# Application of Carbon Footprint Assessment Methodology to the Case of Coated Ivory Board

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The pulp and paper industry, which is closely related to national economic and social development, is an important industry but also contributes high carbon emissions. Therefore, with the advent of the low-carbon economic era, ways to reduce the carbon emissions and to bring about a low-carbon industrial transition of the pulp and paper industry is becoming one of the important academic projects. A system for carbon footprint assessment, namely the Publicly Available Specification (PAS) 2050 methodology, is introduced in this paper. Based on the analysis and assessment of the carbon footprint ($CO_2$ equivalent emissions) for the Coated Ivory Board production lines, it was used to provide a scientific basis and approach for reduction of carbon emissions and formulate the corresponding measures for carbon emissions reduction of China's pulp and paper industry. The business to business carbon footprint, for which steps of the life cycle are included in Coated Ivory Board production, was analyzed and calculated. The results showed that there were 888 kg of $CO_2$ equivalent emissions per metric ton of Coated Ivory Board, in which the largest part, accounting for 57.5%, was associated with purchased electricity, followed by fuel oil at 40.2%, and others accounted for 2.3% of the $CO_2$ equivalent emissions.

*Keywords: Low-carbon economy; Carbon footprint; Energy consumption; Pulp and paper industry; Coated ivory board*

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## INTRODUCTION

The paper industry in China has maintained moderate growth in recent years, and the national production and consumption of paper products have been highest in the world since 2009. However, the annual per capita consumption of paper/paperboard is much lower than that of the developed countries (which exceed 200 kg per person), with just 72 kg per person in 2013. Therefore, there is still great room for paper industry development in China (China Paper Association. 2014). Market competition has become more and more aggressive, and in addition, environmental investment and the operational costs for China's paper enterprises has increased because of the policies of energy saving and reduction of discharges. In all, China's paper industry is in the midst of structural adjustment, transition, and upgrading, and there is a quest for the new breakthroughs.

To address global climate change and energy security issues and to seize a favorable position in the process of establishing a new international order, many developed countries have to adjust their development strategies by transitioning to a low-carbon economy. The development of a low-carbon economy, as a way to address climate change, coordination of socio-economic development, and energy security, has gradually been recognized more by the majority of countries. A low-carbon economy has become a new economic model for development in the 21st century. Carbon source and "carbon footprint" calculations are the starting points for gaining an understanding of a low-carbon economy. Carbon footprints of products are very important to assess greenhouse gas (GHG) emissions. The "PAS 2050 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" was compiled in October 2008 by the British Standard Institutions (BSI), and it was revised in 2011. The revision of PAS 2050:2011 had been undertaken by BSI to update the specification for quantifying the life cycle GHG emissions of goods and services in line with the latest technical advances and current experience. Estimating carbon footprints of products comprised five basic process in this specification, namely, making a flow chart, identifying the system boundary and priorities (the sources of GHG emissions associated with products that fall inside the system boundary), the data requirements for carrying out the analysis, the calculation of the results, and uncertainty analysis (BSI 2008, 2011). It has been widely used to evaluate its GHG emissions of goods and services, and has become a common evaluation standard for carbon footprints (Yuan and Huang 2011).

The Chinese government pays high attention to climate change issues. According to the requirements of conventions and all previous contacting conferences, a series of policies and actions have been carried out to fulfill the Chinese commitment. In 2006, China brought up an obligatory target of unit GDP energy consumption in 2010, to be reduced by 20% than that of 2005. In 2007 China first formulated and implemented a national plan on tackling climate changes. In 2009, the government committed itself to an action objective to cut energy consumption per unit GDP by 40% to 60%, and carbon dioxide emissions per unit GDP by 40% to 50% by 2020 from the 2005 level, as spelled out in "China Sustainable Development Strategy Report 2009--China's Approach towards a Low Carbon Future" and "China's Policies and Actions for Addressing Climate Change (2011)".

With respect to the paper industry, the relevant "12th five-year" plan (by 2015) set an obligatory target to reduce energy consumption by 22%, for paper and paperboard and by 18% for pulp, to reduce water consumption by 18% for paper and paperboard, and main pollutant emissions by 10% to 12% based on 2010 (NDRC *et al*. 2012). These goals were based on the metric tons of paper/paperboard and comprehensive energy consumption at the end of the previous period, *i.e.* "11th five-year plan". To achieve these goals, the domestic industries are exploring the establishment of a low-carbon product standard, identification, and authentication system, in order to save energy consumption and carbon emissions based on statistical accounting. The carbon footprint of the PVC plastic industry is spelled out in their product certification, where it is stated that production of 1 t of PVC yields 1765 kg of $CO_2$ equivalent emissions (business-to-business) (Ma and Xin 2011). Similarly, for the carbon footprint of hemp product the corresponding values are: 1 t of hemp yields and 5499 kg of $CO_2$ equivalent emissions (cradle-to-gate) (Yang *et al*. 2012). For the carbon footprint of tissue paper product, the emissions are: 1 t of tissue paper and 1681 kg of $CO_2$ equivalent emissions (cradle-to-gate) (Wang 2013). The steel industry's production of 1 t of steel yields 2245 kg of $CO_2$ equivalent emissions (cradle-to-gate) (Zhang *et al*. 2013). By contrast, the carbon footprint of 1 t of particleboard is equivalent to -939 to 188 kg $CO_2$ eq/$m^3$ (cradle-to-gate); 107 to 201 kg $CO_2$eq/$m^3$ (cradle-to-grave; incineration), and -692 to 433 kg $CO_2$eq/$m^3$ (cradle-to-grave; landfill) (Garcia and Freire 2014). When straw material is used to produce bleached cultural paper, the production of 1 t of product yields 2072.5 kg of $CO_2$ equivalent emissions (Zhang and Zhang 2013). However, there has not yet been an instance of carbon footprint evaluation for market pulp board producing coated ivory board. As is well known, the production line of coated ivory board is a typical papermaking method including the coating process. In addition, coated ivory board is a relatively high value-added product with good quality and a large amount. It is mainly applied to tobacco packaging, medicine packaging, cosmetics packaging, food packaging, liquid packaging, and production of clothing tags, postcards, invitations, greeting cards, *etc*. This makes it necessary to evaluate the carbon footprint for a production line of coated ivory board.

## Low-carbon Paper Industry

Papermaking has been known for its high GHG emission globally among the traditional paper industry, due to its energy intensive processes. The modern papermaking industry is a technology-intensive, capital-intensive, and highly automated industry. It has the typical characteristics of a circular economy and the obvious advantages of low-carbon development (Liu 2009; Li 2010; Zhang *et al*. 2010; Cong *et al*. 2011; Chen 2011). The entire paper industry chain is first examined from a low-carbon economic perspective. A key feature of the industry is its integration with forest carbon sinks. Plant growth through photosynthesis fixes carbon in fiber. Papermaking uses the plant fiber as its main raw material, taking advantage of the fact that it is a renewable resource and a carbon sink (paper is only from a renewable resource if harvested forests are replanted and no deforestation occurs). Other advantages of cellulosic fibers are their recycling ability and low-carbon emissions during a production cycle. Water, chemical raw materials, and waste paper all can be recycled in the process of papermaking. Black liquor, sludge, and methane can be effectively used as biomass energy to reduce fossil energy consumption and carbon dioxide emissions. Papermaking also has the advantage of being a mature technology. Application of techniques such as cultivation technology and planting technology of papermaking materials, fiber processing technology, energy-saving and water-saving technology, and pollution treatment technology can reduce the consumption of raw material resources, water resources, forest land resources, and promote development in the paper industry. This suggests that the paper industry has the great potential to become a low carbon industry.

The next step is to test and account for the carbon flow in a pulping and papermaking system. The system boundary for this project is the blue line. The system boundary for the assessment of GHG emissions for an input that is made available or used in a business-to-business manner shall include all emissions that have occurred up to, and including, the point where the input arrives at a new organization (including all upstream emissions). Downstream emissions shall be excluded from the system boundary GHG emissions assessments carried out for business-to-business assessments. Carbon emissions in the whole system are mainly from the burning of fossil fuels. Plant photosynthesis plays the role of carbon sequestration, so that paper products have a function in carbon storage; *i.e.* they act as a carbon sink. While they are in use, the paper products will also be part of carbon emissions, but on the whole, paper products have the effect of carbon storage. According to the Kyoto Protocol accounting rules, carbon emissions produced by biomass fuels are not included in carbon dioxide emissions. A carbon flow diagram of the pulping and papermaking system is shown in Fig. 1 (Liu *et al.* 2011; Zhang and Zhang 2012).

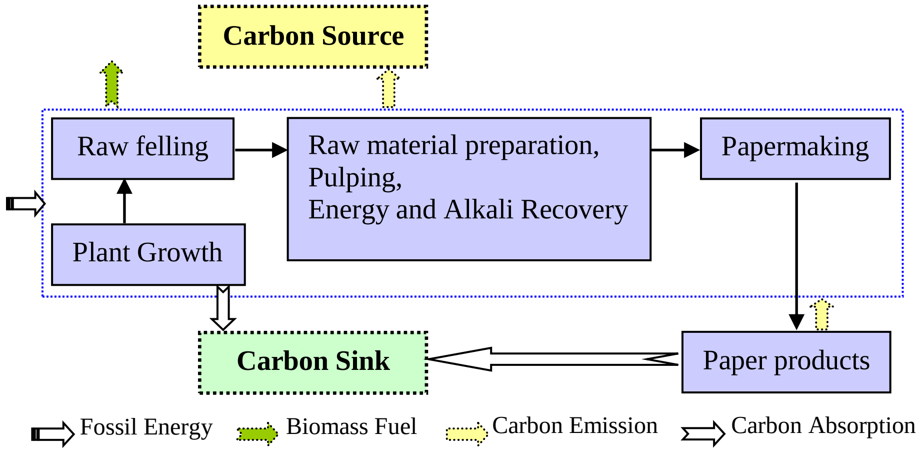


**Fig. 1.** Carbon flow diagram of the pulping and papermaking system

## METHODOLOGY

### Application of Carbon Footprint Assessment Methodology on Coated Ivory Board

The PAS2050 standard was used to evaluate the carbon footprint of coated ivory board with a specific unit: $CO_{2e}$ (GHG emissions are converted into $CO_2$ equivalent emissions in the paper). Specific steps are as follows.

*Determine the functional unit*

The functional unit is 1 metric ton coated ivory board.

*Determine the system boundary*

The carbon footprint of coated ivory board = raw materials + energy + production process + packaging and storage + transportation.

Note: Purchase of raw materials includes commodity pulp board, fuel oil, LPG, *etc*. The evaluation model is business to business (B2B), which includes only from raw materials entering the factory to produce the product and transporting to the next group, including the distribution and transportation to commercial customers (Fig. 2), and it does not include the additional production step and the final product distribution, retail, consumer using and disposal, and reuse.

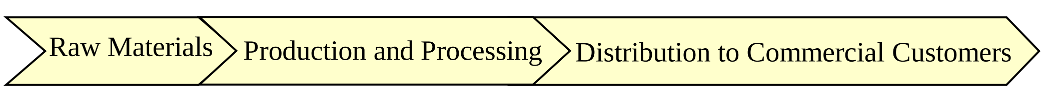


**Fig. 2.** Production and sales process of Coated Ivory Board

The material balance diagrams of one production line of coated ivory board are shown in Figs. 3 through 6.

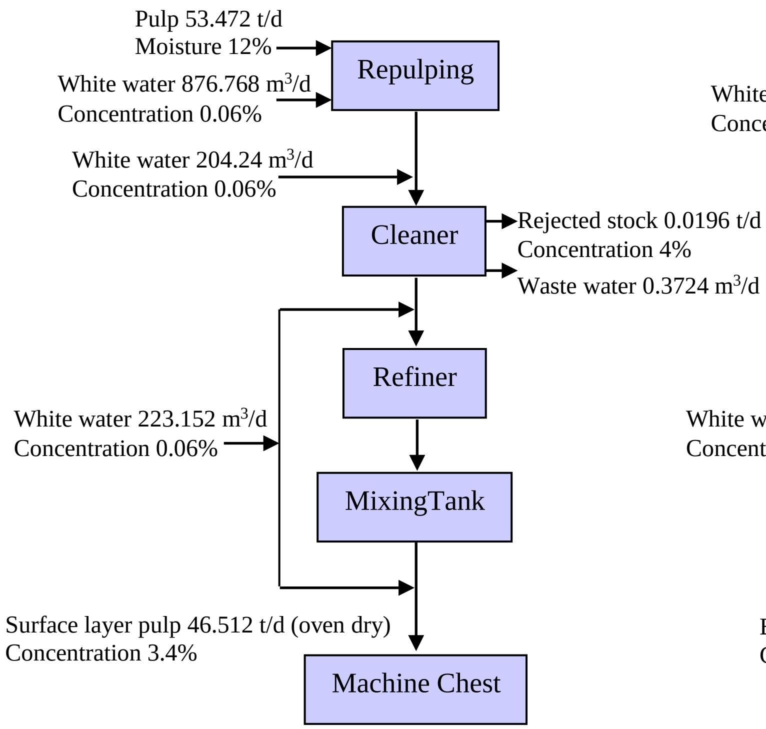


**Fig. 3.** Material balance diagram of surface layer pulp

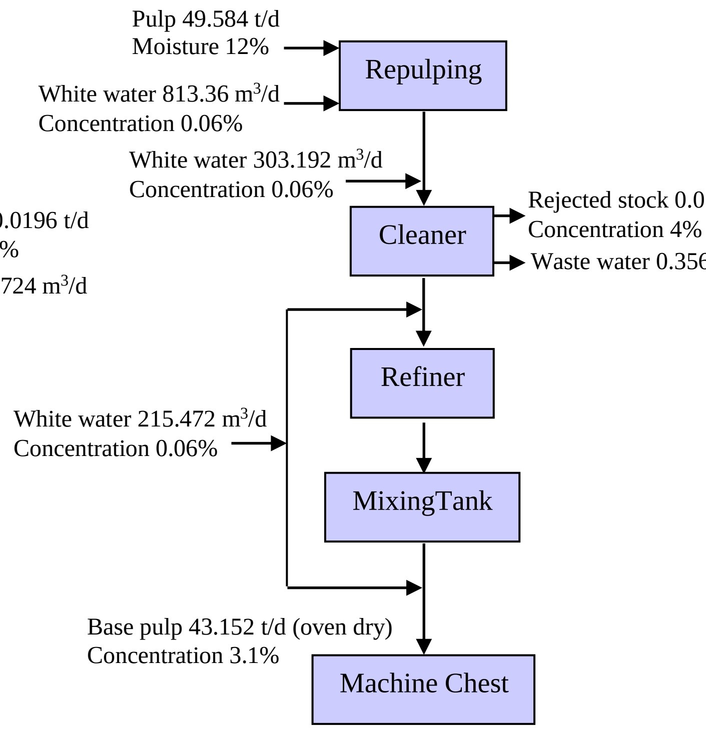


**Fig. 4.** Material balance diagram of base pulp

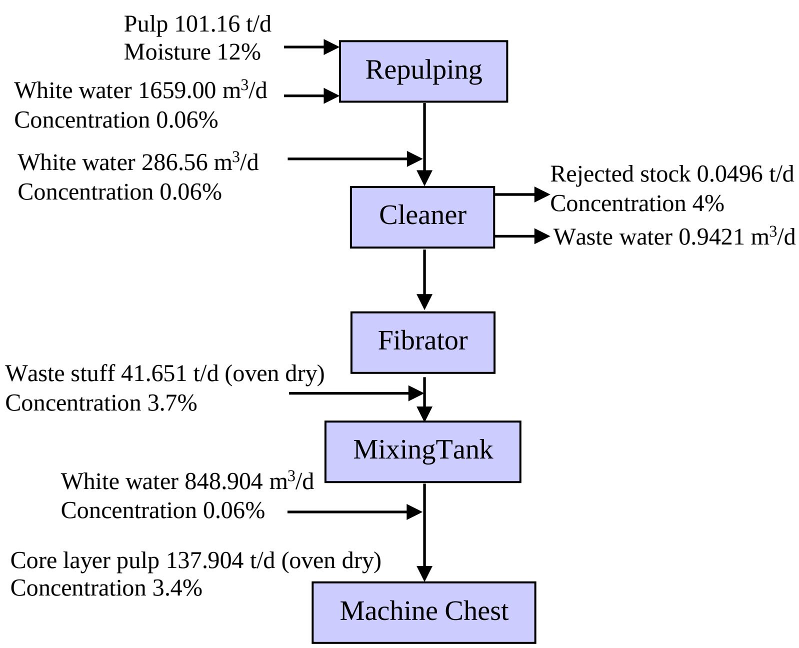


**Fig. 5.** Material balance diagram of core layer pulp

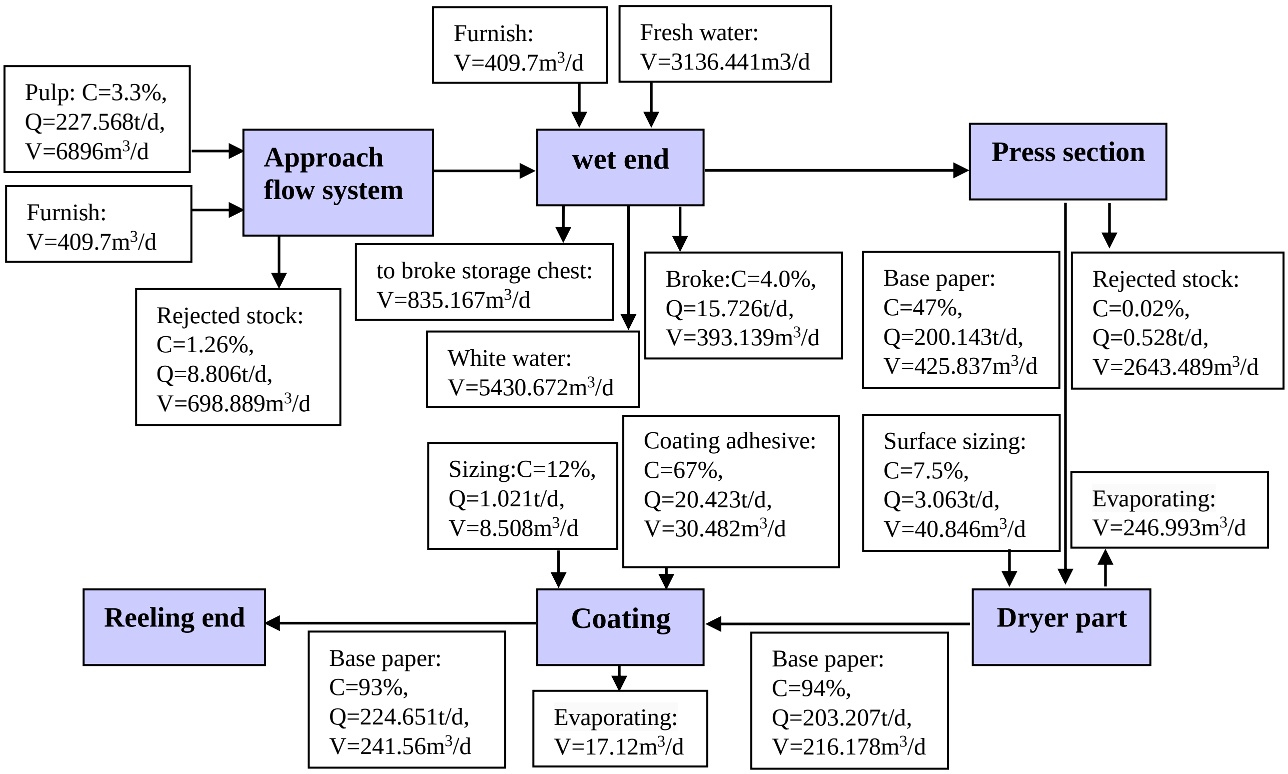


**Fig. 6.** Material balance diagram of paper machine

*Data collection*

Two classes of data are needed to calculate the carbon footprint: activity data and emission factors. Activity data and emission factors were derived from primary or secondary data. Primary data that targeted a specific product's life cycle are measured directly by the person in the supply chain. Secondary data are external measurement not for specific products, but an average of similar processes or materials or general measurements (such as the industry report or summary data).

The following method was used to calculate the GHG emissions for a functional unit:

1. Primary activity data and secondary data shall be converted to GHG emissions by multiplying the activity data by the emission factor for the activity. This shall be recorded as GHG emissions per functional unit of product.
2. GHG emissions data shall be converted into $CO_{2e}$ emissions by multiplying the individual GHG emissions figures by the relevant GWP.
3. The results shall be added together to obtain GHG emissions in terms of $CO_{2e}$ emissions per functional unit. When the result is calculated, the result shall be: business-to-business: the point where the input arrives at a new organization, including all upstream emissions.
4. The GHG emissions shall then be scaled to account for any minor raw materials or activities that were excluded from the analysis by dividing the estimated emissions by the proportion of emissions calculated for the anticipated life cycle GHG emissions.

Energy consumption and product output of coated ivory board in the process of production and sales are shown in Table 1.

**Table 1.** The Statistical Table about Energy Consumption and Product Output of Coated Ivory Board in the Process of Production and Sales

| Item | Substance Name | Unit | Dosage /Output |
|---|---|---|---|
| Energy consumption in producing process | Purchased electricity | kW·h | 141220000 |
| | Fuel Oil | Metric tons | 29670.59 |
| | Liquefied Petroleum Gas | Metric tons | 1410.64 |
| Energy consumption in Transporting process | Diesel | Metric tons | 246.4 |
| | Gasoline | Metric tons | 73 |
| Production | Coated Ivory Board | Metric tons | 269777.62 |

*Carbon footprint calculation*

Carbon footprint calculations related emission factors are described.

(1) The global warming potential (GWP)

| Greenhouse gas | Formula | GWP |
|---|---|---|
| Carbon dioxide | $CO_2$ | 1 |
| Methane | $CH_4$ | 25 |
| Nitrous oxide | $N_2O$ | 298 |
| * The parameters in this paper from IPCC 2006-2 Energy. | | |

(2) Electricity emission factors

China Southern Power Grid：0.9762 kg $CO_2$ equivalent emissions per kW·h of electricity. These data are from the National Development and Reform Commission (NDRC) on Climate Change of People's Republic of China in 2010.

Emission factors for fuel oil, LPG, Diesel and Gasoline (2006 IPCC Guidelines. 2006).

(3) Fuel Oil Emission Factor

| Fuel Oil Emission Factor | Calculate Process | Results |
|---|---|---|
| $CO_2$ ($Ef_1$) | 1kg × 41816 kJ/kg × 77 400 kg$CO_2$/TJ | 3.2365584 kg$CO_2$ |
| $CH_4$ ($Ef_2$) | 1kg × 41816 kJ/kg × 3 kg$CH_4$/TJ | $1.25448\times10^{-4}$ kg$CH_4$ |
| $N_2O$ ($Ef_3$) | 1kg × 41816 kJ/kg × 0.6 kg$N_2O$/TJ | $2.50896\times10^{-5}$ kg$N_2O$ |

(4) Liquefied Petroleum Gases (LPG) Emission Factor

| LPG Emission Factor | Calculate Process | Results |
|---|---|---|
| $CO_2$ ($Ef_4$) | 1kg × 50179 kJ/kg × 63 100 kg$CO_2$/TJ | 3.1662949 kg$CO_2$ |
| $CH_4$ ($Ef_5$) | 1kg × 50179 kJ/kg × 1 kg$CH_4$/TJ | $5.0179\times10_{-5}$ kg$CH_4$ |
| $N_2O$ ($Ef_6$) | 1kg × 50179 kJ/kg × 0.1 kg$N_2O$/TJ | $5.0179\times10_{-6}$ kg$N_2O$ |

(5) Diesel Emission Factor

| Diesel Emission Factor | Calculate Process | Results |
|---|---|---|
| $CO_2$ ($Ef_7$) | 1kg × 42652 kJ/kg × 74 100 kg$CO_2$/TJ | 3.1605132 kg$CO_2$ |
| $CH_4$ ($Ef_8$) | 1kg × 42652 kJ/kg × 3 kg$CH_4$/TJ | $1.27956\times10^{-4}$ kg$CH_4$ |
| $N_2O$ ($Ef_9$) | 1kg × 42652 kJ/kg × 0.6 kg$N_2O$/TJ | $2.55912\times10^{-5}$ kg$N_2O$ |

(6) Gasoline Emission Factor

| Gasoline Emission Factor | Calculate Process | Results |
|---|---|---|
| $CO_2$ ($Ef_{10}$) | 1kg × 43070 kJ/kg × 74 100 kg$CO_2$/TJ | 3.191487 kg$CO_2$ |
| $CH_4$ ($Ef_{11}$) | 1kg × 43070 kJ/kg × 3 kg$CH_4$/TJ | $1.2921\times10^{-4}$ kg$CH_4$ |
| $N_2O$ ($Ef_{12}$) | 1kg × 43070 kJ/kg × 0.6 kg$N_2O$/TJ | $2.5842\times10^{-5}$ kg$N_2O$ |

(7) The Calculation Results

The following equation was used to calculate the total emissions of $CO_2$ equivalent,

$$GHG_a = \sum_a F_a \cdot Ef_a \qquad (1)$$

where $GHG_a$ is the emissions of $CO_2$ equivalent (t), $Ef_a$ is the emission factor, $F_a$ is the fuel consumption (kg), and the subscript "a" represents the kind of Fuel (for example fuel oil, LPG, diesel, or gasoline).

**Table 2.** The Calculation Results of Carbon Footprint

| $CO_2$ equivalent emissions | Calculation Process | Results |
|---|---|---|
| Purchased electricity ($GHG_1$) | 141220000kWh × 0.9762kg/kWh | 137858.96 Metric tons |
| Fuel oil ($GHG_2$) | $29670.59\times(3.2365584\text{kgCO}_2\times1+1.25448\times10^{-4}\text{kgCH}_4\times25+2.50896\times10^{-5}\text{kgN}_2\text{O}\times298)\times10^{-3}$ | 96345.45 Metric tons |
| LPG ($GHG_3$) | $1410.64\times(3.1662949\text{kgCO}_2\times1+5.0179\times10^{-5}\text{kgCH}_4\times25+5.0179\times10^{-6}\text{kgN}_2\text{O}\times298)\times10^{-3}$ | 4470.37 Metric tons |
| Diesel ($GHG_4$) | $246.4\times(3.1605132\text{kgCO}_2\times1+1.27956\times10^{-4}\text{kgCH}_4\times25+2.55912\times10^{-5}\text{kgN}_2\text{O}\times298)\times10^{-3}$ | 781.42 Metric tons |
| Gasoline ($GHG_5$) | $73\times(3.191487\text{kgCO}_2\times1+1.2921\times10^{-4}\text{kgCH}_4\times25+2.5842\times10^{-5}\text{kgN}_2\text{O}\times298)\times10^{-3}$ | 233.78 Metric tons |
| Sum of the total emissions of $CO_2$ equivalent | Total Emissions = $\sum_{i=1}^{n} GHG_n$ (n = 5) | 239,689.98 Metric tons |
| Coated Ivory Board Production | | 269777.62 Metric tons |
| $CO_2$ equivalent emissions of per metric ton production | | 888.47 kg |

Table 2 gives the calculation of the carbon footprint in coated ivory board production. It is shown that there are 888 kg $CO_2$ equivalent emissions per metric ton production, in which the maximum part accounted for 57.5%, was caused by purchased electricity, followed by fuel oil at 40.2%, and others accounted for 2.3% of $CO_2$ equivalent emissions.

*Uncertainty Analysis*

Uncertainty analysis for product carbon footprint is a kind of control for the accuracy of results from carbon footprint evaluation, and its purpose is to evaluate the reliability of the carbon footprint data and the calculation process. The uncertainty is acceptable in the study because the proportion of carbon footprint assessment about the other GHG such as nitrogen oxide emissions in some process is too small and negligible.

It is possible to reduce the sources of uncertainty through the following steps: (1) using highly accurate primary activity data instead of secondary data; (2) using more accurate and reasonable secondary data, (3) carrying out the process of calculation with more meticulous tallying and reality checking; and (4) consulting with industry experts to review the carbon footprint.

## CONCLUSIONS AND RECOMMENDATIONS

The PAS2050 methodology for the carbon footprint assessment was introduced in this paper. Based on the analysis and assessment of the carbon footprint ($CO_2$ equivalent emissions) for the coated ivory board production lines, it would provide a scientific basis and approaches for the reduction of carbon emissions and formulate the corresponding measures for carbon emission reduction of the paper industry in China. The carbon footprint in coated ivory board production: 888 kg $CO_2$ equivalent emissions per metric ton production (business-to-business). The major part of this amount, accounting for 57.5%, was caused by purchased electricity, followed by fuel oil at 40.2%, and others accounted for just 2.3% of the $CO_2$ equivalent emissions. The calculation results show that the carbon footprint of coated ivory board products is mainly attributable to fossil energy consumption. Since the production enterprises are using recovered waste pulp board as raw material, the carbon footprint value of coated ivory board is relatively small.

In an effort to reduce fossil energy consumption and also to reduce carbon emissions during production of coated ivory board life cycle, the enterprise can employ many methods such as following (Wiebren *et al.* 2003; Dasappa *et al.* 2003; Canadell and Krschbaum 2007; Jou *et al.* 2010; Yu 2010):

1. To expand the use of biomass fuels, and improve their efficiency of utilization.
2. To adopt energy-saving technology to reduce the use of fossil fuels consumption.
3. To develop the forestry base to increase the forest carbon sink and realize the formation of forest-paper integration for low carbon production of papermaking.
4. To improve the efficiency of the management and operation model.

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