A Representative Study of CO_2 Emissions and Carbon Intensity Based on a Case of a Pulp and Paper Mill in China: Calculation and Analysis

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In 2017, a carbon emissions trading market will be launched nationwide by the China government. Calculating the enterprise carbon emissions is an important prerequisite and basis for trading. This paper discussed types of greenhouse gases, calculation boundaries and methods, energy consumption, carbon emissions, and intensity of a representative integrated pulp and paper mill in China based on China Guidance and Greenhouse Gas Protocol Tools. The results showed that there were 435,000 tonnes (t) of CO_2 emissions from that mill in 2014 that did not contain emissions of biomass energy, which was 8 times higher than that of fossil energy. The pulp carbon intensity based on the mill was 0.230 t CO_2/Adt, which accounted for 7.50% to 57.4% in other pulps' based on the product. Intensity based on Gross Domestic Product (GDP) was 1.090 t CO_2e/1000 USD and accounted for 56.8% intensity in the China paper industry. The intensity based on sales accounted for 52.6% in the first-class enterprise in the developed country. It also showed that intensity was influenced by the species of raw material, energy, and products, which provided the mill with measures for energy saving and emissions reduction to obtain the redundant carbon emissions in the trading.

Keywords: Energy consumption; Carbon dioxide emissions; Pulp and paper industry; Carbon emissions trading; Carbon intensity

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INTRODUCTION

Due to global warming caused by the greenhouse effect, greenhouse gas (GHG) emissions and carbon footprints are highly valued by human society. Carbon Emissions Trading (CET) is one of the most important emissions reduction mechanisms of the Kyoto Protocol and has received global attention.

At the Copenhagen Conference in 2009, China pledged that CO_2 emissions per unit Gross Domestic Product (GDP) would drop 40% to 45% by 2020. China put the content of GHG emissions control first in the national economy and social development aspects of the 12th five-year plan (2011 to 2015) in 2011, putting forward five-year period obligatory targets by 2015 to reduce CO_2 emissions per unit GDP by 17% (reaching 20%) and to reduce energy consumption per unit GDP by 16% (reaching 18.2%) (The State Council 2011a; The State Council 2016). Furthermore, the state council allocated the national carbon intensity among the provinces, autonomous regions, and municipalities (The State Council 2011b).

To fulfill emissions reduction commitments and protect resources and the environment, China has launched the pilot CET in two provinces and five cities in 2011. In late 2017, CET online will be launched nationwide by the Chinese government, which will be a milestone in environment protection. The mills will be required to enter data into CET online in key industries, such as the petrochemical, chemical, building materials, steel, non-ferrous, paper, electric, and aviation industries, whose comprehensive energy consumption reached 10,000 tonnes of standard coal equivalent (tce) each year from 2013 to 2015 (NDRC 2016). Therefore, the enterprise GHG emissions report must be submitted, including the basic enterprise information, the main product information (the name, unit, and production), and the relevant energy information (the comprehensive energy consumption and GHG emissions). The CET market will become the biggest market in the world with an annual CET volume of 5 billion tonnes (t) (with Europe in second at 2 billion t) (Liu 2016). Essentially, the GHG emissions report in the key mill will be common for the annual work in the future and it will be closely connected with assets in the CET market.

With advancements in production processes and equipment technology, higher product quality and variety, and more intensive scaling in recent decades, the China paper industry (CPI) has maintained sustainable, steady, and rapid development and has become one of the most important pillar industries of the national economy (Zhang 2015). The annual output, consumption, and annual per capita consumption of the paper and paperboard in China have been increasing with the average annual growth rates of 5.71%, 5.13%, and 4.61% respectively from 2005 to 2014 (CPA 2016; CTAPI 2016; Kuang 2016). China has exceeded America in paper and paperboard production and consumption since 2009 and became the largest producer in the world, accounting for 26% of the global total (CTAPI 2016; Lin and Zheng 2017). Although the annual per capita consumption of paper and paperboard (75 kg) in China has exceeded the world's average annual per capita consumption of 57 kg in 2015, it is much lower than in many developed countries (317 kg in Belgium, 256 kg in Austria, 246 kg in Germany, 236 kg in United Arab Emirates, 235 kg in Finland, and 224 kg in America) (Kuang 2016). Therefore, there is still great room for development for the paper industry in China.

As an industry with the fourth largest consumption of energy worldwide (Trudeau *et al.* 2011), the paper industry consumed 5.95 EJ of final energy in 2014, of which CPI accounted for 19% (NBSC 2015; Elhardt 2016). The carbon emissions in CPI accounted for 29% of the global total (McGrath 2014). This amount will continuously increase in the future. Because the energy structure of CPI is dominated by coal, with a proportion of approximately 50% (Lin and Zheng 2017), environmental protection will be a larger challenge in the future. At present, most research about carbon emissions calculations are based on products, mainly referring to paper and paperboard. There is minimal research based on mills and fewer research based on pulp products alone. Zhang *et al.* (2015) calculated the carbon emissions of coated ivory board products, using the Publicly Available Specification (PAS) 2050 methodology. Ratnasingam *et al.* (2015) calculated the carbon emissions of two kinds of tropical hardwood sawn timber products, using the life cycle approach. Kong *et al.* (2013) calculated the carbon dioxide emissions of a paper mill in the Guangdong province, using the energy audit approach and considered only coal and diesel fuel. In order to better understand and compare with the carbon emissions, carbon intensity can be selected to express the energy efficiency (Peng *et al.* 2015; Wang *et al.* 2016). Carbon intensity is defined as CO_2 emission per unit of product yield or GDP.

Wang *et al.* (2016) calculated the carbon intensity between CO_2 emission and paper product yield and analyzed the causes of change from 2005 to 2012. Peng *et al.* (2015) adopted the energy use per unit of GDP or gross output value to indicate the energy efficiency.

Carbon emissions calculations based on products are prone to unclear energy boundaries, and thus results will be inaccurate for a mill with more varieties and production lines, especially for an integrated pulp and paper mill. The calculations coming from a mill will be convenient for the regional total control and CET, and beneficial for finding further measures aimed at energy saving and emissions reduction. In addition, carbon emissions coming from a mill can be used to evaluate whether a mill is representative of the technology and scale of the industry. Therefore, as China's CET market launches, it is necessary to calculate carbon emissions coming from a mill.

Moreover, the GHG Protocol is considered one of the most influential standards (WRI and WBCSD 2012). Almost all the world's GHG accounting standards are based on the GHG Protocol. It provides the calculation tools for estimating GHG emissions from pulp and paper mills (hereinafter referred to GHG Protocol Tools) (ICFPA 2005). In China, the calculation method and report guidance of GHG emissions for the paper and paper products enterprise (hereinafter referred to China Guidance) (NDRC 2015) was made to calculate carbon emissions based on the corporate level. Although the basic framework and definitions of China Guidance are consistent with GHG Protocol Tools, there are some differences between them. Firstly, GHG Protocol Tools list all the details and general aspects of calculating carbon emissions while China Guidance is simplified and specific for application with localized mills. Secondly, carbon emissions from biomass energy combustion are calculated but not included in the total emissions in the GHG Protocol Tools; these emissions are not calculated in the China Guidance. Thirdly, the emission factors differ because of the differences in the fuel carbon oxidation rate in relation to the actual production conditions.

This paper studied a large integrated pulp and paper mill, located in Shandong province, east of China. The mill has the largest wood pulp production (CPA 2016) and is the benchmarking enterprise in the China paper industry with advanced processing, equipment, and management. Based on the China Guidance and the actual measured values in the corporate lab, the mill's carbon emissions were calculated in this paper, including emissions from biomass energy listed alone according to GHG Protocol Tools. Furthermore, the carbon intensity was calculated on the base of the main product of the studied mill (TSM) and macro-indicators. Lastly, the influence factors of intensity were analyzed, which provided TSM with further measures for energy saving and emissions reduction. This paper will provide the scientific basis for CET and assessment of TSM, provide guidance on calculating the carbon emissions of a mill in CPI as a standard framework, and help the international community learn about the carbon emissions level of a representative integrated pulp and paper mill in CPI.

EXPERIMENTAL

Estimating enterprises of GHG emissions comprised some of the basic processes in the China Guidance; namely, which GHGes to determine, how to determine the calculation boundary, where to collect data, and how to calculate the carbon emissions in the mill. The GHG Protocol generally allows companies to ignore emissions that are so small that they do not significantly impact the estimation of overall emissions (ICFPA 2005). Therefore, the calculation process was simplified in the section of Types of GHGes, Calculation boundary and Methods.

Materials

The details of TSM

The TSM in this paper is located in Shandong province in east China. It is an integrated pulp and paper mill. The raw materials for pulping were a variety of wood that included Thailand eucalyptus, Australian eucalyptus, Chinese eucalyptus, Indonesian acacia, Vietnamese acacia, and some hardwood. The TSM has two pulp board machines (PB_s) and two paperboard machines (BM_s) that produced hardwood bleached kraft pulp (HBKP), northern bleached softwood kraft pulp (NBKP), coated ivory board, and liquid packaging board (LPB). The BMs used self-generated pulps with the proportion of approximately 10%, and purchased bleached chemi-thermalmechanical pulp (BCTMP) as the middle layer of paperboard. The details of PB_s and BM_s are shown in Table 1.

Table 1. Details of TSM's Pulp and Paper Machines

Machine No.	Production Speed (m/min)	Capacity (Adt*/day)	Wire Section	Web Width (mm)	Press Section	Production Water Content (%)
PB_1	60 to 140	500	Web formation	3525	Double wire presses, heavy press	10 to 13
PB_2	80 to 250	2800	Dewatering plates, vacuum systems	8210	Shoe presses	10
BM_1	500	450 to 600	Fourdrinier	3625	Suction, blind and smoothing press	7
BM_2	900	1013 to 1297	Fourdrinier	4600	Shoe and smoothing press	7

*Acronyms: Adt: air dry tonne

The material of calcium carbonate ($CaCO_3$) was purchased from Beishan Mining Co., Ltd. (Anhui province, China). The BCTMPs were purchased from Eurocell International Ltd. (Hong Kong, China), Millar Western Forest Products Ltd. (Alberta, Canada), and Marubeni Canada Ltd.(Vancouver, Canada).

Types of GHGes

Three kinds of GHGes were focused on the GHG Protocol Tools according to the contributions of greenhouse effect; namely CO_2, CH_4, and N_2O. Carbon resources with lower content could be ignored as they have less influence on the calculation of carbon emissions. In the China Guidance, only carbon emissions caused by CO_2 and CH_4 were calculated. The TSM in this paper adopted the aerobic method in the wastewater treatment plant, where no CH_4 was generated. Therefore, the authors used CO_2 emissions in place of GHGes to calculate the total carbon emissions in TSM.

Calculation boundary

Figure 1 shows the calculation boundary of this study according to the China Guidance. The boundary was limited to estimate carbon emissions from the manufacturing process of pulp and paper and emissions generated from raw material transportation and utilization. The emissions were divided into five categories.

The first category included emissions from burning fuels. Fossil fuels included coal, natural gas, diesel oil, propane gas, liquefied gas, and heavy oil. Biomass energy included wood dust, black liquor, and methanol. Methanol was produced through the pulping process in wood digester and was collected for biomass energy. When fuels are fully burned with oxygen, CO_2 is emitted. Biomass energy emissions were calculated alone and were not included in the total CO_2 emissions in TSM. The second category included emissions from process production, mainly referring to emissions from purchased $CaCO_3$ decomposition in TSM. The third category comprised of emissions from the net purchased electricity consumption in the electricity generation enterprise. The fourth category comprised of emissions from the net purchased steam consumption in the thermal generation enterprise. The fifth category comprised of CH_4 emissions from wastewater treatment, where TSM adopted the aerobic method in the wastewater treatment plant, where no CH_4 was generated.

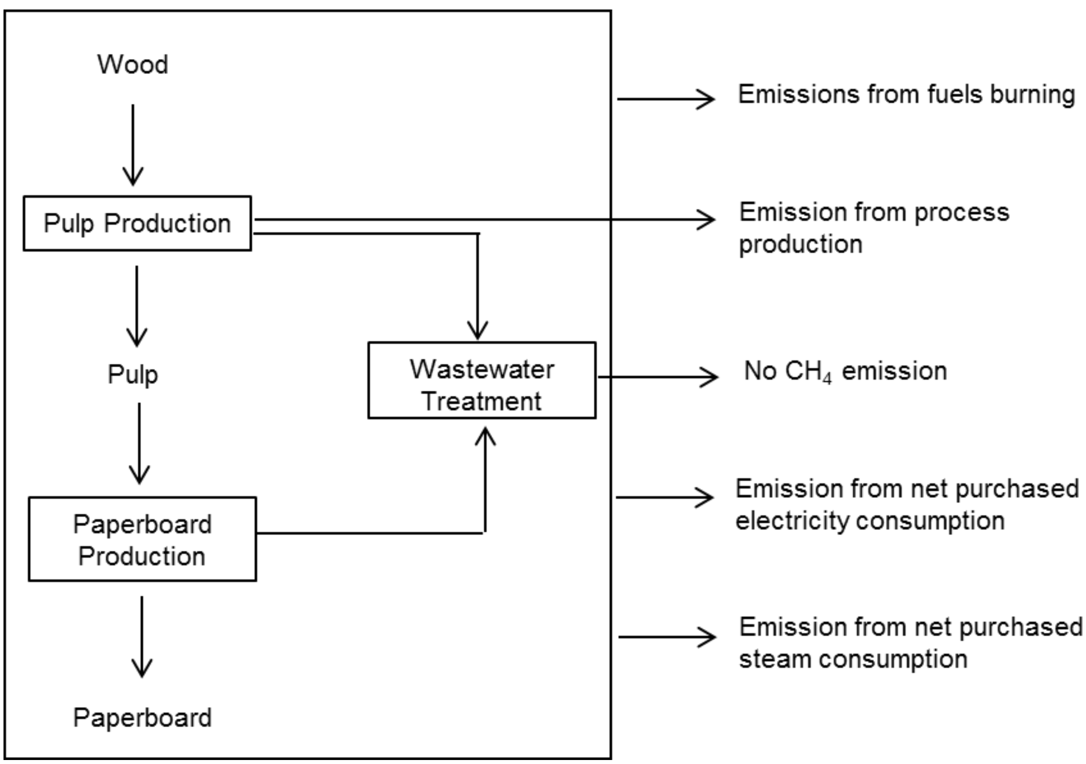

Fig. 1. The calculation boundary in the subject mill (TSM)

CO_2 emissions equations

The following equations were used to calculate the total CO_2 emissions in TSM,

$$E = \sum_{i=1}^{3} E_i \quad (1)$$

where E is the total CO_2 emissions (t CO_2) in TSM, E_1 is the CO_2 emissions of fossil energy and biomass energy (t CO_2), E_2 is the process CO_2 emissions (t CO_2), and E_3 is the CO_2 emissions (t CO_2) of net purchased electricity and steam. The CO_2 emissions of fossil energy and biomass energy is as follows,

$$E_1 = \sum_{i=1}^{n}(AD_i \times EF_i) \tag{2}$$

where AD_i is the i energy activity data (GJ), EF_i is the CO_2 emission factor of i energy (t CO_2/GJ), and the subscript "i" represents the kind of energy. The i energy activity data is as follows,

$$AD_i = NCV_i \times FC_i \tag{3}$$

where NCV_i is the average lower calorific value of i energy (GJ/t for solid and liquid energy, GJ/Nm^3 for gaseous energy), and FC_i is the fuel consumption of i energy (t for solid and liquid energy, Nm^3 for gaseous energy). The CO_2 emission factor of i energy is as follows,

$$EF_i = CC_i \times OF_i \times \frac{44}{12} \tag{4}$$

where CC_i is the carbon content unit calorific value of i energy (t C/GJ), OF_i is the carbon oxidation rate of i energy, and 44/12 is the coefficient converting carbon into CO_2. The process CO_2 emissions is as follows,

$$E_2 = FC \times EF \tag{5}$$

where FC is the limestone consumption (t) and EF is the CO_2 emissions factor when limestone was calcined (t CO_2/t). The CO_2 emissions of net purchased electricity and steam is as follows,

$$E_3 = \sum_{i=1}^{n}(FC_i \times EF_i) \tag{6}$$

where FC_i is the i energy activity data (MWh for electricity or GJ for steam), EF_i is the CO_2 emissions factor of i energy (t CO_2/MWh for electricity or t CO_2/GJ for steam), and the subscript "i" represents the net purchased electricity and steam.

Carbon intensity

The carbon intensity was calculated as follows,

$$\text{Carbon Intensity} = \frac{E}{X} \tag{7}$$

where X of the intensity is the main product yield, GDP, and sales. In relation to the definition of enterprise property according to GB 3544-2008 (2008), the main product of TSM is the pulp product.

Methods

To calculate the CO_2 emissions, it was necessary to collect the FC_i, NCV_i, and EF_i. The FC_i was mainly collected from enterprise energy balance forms, the raw material consumption forms, the financial statements, the procurement invoices, and other audit reports. The NCV_i and EF_i were derived first from the actual measured values in the corporate lab, and then from the default values in China Guidance. The power grid emissions factors varied for different regions in China and were obtained from China's Baseline Emission Factors for Regional Grids in 2014 (NDRC 2014).

The NCV_i of bituminous coal, heavy oil, wood dust, black liquor, methanol, and low press stream, and the EF_i of methanol was measured in the lab. The EF_i of wood dust, black liquor, and methanol were substituted by the value of bituminous coal. The NCV_i and EF_i of propane gas and liquefied gas was substituted by the value of liquefied petroleum gas. For the North China Power Grid, the emission factor was 0.541 t CO_2/MWh in 2014.

To compare carbon intensity with the paper industry and other mills, the original data was collected from resources as follows: World Bank provided the GDP and total GHG emissions of various countries; China Statistical Yearbook (2006-2015) provided the value-added industry of CPI to calculate the carbon intensity of CPI; Wang *et al.* (2016) calculated the total GHG emissions of CPI, from which the emissions of biomass energy were excluded.

RESULTS AND DISCUSSION

TSM's Energy System

Fossil fuel was converted through a combined heat and power facility to generate electricity and steam, which were the final forms of energy used in the production process. Figure 2 shows a simplified graphic rendering of the energy flow at TSM.

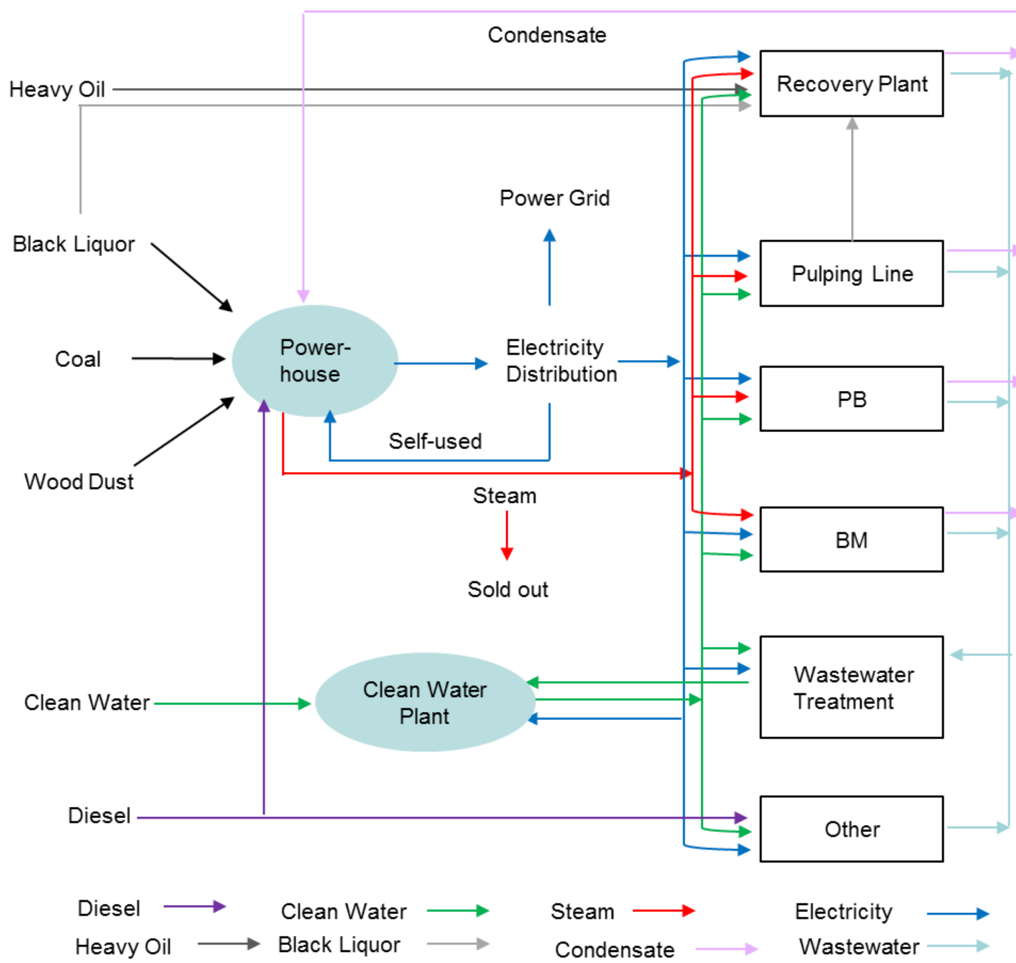

Fig. 2. Energy flow at TSM

The alkali recovery plant was TSM's biggest consumer that accounted for 91% of total energy consumption. The second biggest consumer was the powerhouse with 8.9%, and the third consumers were PBs and BMs. The raw water was pumped into the clean water plant and the effluents exhausted from each plant were sent to the wastewater treatment plant that consumed only electricity. The chemical preparation and compressed-air system required only a small amount of steam and electricity compared to other plants.

TSM's Energy Consumption

All of the energy types were divided into primary energy and secondary energy. The primary energy contained biomass energy and fossil energy. In 2014, the TSM's total energy consumption was 1,512,000 tce, as is shown in Table 2. The TSM corresponded with the conditions of CET online in 2017. The biomass energy was the key source of TSM, with the proportion of 88.3% based on black liquor. Fossil energy merely accounted for 11.9% in the total consumption based on bituminous coal and heavy oil. The secondary energy accounted for 5.4%.

Table 2. TSM's Energy Consumption in 2014

Different Energy			Consumption
Primary Energy	Biomass Energy	Wood Dust	29,300 tce
		Black Liquor	1,290,000 tce
		Methanol	14,000 tce
		Subtotal	1,335,000 tce
		The percentage of total	88.3%
	Fossil Energy	Bituminous Coal	92,900 tce
		Natural Gas	2,500 tce
		Subtotal	95,000 tce
		The percentage of total	6.3 %
Secondary Energy		Heavy Oil	82,000 tce
		Diesel Oil	1,960 tce
		Propane Gas & Liquefied Gas	1.353 tce
		Net Purchased Electricity	-1,540 tce
		Net Purchased Steam	-1,160 tce
		Subtotal	81,700 tce
		The percentage of total	5.4%
Total Energy Consumption			1,512,000 tce

TSM's CO_2 Emissions Calculation

The parameter values are shown in Tables 3 and 4. As shown in Table 5, a total of 435,000 t CO_2 was emitted from TSM in 2014, with the proportion of 0.36% in CPI in that year. The combustion of fossil fuels was the main source of CO_2 emissions, which accounted for 99.8% of the total emissions, of which 98.1% was contributed by bituminous coal and heavy oil. The limestone in the production process contributed to 11,400 t CO_2 with the proportion of 2.62% of the total emissions. There were no CO_2 emissions emitted by electricity and steam because the yield of energy sold to the outer company was much larger than that bought from the national power grid. That is to say that the TSM took in 10,500 t CO_2 .

About 3,470,000 t CO_2 was emitted by biomass energy, of which 97.1% CO_2 emission was emitted by black liquor after pulping. The other emissions were emitted by wood dust from screening the wood and methanol collected from black liquor. The biomass energy came from the wood, and the CO_2 emissions as wood was burnt up can offset the CO_2 absorptions as trees grown up. This process was carbon neutral and no net CO_2 was emitted. Therefore, the emissions were not included in the total but needed to be calculated alone. Biomass energy saved a large amount of fossil energy and also has reduced the release of net carbon emissions into the atmosphere. Wang *et al.* (2016) calculated the carbon emissions in CPI during 2005 to 2012 and the biomass energy contributed from 23% to 26% in total, while the corresponding data was 88.9% in TSM (when it was included in the total), which was 8 times higher than that of fossil energy. If the biomass energy was not reused in TSM, the total emissions would be increased greatly.

Table 3. The CO_2 Emissions Calculation of the Fossil Energy and Biomass Energy according to Eqs. (1 through 4)

Different Energy		FC_i (t or Nm^3)	NCV_i (GJ/t or GJ/Nm^3)	CC_i (t C/GJ)	OF_i	E_1 (t CO_2)
Fossil Energy	Bituminous Coal	123,844	21.997	0.0261	93%	242,000
	Natural Gas	1,889,106	0.0389	0.0153	99%	4,080
	Heavy Oil	59,894	40.355	0.0211	98%	183,000
	Diesel Oil	1,347.479	42.652	0.0202	98%	4,170
	Propane Gas & Liquefied Gas	0.79	50.179	0.0172	98%	2.450
Biomass Energy	Wood Dust	120,668	7.121	0.0261	93%	76,400
	Black Liquor	3,497,520	9.945 (PB_1), 11.029 (PB_2)	0.0261	93%	3,369,000
	Methanol	24,824	16.622	0.0165	98%	24,400

Table 4. The CO_2 Emissions Calculation of Other Energy according to Eqs. (5 and 6)

Energy	FC_i (t or MWh or GJ)	EF (t CO_2/t or t CO_2/MWh or t CO_2/GJ)	Ei (t CO_2)	Remarks
Limestone	28,095	0.405	11,400	E_i is equal to E_2
Net Purchased Electricity	-12,552	0.541	-6,790	E_i is equal to E_3
Net Purchased Steam	-9,069	0.414	-3,750	

Table 5. The Total Carbon Emissions in TSM

Item		Total in 2014	Proportion in Total	Remarks
Paperboard production Yield (t)		265,000	-	
Pulp production Yield (Adt)		1,890,000	-	
CO_2 Emissions (t CO_2)	Fossil energy	434,000	99.81%	
	Process energy	11,400	2.62%	
	Net purchased electricity and steam	-10,500	-2.43%	
	Biomass energy	3,470,000	-	
	Subtotal	435,000	-	Not including the carbon emissions by biomass energy
	Subtotal	3,900,000	-	Including the carbon emissions by biomass energy

Comparison of Carbon Intensity

Based on pulp product and mill's calculations

The carbon intensity was chiefly influenced by the species of raw material. As shown in Table 6, the carbon intensity based on TSM was relatively lower than other pulps that were based on the product. The TSM's pulp was mainly market pulp. The results showed that 0.230 t CO_2/(Adt pulp) based on TSM's calculation was released into the atmosphere, accounting for 35% to 57.4% of the intensity calculated based on product in other wood pulps, 7.5% in wheat pulp, and from 30.8% to 42% in waste paper pulp.

Compared with the carbon intensity of three kinds of pulp, the intensity of waste paper pulp was highest, followed by straw pulp, and then wood pulp. The reason was that the alkali recovery plant for wood pulp could recover energy and carbon emissions of black liquor that were not included in the total determined by TSM, while straw pulp could merely recover less energy, and waste paper pulp had no recovery plant. The proportion of wood pulp, waste paper pulp, and non-wood pulp consumption in CPI were 28%, 65%, and 7% respectively in the total (CPA 2016), while the corresponding figures in developed countries were 63%, 33.6%, and 3.4% respectively (Wang and Mao 2013). Therefore, China's paper industry should increase the rate of wood pulp or improve straw pulp energy recovering with advanced processing and equipment.

Table 6. Comparison of Carbon Emissions with Previous Studies

Pulp Species	Calculation Object	Carbon Intensity (t CO_2/Adt)	References	Calculation Method
HBKP, NBKP	Mill	0.230	This study	China Guidance and GHG Protocol Tools
Chemical wood pulp	Product	0.657	Wang *et al.* 2013	IPCC 2006
Wheat pulp	Product	3.077	Wang *et al.* 2013	IPCC 2006
Waste paper pulp	Product	0.746	Wang *et al.* 2013	IPCC 2006
Non-market Wood pulp	Product	0.117	Chen *et al.* 2014	IPCC 2006
Market wood pulp	Product	0.401	Chen *et al.* 2014	IPCC 2006
Waste paper pulp	Product	0.548	Chen *et al.* 2014	IPCC 2006
Chilean pine bleached pulp	Product	0.540	González *et al.* 2011	ISO 14040 (2006) and PAS 2050 (2008)
Chilean eucalyptus bleached pulp	Product	0.459	González *et al.* 2011	ISO 14040 (2006) and PAS 2050 (2008)

Based on the micro-indicators' calculations (GDP)

The carbon intensity was chiefly influenced by energy structure, industry structure, technology and management level, and energy intensity.

Global carbon intensity showed a noticeable linear decrease from 2003 to 2012 (R^2 = 0.920, 0.973 respectively). As shown in Fig. 3, the rate of decline in China's carbon intensity with the proportion of 11.1% was greater than that of the world with the proportion of 5.24%. Since 2005, GHG emissions in China became largest in the world, exceeding America, and increased year by year by a rate of 23.3% in 2012. The comparison of carbon intensity in the main developed and developing countries in 2011 is shown in Fig. 4. Carbon intensity in the developing countries was 5.2 times higher than that in the developed countries and 2 times higher than that of the world average, while the intensity in the developed countries was merely three eighths of the world average. The reason was mainly due to the difference in energy structure, technology, and management level. The energy structure of the paper industry in the developed countries was mainly made up of biomass energy, natural gas, and electricity (Peng *et al.* 2015), while the corresponding energy structure in the developing countries was mainly fossil energy.

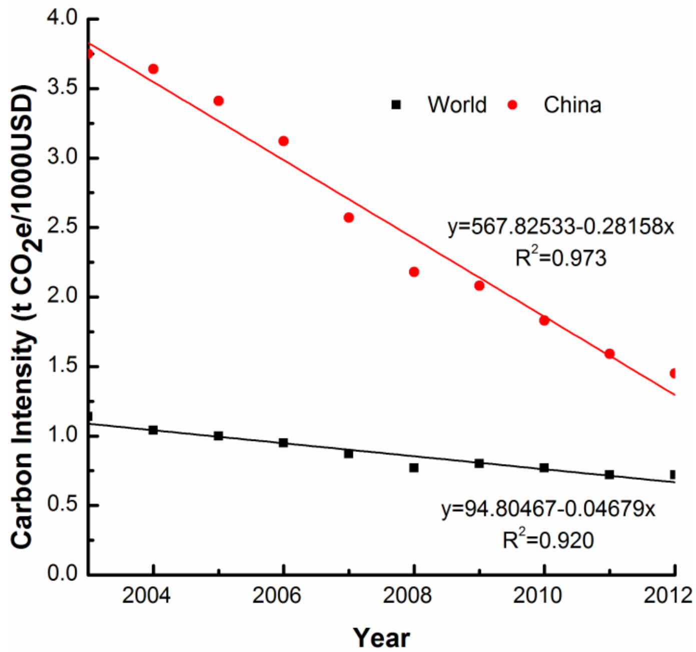

Fig. 3. The carbon intensity in the world and China from 2003 to 2012

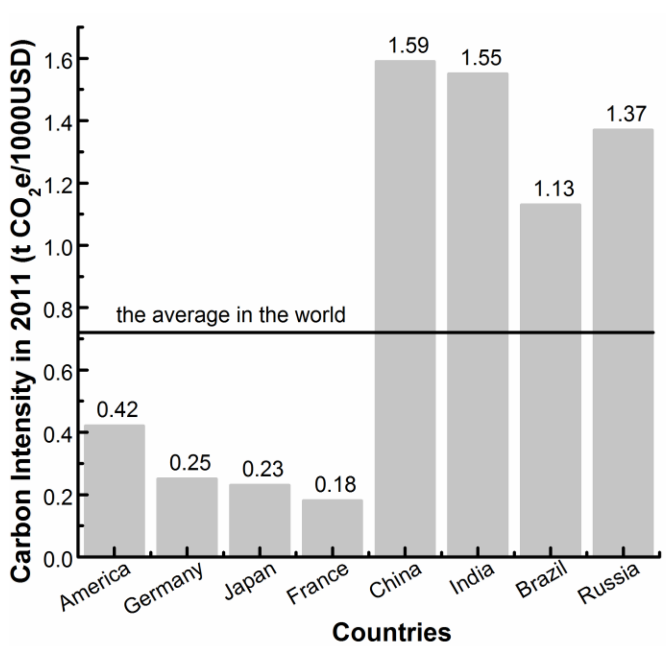

Fig. 4. The carbon intensity of main developed and developing countries in 2011

The carbon intensity in CPI has continuously decreased (excluding the carbon emissions of biomass energy) from 2005 to 2012 and could be divided into three stages, as shown in Fig. 5. The first stage was from 2005 to 2008. Carbon intensity in 2005 was 6.58 t CO_2e/1000 USD (e is the acronym of equivalent), which was 6.58 times higher than that of the world average and 2 times higher than that of China's average. This was because CPI was one of the key industries of energy consumption and carbon emissions. Additionally, there were special conditions in the CPI, such as the special raw material structure with a lower percentage of wood pulp and higher percentage of non-wood pulp, energy structure with mainly fossil energy, lower intensive industry, lower technology and management level, and lower alkali recovery. With the rapid development of the industry and importance of environmental protection, carbon intensity decreased by 20% yearly from 2006 to 2008. The second stage was from 2009 to 2011 with a lower rate. This indicated that the space of reducing the energy consumption and emissions through the further technology promotion was getting smaller. The third stage was from 2012. Carbon intensity in 2012 was 1.73 t CO_2e/1000 USD and saw a large decline of 22.2% compared with 2011. This was mainly due to the elimination of backward production capacity in CPI.

According to the curves of carbon intensity, the intensity in 2014 was 0.570 t CO_2e/1000 USD in the world, 0.723 t CO_2e/1000 USD in China, and 1.92 t CO_2e/1000 USD in the CPI. The intensity in TSM in 2014 was 1.09 t CO_2e/1000 USD, which accounted for 56.8% in the CPI but was higher than the average in China and the world average. As a result of the higher energy consumption in the paper industry and the China's energy structure being dominated by fossil energy, the GHG emissions were higher.

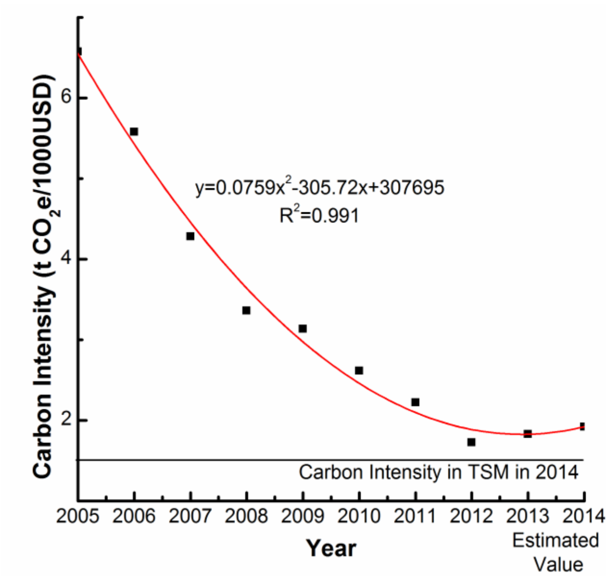

Fig. 5. The national carbon intensity in CPI from 2005 to 2014 (red curve line) and intensity in the subject mill in 2014 (1.09 t CO_2e/1000 USD)

Based on the micro-indicators' calculations (sales)

According to "the carbon intensity list of non-fossil energy enterprises in China" report (WWF 2013) and based on sales, the carbon intensity of the CPI with 0.550 t CO_2e/1000 USD was lower than the transportation industry but higher than other sectors in 2012. Based on sales calculations, the carbon intensities of American international paper (IP) enterprise and TSM were 0.572 t CO_2e/1000 USD and 0.300 t CO_2e/1000 USD, respectively. The IP enterprise that ranked first in the world paper industry had more advanced technology, management levels, and energy structures than TSM. However, the carbon intensity of the IP enterprise was 1.9 times higher than that of TSM. This indicated that the carbon intensity was also influenced by the product structure of the enterprise, and the TSM was typical in the CPI.

Measures for energy saving and emissions reduction in TSM

According to the factors that influenced the carbon intensity, TSM was provided with many further measures for energy saving and emissions reduction to obtain the redundant carbon emissions in the CET market. These measures include enhancing management, adopting energy-saving and emissions reduction technology, making use of self-produced energy and biomass energy instead of fossil energy, increasing the export of sufficient electricity and steam, and improving fuels' combustion efficiency.

CONCLUSIONS

1. Total energy consumption by the mill in 2014 was 1,512,000 tce. Biomass energy was the key source of the mill, which accounted for 88.3% of the total, including wood dust, black liquor, and methanol. The fossil energy merely accounted for 11.9% based on bituminous coal and heavy oil. The results indicated that the mill had good energy recovery and reuse.
2. There were 435,000 t CO_2 emissions at the mill in 2014. The combustion of fossil fuel was the main source of CO_2 emissions and accounted for 99.8% of the total, 98.1% of which were attributed by bituminous coal and heavy oil. The limestone in the production process contributed to 11,400 t CO_2, which accounted for 2.62% of the total. There were no CO_2 emissions emitted by electricity and steam.
3. There were 3,470,000 t CO_2 emitted by the biomass energy, not included in the total emissions of the mill. It accounted for 88.9% when included in the total and was 8 times higher than that of fossil energy. The biomass energy made no attribution to GHG in the atmosphere but saved a large amount of fossil energy and reduced the release of net carbon emissions into the atmosphere.
4. Based on the product and mill's calculations, the carbon intensity was chiefly influenced by the raw material species. The mill's pulp carbon intensity was calculated as 0.230 t CO_2/Adt, which accounted for 35.0% to 57.4% of the intensity calculated based on the product in other wood pulps, 7.50% in wheat pulp, and from 30.8% to 42% in waste paper pulp. This was mainly due to the different energy recovery degree in an alkali recovery plant.
5. Based on the micro-indicators' calculations, the carbon intensity was chiefly influenced by energy structure, industry structure, technology and management level, and energy intensity. Based on the GDP's calculations, the intensity of the mill in 2014 was 1.09 t CO_2e/1000 USD, which accounted for 56.8% of the intensity in CPI but higher than the average in China and in the world. Based on sales' calculations, the intensity of the mill accounted for 52.6% in the first-class enterprise in the developed country.

6. According to the factors that influenced carbon intensity, the mill was provided with many further measures for energy saving and emissions reduction to obtain the redundant carbon emissions in the CET market.

ACKNOWLEDGMENTS

This research was supported by grants from the Open Foundation of Jiangsu Provincial Key Lab of Pulp and Paper Science and Technology at Nanjing Forestry University, the Open Foundation of State Key Lab of Pulp and Paper Engineering at South China University of Technology (201780), and the Priority Academic Program Development of Jiangsu Higher Education Institution (PAPD).

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Article submitted: March 17, 2017; Peer review completed: June 25, 2017; Revised version received and accepted: June 27, 2017; Published: July 11, 2017.
DOI: 10.15376/biores.12.3.6157-6172