Journal of Cleaner Production 69 (2014) 199–207

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Analysis of the global warming potential for wood waste recycling systems

Mi Hyung Kim [a,*], Han Byul Song [b]

[a] Department of Environmental Planning, Graduate School of Environmental Studies, Seoul National University, San 56-1, Sillim-dong, Gwanak-gu, Seoul 151-742, Republic of Korea
[b] Department of Chemical and Biological Engineering, University of Colorado, Boulder, CO 80309, USA

ARTICLE INFO

Article history:
Received 22 December 2012
Received in revised form
8 January 2014
Accepted 12 January 2014
Available online 24 January 2014

Keywords:
Wood wastes
Environmental benefit
Life cycle assessment
Carbon storage
Global warming

ABSTRACT

Wood waste is a renewable resource that can be recycled for particleboard production or energy production. Particleboard is the most common product of wood waste recycling, and energy production using biomass has been highlighted for energy recovery and the reduction of greenhouse gas emissions in recent years. The aim of this study was to evaluate the environmental benefits of particle board production and energy production using wood wastes. The system expansion method was applied to the quantification of the environmental benefit of two different recycling systems. Life cycle assessment methodology was used to analyze the environmental impacts of the systems, and the functional unit was 1 tonne of wood wastes. The results for both recycling systems showed that the particleboard from wood wastes produces −428 kg CO_2-eq compared to particleboard from fresh woods, and the energy production using wood wastes is −154 kg CO_2-eq compared to that of the combined heat and power generation process. The concept of temporary biomass carbon storage was applied to the study.

1. Introduction

Wood is a renewable resource that can be used for wood products and energy production (Jungmeier et al., 2002a,b). Recycled wood waste can replace virgin raw materials and reduce the expenses for logging and transportation and for disposal such as incineration or landfilling. The recycling of wood waste can decrease environmental burdens through the reduction of materials, water, and energy used in production processes compared to when virgin raw materials are used; therefore, it is expected that recycling methods will be necessary given the current critical situation characterized by the exhaustion of fossil fuel, the increase in oil prices to record highs, the increase in the occurrence of natural disasters due to climate change, and inquiry of carbon reduction (Zhong et al., 2010; Burnley et al., 2012).

The amount of carbon dioxide released into the atmosphere while wood is burning or decomposing is the same as that absorbed by the tree during growth. The released carbon dioxide is collected again within a neutral carbon cycle; thus, it does not contribute to global warming. However, material recycling, such as the production of particleboard, keeps the absorbed carbon continuously inside the wood products for a long period.

Nebel et al. (2009) studied the environmental impacts associated with the production of 1 kg of particleboard and 1 kg of plywood. The study showed that wood products from wood waste have carbon storage capabilities greater than the carbon discharged in the production process; thus, wood products offset the impact of global warming. Another study showed the environmental impacts of a particleboard production process for 1000 ft^2 of particleboard production in Canada by life cycle assessment (LCA). The global warming potential (GWP) was 311.2 kg CO_2-eq, and approximately 88.2% and 8.2% of the GWP was generated from the use of fossil fuel in the production process and transportation, respectively (ASMI, 2009). Rivela et al. (2006a) constructed inventories of a particleboard production process. The process included wood preparation, board shaping, and board finishing. The results showed that the environmental risks impacting global warming were finishing, shaping, and preparation, in descending order. The study compared heat production using a biomass fuel (woodchips) with heat production using liquefied natural gas (LNG). The results showed that the energy system using LNG contributed more to climate change than that using waste wood. Another study constructed two scenarios: particleboard manufacturing using recycled wood waste, with energy generated from non-renewable sources; and particleboard production using conventional wooden resources, with energy generated from the combustion of wood waste. The study showed that the direct use of wood waste for particleboard

* Corresponding author.
E-mail address: mhkim9@snu.ac.kr (M.H. Kim).

0959-6526/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2014.01.039

manufacturing seemed to be more favorable from an environmental perspective (Rivela et al., 2006b). Wilson (2009) constructed a life cycle inventory of a particleboard production process, including the measurement of the carbon storage within the panel. The study showed that the carbon stored in 1 m^3 of particleboard was −1290 kg CO_2-eq, based on a 52.4% carbon content in wood. The carbon store is treated as a negative value when determining the carbon flux. The storage of −1290 kg CO_2-eq in the particleboard offset its carbon footprint of 392 kg CO_2-eq, yielding a net cradle-to-gate carbon flux of −898 kg CO_2-eq for the product.

The objective of the study was to evaluate the environmental impacts of wood waste recycling systems, particleboard production and combined heat and power (CHP) generation. Tax issues in carbon emission regulations associated with climate change are an important international concern (Kim et al., 2013). Therefore, the characteristic GWP was finally selected as an environmental indicator to evaluate the impacts of global warming. Each GHG value is quantified as carbon dioxide equivalents, according to IPCC (Intergovernmental Panel on Climate Change) indicators (IPCC, 1997). The GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

2. Methodologies

2.1. Goal and scope definition

The goals of the study were to evaluate and compare the environmental impacts of two scenarios, the particleboard production process and the process of energy recovery by CHP generation, using LCA methodology according to ISO 14040 (2006) and 14044 (2006). The carbon storage capabilities of wood were calculated, and then the environmental impacts of this temporary carbon storage on global warming were evaluated.

2.2. Scenario construction and process description

This study was performed to evaluate and compare wood waste recycling systems, material recycling and energy recovery systems. The reference flow was 1 tonne of wood waste.

- Scenario 1: Material recycling

GWP from particleboard production + environmental benefit + carbon storage in particleboard.

- Scenario 2: Energy recovery

GWP from combined heat and power plant + environmental benefit.

2.2.1. Process of particleboard production

Material recycling of wood waste includes the production of particleboard or MDF (medium density fiberboard). These methods have the advantage of repeated recycling under separate collection. Particleboard is produced from industrial wood residues such as shavings, sawdust, plywood trim, fine particles, chips, or urban wood waste chips. Particleboard is mostly used in industries as a substitute material for making household or office furniture, kitchen and bath cabinets, store fixtures, door components and, to a small degree, in flooring. Wood waste is a high-quality substrate for making particleboard due to the characteristics of wood waste, which include a density between 0.5 g/cm^3 and 0.9 g/cm^3 and a water content less than 25%; therefore, it is preserved from bacterial attack.

Particleboard is manufactured by mixing wood particles or flakes together with resin and forming the mix into a sheet, as shown in Fig. 1. The raw wood waste is fed into a disk chipper with between four and 16 rapidly spinning blades. The particles are first dried, after which any oversized or undersized particles are screened out. Resin is then sprayed through nozzles onto the particles. Panel production involves various other chemicals including wax, dyes, wetting agents, and release agents to make the final product water resistant, fireproof, or insect-proof, or to give it some other quality. After the resin has been mixed with the particles, the mixture is made into a sheet. In graded-density particleboard, the rotating flakes are spread by an air jet that throws finer particles farther than coarse ones. The sheets are then cold compressed to reduce their thickness and make them easier to transport. The sheets are compressed again under pressures of 2∼3 MPa and temperatures between 140 °C and 200 °C. This process sets and hardens the glue. The boards are then cooled, trimmed and sanded.

2.2.2. Combined heat and power plant using woodchips

Woodchips and wood pellets from wood waste are used as fuels for woodchip boilers or stoves, as well as combined heat and power generation. Wood fuel contributes to air pollution less than fossil fuel and is available for storage as well as transportation and thus has a high economic efficiency as a replacement for traditional fossil fuel (Vinterbäck, 2002). Wood pellets have a high energy density and low water content because they are compacted under pressure; when used for heating, 1 tonne of wood pellets equals 120 gallons of heating oil (MDES, 2007). Approximately 1937 kg of CO_2-eq can be avoided per tonne of pellets used for electricity generation in the Netherlands; therefore, the use of pellets can achieve substantial GHG savings (Pa et al., 2012). Oil costs and wood waste disposal costs can be decreased if power plants and boilers replace traditional fossil fuels with renewable energy derived from wood waste. The most important benefit of bioenergy is greenhouse gas reduction by substituting fossil energy (Jungmeier et al., 2003).

Woodchips are medium-sized solid materials made by cutting or chipping larger pieces of wood. Woodchips are traditionally used as a solid fuel for heating buildings or in energy plants for generating electric power from renewable energy. The advantages of woodchips are their low cost and controlled fuel value. Wood fuel is attractive in light of the energy crisis and climate change because biomass is widely available and is carbon neutral. This solid biofuel is made of wood waste, forest residue, and construction materials in the form of woodchips and wood pellets. Energy is recovered by burning or gasification through heat transformation, and electricity is then generated. Waste heat discharged from a cooling process is usually used for room heating or hot water supply. Another advantage is that wood fuel does not have any waste disposal issues because burning woodchips results in the production of biochar, which can be used as a plant fertilizer.

Wood has three main components. Cellulose, which is derived from glucose, constitutes approximately 41∼43%. Next in abundance is hemicellulose, which represents 20∼30%. Lignin is the third component, constituting approximately 23∼27%. The high pressure of the press causes the temperature of the wood to increase greatly, and the lignin plastifies slightly, forming a natural glue that holds the pellets together as it cools. Wood fuel is expected to replace residual fuel oil (No. 6 fuel oil) or LNG in combined heat and power plants due to carbon reduction policies or regulations such as renewable portfolio standards. The combined heat and power process includes a wood pellet storage silo, input hopper, boiler, steam turbine and generator, and bag filter (Fig. 2).