A Comparative Analysis of Carbon Dioxide Emissions in Coated Paper Production

Key Differences between China and the U.S.

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Abstract

This technical report compares carbon dioxide emissions from the production of freesheet coated paper in the Chinese paper industry with the same paper produced by NewPage Corporation, the largest North American manufacturer of coated paper products. By analyzing the supply chains for the Chinese and NewPage manufacturing facilities, the report highlights differences in the carbon burden based on two key components of the lifecycle—carbon dioxide emissions from transportation and energy in pulp and paper production. The carbon burden from these two components for coated freesheeet paper manufactured in China's industry is significantly higher than for NewPage's coated freesheet paper. It should be noted that this study is a partial, comparative lifecycle inventory of carbon dioxide emissions in coated freesheet paper. The study also reviews emerging science on carbon pooling given varying forest types and harvesting practices, and offers the methodological building blocks for how fiber acquisition might be modeled for the comparison. We find that the fiber acquisition component has substantial implications for accounting for the carbon burden in both supply chains.

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Executive Summary

This report provides a comparison of carbon dioxide emissions from the production of coated freesheet paper in the Chinese paper industry with coated freesheet paper produced by United States (U.S.)-based NewPage Corporation, the largest coated paper manufacturer in North America. The study tests the hypothesis that carbon dioxide emissions inherent in the production of coated freesheet paper vary greatly depending on where and how it is produced, where the raw materials used to make it are extracted and processed, and where it is sold. The results of the study provide evidence that the distribution of production locations in each supply chain makes a significant difference in the overall emissions of carbon dioxide (CO_2).

The research presented in this report focuses on three aspects of spatial differences in the production of coated paper that are hypothesized to be different between China and the U.S. These three are as follows: integrated vs. non-integrated pulp and paper production; the fuel mix of direct and indirect energy used in pulp and paper production; and long versus short transportation distances. The magnitude of differences between the supply chains are estimated using models created for two stages in the lifecycle in each supply chain: transportation of fiber and finished paper and energy used in pulp and paper production.

Carbon release from forestry due to fiber acquisition is a crucial emerging issue in calculating the carbon burden of paper products. It is also likely that emissions of greenhouse gases (GHGs) from forestry vary by the geographical distribution of the supply chain, depending upon forest types and harvest or plantation practices. The final section of the report includes an extensive discussion of this issue in the context of these two supply chains.

The report is organized with opening sections giving an overview of the supply chains for China and NewPage and delimitation of the study scope. Next are sections for each of the two emissions models: transportation and pulp and paper production, followed by a section discussing carbon loss from forestry. Each of these sections are summarized below.

1. Overview of the Chinese and U.S. Coated Paper Industries

China is now the second largest producer of paper, after the U.S., and coated paper is one of the fastest growing segments of this sector. In China, Asia Pulp and Paper's (APP) Gold East Paper mill is by far the largest producer. APP produced about 15% of the total production of coated papers of all types in China in 2008. NewPage Corporation is the largest manufacturer of coated paper (of all types) in North America with approximately 35% of 2008 North American production capacity, followed by Verso Paper (17%) and Sappi Corporation (14%). China is the world's largest importer of pulp. In 2007, China's top six pulp providers were as follows: Canada (20% of the total), Indonesia (18%), Brazil (14%), Russia (14%), the United States (11%), and Chile (10%). The wood supply structure for NewPage's facilities is primarily locally sourced. Most fiber is sourced by harvesting wood from managed native forests within approximately a 100 mile radius of each facility, with approximately 10% of NewPage's total fiber requirements imported as pulp from Canada (based on 2007 data). The use of recycled fiber in production of coated paper of all types is small in both the U.S. and Chinese supply chains. For example, recycled fiber made up 3% of total fiber for NewPage in 2007. For the Chinese supply chain, the figure is 7%. For coated freesheet paper, industry data for both supply chains revealed virtually no use of recycled fiber. Thus, the study focuses on fiber inputs of wood and pulp.

2. Study Scope and System Boundary

This study is structured as a partial comparative lifecycle inventory of carbon dioxide emissions. It is not a full "carbon footprint" of the coated freesheet product in either supply chain. There are numerous stages and elements in the full lifecycle of coated freesheet paper that are not analyzed in this study (see Table 2.1). As noted above, among the most prominent of these is carbon dioxide emissions associated with land use change, such as timber harvest due to fiber acquisition. Additional basic scientific research is needed to make an accurate comparison of these emissions across the two supply chains. There are also several other lifecycle stages and elements that are excluded. Omission is due to data unavailability or suitability to the purpose of the study. For several of these elements, it seems likely that the processes and carbon dioxide emissions differ little between the two supply chains. Throughout the study, comparisons are drawn using the same data sources to characterize energy use as well as emission factors for both supply chains. This ensures that the comparison is not rendered inaccurately due to higher data resolution for one supply chain. Although, it is important to note the study does not refer to the entire U.S. industry; rather it focuses solely on the carbon dioxide emissions associated with NewPage's production.

3. Transport

The research includes a study of CO_2 emissions from transportation in each supply chain. The study includes transportation of pulp to paper mills, and of finished paper from paper mills to Los Angeles, CA, a major U.S. point of purchase. Overall, there is more transport of materials in the Chinese supply chain, because pulp comes from all over the world, and the Chinese paper mills are far from U.S. markets. For example, pulp travels on average over 5,000 miles to the mills in China compared to about 1,500 miles for the U.S. mills. The transportation study does not include emissions from the transport of chemical and other non-fiber additives or wood fiber to the pulp mills. Instead, it focuses on transport of two of the principal constituents in the supply chains: pulp and finished paper. Both are areas where we expected significant differences between the two supply chains.

Findings

Emissions of carbon dioxide from transportation for the Chinese coated paper industry are about eight times higher than for NewPage coated paper. Estimated carbon dioxide emissions from transportation for coated freesheet paper delivered to the Port of Los Angeles totals 187 Kg of CO_2 per finished metric ton (FMT) for the Chinese industry and 23 Kg of CO_2 per FMT for NewPage. It is important to note, however, that transportation emissions are much smaller than emissions from pulp and paper production.

4. Pulp and Paper Production

Previous studies conclude that the major component of CO_2 emissions in the paper lifecycle is found in the production/use of process steam (heat) and electricity in pulp and paper manufacturing (Gower, 2006; NCASI, 2005). This study compares the U.S. and Chinese supply chains with models of energy and fuel use based on global industry data. Emission factors used to calculate carbon dioxide emissions from the burning of fossil fuels across the global supply chain are analogous to those used in the IPCC's 2006 methodology for national emissions inventories.

Findings

The NewPage carbon footprint from embedded energy in manufacturing is about 42% lower than the footprint for the Chinese manufacturing: 1,432 Kg of CO_2 per FMT for the U.S. (NewPage) vs. 2,478 Kg of CO_2 per FMT for China. Results confirm the importance of the fuel mix in driving the carbon footprint for embedded energy in manufacturing coated freesheet paper, as well as efficiency gains with higher levels of integrated pulp and paper production in the U.S. China's extended supply chain for coated paper manufacturing uses more energy overall, and has much more coal fuel in its production. The U.S. (NewPage) supply chain uses less energy overall, and has more biomass energy available for production. Cleaner fuels like natural gas displace the use of coal. When coal is used, co-firing with biomass sources makes it much more efficient with respect to CO_2 emissions. Also, when electricity is used from the grid, energy sources in the U.S. grid are less carbon intensive than for grid electricity in China.

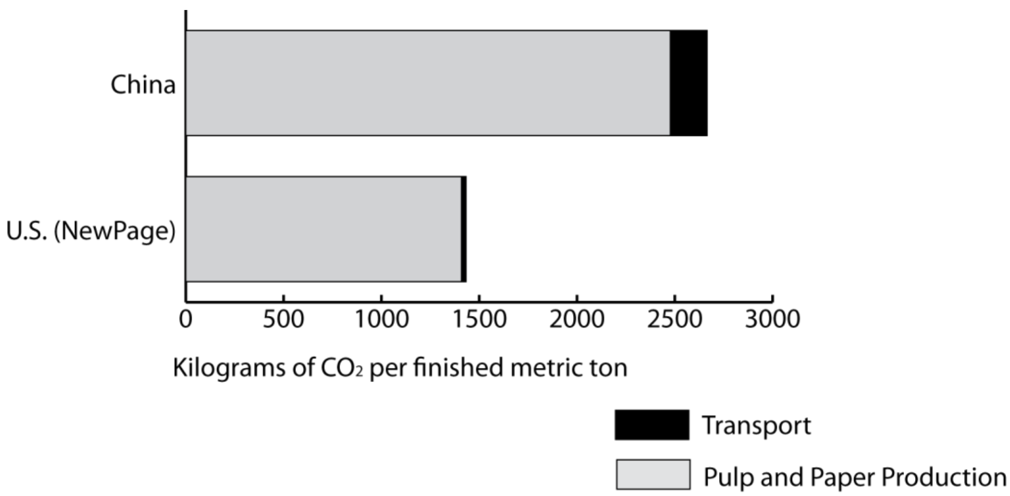

Figure 0.1 Comparison of Carbon Dioxide Emissions for Coated Freesheet Paper Production

5. Fiber Acquisition

Forests play an important role in stabilizing the global climate. Both the types of forests and forest management practices vary substantially between the two supply chains. As forests are harvested and/or replanted, or harvested and converted to other land uses, the potential exists for the net release of GHG's into the atmosphere. In this section of the study, we discuss the variables that would need to be accounted for to accurately model and compare the carbon loss due to timber harvest for two supply chains. The carbon burden hinges on many factors, including harvest practices, plantation management, and the types of forests that are impacted. This section also provides the foundations for building a general methodology to account for these factors at the product level. Two key issues highlighted are considerations regarding spatial and temporal scales that should be incorporated into the model.

6. Conclusions and Future Research

This study reveals that not all papers are created equally. The geography of paper production matters a great deal for the environment. The supply chains for China's industry produce larger emissions of carbon dioxide, primarily from fuel used to produce the pulp and the paper (see Figure 0.1). More research is needed to understand how the geography of paper production and consumption affects the full "carbon footprint" and the overall environmental burden (on a total lifecycle basis).

1. Overview of the Coated Paper Industry in China and the U.S.

Since 1990, China has accounted for more than 50% of the world's overall growth in paper and paperboard (Barr and Demawan, 2005). China is now the second largest producer of paper, after the U.S., and coated paper is one of the fastest growing segments of this sector. Figure 1.1 shows the top Chinese coated paper manufacturers in terms of metric tons produced.

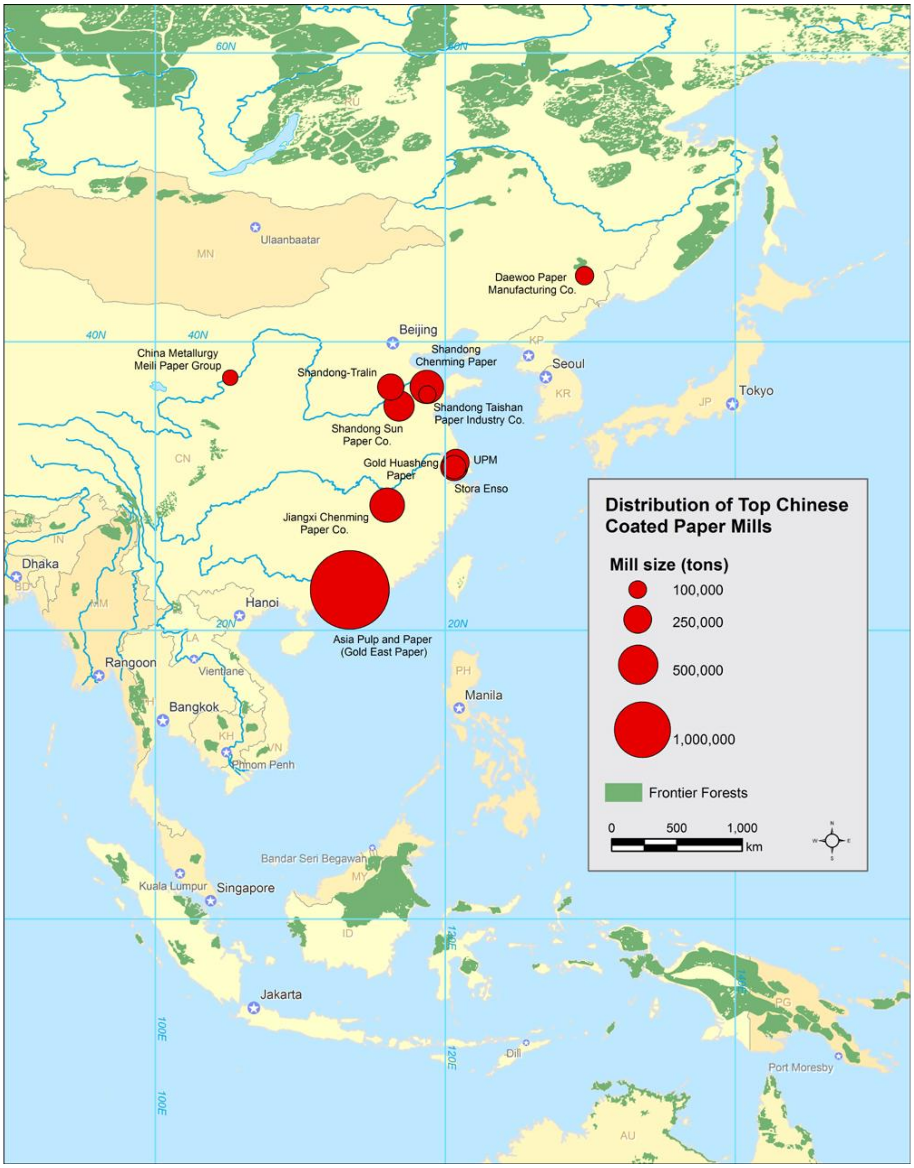

Figure 1.1 Major Coated Paper Manufacturers in China, 2007

Sources: Map by Authors/Data from World Resources Institute, 2007; RISI, 2007: ESRI, 2007.
Note: Production figures are in metric tons. Frontier Forests refer to forests that are largely intact natural forests as defined by the World Resources Institute.

In China, Asia Pulp and Paper's (APP) Gold East Paper mill is by far the largest producer. APP has a capacity of approximately 2.8 million metric tons of coated paper in 2007 or about 15% of the total production of coated papers of all types in China (Resource Information Systems Incorporated (RISI), 2007). No other single producer accounts for more than 10% of the total. Figure 2.2 is a map of the locations of APP's most important facilities.

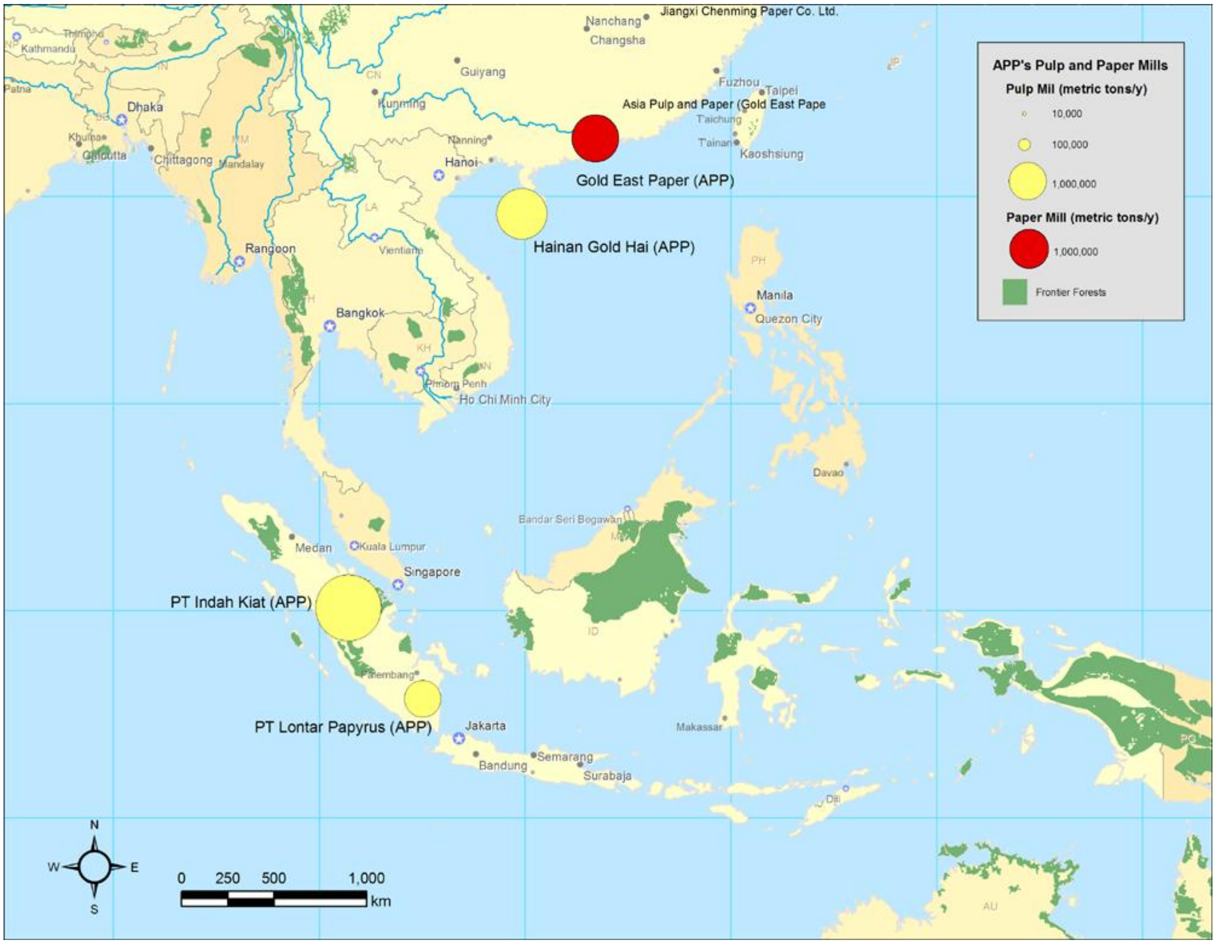

Figure 1.2 Geographic Distribution of APP's Major Pulp and Paper Mills in Asia

Sources: Map by Authors/Data from World Resources Institute, 2007; RISI, 2007: ESRI, 2007.
Note: Production figures are in metric tons.

To compare the Chinese and U.S. coated paper supply chains, this study focuses on production at NewPage Corporation, the largest coated paper manufacturer in North America. NewPage has a total annual production capacity of approximately 3.3 million short tons of coated paper, which represents approximately 35% of 2007 North American production capacity. Verso Paper represents about 17% of the total, followed by Sappi Corporation at about 14% (Resource Information Systems Incorporated (RISI), 2007 and NewPage Internal Numbers). For this study we focused on six facilities that made coated freesheet paper in 2007. These facilities are generally located in the upper Midwest and Northeast in the vicinity of working forests.   One note of caution:

this study should not be viewed as representative of the entire U.S. coated paper industry, because we focused on one company, and further on only the facilities of that company that make coated freesheet paper. However, NewPage is a large enough producer to make for meaningful analysis as compared to the industry in China.

Throughout this study, figures for coated paper manufacturing in China and the U.S. are drawn from an analysis of industry software called *Cornerstone* produced by RISI (2007). In its flow sheets, *Cornerstone* tracks inputs to production and outputs by facility, in a materials balance framework. Data were extracted from the flow sheets for total output of coated papers of various types, and also for inputs to each type. Although *Cornerstone* does not include a complete list of every paper producer, it is the most thorough data available for the industry on a global scale. The data used in this study represent annual production for 2007.

Fiber Supply Structure - China

The rise of the Chinese paper sector has transformed an industry once consisting of numerous small-scale pulp mills that were heavily reliant on non-wood fibers to one that now imports large quantities of pulp and wastepaper to feed huge, modern mills (Vickers Securities, 2005). Slightly less than 50% of the fiber supply (pulp and wastepaper) used by Chinese paper producers comes from imports (Figure 1.3), including 33% from waste (or recovered) paper, 14% from wood pulp, and a small percentage from non-wood pulp.

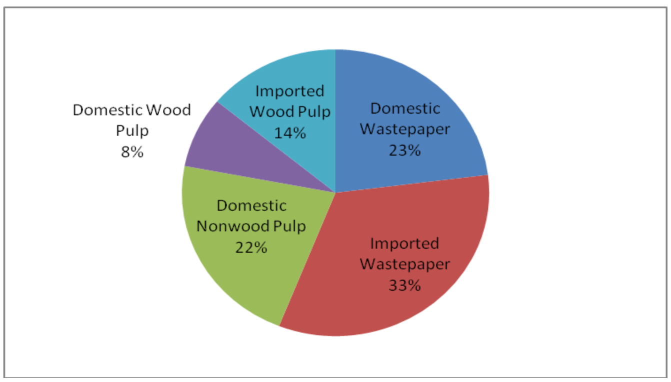

Figure 1.3 Breakdown of China's Paper Supply Sources, 2005
Source: UN Comtrade

Domestically produced wood pulp currently provides about 8% of China's paper supply source. China is the world's 9th largest wood pulp producer, with about 70% of total production coming from large mills less than 10 years old (Wood Resources International and Seneca Creek Associates, 2007). Information on domestic wood supplied to Chinese pulp mills is difficult to obtain, but an estimated two-thirds is coming from domestic plantations. The rest is uncertain. Suspiciously sourced wood fiber is likely to account for at least 10% according to Wood Resources International. Imported chips represent at least 6% of the wood fiber consumed in the production of domestically produced wood pulp, with the two largest suppliers being Australia and Vietnam.

China is the world's largest importer of pulp. The Chinese government has taken steps to reduce this reliance by subsidizing the development of fast-growing plantations. China has approximately 1.65 million hectares of eucalyptus plantations, with many of them located in China's southeastern provinces (American Forest & Paper

Association, 2004). The government has allocated an additional 5.8 million hectares for plantation development over the next decade and provides an array of subsidies to this industry (Barr et al., 2005).

These efforts notwithstanding, analysts generally concur that the Chinese paper industry will remain heavily reliant on imported pulp, woodchips, and recovered paper for at least the next decade (Barr et al., 2005).[1] Dennis Neilson, director of New Zealand forestry consulting firm Dana, notes that the plantation program is far behind schedule and that the growth rates for poplar trees have been so poor that the government is now discouraging planting of that species altogether. Other challenges include a logging ban throughout most of China's natural forests and the emergence of low-cost pulp from regions like Brazil and Indonesia.

Coated paper manufacturing in China is particularly reliant on imported wood fiber because unlike other types of paper manufacturing in China, it uses very little recycled paper or low quality (vegetable) fiber. Also, only one facility in China (Jiangxi Chenming Paper Co.) uses any wood directly in its production process. The use of this wood as a feedstock is very small relative to the use of pulp at this plant and all the others in China. There is also a slight amount of straw being used in some of the production.

Of the total fiber supply for making coated paper in China, only 7% comes from wastepaper. Given that China imports a large quantity of recycled paper, it is likely that a significant share of this fiber is also imported. Table 1.1 gives the breakdown for the major fiber sources for coated paper in China. There is essentially no recycled fiber reported in the *Cornerstone* flow sheets for coated freesheet paper, the focus of this study. Overall, coated paper manufacturing in China relies upon imported and, to a lesser extent, domestic production of pulp. The fiber used for coated freesheet paper manufacturing is either BHKP or BSKP. Thus, analysis of the supply chain for China in this study focuses on these two major constituents.

Table 1.1 Major Fiber Sources for Coated Paper (all types) in China

Major Fiber Sources	ADMT/ per day	% of Feedstock
Bleached Hardwood Kraft Pulp	4367	64%
Bleached Softwood Kraft Pulp	1496	22%
Bleached Chemical Thermo-Mechanical Pulp [2]	481	7%
Sorted Office Papers	208	3%
Old Newspapers	281	4%
Total Fiber Sources	6833	100%

Source: Authors' analysis of RISI, 2007.

[1] *UPM's 350,000 metric ton paper mill in Changhsu, China relies on imported pulp, now primarily from Uruguay and before from Indonesia, Finland and Canada. The company pulled out of a joint venture to build a pulp mill and establish plantations in Guangdong province in November 2004 (Barr et. al, 2005).*

[2] *There are also about 7% of inputs to coated paper from bleached chemical thermo-mechanical pulp. This type of pulp is reported only at the APP plant. More than 80% of this type of pulp is produced in Canada. However, because it is small part of the major inputs, and because we had no specific data on the location of production, we excluded it from further analysis.*

Pulp import structure

The analysis of the Chinese import structure focuses exclusively on BHKP and BSKP, by far the most important fiber materials in coated paper. China is the world's largest importer of pulp. Table 1.2 shows pulp imports, from 2002 to 2006, by type of pulp. Sulfate pulp, which totals about 80 percent of all imported pulp, includes BHKP and BSKP. China's top six pulp providers are as follows: Canada (20% of the total), Indonesia (18%), Brazil (14%), Russia (14%), the United States (11%), and Chile (10%). Figure 1.4 shows the location of the world's largest BHKP and BSKP pulp mills.

Table 1.2 China's Pulp Imports, 2002-2006 (kilotons per year)

Grade	2002	2003	2004	2005	2006	% +/- pa	% (2006)
Mechanical Pulp	146	89	76	60	71	-17%	0.9%
Dissolving Pulp	200	269	290	294	393	18%	4.9%
Sulfate Pulp	4,475	4,937	6,034	6,258	6,406	9%	80.4%
Sulfite Pulp	54	50	67	41	51	-1%	0.6%
Chemi-Mechanical Pulp	357	644	751	868	967	28%	12.1%
Recovered Material Pulp	32	45	102	72	77	24%	1.0%
Total	5,265	6,034	7,319	7,592	7,965	11%	100%

Source: World Trade Atlas, Global Trade Information Services (GTIS)

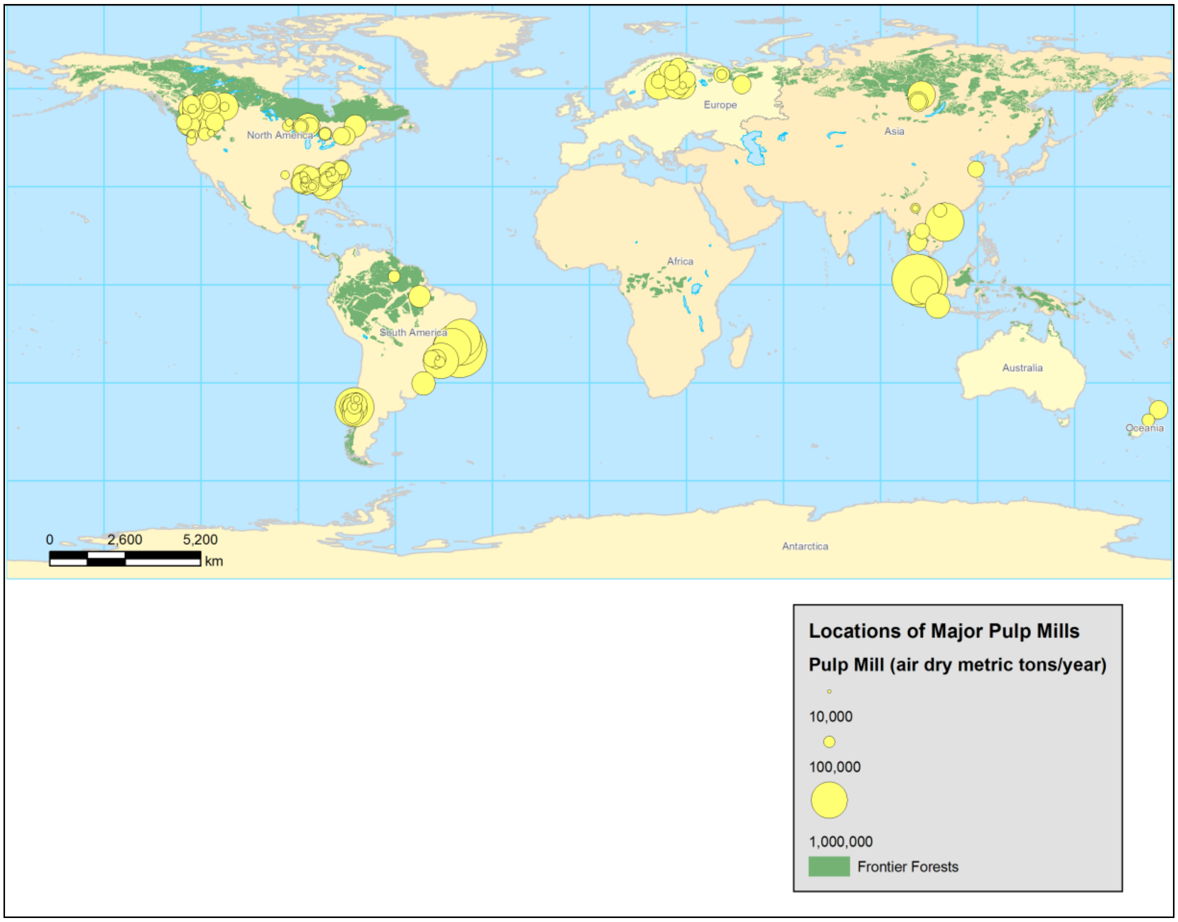

Figure 1.4 Major Pulp Mills across the Globe, 2007

Sources: Map by Authors/Data from World Resources Institute, 2007; RISI, 2007.

Bleached Hardwood Kraft Pulp (BHKP)

Driven by rapidly expanding production of books and magazines, advertising, and copy paper, China's imports of BHKP have grown enormously over the past decade (Barr et al., 2005). BHKP imports rose from 123,000 tons in 1995 to about 3.1 million metric tons in 2007. As shown in Figure 1.4, over 75% of China's BHKP imports come from three countries: Indonesia (35% of the total), Brazil (27%), and Chile (14%).

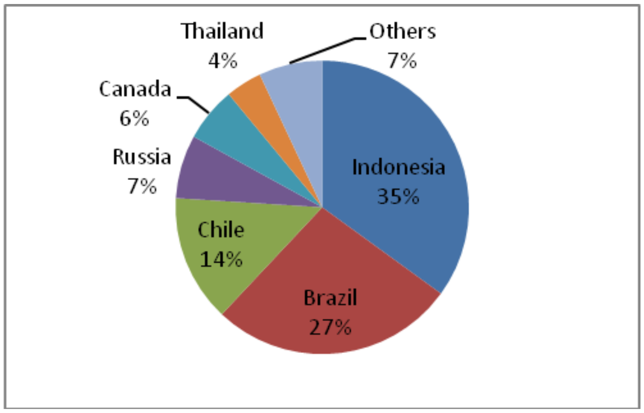

Figure 1.5 Chinese Imports of Bleached Hardwood Kraft Pulp, by Country, 2007

Source: World Trade Atlas, Global Trade Information Services (GTIS). HTIS Code: 470321.

Indonesia

A significant portion of China's imports of BHKP from Indonesia are structured as integrated sales by affiliates of the Asia Pulp & Paper (APP) and APRIL groups, each of which manages pulp mills in Indonesia and paper production facilities in China (Pirard and Rokhim, 2006). In January 2007, BISNIS Indonesia reported that two companies are planning to invest a total of US$3 billion in new pulp mills (Lang, 2007). Indonesian company PT Garuda Kalimantan Lestari plans a 1.2 million ton capacity pulp mill and associated chemical plant in West Kalimantan. PT Kaltim Prima Pulp & Paper plans a 1.2 million ton capacity pulp mill in East Kalimantan (Lang, 2007).

Brazil

Brazil is the world's 7th largest pulp producer and the second largest pulp exporter. More than half of Brazilian production is exported. Brazilian pulp exports are expected to reach 7.4 million metric tons by 2012 (Table 1.3). Virtually all of the growth in pulp production in Brazil has been in bleached short-fiber (eucalyptus) pulp, which makes up 80% of total pulp production. Brazil is now the world's lowest cost producer of BHKP. Aracruz is the world's largest producer of bleached eucalyptus pulp, producing about 27 per cent of the world's total. The company produces a total of 3 million metric tons of pulp a year, and has an area of almost 280,000 hectares of industrial tree plantations plus about 90,000 hectares grown under contract with farmers (Wood Resources International and Seneca Creek Associates, 2007)

Table 1.3 Brazil's Pulp and Paper Investment Program, 2002-2012

	2002	***2012***	***% Increase***
Area Planted (BRACELPA Companies)	*1.4 million ha*	*2.6 million ha*	*+86%*
Pulp Production (million Mt)	*8.0 Mt*	*14.5 Mt*	*+81%*
Paper Production	*7.7 Mt*	*13.4 Mt*	*+74%*
Pulp Exports	*3.5 Mt*	*7.4 Mt*	*+111%*
Paper Exports	*1.4 Mt*	*2.0 Mt*	*+43%*

Source: Brazilian Pulp and Paper Association

Bleached Softwood Kraft Pulp (BSKP)

China's imports of BSKP grew from 429,000 metric tons in 1995 to about 3 million tons in 2007. To add flexibility and strength to paper products, BSKP, due to its long fiber content, is commonly mixed with other types of pulp (Barr and Demawan, 2005). In 2007, as shown in Figure 1.6, China obtained 71% of its BSKP imports from four countries: Canada (28%); Chile (15%); Russia (14%); and the United States (14%).

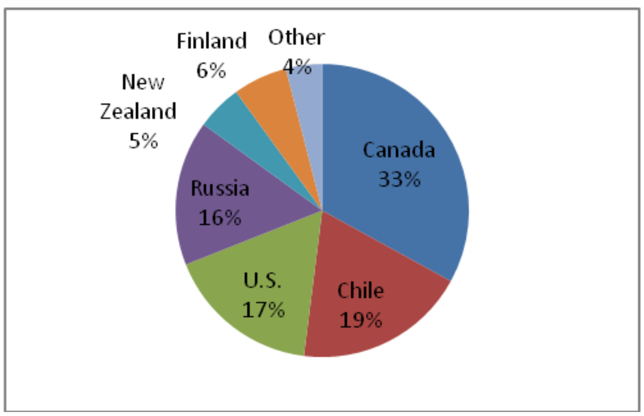

Figure 1.6 Chinese Imports of Bleached Softwood Kraft Pulp, by Country, 2007

Source: World Trade Atlas, Global Trade Information Services (GTIS). HTIS Code: 470329.

Fiber Supply Structure - NewPage

The wood supply structure for NewPage's facilities, by contrast, is primarily locally sourced. Most fiber is sourced by harvesting wood from managed native forests within approximately a 100-mile radius of each facility. Detailed records are maintained on the amount of wood harvested by state and county. As of May 2008, NewPage had twelve paper mills. Six of these mills make coated freesheet paper and so were included in this study (Escanaba, MI; Luke, MD; Rumford, ME; Wickliffe, KY; Kimberly, WI (closed September 2008); and Wisconsin Rapids, WI). Of these six, two mills, Kimberly and Wisconsin Rapids, use imported pulp. At the Wisconsin Rapids mill, most pulp comes from a facility in the area, and the remaining 7% is imported from Canada. For the Kimberly, Wisconsin mill, 42% comes from NewPage Wisconsin Rapids, 42% from Canada, 10% from other US suppliers and 6% is recycled pulp.   The mills use more BHKP than BSKP. Most BHKP is transferred between NewPage mills, and most BSKP is imported from Canada. Imported pulp from Canada constitutes approximately 10% of the required fiber. Nearly all of the NewPage's coated freesheet mills are fully integrated for pulp and paper production, as described in the following section.

2. Study Scope and System Boundary

This study does not provide a full carbon footprint for coated freesheet paper production, an effort that would be highly complex and would require significantly more data collection and analysis than afforded for the comparative purpose of this study. Table 2.1 summarizes the major stages and elements that are included or excluded for the partial lifecycle inventory. As shown in the table, elements where emissions of carbon dioxide are assumed to be roughly the same between the two supply chains are not analyzed. These elements could be the subject of further study.

Table 2.1 Partial Lifecycle Delimitation

Lifecycle Stage/Element	Include	Rationale
	Fiber Acquisition	
Carbon loss from forestry	No	Inadequate scientific basis for comparison. See discussion in Section 5.
Harvesting equipment emissions	No	Assume minimal difference in supply chains.
Use of recycled paper fiber	No	No recycled fiber in coated freesheet production reported in the *Cornerstone* data for either supply chain.
	Pulp and Paper Manufacturing	
Fossil fuel use at pulp and paper mills	Yes	See Section 4.
Electrical energy use at pulp and paper mills	Yes	See Section 4.
Biomass fuel emissions at pulp and paper mills	No	Inadequate scientific basis for comparison. See discussion in Section 5.
Mining & manufacturing of coated paper additives	No	Assume minimal difference in supply chains.
Wastewater treatment	No	Data unavailable.
Calcium carbonate precipitation	No	Data unavailable.
	Transportation	
Wood from forest to pulp or (integrated) paper mill	No	Assume minimal difference in supply chains.
Fiber from pulp mill to paper mill	Yes	See Section 3.
Finished paper to U.S. consumer	Yes	See Section 3.
Transport of coating additives	No	Assume minimal difference in supply chains.
	End of Life/Disposal	
Consumer paper disposal (landfill, incineration, or recycling)	No	Not relevant for comparison of production in the two supply chains.

This study focuses on areas of the supply chain believed to be significantly different between the two production systems. For consumption in a single hypothetical U.S. location, the focus is on production emissions. As noted in the previous section, the geographical characteristics of production of coated freesheet paper are very different in these two supply chains. Given this variation, we hypothesize important differences in the transportation and energy use in pulp and paper plants. It is appropriate to model these lifecycle elements to better understand the magnitude of these differences.

Transportation

The scope of transportation emissions considered here includes the shipping of pulp to paper mills (in cases of non-integrated production) and the shipping of finished product to the consumer market. For this study, the consumer of coated paper is scoped at the level of the printer or merchant (i.e., not through to the individual consumer's mailbox or retail outlet). The study also does not include the transport of wood to the pulp mill (or the integrated facilities), nor does it include transportation for any other materials used in coated paper manufacturing. Results provide an indication of the relative magnitude of transportation emissions in driving differences in emissions of carbon dioxide for coated freesheet paper made in China and the U.S. (NewPage).

Pulp and paper production

In terms of pulp and paper production, the analysis focuses on energy use at mills (both integrated and non-integrated). In the case of non-integrated paper mills, the carbon dioxide emissions embedded in pulp coming from upstream pulp mills is apportioned for the product total. The analysis includes estimates for emissions from both fossil fuels and electrical energy from the grid. It is possible that in some mills the emissions of carbon dioxide are reduced through absorption for production of precipitated calcium carbonate. Also, it is possible that some mills use additional energy to operate wastewater treatment facilities. There is inadequate data to account for this in both supply chains.

In both integrated and non-integrated production, wood scraps and residuals of pulping are an important fuel source. At the present time the IPCC and national authorities consider such biomass fuel (i.e., "hog" or "black liquor") to be a renewable fuel. Thus, for the purposes of national inventories, carbon dioxide emissions from hog and black liquor used in pulp and paper production are not included in total emission calculations. The emissions are counted for purposes of crosschecking and to avoid double counting (IPCC, 2006). Under the United Nations Framework Convention on Climate Change (UNFCC), the carbon dioxide from biomass in national inventories is counted in surveys of forested land. Including combustion emissions in the national-level inventory would lead to double counting.

The long-standing assumption for renewable fuels has been that carbon dioxide released from combustion of the biomass is re-absorbed fast enough by agricultural or forested land managed to renew stocks of fuel so as to balance the GHG warming potential inherent in the use of the fuel. With increased biofuel production, this assumption is under increasing scrutiny. Recent studies show that if land is diverted from an existing use with high carbon sequestration function to make way for biofuel crops, the result may be higher than expected net release of carbon dioxide into the atmosphere (Searchinger et al., 2008).

The assumption of carbon neutrality for woody biomass and harvest from forested land is also currently under scrutiny (Ford, 2009). For inventories at the product level, an appropriate emissions factor for biomass fuels must be determined based upon the underlying changes to land use. In the context of evolving science, such emission factors were not available to make a reliable comparison of the U.S. (NewPage) and Chinese supply chains. Thus, the carbon dioxide emissions from biomass fuels were not included in this study.

Combustion of biomass fuels also emits small amounts of GHG's other than CO_2. As these gases do not fit the same role in the global carbon cycle as carbon dioxide in biomass, they may warrant further scrutiny (Tarnawski, 2004). Nevertheless, on a carbon-equivalent basis, they are seen to be relatively insignificant compared to emissions of CO_2 in the overall manufacturing process. Moreover, there is no reason to suspect that such emissions would differ significantly between the U.S. and Chinese supply chains.

While non-fiber additives and make-up chemicals are sizeable components of the paper (about 1/3 by mass) and these constituents may vary somewhat in terms of composition and environmental burdens in the supply chain, they are excluded from the scope of this study. In general, these elements were not deemed to be significantly different as the basic mining and chemical production processes for these additives appear to be relatively uniform in the global economy. Also, some elements are excluded due to data unavailability. This element would be critical for a full carbon footprint of coated freesheet paper, and could be the subject of further investigation for comparative analysis.

Fiber acquisition

For the same reason, the partial inventory in this study does not include an estimate of carbon dioxide emissions from fiber in the paper associated with land use changes due to forestry operations. Methods and protocols for determining the emissions from this source are in flux at this time. Additional basic scientific research is needed. It is important to note that the magnitude of these emissions may be highly significant relative to the magnitudes of the two phases inventoried here. The implications of this for comparative analysis of carbon dioxide emissions warrant the extended discussion that appears in Section 5 of this study.

Because RISI's *Cornerstone* data reports no recycled fiber in either supply chain for coated freesheet production, the use of recycled fiber is not part of the scope of this study. It should be noted that for other types of coated paper, and especially uncoated paper of many grades, the use of recycled fiber would be very important to account for in a geographical comparison of carbon dioxide emissions. The analysis would need to include the energy used in sorting and transporting the recycled fiber to the mill. In general, recycled paper has a high level of embedded energy that offsets both the need to harvest new fiber and the energy requirements to process at the paper mill (Ford, 2009).

Other clarifications

Finally, GHGs other than carbon dioxide may play a role. For example, the full footprint of coated paper is certainly impacted by methane or carbon dioxide released from disposal practices (i.e., landfilling, incineration or recycling). Given variations in municipal solid waste disposal/recycling systems and distances between consumers and recycling facilities, the end of life impacts may also vary substantially depending upon where the paper is consumed. These emissions are beyond the scope of this study, which focuses on production up to the point of consumption.

Although NewPage Corporation is the largest North American manufacturer of coated paper, it is also important to note that this report does not refer to production of coated freesheet paper for the entire U.S. industry, but rather solely the emissions in NewPage's product. However, to ensure accurate comparisons, data are drawn from the same industry sources for both supply chains. To characterize paper production volumes, as well as energy use in pulp and paper production, the study uses facility data from the industry data source *Cornerstone*. For emission factors, the study relies upon national averages for all the countries involved in both supply chains from the International Energy Agency (IEA). The only exception to this rule is the characterization of pulp imports. For China's industry, we rely on global trade data combined with standard industry facility data to model the likely origin of pulp around the world. For NewPage's supply chain, pulp imports are much more limited, and we drew on facility averages from standard industry data for specific facilities identified as providing pulp for NewPage.

3. Transportation

Emissions of carbon dioxide from transportation throughout a product's lifecycle also depend on where the product is produced, where the raw materials used to make it are extracted and processed, and where it is sold. This section investigates the impact of the varying global distribution of the Chinese and U.S. (NewPage) coated paper supply chains. In the case of fully integrated mills, the pulp and paper are produced at the same location, thereby eliminating the need to transport pulp from distant locations. In the case of the Chinese coated paper industry, in many instances, pulp is imported from around the world by container ship to the paper mill, and finally back to the US consumer market.

Method

The large number of facilities dispersed around the globe complicates estimates of transportation emissions, particularly for China's industry. The specific elements of the methods used are detailed in two sections below. The basic approach is to first estimate the distances that various quantities of pulp and finished paper travel. A weighted average model is created using a Geographic Information System (GIS) to estimate the likely (total) distance that pulp is traveling from mills to papermaking facilities. A similar weighted average approach is applied to assess the distance that finished paper travels from papermaking facilities to the U.S. consumer. Distances are further classified by likely mode of transportation (ship, rail, and truck). Emission factors are applied once the mass, distance, and modes of pulp and paper moving in the supply chain have been estimated. All results are expressed in metric ton of finished paper.

Method to calculate distances

Using weighted averages based upon inputs to production, the import structure, and known pulp production around the world, we built a model to estimate what the journey looks like for a metric ton of coated paper made in China. Generating this model has four basic steps:

1. Identify the fiber input sources of China's major coated paper mills

   Data compiled from *Cornerstone* provide information for the fiber inputs of each paper mill. As pulp from domestic versus imported sources was not provided in these flow sheets, the model uses existing (aggregate) data of domestic production versus imports of pulp for China. As with the forestry and energy emissions models, figures were derived by mirroring the proportion of domestic to imported pulp for the paper industry in China as a whole.

2. Determine the specific sources of imported and domestic pulp

To determine the country origin of the imported pulp, 2007 *World Trade Atlas* data for BSKP and BHKP was used (see figures 1.5 and 1.6). The small residual in the "other category" was allocated equally to all the major importers for each type of pulp. To determine the specific origin of the pulp in each country, relative proportions were allocated to the major pulp mills in these countries, using data provided in *Cornerstone*. More specifically, the model weights the pulp production within each country by pulp mill, and assumes that the imported pulp is allocated in proportion to production for each mill. Using the same *Cornerstone* pulp mill data, the process to determine the location of domestic Chinese pulp fraction was essentially the same.

3. Calculate the distance (by mode of transport, including ship, rail, and truck) from each pulp mill to each Chinese coated paper mill

To estimate these distances, the exact longitude and latitude for the 116 pulp mills and the 11 Chinese paper mills was identified using a batch Geocoder (www.batchgeocode.com). Then the distances from each of these pulp mills to each of the paper mills were calculated, resulting in more than 1200 possible route variations. Finally, the distance from each of the Chinese paper mills was calculated to a final consumer destination (i.e., printing/distribution center). These distances were calculated using a suite of tools, including Google Map and a web tool (www.netpas.net) that allows the user to input origin and destination ports to calculate shipping routes and distances. If a mill was located less than 250 miles from a marine port or final destination mill, then truck was assumed to be the land transport mode of choice, if more than 250 miles, then rail was the assumed mode. The consumer end point was calculated as arrival at the Port of Los Angeles. Los Angeles was chosen as a representative destination for U.S. consumers. It is likely to be conservative with respect to the difference in transportation emissions between the Chinese and U.S. (NewPage) industries. This is because NewPage facilities are located primarily in the Midwest and East Coast, so Los Angeles is among the longest distances that NewPage paper travels to reach a major U.S. consumer market.

4. Calculate the total average weighted distance for delivery in the U.S.

Average distances for delivery of coated freesheet paper from China in each of the consumer markets were calculated by using a weighted average. Distances for BHKP and BSKP (already weighted by country and pulp mill) were weighted by their use in each paper mill, and the distance from each paper mill to U.S. markets was weighted by the total production of each paper mill as a share of overall production of coated freesheet paper. We created an analogous (weighted) model for the NewPage supply chain for delivery from paper mills to Los Angeles. In the few instances where pulp is used in the NewPage supply chain; we were able to identify the specific pulp and paper mills involved, so we calculated distances from pulp mills to the paper mills.

Method to estimate carbon dioxide emissions

It is perhaps obvious from the long distances that pulp and finished paper travel through the Chinese industry's supply chain, and on to the U.S. consumer market, that carbon emissions from transportation would be higher relative to paper produced in the U.S. Also, previous studies, focusing on integrated production, have shown transportation emissions to be small relative to other lifecycle phases (Gower, 2006). However, it is not clear how significant the extended supply chain, drawing pulp from around the world, would be in increasing emissions for

Chinese coated paper, relative to the differences in carbon dioxide emissions identified below for the energy consumed in pulp and paper production. The procedure required to calculate the magnitude of differences in transportation emissions includes four basic sequential steps, detailed below:

1. Determine the total mass of pulp and finished paper, by distance and mode.

   The distance calculations for each supply chain, as described above, were embedded in a model to calculate the mass of pulp and finished paper moving by mile and mode. Again, this is modeled as a weighted average for each mill in China based on known trade statistics and pulp and paper mill outputs. The same procedure is employed using weighted averages from RISI flowsheets for the U.S. (NewPage) supply chain. The only exception is that the small amount of pulp imported for the U.S. (NewPage) supply chain is traced to specific pulp mills based on actual data. For each paper mill in both supply chains, the model calculates the amount of the pulp or paper and the distance it is being moved to the Los Angeles consumer market by shipping mode (truck, rail and ship).

2. Calculate energy by mode and fuel types.

   Once the amount (mass) of material moving and distances are known, then the materials in the supply chain are multiplied using factors developed by the Interface Corporation as part of the U.S. Environmental Protection Agency's SmartWay Transport program to obtain estimates of the energy required.[3] These factors provide the average energy intensity for freight being moved by various modes. The factors for tractor-trailer, rail, and ocean freighter (residual or bunker fuel) were selected to apply to distances for each mode. Resulting calculations give an estimate of the energy in British Thermal Units (BTU's) used to move the material in the supply chain. For a summary of factors used for energy and emissions see Table 2.1.

Table 3.1 Energy and Emission factors by Transport Mode

Transport Mode	Energy (BTU/ton mile)	Carbon Dioxide (lbs/million BTU)
Ship	190	174
Truck	1,945	162
Rail	514	162

3. Apply emission factors for fuel types.

   To move from energy consumed by each shipping mode to emissions estimates, the model used emission factors that track the emission per unit of energy from the burning of various fuel types. These factors track emissions from combustion of fuels in engines of vehicles and ships (i.e., the "pump to wheel" or "pump to propeller" portion of the fuel cycle). The emission factors for carbon dioxide are taken from the U.S. Energy Information Administration (EIA) at the Department of Energy (voluntary carbon reporting program).[4] The factor for distillate fuel (No. 2 diesel fuel) was used for energy consumed by trucks and

[3] *see http://www.interfacesustainability.com/smartway.html, accessed on May 1, 2008*

[4] *See www.eia.doe.gov/oiaf/1605/coefficients.html, accessed on May 1, 2008*

trains and the factor for residual fuel (No.'s 5 and 6, or bunker fuel) was used for energy consumed by ships. After summing estimated annual emissions for each supply chain, the emissions figure was divided by the annual production total to give carbon dioxide per finished metric ton.

One important note about this method is that these estimates are not transparent with respect to differences in transportation technologies (e.g., vehicles, fuel composition, etc.) between the U.S. and China or for that matter any of the many nations producing pulp for the paper mills in China. Data were not available to track these factors independently for truck and rail transport for China and the numerous countries serving its supply chain. Thus, the technology levels in the energy and the emission factors are averages based on recent U.S. estimates. For all the regions—U.S., China, and the major pulp producing countries—estimates are based upon the same emission factors, derived from a mix of U.S. technologies. The main value of the analysis is that it tracks differences that result from the combination of distance, mass and mode of transportation in each facility's supply chain.

Some differences in efficiencies or emissions may exist, especially from truck or rail fleets across the countries in the supply chain. However, it seems unlikely that these differences are large since regulatory controls for carbon dioxide are only now emerging. As regulations are adopted, increased differences may be seen if fleet efficiencies or fuel types vary significantly among the countries.

Results

The difference in distances traveled by pulp and paper in the supply chain for China's industry, and for the U.S. (NewPage) supply chain turned out to be striking. Pulp in the Chinese supply chain takes a long journey before it reaches the papermaking plant in China. As an average for all facilities in China's supply chain, BHKP travels about 118 miles by truck, 705 miles by rail, and 4,579 miles by ship from the pulp plant to the papermaking facility. After production is finished, the paper travels around 7,000 miles to reach U.S. consumers in Los Angeles. For the U.S. supply chain, only a small amount of pulp (BSKP) travels from Canada to reach mills in the upper Midwest. These pulp mills are located about 1,500 miles from the paper mills. (The short distances that most fiber travels from forest to the integrated mill and the distance from forest to pulp mill are not factored into the transportation emissions in either supply chain.) As NewPage's coated paper mills are located mostly in the upper Midwest and to a lesser extent the Northeast, the weighted average distance for finished paper to Los Angeles (by rail) is 2,425 miles.

Carbon dioxide emissions from transportation of pulp and finished paper in the Chinese industry's supply chain are about 187 Kg for each finished metric ton. Due to the long distance to Los Angeles, much of these emissions come from shipping finished paper to the U.S. Emissions from importing pulp from around the globe are significant, but less than for transportation of the finished paper. These emissions are about eight times higher than NewPage's estimated carbon dioxide emissions of about 23 Kg for each finished metric ton. However, relative to the estimate below for carbon dioxide emissions in pulp and paper production, transportation emissions are a very small part of the carbon burden of coated freesheet paper. This is true even for the highly dispersed supply chain feeding China's industry. Thus, this finding is generally consistent with other studies of paper life cycles.

4. Pulp and Paper Production

This section explores the pulp and paper manufacturing lifecycle stage of the coated paper by comparing fossil-fuel energy use and related carbon dioxide emissions in supply chains for China and the U.S. The analysis tracks the energy used at each step in the paper and pulp manufacturing process. It includes energy used in the manufacturing facilities for pulp and paper, but does not include energy consumed in making chemicals, clay or other inputs. Previous studies find that the major component of carbon dioxide emissions in the paper lifecycle is found in the production/use of process steam (heat) and electricity in pulp and paper manufacturing (Gower, 2006; NCASI, 2005). Thus, this study focuses on carbon dioxide emitted from the fossil fuels and grid electricity consumed in the manufacturing process.

For purposes of assessing energy use and related carbon dioxide emissions, the supply chain can be divided into two primary fiber supply chains, and the paper manufacturing facilities. The two primary pulp sources for coated freesheet paper are BHKP and BSKP. These standard pulp designations describe both the fiber input (hardwood vs. softwood) and the pulp-making process (Kraft). The diagram below shows the major components of the supply chain and major uses of fossil-fuel energy for manufacturing the final product.

As noted in Section 1 of this report, the industry in China relies heavily on imports of pulp. Thus, Figure 4.1 depicts most production in the Chinese industry, which unlike the U.S., is not "integrated." Pulp is made around the world and shipped to the paper mill in China. In terms of manufacturing, this requires additional inputs of energy, as noted in the diagram, to dry the pulp, and then re-wet and warm the pulp for the paper making process. In non-integrated production, pulp mills also often co-generate electricity for internal use and for the grid. This study includes a sensitivity analysis for the effect of this co-generation in displacing power production. In general, it is not seen as significant in the comparison (see results below).

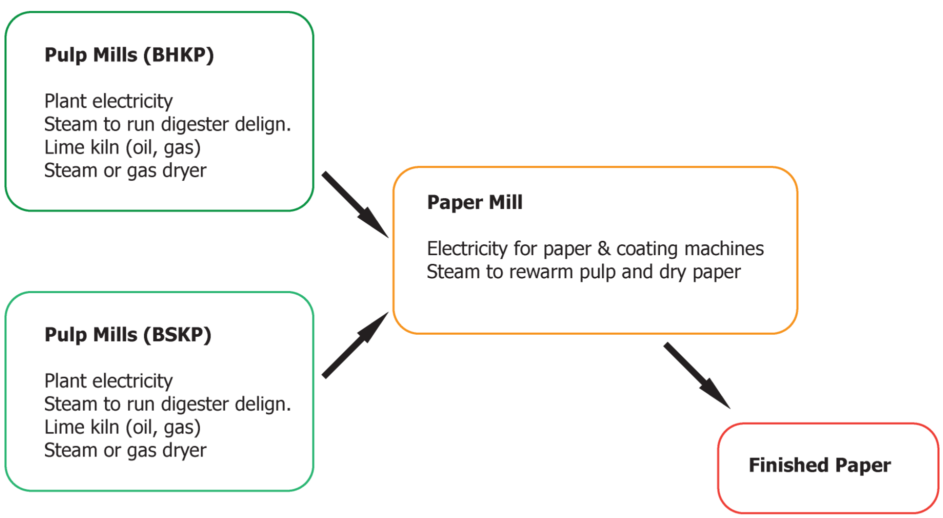

Figure 4.1 Non-Integrated Pulp and Paper Production

The use of integrated vs. non-integrated production is generally a function of the location of the paper producing facility. When the paper production occurs in a forested region, integrated production is made possible. In the U.S., paper production facilities are typically located in forested regions. Thus, in the NewPage supply chain, pulp and paper are nearly always made in the same mill. As noted in Section 1, the fiber source for most of the U.S. supply chain is wood and chips from forests nearby the plants. In integrated production, both the pulp and paper manufacturing take place in one facility, and any electrical energy co-generated from making pulp is used to run both pulp and papermaking machinery (including coaters).

In the pulp and paper manufacturing process, boilers are co-fired with fossil fuels and biomass energy sources. In some mills, specific biomass sources are identified and purchased to supplement the use of fossil fuels. In all pulp mills and integrated pulp/paper mills, the biomass source includes residuals from production. Wood scraps from debarking and grinding of trees for the pulp making process are burned. This biomass source is known in the industry as "hog." After processing into a solid fuel, residual waste from the delignification process known as black liquor is almost always burned in the recovery boilers.

In modern integrated mills, the co-firing of fossil fuels with biomass for combined heat and power (CHP) generation is notable for its efficiency in terms of minimizing carbon dioxide emissions. Biomass is burned most efficiently in a co-fired process where a fossil fuel dries and ignites biomass of various grades for a complete burn despite the lower heat content of most biomass fuel relative to fossil fuel. In a 2008 study of boilers at a paper plant in Minnesota, the U.S. Environmental Protection Agency (EPA) finds that co-firing of biomass with coal gives a 90% reduction in carbon dioxide emissions over firing of coal alone. The study takes into account the carbon dioxide emissions from transporting the large quantity of biomass (EPA, 2008). However, it does not count carbon dioxide emissions from combustion of the biomass itself.

Method

This analysis compares the differences in energy use and related carbon dioxide emissions between the Chinese and U.S. (NewPage) supply chains. The model tests the effect of the differences in the production process (non-integrated vs. integrated), and the spatial distribution of production. In particular, pulp suppliers to China are located around the world and different types of fossil fuel energy and electricity grid characteristics apply in each location. To estimate carbon dioxide emissions for coated paper produced in China, several sub-models were developed and linked. These include:

- Model of the BHKP supply chain
- Model of the BSKP supply chain
- Model for Coated Paper Manufacturing in China

Working together, these models estimate the total kilograms of carbon dioxide emitted from production energy for each finished metric ton of paper produced in China. A somewhat simpler model is developed to make the same estimate for NewPage's production in the United Sates. Within the U.S., most production occurs in integrated mills, and a small amount of imported pulp comes from Canada.

Model for the BHKP supply chain for China

According to an analysis of World Trade Atlas 2007 data, the leading producers of BHKP for China are China, Indonesia, Brazil, and Chile. Data from RISI's *Cornerstone* give the output totals for each mill reported in each of these countries. *Cornerstone* likely omits some small mills. However, it seeks to capture most of the pulp and paper made for the global market. By combining trade data and data from *Cornerstone*, an estimate can be made of the average proportion of the BHKP supply that each pulp mill provides to paper mills in China. Within each of these countries, a few large facilities often account for the bulk of production. This means that the largest pulp mills in the largest supplying countries account for much of the pulp produced for coated paper mills in China. For example, we estimate that the Hainan Gold Hai Pulp and Paper facility located on Hainan Island (China), produces approximately 30% of the BHKP used in production of coated paper in China.

In order to derive the carbon dioxide emitted for each metric ton of pulp created in the BHKP supply chain, we multiply the magnitude of the mills contribution to the pulp supply by the fossil fuel sources reported for that mill. This creates a "weighted average" of the carbon burden for manufacturing a metric ton of pulp and is expressed as the following basic formula:

$$\% \text{ of BHKP Supply} * TJ/ADMT * Kg\ CO_2/TJ = Kg\ CO_2/ADMT$$

Where,

Energy Factor; TJ/ADMT =terra joules/air-dried metric ton pulp for each fuel type

Emissions Factor; Kg CO_2/TJ= Kilograms of carbon dioxide per terra joule for specific types of fuel.

The fraction of Kg CO_2/ADMT based upon the estimated global allocation of production is then summed across all producers to give a single estimate of kilograms of carbon-dioxide per air-dried metric ton of BHKP in the supply to mills in China.

We calculate the energy factor by taking data on the mass or volume of the various fuel types, provided in the *Cornerstone* data, and converting it with energy content factors specific to the fuel. This is essentially the same methodological approach that the IPCC and IEA use to estimate carbon dioxide emissions for national economies (IEA, 2007). In this "Tier 1" approach, annual apparent fuel consumption for each country is calculated against the carbon content of fuels supplied to the country as a whole. In all cases, we use the "higher heating value" as appropriate for power production. Approaches for specific fuels are noted below.

Fuel oil

On its flow sheets, *Cornerstone* gives oil consumption in "barrels" (bbl). In its consumption data, *Cornerstone* also reports the particular distillate of fuel oil used at each mill. Nearly all mills in the data set use either fuel oil no. 2 (or light fuel oil, i.e., "diesel") or fuel oil no. 6 (or heavy fuel oil, i.e., residual fuel oil, "RFO"). To convert from barrels to terra joules, the oil volumes must first be converted to mass. Conversion figures giving fuel oil density from the Canadian government were employed:[5] for no. 2 (light) fuel oil 7.49 bbl/metric ton and for no. 6 (heavy) fuel oil 6.33 bbl/metric ton.

To convert from mass into energy content, figures from the IEA (2007) report are employed. The IEA gives the energy content of no. 2 (light) fuel oil as 43.33 TJ/metric ton, and for no. 6 (heavy) fuel oil as 40.19 TJ/ metric ton. Carbon dioxide emission factors are also slightly different for the different distillates. For carbon dioxide emission factors for the fuel types, we rely upon the 1997 IPCC default factors as listed in the National Council for Air and Stream Improvement's calculation tools report (NCASI, 2005). We assume the same correction factors for

[5] See www.statcan.can/english/freepub/57-601-XIE/00204/appendix1.htm.

unoxidized carbon as used by the IPCC: for, no. 2 (light) fuel oil the emissions factor is 73,400 kilograms of carbon dioxide/TJ, and for no. 6 (heavy) fuel oil, the emissions factor is 76,600 kilograms of carbon dioxide/TJ.

In only a few instances, the particular distillate of fuel oil was unknown from the *Cornerstone* data set. In these instances, the model averages values of no. 2 and no. 6 fuel oils for density, energy content and carbon dioxide emissions. The rationale for this is to reduce the risk of error by choosing middle values between the two likely distillates.

Natural gas

For natural gas, we take a figure for the higher heating value as provided in a study from the U.S. Department of Energy, Oak Ridge National Laboratory. They give the energy content of natural gas as 1,027 BTU/cubic foot. This is close to the value given by the U.S. Energy Information Agency (EIA) (1,031 BTU/cubic foot). The EIA value is used in computing the U.S. carbon dioxide inventory. We use standard conversion factors for energy and volume to transform this into TJ/cubic meter. The model uses the 1997 IPCC default factor, as corrected for unoxidized carbon for natural gas: 55,900 kilograms of carbon dioxide/TJ. As assumed in IEA (2007), energy content and emission factors for natural gas are estimated to be essentially consistent from country to country.

Coal

For coal, the situation is complicated by the inconsistency of the fuel. Fuel listed as “coal” in reality describes a continuous range of solid organic fuels covering a fairly large span of energy content values, and with different air pollution emissions profiles. The coal actually used in a given facility may reflect either the local sources or the import market (IEA, 2008). The IEA tracks the apparent consumption of different types of coal for specific industrial sectors (for the OECD countries), and for overall consumption for all countries.

For purposes of tracking national consumption, the IEA divides the range of coal types into two basic groups. For all but 11 countries, hard coal (or steam coal) is reported as the sum of anthracite and other bituminous (energy content greater than 23.9 Giga Joules/Metric Ton). Soft coal (or brown coal) is reported as the sum of sub-bituminous coal and lignite (energy content less than 23.9 Giga Joules/Metric Ton). The BHKP supply chain does not have any of the 11 counties that are an exception to this rule.

For each country, the IEA reports the amounts of hard/steam and soft/brown coal consumed. For the OECD countries, the IEA reports consumption of the coal types by sector, including the pulp and paper sector. Unfortunately, these data are not available for the non-OECD countries. Therefore, we use the overall consumption figures (for 2006) as the basis for estimating the type of coal consumed in the BHKP supply chain. From the total consumption figures, a ratio of steam coal to brown coal is created for each country. It is assumed that this ratio is an adequate estimate of the type of coal being used in each facility for a given country.

As an estimate of energy content for hard/steam coal, we use an average of the highest heating values given by the IEA (2008), for anthracite and bituminous coal, for a value of 30.6 GJ/Metric Ton. For soft/brown coal, we use an average of the highest heating values given by the IEA (2008), for sub-bituminous coal and lignite, for a value of 20.7 GJ/Metric Ton. The model then tracks the TJ/FMT from both types of coal.

For carbon dioxide emission factors for the fuel types, we again rely upon the 1997 IPCC default factors as listed in NCASI (2005). We use an averaging procedure similar to the one used to estimate energy content for the two major types. We average anthracite and bituminous to reach 94,520 Kg CO_2/TJ. We average sub-bituminous and lignite to obtain 96,680 Kg CO_2/TJ.

Electricity from the grid

One other source of “fuel” for pulp plants is electrical energy from the grid. Although many pulp plants create more electrical energy than they need, some still require additional electricity from the power grid. The IEA (2007) provides an estimate of average carbon dioxide emissions per kilowatt-hour for electricity from the grid in each country. This estimate is derived from the mix of coal, natural gas, nuclear, oil, and hydropower and other renewable energy in use in each country. When plants require more electricity than they produce, a complete inventory of carbon dioxide from energy use requires including the electricity imported from the grid at each facility.

It is important to note that when plants produce more electricity than they need, the model treats the electrical energy requirements for these plants as zero. NCASI’s (2005) methodology recommends this approach. Another approach would be to treat the displacement of power production that otherwise would have occurred as an offset to carbon dioxide emitted elsewhere in the system. Many of these plants in the Chinese industry’s pulp supply chain sell some electricity back to the grid. As part of the study, a sensitivity analysis was conducted to assess the importance of these net energy producers in the overall system. Calculating offsets based upon the IEA (2007) grid averages for each country demonstrates that this energy production is relatively unimportant in the overall carbon picture. The carbon dioxide emissions estimate changes by only about 1 percent.

Model for the BSKP supply chain for China

BSKP production for China’s coated paper mills also occurs around the world. According to an analysis of World Trade Atlas 2007 data, the leading producers of BSKP for China are China (36%), Canada (12%), Chile (12%), the U.S. (11%), Russia (10%), Finland (4%), and New Zealand (3%). Like with the BHKP model, estimates of production for specific mills within each country are based upon data from RISI’s *Cornerstone* tool. The largest plants in the largest supplier countries are again estimated to make up the bulk of the supply. In the case of BSKP, the Yunan Yunjing Forestry & Paper facility in Jingu, China, and also the Guangxi Naning Phoenix Pulp facility in Naning, China are estimated to be the major suppliers. In fact, the model estimates that most of the total BSKP produced by these plants is consumed in coated paper production.

The model combines the estimated global allocation by mill with energy use by fuel type, and specific fuel emission factors in essentially the same approach as with BHKP. All the formulas given above apply in parallel in the BSKP model. The lone significant difference is with the estimates for the types of coal being used.

Coal types in the BSKP model

The U.S., Finland, and New Zealand are among the 11 countries that are exceptions to the rule for classification of coal types (IEA, 2008). For these countries sub-bituminous coal is grouped together with anthracite and other bituminous coal in the category hard (or steam) coal. For these countries, the category soft (or brown) coal includes only lignite. As with the BHKP model, we use the overall consumption figures from the IEA (for 2006) as the basis for estimating the type of coal consumed in the BSKP supply chain (i.e., brown vs. steam coal). However, to take into account the different definitions of steam coal and brown coal for the U.S., Finland, and New Zealand, the model makes adjustments to the energy content and emission factors for coal in those countries. For energy content, the model averages the IEA's highest heating values for anthracite, bituminous and sub-bituminous in the category steam coal (28.4 GJ/metric ton). For brown coal, the model uses the highest heating value for lignite (20.7 GJ/metric ton). For carbon dioxide emission factors for the U.S., Finland, and New Zealand, we again rely on the 1997 IPCC default factors listed in NCASI (2005). The emission factors are adjusted to reflect the different coal definitions. For steam (hard) coal we average the emission factors for anthracite, bituminous and sub-bituminous coal, adjusting for unoxidized carbon (96,333 Kg CO_2/TJ). For brown (soft) coal we use the emissions factor for lignite (99,180 Kg CO_2/TJ), again adjusting for unoxidized carbon.

Note on units in the BSKP model

One other brief note about the BSKP model is that the inclusion of U.S. (and sometimes Canadian) data from *Cornerston*e requires particularly close attention to the reported units. For U.S. data, mass is often reported in short tons instead of metric tons, and natural gas volumes are reported in thousands of cubic feet, rather than cubic meters. Appropriate unit conversions are applied throughout the model calculations, and results are reported in the metric system.

Model for coated paper manufacturing in China

The model for coated paper manufacturing in China follows much the same approach as the pulp models. Energy use is again determined following data from *Cornerstone* for coal, oil, natural gas and grid electricity consumption at each facility. For paper manufacturing, the energy use is measured for each finished metric ton (FMT) of product. In all but one plant, the energy re-warms and re-wets the pulp, and also drives the paper and coating machines. In the one plant where production is integrated, the energy use measures the total process of pulp and paper manufacturing.

The model creates a weighted average by considering production in each plant relative to the total production of coated paper for China for the year. By far the largest coated paper plant is the Asia Pulp and Paper (APP) facility in Dagang, China. This plant alone produces about one half of the annual supply. It produces just freesheet commodity grade coated paper. The other 11 plants share the remaining production about equally, producing both premium and commodity grade coated freesheet paper. In general, premium grade paper requires slightly higher levels of energy inputs. This analysis aggregates both grades of paper into a single value for coated freesheet paper.

The model calculates the carbon dioxide emissions of coated paper by integrating the calculation of energy and emissions at the paper manufacturing facility with the emissions embedded in the BHKP and BSKP supplies. The sum of the following three formulae gives the carbon dioxide per finished metric ton of coated paper:

(1)

% of Coated Paper Supply * TJ/ADMT *Kg CO_2/TJ = Kg CO_2/ADMT

Where,

Energy Factor; TJ/ADMT =terra joules/air-dried metric ton pulp for each fuel type

Emissions Factor; Kg CO_2/TJ= Kilograms of carbon dioxide per terra joule for specific types of fuel. This formula is calculated for coal, oil, gas and grid electricity as in the pulp models.

(2)

(% of Coated Paper Supply * BHKP Input (ADMT/FMT))

* 540 Kg CO_2/ADMT = Kg CO_2/ FMT

Where,

The BHKP Input (ADMT/FMT) is given by *Cornerstone* for each facility, and the emissions factor for BHKP is derived from the BHKP supply chain model for China (see results below).

(3)

(% of Coated Paper Supply * BSKP Input (ADMT/FMT))

* 405 Kg CO_2/ADMT = Kg CO_2/ FMT

Where,

BSKP Input (ADMT/FMT) is given by *Cornerstone* for each facility, and the emissions factor for BSKP is derived from the BSKP supply chain model for China (see results below).

Model for the U.S. (NewPage) supply chain

As production in NewPage's facilities in the U.S. is almost entirely integrated, there is no need to build extensive models of the BHKP and BSKP supply chains. Energy used in pulp manufacturing is captured in the *Cornerstone* summary figures for paper manufacturing at each integrated facility. The method for the U.S. model parallels the methods identified above for calculating energy use by fuel type for each finished metric ton (FMT) of paper. The study relies upon the same RISI data for energy use in facilities and the same sources for national emission factors data used to analyze the Chinese industry.

The use of imported pulp in the U.S. (NewPage) supply chain is much more limited than for the Chinese industry. The NewPage plants making coated freesheet paper located in Kimberly and in Wisconsin Rapids do use pulp brought in from outside the plant. The source mills for these plants are either the Wisconsin Rapids plant itself, or plants in Canada or the U.S., using mostly natural gas, biomass (including hog fuel), and grid electricity as energy sources. Due to the small number of pulp plants involved, these plants were specifically identified using NewPage's internal supplier data. This is slightly different than the approach taken for the supply chain for the Chinese industry where pulp plants were identified using trade data and weighted averages from industry data. However, after we identified the plants, we used the same *Cornerstone* flowsheet (industry) data and national average emission factors in an analogous process for calculating carbon dioxide emissions from pulp production. These emissions are minimal relative to emissions from the integrated facilities.

Results for the Chinese Industry's Supply Chain

The models described above create estimates for carbon dioxide emissions from fuel used in BHKP and BSKP manufacturing, as well as paper manufacturing for the Chinese industry. The results are reported in the three sub-sections below.

Major sources of carbon dioxide emissions from BHKP production

As can be seen from the bar graph below, the major driver of the carbon dioxide emissions in production of BHKP is coal-fired boilers. Of the countries making BHKP, China uses by far the most coal-fired energy per metric ton of pulp. Indonesia also uses coal, but the level of coal being used is dwarfed by the use in China. In many ways, as can be seen on the chart below, it is the use of coal-fired power, particularly at the large pulp mill in Hainan, which drives the carbon profile of the BHKP. In contrast, Canadian facilities, which are a much smaller part of the supply chain for BHKP, use no coal-fired boilers, relying mostly on natural gas and biomass fuel.

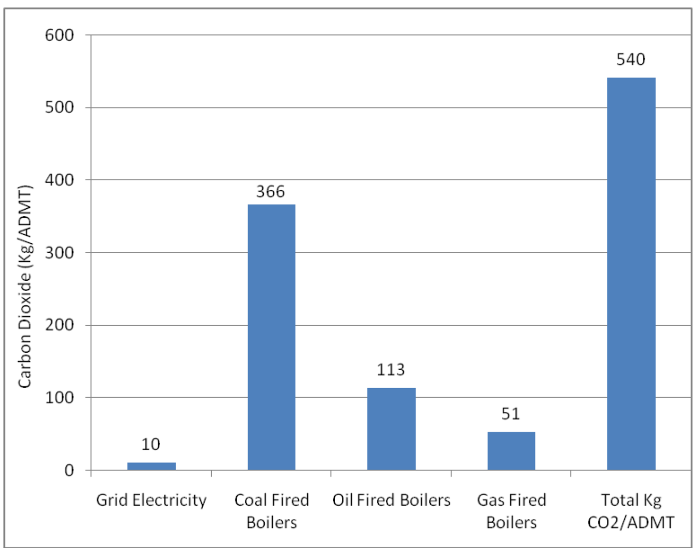

Figure 4.2 Carbon Dioxide Emissions per metric ton of BHKP by Energy Type

Major sources of carbon dioxide emissions from BSKP production

As can be noted in the bar graph below, coal-fired boilers also mostly drive carbon dioxide emissions for BSKP. The major portion of the supply estimated as originating from the pulp plants located in Jingu and Naning China is produced using only coal and oil. These two plants produce all of their own electricity. The Yunan Yunjing Forestry & Paper facility in Jingu, China reports the highest intensity of coal use among all the BSKP suppliers in the global model for China's industry at 0.269 metric tons/ADMT of pulp. The plants in China are the main drivers of the coal-fired carbon dioxide emissions. The plants in Canada and Chile report no use of coal. In the U.S. and in Russia, some plants report fairly high use of coal, but they are estimated to be relatively small suppliers overall.

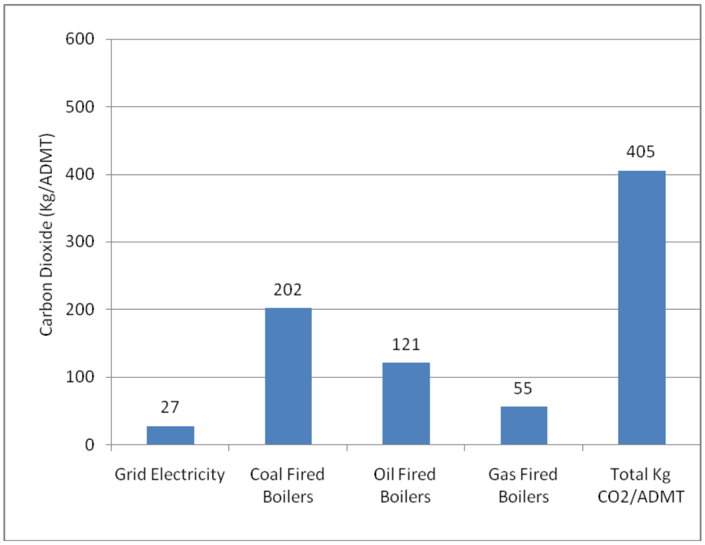

Figure 4.3 Carbon Dioxide Emissions per Metric ton of BSKP by Energy Type

Summing up: Carbon Dioxide Emissions in China's Coated Paper Facilities

The carbon dioxide emissions from energy used in the production of coated freesheet paper in China is also driven almost entirely by the extensive use of coal-fired boilers. The largest coated freesheet paper plant, the APP facility in Dagang, China, also has the highest intensity of coal use among all the facilities (0.839 metric tons of coal/FMT). As seen in the bar graph below, the use of grid electricity and gas-fired boilers are essentially insignificant to the carbon dioxide emissions from manufacturing coated paper in China. The energy and carbon dioxide emissions embedded in the pulp supply chains is significant, but again is overwhelmed by the use of coal-fired boilers. Summing all of these emissions together gives an estimate of 2,478 Kg of carbon dioxide from energy use for each finished metric ton of coated paper produced in the Chinese supply chain.

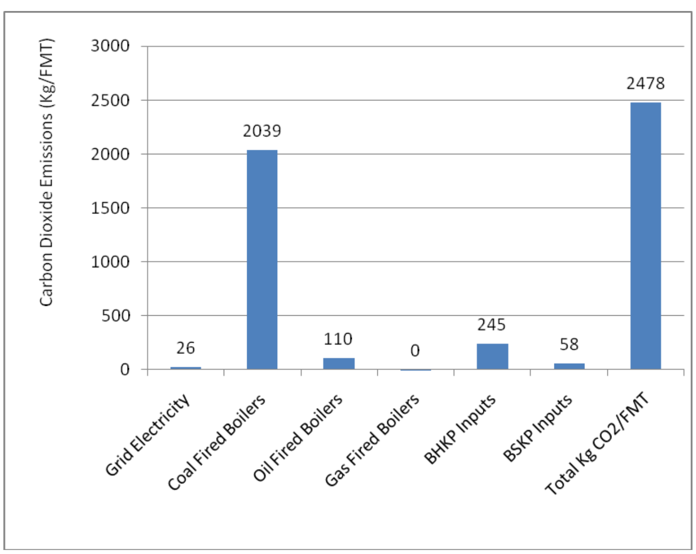

Figure 4.4 Carbon Dioxide Emissions from Embedded Energy for Coated Freesheet Paper Made in China

Results for the U.S. (NewPage) Supply Chain

Given the high carbon burden of burning coal, it is not surprising to find that coal-fired boilers are also a significant driver for the NewPage carbon dioxide emissions. However, it is also expected that coal-fired power will be more efficient in the NewPage supply chain because hog biomass is being co-fired in nearly all the facilities. Also, the NewPage supply chain uses natural gas, and grid electricity. These energy sources are cleaner overall, and especially with respect to carbon dioxide emissions. The total estimate for carbon dioxide emissions from energy used to produce NewPage's coated freesheet paper is 1,432 Kg per finished metric ton.

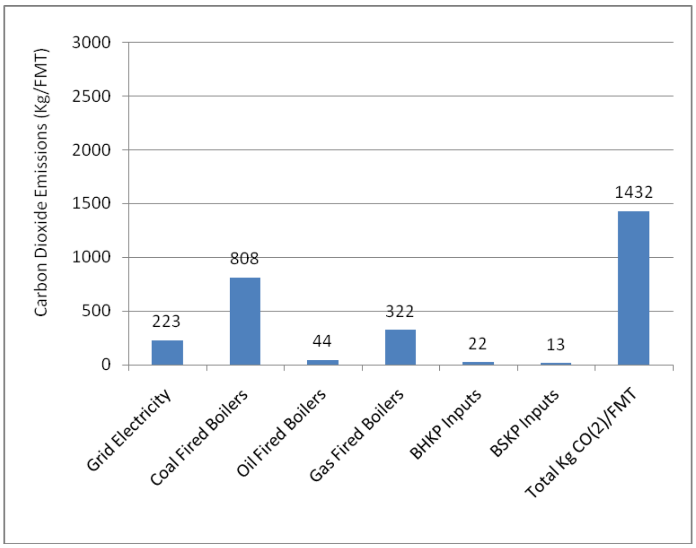

Figure 4.5 Carbon Dioxide Emissions from Embedded Energy for Coated Freesheet Paper made in the U.S. (NewPage)

Comparison

The extended supply chain for China's coated paper manufacturing uses more energy overall, and has much more coal fuel in its production. The U.S. (NewPage) supply chain uses less energy overall, and has more biomass (hog) energy available for production than the Chinese supply chain. Cleaner energy sources like grid electricity, biomass, and natural gas displace the use of coal. The U.S. plants still use coal as an important energy source, but natural gas is used more often to displace coal than in China's industry. When coal is used, co-firing with biomass sources makes it much more efficient with respect to carbon dioxide emissions. The estimated carbon dioxide emissions from energy used to produce coated freesheet paper at NewPage is about 42% lower than for the Chinese industry's supply chain.

Future Research

The results for coated freesheet paper in China and the U.S. support the hypothesis that paper supply chains with higher levels of integrated production are more efficient with respect to lowering greenhouse gas emissions. However, the model appears to be most sensitive to the fuel mix. More detailed data would be needed from the facilities to refine our understanding of the role of integrated production, including new co-generation technologies. Additional research on biomass fuels could provide examples of how biomass fuels are being used in integrated plants. Innovations through which the paper industry is working to further reduce carbon dioxide warrant further study (e.g., alternative fuels made from black liquor, etc.).

5. Fiber Acquisition: Carbon Loss Due to Timber Harvest

The purpose of this section is to provide the reader with a basic understanding of complexities associated with quantifying carbon loss associated with timber harvest, to introduce the basic equations and variables that could provide the basis for a methodological framework to make these calculations, and to explain how a product-level inventory of carbon loss in timber harvest might be incorporated into a comparative lifecycle inventory.

Forests play a vital, yet complex role in the global carbon cycle, as carbon is retained in live biomass, decomposing organic matter, and soil. Forests are carbon pools that are simultaneously accumulating and releasing carbon. Forests cover approximately 65% of the total land surface, and they hold 90% of the total plant biomass carbon in terrestrial ecosystems. They assimilate 67% of the total CO2 removed from the atmosphere by all terrestrial ecosystems, and hold 80% of the total soil carbon in terrestrial ecosystems (Landsberg and Gower, 1997). According to the IPCC, annual loss of forests due to disturbance (harvesting, conversion, fire, insects, pathogens, and wind) contributes as much as 30% of total global greenhouse-gas emissions (GHGs) each year—rivaling emissions from the global transportation sector. The effects of disturbance on the carbon cycle can be divided into two phases: 1) initial disturbance effects on carbon pools and 2) changes in carbon cycle processes during forest ecosystem recovery or succession (Gower, 2003).

Due to such complexity, there is wide variation in the GHG inventories related to sourcing timber. Such inventories depend on numerous factors, including the type of forest ecosystem, the age of the forest, the length of stand rotation cycles, and the forestry practices used to harvest the timber. Research to date is uneven geographically, with forest carbon dynamics far better understood in some regions and countries than in others. Although comparisons across supply chains utilizing different geographies are likely to be very important to accurately inventory emissions, research does not yet provide an adequate basis for such comparisons. Below we expand on a few of the variables, notably forest type and management practices, which make such comparisons difficult.

Forest Type

There is an emerging body of research that suggests that ‘primary’ or ‘frontier’ forests, across a range of geographic regions and ecosystem types, hold significantly more carbon in above-ground and below-ground biomass than do managed forests or plantations (Harmon, Ferrel, and Franklin, 1990; Thornley and Cannel, 2000; Dean et al., 2003). A recent study in the journal *Nature* also concluded that these frontier or primary forests (up to 800 years old) could continue to accumulate carbon for long periods of time (Luyssaert et al., 2008). This is contrary to the long-standing view among many that they are in equilibrium with respect to their carbon balance. Based on the results of this study at least, one can rightly consider some forests on balance (i.e., incorporating net accumulation and net release) to be “carbon positive.” Conservation of these forests arguably takes on heightened importance for stabilizing global climate.

By extension, it follows that these "carbon positive" forest stands can also have a greater negative impact on the global carbon cycle when they are significantly disturbed (such as in timber harvest) or converted to some other land use. The magnitude of such impacts should of course be reflected in accounting for wood products. Logging these forests, in a sense, represents an opportunity cost, as the time necessary for a harvested forest to regain its carbon sink capacity can take many decades.

Although much of the world's biotic carbon is stored in soil, there has been more research to date on the carbon in above-ground and below-ground biomass than on soils. This is an area that will need further research if the full carbon emission impacts from timber harvest are to be properly understood. Schlesinger (1977) found that when frontier coniferous and deciduous temperate forests are converted to secondary forests, the soil carbon declines by about 10 percent and this loss is final rather than an annual value. Guo & Gifford (2002) performed a meta-analysis on the effects of land use change on soil carbon stocks and found that conversion of natural forests to plantations decreased soil carbon content by about 13%. Finally, in soil in particular, there can be the release of methane as a result of anthropogenic activity, such as logging. This is true for many forest biomes, from the boreal forests in the northern hemisphere whose soils release methane when the permafrost melts as a result of anthropogenic activity (Newell, 2004), to the tropical forests of Indonesia when the methane-rich peat soils are drained to plant fast growing plantations (Uryu et al., 2008).

Disturbance regimes and forest management

Carbon loss associated with frontier forest conversion is also dependent on the relative differences in the disturbance intervals (Harmon, 2009). The natural disturbance interval for a given forest ecosystem is set by cycles of fire, pests, droughts, and other non-anthropogenic activity. If the natural disturbance interval is equal to that of the harvest interval, then this managed forest stores less carbon, but often not a great deal less. If the natural disturbance interval is longer than that of the harvest interval, then the managed forest stores a great deal less carbon. Following this same observation, carbon accumulation in plantation forests also depends on frequency of the harvest rotations, as well as the time period since the initial afforestation.

In addition to disturbance intervals, the types of forest practices utilized, ranging from indiscriminate clear-cutting to sustainable forestry, also affects the degree of carbon loss as well as the ability of a forest ecosystem to recover its carbon sequestration capacities after harvest (Magnani et al., 2007). These impacts are not well studied. The Forest Stewardship Council (FSC), which sets forth principles, criteria, and standards for sustainable forestry, still does not have a stated position on carbon loss due to forest practices, although they recently established a Working Group to explore the role that FSC and forest certification can play in frameworks and projects to mitigate climate change. Gower (2003) has called for integrated research that dynamically models the complex interrelationship between the biological carbon cycle (i.e. forest ecosystem) and the industrial carbon cycle (i.e. forest products). To date, most research has focused on forest ecosystems rather than on this integrated dynamic.

Methodologies

Due to such complexity, there is wide variation in the GHG inventories related to sourcing timber. Such inventories depend on numerous factors, including the type of forest ecosystem, the age of the forest, the length of stand rotation cycles, and the forestry practices used to harvest the timber. Research to date is uneven geographically, with forest carbon dynamics far better understood in some regions and countries than in others. Although comparisons across supply chains utilizing different geographies are likely to be very important to accurately inventory emissions, research does not yet provide an adequate basis for such comparisons. Clearly, at least on a global level, more research is needed, before we can accurately model how key variables (forest type, harvest practices, ecosystem type, biomass densities) combine to impact carbon dioxide and other GHG release in the biological-industrial forest carbon cycle. This is essential if one is to inventory carbon loss associated with timber harvest at the product level. This section introduces the building blocks for a methodological framework that might be fruitfully deployed if sufficient base data on forest type, re-growth rates, and forest practices become available. As is clear from our discussion of this preliminary framework, key policy decisions also remain about how to account for other variables that impact product-level inventories.

As a preliminary step, we propose customizing the IPCC's (2006) methodology used to calculate National Greenhouse Gas inventories, namely those methods and equations in the IPCC's *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, especially Chapter 4 (Forest Land) and Chapter 12 (Harvested Wood Products). This guidance document provides equations and methods at a national level for accounting for biomass, dead organic matter and soil carbon stock changes in all land-use categories as well as default factors to convert from forest product unit (e.g. roundwood, paper, etc.) to carbon. The terminology used and methods in this IPCC guidance document are also consistent with Food and Agriculture Organization (FAO) emission factors and activity data for forest categories. These 2006 IPCC guidelines provide three hierarchical tiers (Tiers 1, 2, 3) that range from default emission factors and basic equations to detailed Tier 3 calculations that use sub-country regionally-specific models and can involve primary data collection. The basic IPCC equation used to calculate annual carbon loss due to timber harvest is the following:

$\Delta CB = \Delta CG - \Delta CL$

Where:

ΔCB = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass), considering the total area, metric tons C yr-1

ΔCG = annual increase in carbon stocks due to biomass growth, considering the total area, metric tons C yr-1

ΔCL = annual decrease in carbon stocks due to biomass loss and to organic soil loss, considering the total area, metric tons C yr-1

Note that this calculation excludes annual change in carbon stocks due to variations in dead organic matter, dead wood or litter, and mineral soils. Also note that other impacts such as disturbance, fuelwood removal, fire, and slash are also excluded. However, these can all be included if so desired and if data are available.

Annual increase in carbon stocks due to biomass growth

To calculate the annual increase in carbon stocks due to biomass growth, the following IPCC equation can be used:

$\Delta C_G = A * G_{TOTAL} * CF$

Where:

A= Area of Forest Land Remaining Forest Land

$G_{TOTAL} = Gw * (1+R)$

GW = Average annual above-ground biomass growth (metric tons dry matter (dm) per year)

R = Ratio of below-ground (bg) biomass to above-ground (ag) biomass [metric tons bg d.m. (ton ag dm)$^{-1}$]

CF = carbon fraction of dry matter, ton C (ton dm)-1

Carbon loss in biomass due to wood removals

The most basic approach is to calculate the carbon loss (and growth) in biomass due to a one-time wood removal on one hectare of forested land. Using FAO data, the national average yield per hectare—ranging from 57 cubic meters in Indonesia to 170 cubic meters in Brazil—can be factored into the calculation for specific countries. To calculate this annual carbon loss the following equation can be used:

$L_{wood-removals} = \{H \bullet BCEFR \bullet (1+R) \bullet CF\}$

Where:

Lwood-removals = annual carbon loss due to timber harvest, metric tons C

H = annual wood removals, roundwood, m3 yr-1

R = ratio of below-ground biomass to above-ground biomass, in ton dm below-ground biomass (ton d.m. above-ground biomass).

CF = carbon fraction of dry matter, ton C (ton dm)-1

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), metric tons biomass removal (m3 of removals).

Annual carbon loss from drained organic soils (CO2)

To calculate the annual carbon loss in biomass due wood removals the following equation can be used:

LOrganic = A * EF

Where:

LOrganic = annual carbon loss from drained organic soils, metric tons C yr-1

A = land area of drained organic soils in climate type *c,* ha

EF = emission factor for climate type *c*, metric tons C ha per 1 yr

Calculating carbon loss per finished metric ton

Once the estimated carbon loss from timber harvest (per cubic meter) is determined, one then needs to calculate the carbon loss per wood product. NewPage estimates than an average of 3.64 cubic meters of wood is used per finished metric ton of coated freesheet paper. This estimate is close to the FAO standard conversion factor of 3.65 cubic meters. This conversion factor will vary depending on the density of wood and the efficiency of the pulp mill. According to IPPC default factors, the average density for temperate species is 0.45 and 0.59 for tropical species.

Assuming the default carbon fraction for both types of species is 0.5, the average carbon factor for tropical species is 0.295 metric tons of carbon per cubic meter and for temperate species it is 0.225. If such data were available, ideally one should use carbon factors specific to each tree species. RISI's *Cornerstone*, however, does not always differentiate by specific species. Thus new primary data sources would be required to enumerate species-specific factors for both supply chains.

Pulp mill efficiency should also be factored in. A review of RISI data of pulp mill efficiencies—in terms of wood used to produce a given amount of paper—in the major pulp producing countries revealed that they are relatively similar—ranging from 2.1 to 2.4 metric tons of bleached dried pulp to make a metric ton of paper. This efficiency is of course partially dependent on the density of the wood being used. One needs to decide if this variation in efficiency is significant enough to warrant incorporating figures specific to each mill. Without incorporating wood density or mill efficiency variation, the following calculation can be used:

Average pulp carbon factor *cu. m of roundwood/FMT * 1000 * 44/12 = Kilograms of CO_2 per finished metric ton of coated paper.

Where,

Average pulp carbon factor = metric tons of carbon per cu. m. of roundwood

Cu. m of roundwood/FMT= 3.65 cubic meters

1000 = unit conversion from metric tons to kilograms

44/12 = conversion of elemental carbon to carbon dioxide

Carbon stocks for forestry in IPCC's method are calculated as elemental carbon. In the above equation, in accordance with IPCC guidelines, converting elemental carbon to carbon dioxide is based upon the ratio of the molecular weights (44/12).

Incorporating embedded carbon

All wood products (including paper) are made from fiber that has carbon 'embedded' in it through the product's useful life. As this carbon is not released to the global climate during that life, an appropriate offset factor is typically applied in lifecycle assessment of wood products, including paper (i.e., it is subtracted from the product's overall carbon footprint). At end of life this carbon may be emitted as a GHG. For example, carbon may be released as methane from a landfill or as carbon dioxide following incineration. Therefore, an appropriate factor must be determined with reference to the product's expected life span and end of life disposition.

According to IPCC 2006 (see Chapter 12), the default half-life for paper products is two years before it goes to a landfill or is recycled, while that of solidwood products is 30 years. Coated freesheet paper generally has a longer half-life than other paper products such as newsprint and magazine papers as it is often used in reports, textbooks, and posters. The half-life of the product needs to be determined and incorporated according to the product type and the country where it is in use.

If one were to calculate embedded carbon as the basis to further determine an appropriate offset, it would be achieved by accounting for the carbon in the roundwood (carbon loss from the forest), using the following IPCC equation:

Density (oven-dry metric tons per cubic meter of product) * carbon fraction (metric tons of carbon per oven dry metric tons of wood material) = Carbon factor (metric tons of carbon per cubic meters of product).

Scoping the parameters of the model

The above equations will allow for a narrowly scoped, generalized estimate of carbon loss. Essentially it will be limited to: a) calculating average annual biomass growth (above-ground and below-ground) and b) estimating the annual the carbon loss in biomass and organic soil due to timber harvest. Chapter 4 of the IPCC 2006 Guidance document provides a wealth of data tables that one can use to determine values for each of the variables noted above, such as the carbon factor (CF), above-ground to below ground biomass ratio (R), and biomass conversion and expansion factor (BCEF). These data generally are derived from the broadest levels of forest type. For example, to calculate carbon loss due to the draining of organic soil, emission factors are categorized broadly for tropical forests, temperate forests, and boreal forests. Obviously, there is tremendous variation depending on forest type and local conditions.

Determining geographic scale

As it is designed for national level accounting, the IPCC 2006 Guidance document does not supply data or equations for some key variables that need to be incorporated into a product-based carbon loss model that seeks to estimate the carbon loss associated with the production of specific products. One of these variables is geographic or spatial scale, which can range from millions of hectares of forested land down to a single stand of trees. Spatial scale will influence many factors, including how one would calculate natural disturbance intervals, whether a forest is deemed 'carbon positive', forest species composition, and, of course, the timber harvest yield (in cubic meters) per hectare. The FAO has national timber harvest yield averages for all major timber-producing countries, but this yield can vary widely depending on the geographic scale. So when doing a sub-national analysis, the results will be more accurate if region-specific yields can be obtained.

Determining temporal scale

Perhaps the most important variable to consider is how to incorporate the effects of *time* in the model. As the 2006 IPCC document is designed to calculate national level carbon loss or gain for one year, there is no guidance on what time scale should be deployed. Some studies have used 25 years, others 50 and 100 years. Given the urgency of addressing climate change, some environmental NGOs have called for a 40 or 50 year time period to be the standard (Ford, 2009). The decision on temporal scale is predicated somewhat on the rate of forest re-growth where the timber is harvested.

Closely connected is whether the model will consider specific forests to be in equilibrium or whether they are carbon positive. Also related are research findings at to whether frontier or primary forests fully regain their carbon sequestration capacity after they have been logged. It may be the case that they take so long to regain this original capacity that for purposes of the model they are assumed to have diminished capacity. Research on frontier forests in the Pacific Northwest indicates that average storage after harvest will be about half of the original level (Harmon et al, 1990). If one was to factor in time, and these associated factors, one would then develop a growth model to mimic the rate of growth, this could be linear, nonlinear, exponential, etc. depending on the parameters one selected.

In their meta-analysis on the contribution of the paper cycle to global warming, Subak and Craighill (1999) incorporated carbon loss due to logging of frontier forests by assuming that average storage after harvest was about half of the original level, based on the research by Harmon and others. This essentially tries to factor in science that indicates permanently diminished sequestration capacity, but avoids considerations of specific regrowth rates, harvest practices, and other variables. Using Wood Resources International's (WRI) analysis of fiber sources for the global pulp and paper industry for the base year of 1993, Subak and Craighill divided wood fiber supply by forest type into three land use categories: Plantations, 'Original' Converted forests, and Regrowth forests. 'Plantations' were assumed to be a net carbon sink; although they did not factor in the emissions associated with planting, water, and fertilizer for the plantations, which unlike for the other two categories are significant energy inputs. For Regrowth forests, they assumed that forest regrowth offsets harvest pulpwood – thus a net zero balance. And for Original Converted forests, they assumed the 50% loss. The Subak and Craighill study essentially eliminated the time scale question by making these broad assumptions of the three forest types.

Factoring in timber harvest practices

As noted earlier, clear-cut harvesting has been shown to permanently hinder carbon sequestration capacity. However, research also indicates that in some geographic regions industrial timberlands may be managed both to provide forest products and some degree of carbon sequestration (Birdsey et al., 2006). This reportedly can be done by increasing the sequestration of the below-ground biomass, as well as leaving logging slash, litter, and deadwood on the forest floor. Predominant forest practices, however, generally disregard these carbon pools in favor of sustainable wood yield and site quality (Houghton et al., 1999). Few ecosystem scale studies of carbon storage have been done in managed forests, but based on the ones that have been completed, Gough et al. (2008) offer general recommendations for how soil and residue carbon pools can be enhanced, including conservation tillage, adding organic amendments to the soil, and replanting immediately following harvest to minimize transition from source to sink. This may be particularly successful in the tropics, due to longer growing seasons and the fact that there is greater flexibility to improve sequestration rates through forest management practices (Gough et al., 2008). Intensive management practices will need to quantified, however, in terms of their carbon footprint to ensure that these gains are not offset by the carbon burdens associated with the production of fertilizer, irrigation, and other energy-intensive activities. There is so much variation due to different forest types and practices utilized that this is perhaps the most difficult variable to account for.

Conclusions and future research

Given the globalized nature of China's pulp sources (e.g. Indonesia, Brazil, Russia, Canada, U.S., Chile, and others) in order to do a comparative lifecycle inventory of the carbon loss associated with timber harvest between the Chinese and U.S. (NewPage) coated freesheet paper industries more data on the specific geographic conditions and forest management practices is needed. Based on the preliminary framework outlined here, following Subak and Craighill's approach, one could find that the Chinese supply chain carbon loss due to timber harvest is higher because that industry relies more heavily on pulp produced from wood sourced from frontier forests, particularly Indonesia. This relatively simple calculation of timber harvest loss by country is provided in Table 4.1 and draws upon updated data tables by WRI detailing fiber sources by country and type of forest for the global pulp and paper industry. To determine respective values for each of the variables (e.g. CF, BCEF, R, etc.), emission factors in Chapter 4 of the 2006 IPCC guideline were used. Appendix 1 details the values assigned to these variables for each of the respective countries, by softwood and hardwood.

Table 4.1 Method I, Estimated Annual Carbon Loss due to Timber Harvest, Selected Countries

Country	Harvest Unit (cubic meters yield per ha)	Carbon loss due to biomass removals	Final Carbon loss per cubic meter
		(tons C^{-1})	(Tons C)
		$L_{wood\text{-}removals} = H * BCEF_R * (1+R) * CF$	
		$L_{wood\text{-}removals}$	
Indonesia Hard	59	90.3	0.8
China Hard	67	34.8	0.4
China Soft	67	48.5	0.3
US Soft	116	58.8	0.3
US Hard	116	49	0.2
Canada Hard	106	43.5	0.2
Canada Soft	106	51.6	0.2
Russia Hard	100	40.7	0.2
Russia Soft	100	39.8	0.2
Other Soft	100	48	0.2
Other Hard	100	42.5	0.2
Note: Carbon Dioxide only. Harvest yield figures taken from FAO FRA global assessment.			

Sources: Data are from the IPCC (2006), with the exception of the harvest yield figures which are from the FAO FRA global assessment report.

However, this approach lacks proper nuance because it essentially excludes temporal and geographic scales, forest management practices, and it greatly oversimplifies forest carbon flux dynamics. Furthermore, there is still a knowledge gap with respect to which forests are carbon positive. There are likely many smaller stands of forests with high carbon sink values that are not classified as ‘frontier’ due to their size or due to lack of adequate mapping. The frontier forests maps generated by the World Resources Institute (WRI) and which have become the de facto standard for what counts as ‘frontier’ forests were developed for the purpose of identifying biodiversity values, not carbon values. Thus, they focus on measuring contiguous forest areas that serve biodiversity protection goals.

Accurately comparing carbon loss from timber harvest for the Chinese and U.S. (NewPage) supply chains requires more data on forest types, re-growth rates, and harvest practices in the primary countries that supply pulp to these industries. Some information is available for a few of these countries, particularly the US and Canada. However, without this same level of detail for all seven countries that supply pulp to these industries, it is not possible to accurately compare carbon loss due to fiber acquisition.

It would be particularly important to have robust data on the carbon balance of plantations. Some scientists believe that plantations are carbon positive, even after accounting for energy intensive activities such as planting, irrigation, and fertilizer treatments. Others believe that these activities, if properly accounted for in a lifecycle assessment, would outweigh the carbon benefits of plantations. Further, there are cases where plantations are developed on denuded lands, effectively transforming a land area with minimal carbon sequestration ability into one that could effectively be a carbon sink. Tropical forest plantations in particular experience rapid re-growth and China is more reliant on these forests than are paper manufacturers in the U.S. A full accounting of the carbon benefits of relying on plantation fiber needs to be incorporated to accurately compare these two supply chains.

Next steps

As a way forward, we suggest that a methodology be developed that customizes the methods outlined in the 2006 IPCC Guidance document. This section of our study has presented readers with the key equations to be used in this modified methodology: carbon gain due to biomass growth, carbon loss due to timber harvest, carbon loss from drained organic soils, carbon loss per finished metric ton, and incorporating embedded carbon. This methodology would also need to incorporate geographic and temporal scale, and address emerging science on frontier forests and the effects of forest management practices on carbon sequestration to the degree that is possible without making the methodology so contingent and complex that it is unusable. This will require developing a methodology that is flexible and allows for new data and science to be incorporated as it emerges.

To develop and refine this methodology, we suggest that geographic scope be narrowed to compare two major pulp producing regions that harvest timber from frontier forests, managed forests, and plantations— such as Canada and Indonesia (Sumatra). We believe research on the two pulp producing regions would provide evidence of how GHG emissions can vary depending upon the particular forest type and the harvest practices. Scientific research suggests that in some forest regions, such as Riau Province in Sumatra, GHG emissions are much higher than in other regions. In Riau alone, it is estimated that the annual carbon dioxide emissions resulting from deforestation, peat decomposition and peat fires between 1990 and 2007 was 0.22 giga tons (Uryu et al., 2008). Research highlighting this key component of the paper cycle would provide a clearer picture, from a GHG emissions perspective, that it is better to source wood from one region rather than another depending on the forest type and the harvest practices deployed. It would also lead to the development of a model that could ultimately be deployed for other regions and countries as ongoing research progressively unweaves the complex relationship between the forest and industrial carbon cycles.

6. Appendices

Useful Terms

These definitions have been taken directly from the IPCC's guidance report on forestry and greenhouse gas emissions calculations.

Above ground biomass

All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.

Above-ground biomass growth

Oven-dry weight of net annual increment of a tree, stand or forest plus oven-dry weight of annual growth of branches, twigs, foliage, top and stump. The term "growth" is used here instead of "increment", since the latter term tends to be understood in terms of merchantable volume.

Below-ground biomass

All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.

Biomass conversion and expansion factor (BCEF)

A multiplication factor that coverts merchantable volume of growing stock, merchantable volume of net annual increment, or merchantable volume of wood-removal and fuelwood-removals to above-ground biomass, above-ground biomass growth, or biomass removals, respectively. Biomass conversion and expansion factors for growing stock (BCEFS), for net annual increment (BCEFI), and for wood-removal and fuelwood-removals (BCEFR) usually differ. As used in these guidelines, they account for above-ground components only.

Biomass Removals

Biomass of wood-removal and firewood-removals plus oven-dry weight of branches, twigs, foliage of the trees or stands removed.

Carbon content

Absolute amount of carbon in a pool or parts of it.

Carbon fraction (CF)

Metric tons of carbon per ton of biomass dry matter.

Conversion factor

Multiplier that transforms the measurement units of an item without affecting its size or amount. For example, basic wood density is a conversion factor that transforms green volume of wood into dry weight.

Deadwood

Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).

Forest Plantation

Forest stands established by planting or/and seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at planting, even age class, and regular spacing.

Harvest Yield

The amount of cubic meter harvested per a given plot, usually a hectare. The global average timber yield per hectare is 110 cubic meters.

Litter

Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for dead wood (e.g., 10cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil

Natural forest

A forest composed of indigenous trees and not classified as a forest plantation.

Organic soils

Soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below (FAO, 1998): 1) Thickness of organic horizon greater than or equal to 10cm. A horizon of less than 20cm must have 12 percent or more organic carbon when mixed to a depth of 20cm. 2) Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter). 3) Soils are subject to water saturation episodes and have either:

1. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
2. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
3. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Pool/Carbon pool

A reservoir. A system which has the capacity to accumulate or release carbon.

Roundwood

All roundwood felled or otherwise harvested and removed; it comprises all wood obtained from removals e.g., quatities removed from forests and from trees outside forests, including wood recovered from natural felling and logging losses during a period. In the production statistics, it represents the sum of fuelwood, including wood for charcoal, saw-and veneer logs, pulpwood and other industrial roundwood. In the trade statistics, it represents the sum of industrial roundwood, and fuelwood, including wood for charcoal. It is reported in cubic meters excluding bark.

Soil carbon

Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots of less than 2mm (or other value chosen by the country as diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

Total biomass

Growing stock biomass of trees, stands or forests plus biomass of branches, twigs, foliage, seeds, stumps, and sometimes, non-commercial trees. It is differentiated into above-ground biomass and below-ground biomass. If there is no misunderstanding, possible also just to use "biomass" with the same meaning.

Total biomass growth

Biomass of the net annual increment of trees, stands, or forests, plus the biomass of the growth of branches, twigs, foliage, seeds, stumps, and sometimes, non-commercial trees. Differentiated into above-ground biomass growth and below-ground biomass growth. If there is no misunderstanding, possible also just to use "biomass growth" with the same meaning. The term "growth" is used here instead of "increment", since the latter term tends to be understood in terms of merchantable volume.

Tree

A woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definitive crown. Includes bamboos, palms, and other woody plants meeting the above criteria.

Wood removal

The wood removed (volume of round wood over bark) for production of goods and services other than energy production (fuelwood). The term removal differs from fellings as it excludes felled trees left in the forest. It includes removal from fellings of an earlier period and from trees killed or damaged by natural causes. It also includes removal by local people or owners for their own use. As the term "removal" is used in the context of climate change to indicate sequestration of greenhouse gases from the atmosphere, removal in the context of forest harvesting should always be used as "wood-removal or fuelwood-removal" to avoid misunderstandings.

Forest Classification and Assigned Values, by Country

Country	Forest-Classification Notes	Harvest Yield	Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark)	Ratio of below-ground biomass to above-ground biomass	Carbon fraction of dry matter
		(m^3 per ha)	[tons of biomass removals (m^3 of removals)$^{-1}$]	[tons bg dm(ton ag dm)$^{-1}$]	[tons C (ton dm)$^{-1}$]
			Table 4.5 (IPCC)	zero (0) or Table 4.4 (IPCC)	0.5 or Table 4.3 (IPCC)
		H	**$BCEF_R$**	**R**	**CF**
Indonesia Hard	Gw = natural tropical rain forest; BCEF = humid tropical natural forest; R = tropical rainforest; CF = tropical wood; EF = Tropical	59	2.28	0.37	0.49
Russia Hard	Gw = Natural boreal coniferous; BCEF = boreal hardwood; R = temperate broadleaf forest; CF = boreal broadleaved; EF = Boreal	100	0.69	0.23	0.48
Russia Soft	Gw = natural boreal coniferous forest; BCEF = boreal pine; R = boreal coniferous forest; CF = boreal conifer; EF = boreal	100	0.63	0.24	0.51
Canada Hard	Gw = natural temperate coniferous forest; BCEF = temperate hardwoods; R = temperate continental forest; CF = temperate broadleaved; EF = temperate	106	1.17	0.24	0.48
Canada Soft	Gw = natural temperate continental forest; BCEF = boreal firs and spruces; R = temperate coniferous forest; CF = temperate conifers; EF = temperate	106	0.77	0.24	0.51

US Soft	Gw = natural temperate continental forest; BCEF = temperate other conifers; R = temperate continental forest; CF = temperate conifers; EF = temperate	116	0.77	0.29	0.51
US Hard	Gw = natural temperate continental forest; BCEF = temperate other conifers; R = temperate continental forest; CF = temperate conifers; EF = temperate	116	.73	0.23	0.47
China Hard	Gw = natural temperate continental forest; BCEF = temperate other; R = temperate continental forest; CF = temperate; EF = temperate	67	.89	0.24	.47
China Soft	Gw = natural temperate continental forest; BCEF = temperate other conifers; R = temperate continental forest; CF = temperate conifers; EF = temperate	67	1.1	0.29	.51
Other Hard	Gw = natural temperate continental forest; BCEF = temperate other; R = temperate continental forest; CF = temperate conifers; EF = temperate	100	.73	.24	.47
Other Soft	Gw = natural temperate continental forest; BCEF = temperate other conifers; R = temperate continental forest; CF = temperate (all); EF = temperate	100	0.83	0.29	0.47

Sources: Data are from the IPCC (2006), with the exception of the harvest yield figures which are from the FAO FRA global assessment report.

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