



Contents lists available at ScienceDirect

Applied Energy

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

Estimating carbon emissions from the pulp and paper industry: A case study

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HIGHLIGHTS

- This study calculated carbon emissions from China's Pulp and Paper Industry (CPPI) from 2005 to 2012 with local inventory.
- CO₂ emissions from energy consumption contributed the largest share of total emissions.
- Recovered biomass energy has great potential in reducing total carbon emissions.
- CH₄ generated from sewage treatment should be taken into account in order to achieve low carbon development.

ARTICLE INFO

Article history:

Received 1 March 2016

Received in revised form 28 April 2016

Accepted 3 May 2016

Available online xxxxx

Keywords:

Carbon emissions

Climate change

Industrial process

Low carbon development

Pulp and paper

ABSTRACT

The pulp and paper industry is a high energy consuming and polluting sector, and carbon emissions emitted from this sector are worthy of attention. This article, based upon an analysis of China's Pulp and Paper Industry (CPPI), provides estimates of each of the following: carbon emissions from energy consumption, pre-treatment sector, combustion of condensed black liquor, and methane emitted from incomplete aerobic digestion during sewage treatment of CPPI. During the study period (2005–2012), total CO₂ emissions ranged from 126.0 Mt to 155.4 Mt. Energy consumption was estimated to be the largest source of carbon emissions, however, due to the application of the local emission inventory rather than the IPCC inventory, energy consumption decreased by 4.7%, a lower percentage than was calculated in a previous study. According to this study's estimation, the emissions caused by the recovery of biomass energy contributed 26–29% of the total CO₂ emissions. CH₄ generated from sewage treatment accounted for 9–11% of the total carbon emissions. The CO₂ intensity dropped during the study period, which reflected the improvement of energy efficiency in the pulp and paper industry. The outcome of this study provides not only detailed information about CPPI's carbon emissions, but also a calculation framework for studying carbon emissions from pulp and paper sector in the other regions. It suggests that the local carbon emissions inventory should be used for estimating carbon emissions and to reduce the fossil fuel energy, increase energy recovery from biomass, and that promoting cleaner production is essential to achieve a low carbon development of the pulp and paper industry.

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1. Introduction

Climate change is greatly challenging the sustainability of human society. Efforts have been made to more accurately evaluate the amount of human-induced carbon emissions. Emissions from combustion have been widely studied and reported. As indus-

try is one of the major users of energy, carbon emissions caused by combustion from industrial sectors have also been widely studied and estimated. However, in addition to emissions caused by fossil fuel combustion, industrial processes and waste management can also generate carbon emissions. Compared to studies on carbon emissions from combustion, fewer studies focused on the emissions from industrial processes and waste management, especially in the context of developing countries [1]. China, as the largest developing country and carbon emitter, has been significantly developing its industry since the 1980s. A few recent studies have examined the GHG emissions from industrial processes in industrial sectors in China. For example, Hao et al. [2] estimated the

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GHG emissions from the primary aluminum production of China in 2014 accounted for 4% of China's total GHG emissions. Liu [3] estimated carbon emissions of industrial processes from five high carbon intensity industrial sectors in China and found that the carbon emissions of these five sectors in 2013 were equivalent to the total quantities of CO₂ emissions of Spain in the same year. Shan et al. [1] presented the first study on CO₂ emissions from China's lime industry and found that it contributed a significant amount of emissions annually.

This study focused on the pulp and paper sector. The pulp and paper sector has received widespread attention due to its extensive energy demand [4] and high emissions generation [5]. Most of the studies conducted on the pulp and paper industry have centered upon pollutants and waste treatment [6] and cleaner production [7]. There have also been increasing researches on the energy consumption and carbon emissions of the pulp and paper industry worldwide. However, most studies were conducted in developed countries, while much less attention has been given to the pulp and paper industry of developing countries regarding its energy consumption and carbon emissions. Though developed countries dominated the total pulp and paper production in the world and the United States was the largest producer for a long period, China has become the largest paper products producer and the second largest pulp producer in recent years (Fig. 1). Compared to the situation in the developed countries, straw pulp rather than wood pulp contributes a large share of total raw material in CPPI. In addition, the lack of advanced technologies leads to higher energy demands and heavier pollutants generation than in developed countries [8]. Moreover, we found that very few studies in China and other countries estimated GHG emissions from the pulp and paper sector caused by paper mill waste management. Aerobic biological treatment is widely used for sewage disposal, and CO₂ emitted from aerobic respiration is excluded from total carbon emissions due to its biogenic origin [9]. But incomplete aerobic digestion can produce methane emissions, which should be taken into account [10].

This paper is organized as follows. Section 2 presents a comprehensive literature review and identifies the research gaps. Section 3 gives an overview of the pulp and paper production process. Section 4 introduces the methodology and data sources. Section 5 presents the results, which are further discussed in Section 6. Section 7 is the conclusion.

2. Literature review

The pulp and paper industry has been regarded as a very high energy-consuming sector [11,12], and thus many researchers have analyzed energy efficiency and energy saving potentials in the pulp and paper industry from both the technological improvement perspective and the energy policy perspective. Farla et al. [13] examined the energy efficiency development of the pulp and paper industry of eight OECD countries base on physical production data during 1973–1991 and found that the growth of primary energy consumption was significantly reduced due to energy efficiency improvements. However, the carbon emission during the study period was not given in their study. Lopes et al. [14] employed life cycle assessment to study the environmental impacts of two different fuels used in the pulp and paper industry of Portugal and showed that the substitution of heavy fuel oil by natural gas in the paper production process has less environmental impacts. Consonni et al. [15] argued that gasification-based pulp mill bio-refineries should be promoted because of their great potential in offering energy benefits in the United States. Stenqvist [4] examined the energy performance of the Swedish pulp and paper industry with the decomposition method and found energy efficiency

improvement had limited the growth of primary energy use in this sector. With regards to carbon emissions, most researches focused on CO₂ that was caused by energy use in the pulp and paper industry.

Though fossil energy consumption contributes most of the CO₂ in the pulp and paper industry [12], carbon emissions caused by biomass loss during the whole production process of the pulp and paper industry should not be ignored. Carbon emissions such as CH₄ caused by the wastewater treatment process should also be taken into consideration [16]. Additionally, considering that the original resources of the pulp and paper industry are wood and straw, it is important to note that these resources, (wood in particular), play a crucial role in carbon sinks [17]. According to [18], as a unique industrial sector, biomass should be recycled for its high potential in both energy and carbon emissions reduction from a life-cycle perspective. Another two studies have also shown that pulp and paper mills can significantly reduce the net carbon emissions by using and recovering biomass based energy in several European country contexts [19,20]. Black liquor from the pulp production process can be used for producing hydrogen which can potentially replace a large share of motor gas use in countries with a large size pulp and paper industry [21,22]. Except for the few studies reviewed above, the knowledge about biomass-induced carbon emissions in the pulp and paper sector has not been well addressed. Thus, it leads to the first research purpose of this study:

1. CO₂ reduction potentials via biomass energy recovery and GHG emissions from the sewage treatment of the pulp and paper industry should be further addressed.

There have been only a few studies on the pulp and paper industry's energy consumption and carbon emissions in a developing country context and most of them were conducted in China. A study conducted by Kong et al. [23] estimated CO₂ emission and mitigation potentials in CPPI by using conservation supply curve methods. This study found the cost-effective CO₂ emissions reduction potential by applying energy efficiency methods to be approximately 17 Mt CO₂ which is equivalent to 17% of total CO₂ emissions of CPPI. Peng et al. [24] also analyzed energy efficiency and CO₂ reduction and identified the energy saving and CO₂ emission reduction potentials of CPPI. However, the estimated CO₂ emissions of their studies only included those caused by energy consumption during production. Except for China, there have been only a few researches on the pulp and paper industry's energy consumption and CO₂ emission in other developing countries. For example, Poopak and Agamuthu [25] conducted a life-cycle assessment on a paper mill in Iran and found that using bagasse as the raw material and hydroelectricity as the energy source would have less global warming impact. However, Brazil, Indonesia, and Russia, as the other three main developing countries who produce pulp and paper, have rarely been mentioned in the literature concerning energy use and carbon emissions of their pulp and paper sector.

The outcome of the previous studies conducted in China and other developing countries were similarly based on the data of energy use of production and IPCC emission inventory. CO₂ emission can be overestimated with using IPCC inventory according to [26]. Moreover, due to the less advance technology and environmental policy, the pulp and paper industry usually has a poor environmental performance in most developing countries. With the increasing concerns of local environmental issues and also global climate impacts, the environmental standards have to be raised. However, there might be conflicts between local environmental issues and global climate change issues. To meet regional emission standards (much stricter environmental regulations than national standards, see [7]), local industry needs to invest in wastewater

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