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Cradle-to-gate inventory of wood production from Australian softwood plantations and native hardwood forests: Embodied energy, water use and other inputs

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ABSTRACT

With increasing focus on the environmental impacts of alternative land uses and materials, there is a growing need to produce accurate and verifiable life cycle inventories for forestry. A cradle-to-gate inventory was produced for wood from softwood plantations and hardwood native forests across Australia, covering all operations involved in forest establishment, management and harvesting and including transportation of logs and chips to processing facilities. The inventory was primarily based on data provided by forest growers, managers and contractors across seven case study regions. The SimaPro model was used to combine the different operations, and to account for upstream processes associated with the production of fuel and materials used. Forest products included high- and low-grade sawlogs, pulplogs, woodchips and other logs. Inputs were expressed in terms of m^3 product and were allocated to products on an economic basis. Key inputs for wood from softwood plantations included land (0.06 ha m^{-3}), water (0.12 ML m^{-3}), diesel (172 MJ m^{-3}) and fertiliser (0.3 kg N m^{-3}, 0.2 kg P m^{-3}, 0.06 kg K m^{-3}). Key inputs for wood from native forests included land (0.28 ha m^{-3}), water (0.38 ML m^{-3}) and diesel (355 MJ m^{-3}). The largest contributors to total energy use were log haulage (46% for softwood and 45% for hardwood) and harvesting and chipping (29% for softwood and 44% for hardwood). However, the total amount of energy used in the forestry production process (293 MJ m^{-3} for plantation softwood and 527 MJ m^{-3} for native hardwood) was very small relative to the net energy content of the logs harvested, representing just 4% of that in an average plantation softwood log and 6% of that in an average native hardwood log. Thus, forest products have low embodied energy and have strong potential for greenhouse gas mitigation when used for bioenergy.

1. Introduction

With growing awareness of the need to improve the environmental performance of products, Life Cycle Assessment (LCA) is increasingly being seen as a practical method for comparing the impact of alternative materials or processes in a consistent manner. Life cycle inventories (LCIs) and cradle-to-gate inventories (CGIs) provide the raw data for this analysis with the former tracking a product from its initial production to its final disposal and the latter tracking a product through just a portion of its lifespan.

The capacity of forests to sequester carbon, act as a source of renewable materials and energy and provide a range of other environmental services and benefits has seen increasing focus on the development of LCIs for the forest industry (e.g. Hillier and Murphy, 2000; Jungmeier et al., 1999; Kosir, 1999). Forestry CGIs have been developed or adapted for countries in Europe (Dias et al., 2007; Lewandowska et al., 2008; Schweinle and Thoroe, 1997; Seppala et al., 1998) as well as the USA (Gower et al., 2006; Johnson et al., 2005; O'Neil et al., 2010; Sonne, 2006; White et al., 2005). However, most previous forestry LCIs have focussed predominantly on greenhouse gas (GHG) balances, with little specific data on energy use and other inputs that could be used to assess other environmental impacts (e.g. Dias et al., 2007; Seppala et al., 1998; Sonne, 2006; White et al., 2005).

Life cycle inventories for wood production present a challenge because of the long time frames involved in the production process (the time from planting to harvesting can range from a decade to more than a century), the wide variety of operations included (e.g. site preparation, planting, road maintenance, fertiliser application, fire control, harvesting, extraction and haulage), the range of products generated (e.g. sawlogs of varying grades, posts, firewood,

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pulplogs and residues) and difficulty in quantifying non-wood values (biodiversity, tourism, water, etc.; Bosner and Porsinsky, 2008). Further, because tree growth rates, management systems and product characteristics are intrinsically related to the environmental conditions and locations in which forests grow, forestry LCIs can vary substantially for different regions, forest types and management objectives (e.g. Berg and Karjalainen, 2003; Dias et al., 2007; Lewandowska et al., 2008; Profft et al., 2009).

The development of a comprehensive LCI for forestry and forest products in Australia has been seen as a high priority for some years (Higham and Todd, 1998). Therefore, the aim of this study was to develop a CGI for forests in Australia used to produce solid wood products (e.g. sawn timber and engineered wood products). The Australian forestry industry is based on a mixture of native hardwood forests, and softwood and hardwood plantations. Solid wood products are primarily sourced from native forests and softwood plantations, while hardwood plantations are primarily grown for export woodchip (ABARE, 2010). Multiple use native forests, from which native hardwood logs are sourced, cover over 9 million ha and produce a total of 9 million m^3 logs annually, while softwood plantations occupy one million ha and produce 14 million m^3 $year^{-1}$ (ABARE, 2010). Hardwood plantations (mostly *Eucalyptus globulus* Labill.) planted over the past 12 years, occupy about the same area as softwood plantations, but currently produce just 5 million m^3 $year^{-1}$ although this amount is expected to increase substantially over the next 5 years as young plantations mature (Parsons et al., 2007). The present study includes only native hardwood forests and softwood plantations.

Undertaking a CGI for wood production in Australia has a number of unique challenges. These include the large range in climates, tree species and growth rates, and differing management priorities of the various Government agencies and private growers involved in forest management as well as the large number of private contractors involved in forest operations, harvesting and haulage. An important consideration is water-use by forests. In Australia, water is often a limiting factor for forest growth as well as for other uses. Thus, full assessment of environmental impacts of wood production should include accounting for evapo-transpiration (ET) or 'green water' use. However, quantifying the amount of water used is particularly difficult as there is no means to directly measure ET by forests across large areas. Further, the potential impact of water use depends on its origin (e.g. underground aquifers or soil moisture), relative abundance and level of competition for it between alternative land-uses, all of which are highly region-specific (Benyon et al., 2006; Hoekstra, 2009).

Most forestry LCIs have been limited to assessing inputs during growth and harvesting ('cradle-to-gate'; e.g. Johnson et al., 2005) although a few have attempted to follow the full life cycle of wood products ('cradle-to-grave'; e.g. Gower et al., 2006). The only published LCI of forestry in Australia is a partial assessment of primary energy inputs associated with growing and harvesting softwood plantations in one region of NSW, based on now outdated management and harvesting technologies (Wells, 1984). Here, we provide a CGI of inputs to native hardwood and plantation softwood forestry production in Australia from forest establishment to the delivery of logs and woodchips to processing facilities. The data are based on seven case studies from separate regions with major softwood plantations or native forests that are used for wood production. We estimate water use for both plantations and native forests and report on the direct inputs of natural resources (land, water), fuel (mainly diesel), fertiliser and other resources used in the forest production systems. The emissions from these inputs (CO_2 and non-CO_2 greenhouse gases and other emissions to air and water) are considered elsewhere (May et al., 2008; May et al., in preparation).

2. Materials and methods

2.1. Case studies

The inventory was based on seven case studies representative of the primary timber production regions for softwood plantations and hardwood native forests across Australia. The plantation softwood studies included the Green Triangle in south east Victoria and south west SA, Tumut in southern NSW, Fraser Coast in south-east Queensland and south west WA (Fig. 1). The native forest hardwood studies consisted of the Central Highlands in Victoria, central Tasmania and north east NSW (Fig. 1). Total annual log production for the four plantation softwood case studies was 7.0 million m^3 or 49% of mean annual softwood production across Australia for 2003–07, while total annual wood production for the three hardwood native forests case studies was 1.9 million m^3, representing 20% of total mean national production from these systems (ABARE, 2008: Table 2).

The geographic boundaries for the case study regions were based on those used in the National Plantation Inventory (Regions 3 and 4, Parsons et al., 2006) or local management areas (all others, Fig. 1). Data for each case study were sourced from local forest managers (e.g. forest areas, management inputs and wood production), forestry contractors (e.g. for fuel use during harvesting and haulage), or were derived from published studies (e.g. water use). To obtain a representative sample and preserve confidentiality of commercially-sensitive information, data from at least three contractors for each operation were aggregated for each case study region.

2.2. Production processes

The inventory covered wood production from seed/seedling to transport of logs and chips from the forest to processing facilities. The forestry system was divided into a sequence of four primary processes:

(i) Establishment: including production of seedlings in nurseries (plantations) or collection and processing of seed (native forests), site preparation (mechanical disturbance of sites and heaping of harvest slash), slash burning (burning of harvest residues), and planting (plantations) or aerial seeding or coppice management (native forests),
(ii) Management: including chemical application of herbicides or fertiliser (plantations only), fire prevention and control (fuel reduction burning, slashing and surveillance and control of wildfires) and roading (construction and maintenance of forest roads),
(iii) Harvest: including thinning (plantations only), final harvest (clear-felling or selective harvest of stands), and in-field chipping, and
(iv) Haulage: including transport of logs and chips from forest to processing facilities or ports.

Softwood plantations are grown in all states in Australia except the Northern Territory. The main species is *Pinus radiata*, with *Pinus pinaster* grown in drier regions in Western Australia and *Pinus caribaea* and *Pinus elliottii* grown in Queensland. Rotation lengths range from 25–35 years with between one and four thinnings prior to clearfelling. Site preparation is generally mechanical with residues mulched or, more rarely, heaped and burnt. Harvesting is usually by mechanical harvester with logs cut to length at stump and moved to the landing by forwarder, although in some situations (e.g. early thinnings) whole tree harvesting is practiced using a feller buncher and a skidder which snigs the harvested trees to a mobile chipper located at the landing. Transport of all harvested material is by road