ACQ-TREATED VENEER BASED COMPOSITE (VBC) HARDWOOD HOLLOW UTILITY POLES FROM MID-ROTATION PLANTATION THINNED TREES: LIFE CYCLE GHG EMISSIONS

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ABSTRACT

Hardwood plantations are slow to mature with low financial returns in the early stage. Veneer Based Composite (VBC) products from mid-rotation plantation thinned trees are currently being developed at Griffith University in partnership with the Salisbury Research Centre, Queensland Government, which may offer an opportunity to improve the industry's profitability and win new markets. Due to shortage in utility solid hardwood poles, VBC poles are proposed as a potential alternative. In this study, greenhouse gas emissions of alkaline copper quaternary (ACQ) preservative-treated VBC pole was assessed using 'cradle to grave' life cycle assessment methodology. ACQ preservative was used to extend the service life of wood poles due to wood products are commonly to be degraded in wet environments subject to microbial or insect attack. The manufacturing process considered in this study is based on the current technologies in Salisbury Research Centre. Two (2) end-of-life scenarios were considered: landfilling and incineration with energy recovery. The function unit was a 1-metre-length pole with 115mm internal-diameter and 15mm wall-thickness. Global warming potential (GWP100) was calculated using the IPCC 2007 method. Results indicated disposal stage contributed the most impact. Incineration with energy recovery had the lowest GWP impact (0.337kg-CO_2-Eq) followed by landfilling. Transportation distance was identified as a significant parameter affecting the result. Sensitivity analysis indicated that increasing the transportation distance by 100 km would increase the GWP100 by 21% in the incineration option.

KEYWORDS

Life Cycle Assessment, hardwood thinning, veneer based composited, Alkaline copper quaternary, pole.

INTRODUCTION

During the last decade, Australian hardwood plantations have increased by approximately 150% with total area of two million hectares, while 49% of this total is managed as hardwood plantations (Australian Government Department of Agriculture Fisheries and Forestry, 2010). Timber plantations present an opportunity to increase Australian long-term wood supply, while contributing to significant social, economic and environmental values (Australian Government Department of Agriculture Fisheries and Forestry, 2014). As it is essential to produce high quality logs at an early age (30 to 35 years), pruning and thinning are required during the early stage of the plantation to ensure sufficient light, moisture and nutrients are available for the rest of the trees (McGavin et al., 2006). Approximately 50% of the trees are typically cut from the third year during the first thinning, with another 30% removed in the second thinning (10 to 15 years). The removed trees during the second thinning (mid-rotation) are usually considered as low commercial value products due to no viable markets (Underhill et al., 2014). Recently, Veneer Based Composite (VBC) products have been developed at Griffith University in partnership with the Salisbury Research Centre (SRC), Queensland Government, from the logs cut during the plantation second thinning as high value applications (Underhill et al., 2014). These products can be applied to replace various engineered wood products (McGavin et al., 2006; Underhill et al., 2014).

Utility pole is defined as a column to support various public utilities, such as cable, fibre optic cable, and related equipment such as streetlights. These poles are usually sourced from native forest hardwood species (Gilbert et al., 2014). Hardwood is usually seen as the most appropriate solution for manufacturing these poles compared to the alternative materials, such as steel and concrete (Francis & Norton, 2006). However, due to the growing environmental awareness and concerns over the sustainability of forestry practices, agreements have been signed in Australia to phase out logging of native forests. Thus, the supply of hardwood utility poles will decrease sharply (Francis & Norton, 2006). At the same time, the demand for utility poles has increased (Australian Government, Department of Agriculture Fisheries and Forestry, 2014).

The new developed VBC hardwood hollow utility pole presents an alternative to replace traditional hardwood poles (Gilbert et al., 2014), while offering positive environmental and economic. Untreated wood products are easy to degrade in either weather-exposed or wet environments subject to microbial or insect attack (Ibach, 1999), chemical preservation is usually used to extend the service life of wood products (Morrell, 2004). Alkaline copper quaternary (ACQ) is one of the most commonly used preservatives for treating timber products (Bolin & Smith, 2011). Nevertheless, the sustainability of the product in terms of life cycle perspective needs to be established. For this reason, LCA is developed in this paper to assess the environmental performance of the ACQ-treated VBC hardwood hollow utility poles manufactured from mid-rotation hardwood plantation thinned trees.

This paper aims to conduct a LCA study to investigate the environmental performances associated with ACQ-treated VBC hardwood hollow utility poles manufactured from Gympie messmate (*Eucalyptus cloeziana)* mid-rotation plantation thinned trees. The environmental burdens of two different disposal scenarios are assessed to determine appropriate end-of-life treatment. Results of this study might have implications for hardwood plantation owners and utility companies to facilitate a better sustainable management of plantations and utilities networks.

METHODS

The goal of this study is to provide a scientifically based and comprehensive assessment of the environmental performance of the VBC hardwood hollow utility pole manufactured from mid-rotation hardwood plantation thinned trees over its life cycle. The scope of this study includes 'cradle to grave' life cycle inventory of the VBC hollow utility poles. The timbers are obtained from the hardwood plantation located in Queensland. LCI data are collected from AusLCI database, as well as published sources.

For collection of life cycle inventory inputs and outputs, small diameter poles, of 1 meter in length, with nominal internal diameter of 115 mm and 15 mm wall-thickness is assessed as one functional unit. The VBC utility poles are constructed from two half-poles jointed together, while each half pole manufactured from gluing nine veneers. The poles are similar to the ones tested in (Gilbert et al., 2014) and the manufacturing process is detailed in (Underhill et al., 2014).

The system boundary begins with hardwood seedling and ends with the VBC poles being deposited in landfill, recycled or reused. Planting the seedlings, forest management (i.e. site preparation, first thinning and fertilisation), and second thinning are considered in the system boundary of plantation. Transporting thinned logs from the plantation site to the mill is accounted for the pole manufacturing. Seedlings, fertiliser and energy consumptions are considered as inputs in the first stage. The VBC timber pole manufacturing process are divided into several small process units: transportation, debarking and cutting, pre-conditioning, logs peeling, veneer drying, compressing, trimming, VBC utility pole forming, and transporting to the utility lines. The final stage includes pole services in utility system and final disposal (e.g. landfilling and incineration for energy recovery). The system boundary is presented in **Figure 1**. As the thinned log is a by-product from the forestry industry, allocation is required. In this study, economic allocation was used following May et al. (2012). In economic allocation, impacts were distributed among co-products according to their market value.

The global warming potential (GWP100) is investigated in this LCA. OpenLCA software was used to conduct the LCA analysis (GreenDelta, 2014). IPCC 2007 life cycle impact assessment (LCIA) method was used for the characterisation of emissions into the relevant impact category.

LIFE CYCLE INVENTORY (LCI)

The inventory analysis involves data collection and analysis for the cradle-to-grave life cycle of the VBC utility poles. For each stage of the product life cycle, inputs of energy and raw materials, outputs of products, waste, and emissions releases to environment are determined. In addition, hardwood plantation system is assumed in a steady state both with respect to carbon stocks and management operations. This assumption has been used either explicitly or implicitly in most other forestry LCIs (e.g. Schweinle & Thoroe, 1997; Seppala et al., 1998;

Sonne, 2006, Dias et al., 2007). Life cycle inventory (LCI) data are collected from different sources, including published literature and the Australian National Life Cycle Inventory (AusLCI, 2011).

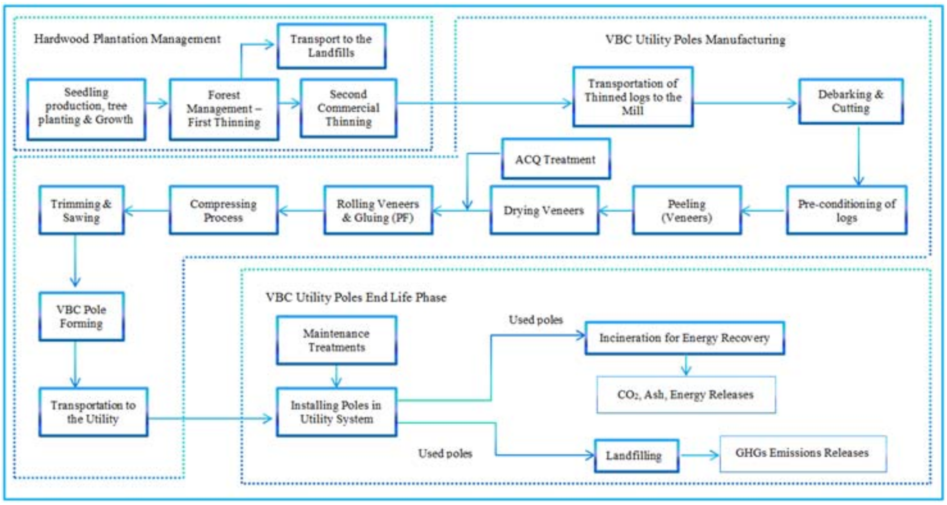

Figure 1 System boundary of VBC pole

Hardwood Plantation Operations

The specific processes during establishment include seedling production, site preparation, slash burning (burning of residues) and planting. Management process includes chemical application of herbicides or fertiliser, fire prevention and control and construction of forest roads. Thinning process starts from first thinning to second commercial thinning. The electricity consumption for greenhouse operations, fertiliser used for seedling production and growth, and the diesel fuel and lubricants required to power equipment during site preparation, fertilisation, and thinning are considered as the inputs. The primary output in this analysis is the green logs from second thinning. The other products, such as non-merchantable slash and brunches are usually treated by mechanical activities or prescribed fire on site, which is not included in the system boundary. Table 1 presents a summary of materials and energy consumption of hardwood plantation.

Table 1 Average fuel and materials consumptions of hardwood plantation per m^3 in QLD region (sourced from May et al., 2012)

Inputs Energy & Materials	Unit	Quantity
Land	ha year m^3	0.08
Water	ML/m^3	0.23
CO_2 sequestration	kg/m^3	1,030
Diesel	L/m^3	6.8
Aviation fuel	L/m^3	0.02
Lubricant	L/m^3	0.12
Tyres	kg/m^3	0.09
Steel	kg/m^3	0.08
Gravel	kg/m^3	640
N Fertiliser	kg/m^3	0.04
P Fertiliser	kg/m^3	0.11
K Fertiliser	kg/m^3	0.08
Herbicide (Glyphosate)	g/m^3	11.4
Herbicide (Simazine)	g/m^3	19.2
Herbicide (Triclopyr)	g/m^3	1.4

VBC Utility Poles Manufacturing

In order to extend the service life of VBC poles, ACQ treatment is assumed in this LCA. The ACQ-treated VBC utility poles manufacturing process are based on current technology used at the Salisbury Research Facility and the LCI data is collected from different published sources.

The production of one function unit of hardwood VBC pole consumes 0.0142 m^3 of green logs. The main inputs considered in the LCI analysis are the hardwood logs from second thinning into the veneer process, leading to veneer input into the VBC process. The logs are green and include wood and bark with moisture content of approximate 50%. The main inputs to manufacture one functional unit of average Australian VBC pole are listed in Table 2.

Table 2. Inputs and outputs to produce one functional units of VBC pole average Australian veneer based composite including energy from veneer production (adapted from Ayres, Ayres & Rade, 2003; Tucker et al. 2009; Wilson, 2009; Puettmann et al., 2013).

Material Inputs	Value/function unit	Unit
Hardwood thinned log	0.0142	m^3
Phenol Formaldehyde Adhesive	0.360	kg
ACQ	0.03	kg
Flour	0.0343	kg
Filler	0.0243	kg
Phenolic Overlay sheets	0.0655	kg
Acrylic Putty	0.0036	kg
Phenol Formaldehyde Putty	0.0012	kg
Transportation	1.91	tkm
Total Energy consumption		
Electricity	0.9123	kWh
Natural Gas	0.0312	m^3
LPG	0.0086	L
Diesel Fuel	0.0135	L
Wood fuel	18.1765	MJ
Water	2.0083	L
Output Products		
VBC Pole	0.006	m^3
Wood waste	2.7875	kg

VBC Utility Pole Service Life

The ACQ-treated VBC utility pole service stage includes transportation of pole, installation, and maintenance during its service life. Steel bolts used to attach the VBC poles and other hardware are installed by the utility, but they are not considered in the LCI analysis due to steel bolts used to mount cross-arms generally are the same for all poles (Bolin & Smith, 2011).

An average distance of 100 km is assumed for pole transportation, which translates to 0.37 tkm per functional unit of pole. Transportation data are sourced from AusLCI database (AusLCI, 2011). An average service life of 25 years is assumed for VBC poles according to the survey conducted by the Salisbury Research Centre (H. Bailleres, personal communication, December 22, 2014). Most utility poles have regular inspection programs around 8 to 12 years (Mankowski, Hansen & Morrell, 2002). An inspection and maintenance program is included in this LCI. Each pole is assumed to be inspected and maintained every 10 years. The treatment model assumes that 0.069 litres/pole of paste is needed per treatment, consisting 2% of copper, 43% borate (DOT), 10% petroleum (as a surrogate for other possible fossil fuel derived ingredients), water, and mineral filler/thickeners. Based on data published by Bolin & Smith (2011), the treatment per functional unit consists of 0.0014 L copper, 0.0297 L borate and 0.0069 L petroleum.

End of Service Life

At the end of service life, poles may have recycling value as treated wood, such as fence posts or landscaping or as fuel to produce process heat and/or electricity. Some utility companies also simply dispose of the used poles as solid waste in landfills. In this study only landfilling and incineration with energy recovery are considered.

Scenario I – landfilling

Disposal stage begins with the poles transport to landfill and includes processing of the landfilling, as well as emissions release. Collection and transportation distance between utility lines and landfill is assumed as approximately 100 km. The landfilling results in 40.164 kg of wood carbon released as carbon dioxide, while 8.453kg of methane released per 1000 kg of wood waste (AusLCI, 2011). At landfills with a CH_4 capture infrastructure, typically up to 75 % of the CH_4 generated is assumed to be captured by the collection system (Ramseur et al., 2009). An analysis of the primary metal components in the wood conducted by Dubey et al.

(2009) indicated that copper and boron concentrations in the ACQ-treated wood samples were 3750+/-125 mg Cu/kg and 510+/-35 mg B/kg. These concentrations are consistent with the manufacturer rated concentration of 4 kg/m^3 (kilogram of total metal oxide components per cubic meter of treated wood).

The landfilling considered in this study includes 100 years of product life after disposal. This time frame is consistent with other solid waste studies (e.g. Diaz & Warith, 2006; El Hanandeh & El-Zein, 2010). The LCI of landfill construction and closure is adopted from Mènard et al. (2003). Landfilling emission outputs data of wood waste is sourced from AusLCI database (AusLCI, 2011). The LCI data for VBC pole in landfill is shown in Table 3.

Table 3. LCI data for wood waste in landfill in QLD region per functional unit (adapted from Mènard et al., 2003; Dubey et al. 2009; AusLCI, 2011)

Input Flow	Value/function unit	Units
Wood and wood-waste, at landfill	3.71	kg
Electricity, low voltage, Australian	0.003	kWh
Transportation	0.371	tkm
Diesel, burned in building machine/GLO U	0.143	MJ
Output Flow	Value	Units
Carbon dioxide, biogenic	0.149	kg
Methane, biogenic	0.031	kg
Non-methane volatile organic compounds, unspecified origin	0.014	kg
Copper	0.015	kg
Boron	0.002	kg

Scenario II – combustion for power generation

VBC Poles recycled for power generation are assumed to be combusted in large cogenerations that include electrostatic precipitators. The transportation distance is assumed 100 km to power plant. During the energy recovery, the wood carbon is released as biogenic carbon dioxide and the combusted preservative carbon will be released as fossil carbon dioxide (Bolin & Smith, 2011). Lin et al. (2007) investigated the ACQ-treated woods during combustion and noted that the released CO gas was about 179.3 ppm. The maximum NO_x of the ACQ treated wood was about 23.5-26.5 ppm. By clarifying the residual elements of discarded ACQ treated wood products; the results indicated the char of the ACQ left an amount of inorganic metal elements, Cu (50.14%) (Lee et al., 2005; Lin et al., 2006). The other components of ACQ were volatilized with the increase in temperature during combustion (Lin et al., 2007).

The LCI of wood waste incineration is based on Australian published sources. The utilities used in the waste incineration plant, the bottom ash from incineration and air pollution residues are included in the system. The bottom ash (approximately 220kg/Mg of treated wood product) is disposed in landfill. The energy recovery through wood waste combustion is modelled as energy credit due to the avoidance of production of materials from virgin feedstock (coal and natural gas) and the gains of electricity. The energy content of wood waste is assumed to be 9.5MJ/kg, while the efficiency of power generation for wood waste is 20% based on NSW Environment Protection Authority (2012). Thus, 10.57MJ of electricity is generated per functional unit of utility pole, while the heat waste is approximately 24.67MJ/functional unit. The LCI data of ACQ-treated wood in incineration is presented in table 4.

Table 4. LCI data of wood waste for energy generation in QLD region per functional unit (adapted from Lin et al. 2007; Ximenes, Robinson &Wright, 2007; Tucker et al., 2009; DCCEE, 2011a,b; NSW Environment Protection Authority, 2012)

Input Flow	Value/ Function Unit	Units/Pole
Wood and wood-waste	3.71	kg
Transportation	0.453	kg
Output Flow		
Electricity	10.57	MJ
Heat, waste	24.67	MJ
Carbon dioxide, biogenic	6.056	kg
Nitrogen dioxide	0.004	kg
CO	0.001	kg
NO_x	0.0001	kg

Cu	0.012	kg
Bottom ash	0.816	kg

RESULTS, ANALYSIS AND DISCUSSION

To assess the processes that result in GWP100 from ACQ-treated VBC utility poles, impact indicator values are added to the entire life cycle stages. The results show that incineration with energy recovery option (0.337 kg $CO_{2\ eq}$) out-performs the landfilling option (2.784 kg $CO_{2\ eq}$) with respect to GWP100 impact. This is mainly due to avoided methane release from the landfill.

Bolin & Smith (2011) conducted a LCA to compare the environmental impacts of pentachlorophenol (Penta) treated solid wooden utility pole to steel and concrete poles. Our study indicates that VBC hollow poles may have higher environmental burdens than penta-treated softwood solid pole when considering landfilling as end of life treatment. On the other hand, the impacts of the VBC poles may be reduced if incineration with power generation is used for disposal. Results of this study also indicate the GWP100 potential of VBC utility poles is lower than similar standard concrete poles (7.225 kg CO2-eq per functional unit) and steel poles (3.68 kg CO2-eq per functional unit) (Bolin & Smith, 2011). That is mainly because fewer raw materials are required for casting VBC poles. Furthermore, the hollow structure makes VBC poles lighter, hence less transportation emissions compared to the much heavier concrete poles. Additionally, during the manufacture of ACQ-treated VBC utility poles, fossil fuel is mostly substituted by wood fuel (wood waste) that burn in the boiler for heating, thus avoiding the GHG emissions generation.

Figure 2 presents the percentage contribution to GHG emissions of each stage during of the two EOL scenarios. Thinned logs, VBC poles in service and the final disposal stages contribute most of the environmental impacts under GWP100, particularly due to transportation, PF resin production and GHGs emissions release during wood decay. Specifically:

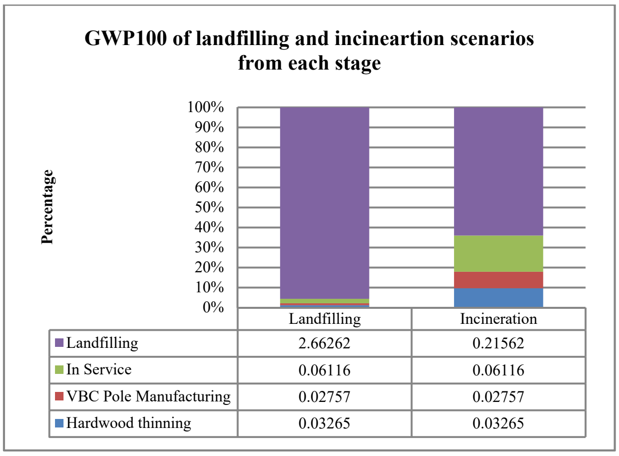

Figure 2 Comparison of emissions from different life stages of each scenario

- In the landfill, approximately 95% of GHG emissions result at the end of the life cycle stage mainly caused by methane release from decay of the treated wood, as well as CO_2 from transportation. However, this result is subject to the assumptions, especially related to GHGs emissions generation and capture. Meanwhile, during the incineration approximately 65% of GHG emissions result at the end of life cycle stage mainly due to waste transportation and GHGs emission generation.
- Natural gas and diesel fuel inputs to the treated VBC pole life cycle mostly mainly occur in the pole manufacturing stage. Approximately 22% of GHG emissions result from the natural gas and diesel fuel combustion due to the veneer pre-conditioning, drying, and compressing process during the manufacturing.
- PF resin manufacturing contributes to 33% of the emissions potentially resulting in GWP100 mainly due to transportation of raw materials.

Sensitivity Analysis

Sensitivity analysis is completed to determine the effects of assumptions change on LCA results. Items or categories, which show high sensitivity effect on impact indicator, are discussed in details below. Additional information and model results are included.

PF resin

PF resin consumption in VBC products is adjusted due to the different manufacturing technologies available. The baseline used in this assessment is 53.6kg/m^3. Two cases are modelled for sensitivity analysis, including: 1) at 10kg/m^3 and 2) at 60kg/m^3. For landfilling option, increasing the PF resin consumption from 10 to 60kg/m^3 is not significantly affecting the GWP100, which only increases by 2% in total due to the final disposal contains extremely high contribution of GWP100. Meanwhile, increasing the PF resin consumption, from 10 to 60kg/m^3 results in total GWP100 rises by 46% (shown in **Figure 3**).

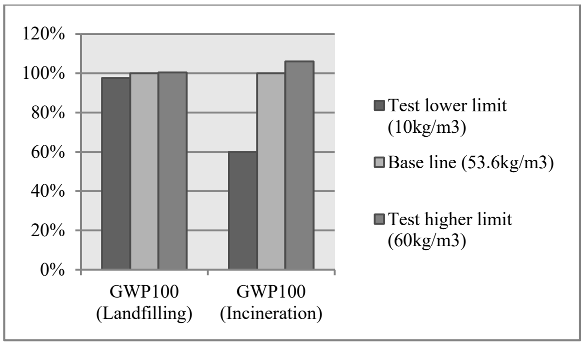

Figure 3 Sensitivity analysis for landfilling and incineration scenarios: PF resin production and consumption

Transportation

In this study, transportation distance of products from manufacturing facility to the utility system is assumed to be 100 km per functional unit with 10% return load. However, distances in the range of 50 -150 km are reported. As expected, changing the transportation distance from 50 km to 150 km only increases the total GWP100 by 1% in landfilling scenario. In the case of incineration, it results in increasing GWP100 by 21% (shown in **Figure 4**).

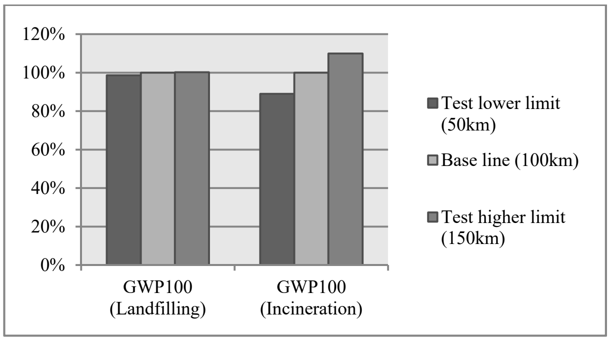

Figure 4 Sensitivity analysis for landfilling and incineration scenarios: transportation distances

Landfilling Disposal

This LCA assumes that 77% of the carbon absorbed by the wood is sequestered after decomposition in landfill, as reported in Barlaz (1998). However, preservative and other inorganic compounds in the disposed wood are expected to retard carbon release when compared to untreated wood (Bolin and Smith, 2011). Two cases are modelled for sensitivity; 50% and 90% of sequestered carbon. The results show that a higher sequestration percentage reduces the GWP impact indicator by approximately 14%, while reducing the sequestration percentage to 50% increases the GWP impact by 30% when compared to the baseline model (**shown in Figure 5**). Nevertheless, a field investigation of wood decay in Australian landfills revealed that wood deposited in landfills have remained virtually intact (Ximenes et al., 2015). Therefore, it is most likely that the GWP of the landfilling option is much smaller than what is predicted in this LCA study.

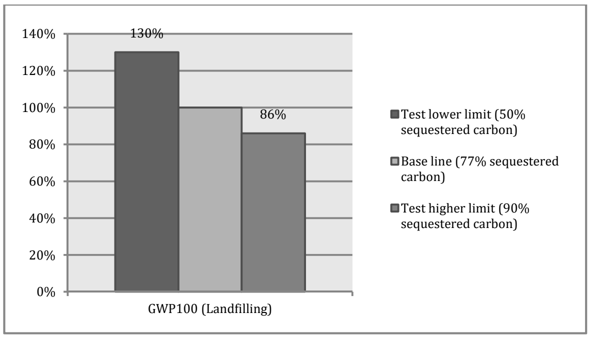

Figure 5 Sensitivity analysis for landfilling scenario: landfilling disposal

Limitations

The scope of the study is limited to boundaries established in the goal and scope documented in this study. Limitations included reliance on published and publically available information in many instances. Such information is assumed to be accurate. The life cycle inventory completed for VBC pole manufacturing is designed to represent the typical poles for traffic light. Nevertheless, the impact of manufacturing the VBC poles may vary according to the technology and scale used. Inventory data for the wood waste disposal are sourced from the Australian LCI database. This study only assessed the GWP100, other impact indicators are not considered. Additionally, the life cycle cost was not evaluated in this study. Further studies using life cycle costing is needed to gain comprehensive understanding of the system. This LCA focused on ACQ-treated VBC poles. While portions of this LCA may apply to poles treated with other preservatives, the overall conclusions only apply to ACQ-treated VBC products.

CONCLUSION

This LCA study assessed the environmental impact of ACQ-treated VBC hollow poles using life cycle methodology. Two disposal scenarios, landfilling and incineration, for end of life treatment were considered. The incineration option presented a better environmental performance than landfilling, mainly due to the avoidance of methane release during the disposal stage. In addition, the energy recovery through wood waste combustion is seen as an energy credit, which offered positive environmental benefit to the incineration scenario. Long distance transportation and fossil fuel consumption due to the thinning process, pole manufacturing and service in utility system were also identified as the main contributors to the GWP100.

This study focuses solely on the environmental performance of the VBC poles. It is recommends that the economic and technical feasibility of the poles and the alternatives should be considered. Further research is required to evaluate the environmental, economic and social impacts to achieve comprehensive understanding of the viability of the proposed VBC hollow utility poles as an alternative solution to hardwood poles for the Australian utility network.

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