Forest Policy and Economics 92 (2018) 181–192

Contents lists available at ScienceDirect

Forest Policy and Economics

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

Life-cycle carbon budget of China's harvested wood products in 1900–2015

Xiaobiao Zhang[a,c], Hongqiang Yang[a,b,c,*], Jiaxin Chen[d]

[a] College of Economics and Management, Nanjing Forestry University, Nanjing 210037, China
[b] Center for the Yangtze River Delta's Socioeconomic Development, Nanjing University, Nanjing 210093, China
[c] Research Center for Economics and Trade in Forest Products of the State Forestry Administration, Nanjing 210037, China
[d] Ontario Forest Research Institute, Ministry of Natural Resources and Forestry, 1235 Queen Street East, Sault Ste. Marie, ON P6A 2E5, Canada

ARTICLE INFO

Keywords:
Carbon budget
Harvested wood products
Life cycle perspective
Carbon stock
Carbon emission
Stock-change approach

ABSTRACT

Harvested wood products (HWP) are essential carbon pool of the forestry sector and can play an important role in climate change mitigation. Since the 10th Conference of Parties to the United Nations Framework Conversion on Climate Change in 2009, HWP have been required to be included in forest management as an additional carbon pool in national greenhouse gas (GHG) inventory reports. China is the largest consumer of end-use HWP and the largest importer of primary HWP in the world. Thus, the carbon stocks and emissions of China's HWP must be accurately assessed for evaluating their contribution to the climate change mitigation potential of global HWP. We developed an analysis framework by using Stock-Change Approach to estimate China's HWP carbon stocks/emissions from a life-cycle perspective, which covers three HWP life-cycle stages, namely, manufacture, end use, and end-of-life disposal. Using this framework, we produced the first-ever life-cycle carbon budget for HWP consumed by China in the period 1900–2015, based on a comprehensive analysis of China-specific data. From 1900 to 2015, total wood fiber input to the HWP carbon system in China was estimated to be 8049 teragrams of carbon dioxide-equivalent (Tg CO_2-eq). Of the total wood fiber input, discarded mill residue, in-use HWP, and HWP disposed of at solid waste disposal sites retained 513, 3284, and 659 Tg CO_2-eq of carbon, respectively, with the remaining 3591 Tg CO_2-eq of wood carbon released back to the atmosphere. Of the total emission, combustion and decomposition of mill residue, burning of fuelwood, and combustion and decomposition of retired HWP accounted for 36.5%, 24.6%, and 38.9%, respectively. Landfill methane emissions were estimated to be 780 Tg CO_2-eq after considering the global warming potential of this greenhouse gas. The net HWP carbon stocks, the sum of the carbon retained by discarded mill residue and the carbon stocks of HWP in use and in landfills, minus landfill methane emissions, increased from 297 Tg CO_2-eq in 1950 to 4456 Tg CO_2-eq in 2015.

1. Introduction

Climate change is a major environmental problem that must be addressed worldwide (IPCC, 2014a). Forests are the largest carbon pool among land ecosystems (FAO, 2010) and store 861 ± 66 petagram carbon (Pan et al., 2011). Enhancing forest carbon sequestration is considered as an important and economical approach to mitigate climate change (IPCC, 2014b). Since the 10th Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2009, harvested wood products (HWP) have been required to be included in forest management as an additional carbon pool in the national greenhouse gas (GHG) inventory report because of its potentially significant contribution in either increasing or reducing atmospheric GHG emissions (UNFCCC, 2009).

China is one of the largest HWP producers and consumers in the world (Buongiorno et al., 2017; Zhang et al., 2015). Hence, it is critical to accurately assess China's HWP carbon emissions/stocks for improving the assessment of global HWP carbon budget. Published China-specific studies mostly focused on estimating the carbon stocks of in-use HWP (Ji et al., 2013; Yang et al., 2014; Yang and Zhang, 2016), and ignored wood carbon balance during HWP manufacturing and HWP carbon stocks/emissions after retired HWP are disposed of (Brunet-Navarro et al., 2016; Ji et al., 2013; Yang et al., 2014). In the present study, we attempted to improve the analysis by developing an analysis framework that quantifies wood biogenic carbon stocks and emissions in the period from 1900 to 2015; a life-cycle perspective was used to have HWP manufacture, end use, and end-of-life disposal life-cycle stages all considered.

Winjum et al. (1998) and Lim et al. (1999) summarized three approaches, namely, Atmospheric Flow Approach (AFA), Production

* Corresponding author at: No. 159, Longpan Road, Xuanwu District of Nanjing City, Jiangsu Province, China.
E-mail addresses: yhqnfu@gmail.com, yanghongqiang@njfu.edu.cn (H. Yang), jiaxin.chen@ontario.ca (J. Chen).

https://doi.org/10.1016/j.forpol.2018.05.005
Received 21 July 2017; Received in revised form 26 April 2018; Accepted 5 May 2018
1389-9341/

Approach (PA), and Stock-Change Approach (SCA), to estimate HWP carbon stocks and emissions. These approaches were later adopted by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2003, 2006a), and were then widely used in various studies (Brunet-Navarro et al., 2016; Yang and Zhang, 2016). Using PA, a reporting country should be responsible for HWP produced by domestic harvests, i.e., the carbon stocks and emissions of imported HWP are excluded from the accounting system, but those of the exported HWP are included. Hence using PA can lead to the largest HWP carbon stocks for a country that has a large net HWP export, compared with using the other 2 approaches (Donlan et al., 2012; Tonosaki, 2009). Using SCA, carbon stocks and emissions are estimated for all HWP consumed by the reporting country, regardless of where the forests are harvested to produce those HWP. In other words, imported HWPs are included and exported HWPs are excluded; therefore, using SCA will result in the largest HWP carbon stocks for a country with a large net HWP import (Green et al., 2006; Skog, 2008). The AFA estimates fluxes of carbon to and from the atmosphere for HWP consumed by a reporting country. All HWP consumed within the national boundary of the reporting country are considered, including imported HWP, while emissions from the exported HWP are excluded. Thus, using AFA will give vast emission removals for a country with large net HWP export (Dias et al., 2009). The above analyses suggest HWP trade is the main factor that affects HWP carbon assessment for a reporting country, and thus influences the selection of HWP carbon accounting approaches (Dias et al., 2009; Donlan et al., 2012; Green et al., 2006; Kohlmaier et al., 2007; Skog, 2008). The PA was recommended by IPCC as the default HWP carbon accounting approach (UNFCCC, 2012; IPCC, 2014c). Using this approach, HWP carbon stock/emission analysis can be integrated with the carbon balance assessment of the forests managed to produce these HWP in a reporting country, which can also ensure that HWP originated from deforestation and forest degradation are excluded from the analysis (Chen et al., 2010; Nunery and Keeton, 2010; Profft et al., 2009; Werner et al., 2010).

However, HWP consuming countries play a critical role in enhancing climate change mitigation potential of HWP. A wood material importer can contribute to increased HWP carbon stocks by maximizing the utilization efficiency of converting industrial roundwood or intermediate HWP into finished HWP (Hashimoto, 2008; Nabuurs and Sikkema, 2001; Werner et al., 2010; White et al., 2005). Using more HWP for long-lived end uses and increasing the recycling and reuse of retired HWP can further increase HWP carbon stocks and reduce emissions (Skog, 2008; Tonosaki, 2009; Dias et al., 2012; Chen et al., 2014). Using more HWP to substitute for carbon-intensive products, such as cement and steel, results in increased reduced GHG emissions (Chen et al., 2018; Kalt et al., 2016; Sathre and O'Connor, 2010). And waste management of the HWP consuming countries determines the fate of the HWP carbon after the HWP reaching the end of their service lives (Chen et al., 2014; Heath et al., 2011; Tonn and Marland, 2007). In summary, using PA—a HWP producing country-focused approach, the potential contribution of HWP consuming countries in enhancing HWP carbon stocks and reducing emissions can be largely underestimated, which may lead to missed opportunities in mitigating GHG emissions. The international intra-industry trade of HWP, a critical part of global forestry industries (Dieter, 2009), can result in additional uncertainty in HWP carbon assessment conducted using the PA.

China has become one of the largest HWP producers and end users in the world, and has played a complicated rule by importing and exporting large amounts of HWP. Therefore, the SCA is likely more appropriate in assessing HWP carbon stocks and emissions for China, since it is a consumption-focused approach that has the simplest data requirements and the lowest uncertainty risk (Bache-Andreassen, 2009).

Ji et al. (2013), Yang et al. (2014), and Yang and Zhang (2016) estimated the HWP carbon stocks in China: HWP production and trade data by major HWP category obtained from FAOSTAT database (http://www.fao.org/faostat/en/#data/FO). Using SCA, Yang and Zhang (2016) estimated that in 2015, the cumulative carbon stock and annual carbon stock increase of in-use HWP in China were 680.63 and 59.63 teragrams of carbon (Tg C); if PA was used, in comparison, the cumulative carbon stock and the annual carbon stock increase of in-use HWP in China were estimated to be 398.87 and 23.21 Tg C in 2015. However, these results are based on HWP production and trade data by major HWP category obtained from FAOSTAT database (http://www.fao.org/faostat/en/#data/FO), and only included carbon stocks of HWP in use (i.e., the wood carbon balance during HWP manufacturing and the fate of retired HWP were not considered). The FAO database often contains estimates made by FAO, while using country-specific datasets can improve HWP carbon assessment (Chen et al., 2018; Dias et al., 2009; Kayo et al., 2014; Skog, 2008). Lun et al. (2012) quantified the carbon budget of China's forestry sector from 1999 to 2008. However, the HWP they analyzed was limited to industrial roundwood rather than broke down to end-use HWP and end-of-life disposal. And the carbon stock was estimated using a simple decay method (Skog et al., 2004) rather than the first-order decay method recommended by IPCC (Pingoud and Wagner, 2006; IPCC, 2014c). Thus, none of these previous studies provided results comparable to those estimated by using a life-cycle perspective.

The objectives of this study include (a) to develop a SCA-based HWP life-cycle carbon stock/emission assessment system based on China-specific data on HWP production, trade, and end uses, and end-of-life disposal, and (b) to produce a life-cycle carbon budget for HWP consumed by China from 1900 to 2015. We aimed to produce a complete HWP carbon stocks/emissions assessment for the first time for China, by considering the 3 HWP life-cycle stages (production, end use, and pose-service disposal) and covering a period from 1900 to 2015.

2. Methodology and materials

To estimate the carbon stocks/emissions for HWP consumed in China using SCA, we obtained China-specific HWP production and trade data by major HWP category. A life-cycle carbon budget analysis system was developed based on a comprehensive analysis of the available data. Methods for quantifying the biogenic carbon stocks/emissions for HWP consumed by China were selected/developed for HWP manufacture, and the subsequent end use and end-of-life disposal life-cycle stages. The production of HWP by HWP category was estimated based on domestic forest harvesting, the net import of roundwood and immediate HWP, and the recycled HWP. The carbon stocks of HWP in use was estimated by HWP category, since we did not have China-specific HWP end uses and the associated service lives for conducting a higher-tier analysis. Carbon dynamics of post-service HWP were also quantified by waste HWP disposal option. The results were presented as cumulative biogenic carbon stocks of HWP in use and at waste disposal sites, minus landfill methane emissions produced by HWP decomposition in landfills. All carbon stocks and emissions in this study were presented as CO_2-equivalent (CO_2-eq), unless otherwise specified. Converting from carbon to CO_2-eq is done by multiplying the molar ratio of CO_2 and carbon (44/12), and converting methane into CO_2-eq was done by considering the molar ratio of CO_2 and methane and the 28-time global warming potential of methane in a 100-year period (IPCC, 2014b).

2.1. Life-cycle carbon budget assessment system

A complete HWP life cycle includes three stages: manufacture, end use, and end-of-life disposal (Chen et al., 2014; Lamers et al., 2014; Mathieu et al., 2011; Skog, 2008). Conducting a national level HWP life-cycle carbon budget assessment relies on a comprehensive analysis of HWP life-cycle data. The primary data that we used include the production and net imports of HWP by major product type, and the fractional shares of waste HWP discarded by disposal options. We obtained these HWP production and trade data from China Forestry