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Environmental performance of straw-based pulp making: A life cycle perspective

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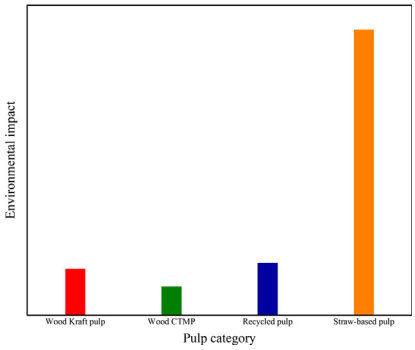
HIGHLIGHTS

- Environmental performance of straw-based pulp making was evaluated through LCA.
- Energy production and chemical inputs are the main contributors to environmental impacts.
- Straw-based pulp making causes higher environmental impacts than wood-based pulp.
- Bio-based carbon emissions should not be overlooked in pulp making industry.

GRAPHICAL ABSTRACT



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ABSTRACT

Agricultural straw-based pulp making plays a vital role in pulp and paper industry, especially in forest deficient countries such as China. However, the environmental performance of straw-based pulp has scarcely been studied. A life cycle assessment on wheat straw-based pulp making in China was conducted to fill of the gaps in comprehensive environmental assessments of agricultural straw-based pulp making. On average, the global warming potential (GWP), GWP excluding biogenic carbon, acidification potential and eutrophication potential of wheat straw based pulp making are 2299 kg CO_2-eq, 4550 kg CO_2-eq, 16.43 kg SO_2-eq and 2.56 kg Phosphate-eq respectively. The dominant factors contributing to environmental impacts are coal consumption, electricity consumption, and chemical (NaOH, ClO_2) input. Chemical input decrease and energy recovery increase reduce the total environmental impacts dramatically. Compared with wood-based and recycled pulp making, wheat straw-based pulp making has higher environmental impacts, which are mainly due to higher energy and chemical requirements. However, the environmental impacts of wheat straw-based pulp making are lower than hemp and flax based pulp making from previous studies. It is also noteworthy that biogenic carbon emission is significant in bio industries. If carbon sequestration is taken into account in pulp making industry, wheat straw-based pulp making is a net emitter rather than a net absorber of carbon dioxide. Since wheat straw-based pulp making provides an alternative for agricultural residue management, its evaluation framework should be expanded to further reveal its environmental benefits.

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1. Introduction

As an indispensable industrial sector, pulp making, which utilizes the cellulose component of biomass, is mainly derived from three sources: wood, non-wood (straw, sugarcane bagasse, bamboo etc.) and waste paper. Dating from the early stages in paper making history, straw like hemp was used to make paper in Han dynasty 2000 years ago. Gradually, bamboo, rice straw and wheat straw were also used to make paper. Compared to straw-based paper making, wood-based paper making emerged later, though the bark of small shrub such as *Broussonetia papyrifera* was used to make paper more than 1500 years ago (Pan, 2009). Modern application of wood to make paper was invented in the early 19th century by Mathias Kroops, who also applied patents for straw, wood and waste paper pulp making technologies (Koops, 2010). Though coming later, wood-based pulp developed rapidly for its advantages in stable resource supply, easy scale-up and high efficiency alkaline recovery. Straw-based pulp plays an important role even in forest deficient countries, such as in China. China is one of the largest pulp and paper producers in the world, and straw-based pulp making has a unique status in Chinese pulp making industry. The intrinsic high ash and carbohydrate content in straw significantly reduces the efficiency of alkaline recovery from the black liquor and increases pollutions emission. Besides, the energy consumption in straw-based pulp making is also more intensive. Consequently, under the pressure of strict environmental pollution control and immerse market competition, the production of straw-based pulp (the main non-wood pulp type) is decreasing dramatically both in terms of rate to total pulp production and absolute production volume (Fig. 1).

Compared with wood-based pulp, straw-based pulp making generates more environmental pollutions, and are more vulnerable to environmental regulations (Wang et al., 2011). However, straw-based pulp plays an irreplaceable role in many occasions for it utilizes agriculture residues to make pulp, which is a big problem in agriculture yet to be solved. Through integrated into other industries, straw-based pulp making could be formed into a circular industrial products chain to promote circular economy with technological innovation. Therefore, comprehensive environmental evaluation of straw-based pulp making is of great importance. Currently, the environmental evaluation on pulp making is mainly for wood-based and recycled pulp, while the studies on the environmental evaluation of straw-based pulp are limited, especially for agricultural straw-based pulp making. Therefore, there is great need to clarify the environmental evaluation scope of straw-based pulp making and study the environmental performance of typical straw-based pulp making processes.

This article tries to fill in this research gap by conducting a life cycle assessment of wheat straw-based pulp making. Study refers to the data from two typical wheat straw-based pulp making companies in China. This article aims to provide a comprehensive environmental impacts of wheat straw based pulp making to fill in the knowledge gap, identify the hotspots of the environmental impacts, find solutions to reduce the environmental impacts, and make a comparison of straw-based pulp with wood-based and recycle pulp making and set the status of straw-based pulp making. The article is set as follows: literature review on previous studies is presented in Section 2; materials and methodology are presented in Section 3; the main results are depicted in Section 4; Sections 5 and 6 respectively present the discussions and conclusions.

2. Literature review

Pulp and paper industry is one of the most indispensable industrial sectors. Nevertheless, it is also associated with high energy consumption, high materials consumption and severe pollution, especially wastewater pollution. To reveal the environmental performance and seek for solutions to tackle environmental burdens in pulp and paper industry, quantities of studies have been conducted at both national (regional) scale and individual pulp and paper mill scale, which varies from environmental burdens quantification, dominant influencing factors identification, new technology implementation, to policy optimization. At national scale, the environmental burden quantification included energy consumption (Fleiter et al., 2012; Laurijssen et al., 2012; Xu et al., 2013), greenhouse gas (GHG) emissions (Gielen et al., 2007; Peng et al., 2015), and water consumption (Francisco et al., 2014). The dominant influencing factors contributing to environmental burdens were identified through various decomposition methods on longitude historical data (Lindmark et al., 2011). The deployment of the new technology to tackle environmental burdens (Fontini and Pavan, 2014; Jönsson and Berntsson, 2012) as well as the optimization of new technology adoption were also discussed in the literature (Meza Solana and Juárez Nájera, 2016; Xu et al., 2013). At individual mill level, the life cycle assessment (LCA) method was widely used to

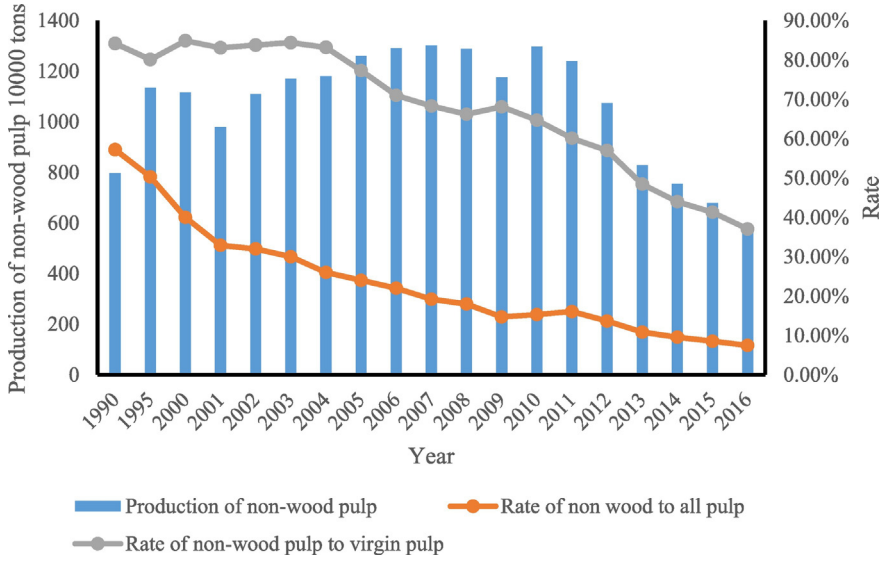

Fig. 1. The production of non-wood pulp and its share to total pulp and virgin pulp production in China.
Data source: Yearbook of pulp and paper production in China.