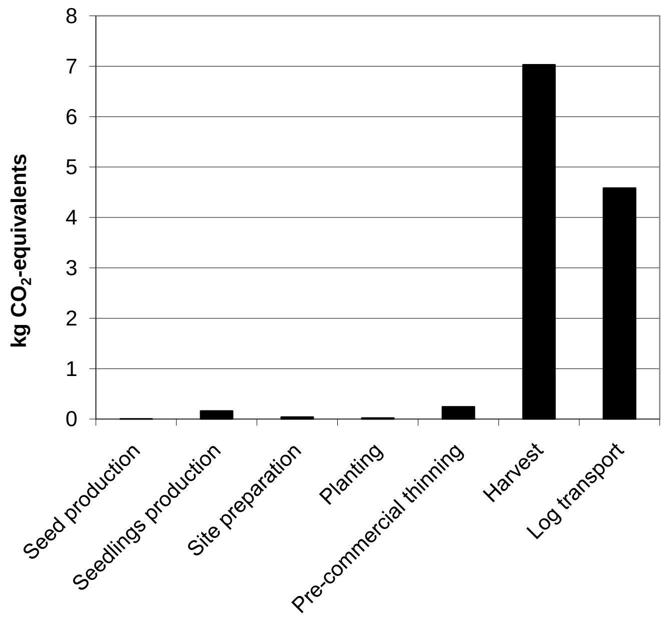

Figure 3. Global Warming Potential (GWP_{100}) for different sub-processes in the sawlog production chain.

Discussion

Wood based products are produced from a raw material that in many parts of the world has a life cycle stage of many decades. In Norwegian forestry it can take more than 100 years from a tree seed germinates to the logs from that tree are delivered to the industry. Obviously, it is difficult to track data for energy consumption and GHG emissions for a sawlog 100 years back in time. To avoid uncertainties connected with historical data and lack of data the present study was performed by estimating energy consumption and GHG emissions based on activity data for Norwegian forestry for the year 2007. There are also several other reasons why this approach is preferred. The forest owner is obligated to ensure that all harvested areas are satisfactorily regenerated to standards, implying that the harvesting process initiates the processes shown in Figure 1. By using new data the LCA-concept can be used to optimize the environmental performance of single sub-processes (eco-design) to improve the environmental performance of a product (in this case sawlogs). Last, but not least; the technological development in forestry during the last decades have increased the consumption of fossil energy, implying that use of present data instead of historical data will not lead to underestimated energy consumption or GHG emissions.

The energy consumption and GHG emissions associated with production and transport to sawmill of 1 m^3 Norwegian softwood sawlogs were in this study estimated to 153 MJ and 12.1 kg CO_2 equivalents, respectively. This is less than 2 % of the energy content or CO_2 equivalents stored in the wood. The processes mainly contributing to energy consumption and GHG emissions were harvesting and transport to sawmill. The energy consumption in this study is approximately at the same level as found in a study performed by Berg & Lindholm (2005). Their results showed energy consumptions varying from 147 MJ to 200 MJ in different regions in Sweden.

The study did not include upstream processes, such as the production of energy carriers or capital goods (machinery, logging roads, buildings, etc.). Additionally, some processes like pruning, fertilization, forest management planning and ditching were not included in the study. Many of these processes are of minor importance in this context. However, the study should be extended and complemented in future.

Despite the limitations mentioned above the results strongly indicate that actions aiming to reduce energy consumption and GHG emissions in the Norwegian softwood sawlog production chain should focus on the processes associated with harvesting and transport.

References

Aasestad, K (2008): The Norwegian Emission Inventory 2008. Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants. Statistics Norway. Reports 2008/48: 252 pp.

Alfredsen, G, Asbjørnsen, BR, Flæte, PO, Larnøy, E (2008): Miljøeffekter ved bruk av tre. Sammenstilling av kunnskap om tre og treprodukter. Oppdragsrapport fra Skog og landskap 03/08. 100 pp.

Berg, S, Lindholm, E-L (2005): Energy use and environmental impacts of forest operations in Sweden. Journal of Cleaner Production 13(1): 33-42.

Börjesson, P, Gustavsson, L (2000): Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives. Energy Policy 28(9): 575-588.

Eriksson, E, Gillespie, A R, Gustavsson, L, Langvall, O, Olsson, M, Sathre, R, Stendahl, J (2007): Integrated carbon analysis of forest management practices and wood substitution. Canadian Journal of Forest Research 37: 671-681.

Gustavsson, L, Karlsson, Å (2006): CO_2 mitigation: on methods and parameters for comparison of fossil-fuel and biofuel systems. Mitigation and Adaptation Strategies for Global Change 11: 935-959.

Gustavsson, L, Sathre, R (2006): Variability in energy and carbon dioxide balances of wood and concrete building materials. Building and Environment 41: 940-951.

Gustavsson, L, Madlener, R, Hoen, H-F, Jungmeier, G, Karjalainen, T, Klöhn, S, Mahapatra, K, Pohjola, J, Solberg, B, Spelter, H (2006a): The role of wood material for greenhouse gas mitigation. Mitigation and Adaptation Strategies for Global Change 11: 1097-1127.

Gustavsson, L, Pingoud, K, Sathre, R (2006b): Carbon dioxide balance of wood substitution: Comparing concrete- and wood-framed buildings. Mitigation and Adaptation Strategies or Global Change 11: 667-691.

ISO (2006): Environmental Management Systems. International Organization for Standardization.

Lippke, B, Wilson, J, Perez-Garcia, J, Boyer, J, Meil, J (2004): CORRIM: Life-cycle environmental performance of renewable building materials. Forest Products Journal 54: 8–19.

Perez-Garcia, J, Lippke, B, Comnick, J, Manriques, C (2005): An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. Wood and Fiber Science 37, Corrim Special Issue: 140-148

Petersen, A K, Solberg, B (2002a): Energiforbruk, klimagassutslipp og kostnadseffektivitet ved bruk av gulvbord i heltre eik sammenlignet med fem alternative gulvløsninger. Rapport fra Skogforskningen 2002(2). 72 s.

Petersen, A K, Solberg, B (2002b): Greenhouse gas emissions, life-cycle inventory and costefficiency of using laminated wood instead of steel construction. Case: Beams at Gardermoen airport. Environmental Science & Policy 5(2): 169-182.

Petersen, A K, Solberg, B (2002c): Limtre eller stål? En analyse av energiforbruk, klimagassutslipp og kostnadseffektivitet. Rapport fra skogforskningen 2002(1). 60 pp.

Petersen, A K, Solberg, B (2003): Substitution between floor constructions in wood and natural stone: comparison of energy consumption, greenhouse gas emissions, and costs over the life cycle. Canadian Journal of Forest Research 33: 1061-1075.

Petersen, A K, Solberg, B (2004): Comparison of GHG emissions and costs over the life cycle of flooring materials. Climatic change 64: 143-167.

Petersen, A K, Solberg, B (2005): Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden. Forest Policy And Economics 7(3): 249-259.

Sathre, R, Gustavsson, L (2009): Using wood products to mitigate climate change: External costs and structural change. Applied Energy 86: 251-257.

Schlamadinger, B, Apps, M, Bohlin, F, Gustavsson, L, Jungmeier, G, Marland, G, Pingoud, K, Savolainen, I (1997): Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems. Biomass and Bioenergy 13: 359-375.

SFT (2007): Revised National Inventory Report 2007 Norway. Greenhouse Gas Emissions 1990-2005 Reported According to the UNFCCC Reporting Guidelines. Statens forurensningstilsyn. 276 pp.

SSB (2009): Statistics Norway. www.ssb.no

Upton, B, Miner, R, Spinney, M, Heath, LS (2008): The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States. Biomass and Bioenergy 32: 1-10.

Wærp, S, Flæte, PO, Svanæs, J (2008): MIKADO - Miljøegenskaper for tre- og trebaserte produkter over livsløpet. Et litteraturstudium. SINTEF Byggforsk. Prosjektrapport. 65 pp.