Carbon's Potential to Reshape Supply Chains in Paper and Print: A Case Study

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Abstract

Interest in carbon has been growing, with academics, governments, the private sector, and civil society engaged in efforts to manage emissions. The purpose of this case study is to identify the origins and evolution of carbon management along a supply chain in the paper and print sector. It uses results from in-depth interviews to suggest a possible framework for assessing carbon's impact on the supply chain. We find that the use of biomass for energy and low-carbon transportation, such as rail and sea-based barges, can reduce the carbon footprint of a paper product. The interviews reveal that upstream and downstream supply chain actors are shaped by different pressures. Energy-intensive, upstream actors manage their carbon footprints in order to save energy and in anticipation of regulated carbon emissions. Downstream actors, in contrast, manage carbon in order to strengthen their corporate brand and maintain market share. Businesses trying to balance short-term costs, long-term profitability, and the maintenance of a corporate brand have identified carbon as a means for progress on all three fronts.

Keywords: Pulp and paper; carbon footprint; sustainable supply chain management.

Introduction

The challenge of climate change is significant. Shifts in global temperatures, weather patterns, and sea levels may adversely impact ecosystems and societies alike (Garnaut Review 2008). To address this challenge, governments, corporations, civil society, and scientists are collaborating in efforts to mitigate and adapt to the impacts of climate change (U.S. Climate Action Partnership 2008). Mitigation strategies are focused on efforts to limit and reduce carbon emissions, often through the monetization of carbon. Carbon, in short, is poised to have a price. Any business that emits carbon will pay for its emissions. This development has implications for supply chains. Monetized carbon may force supply chains to consider a new cost.

It is the purpose of this paper to fill a gap, exploring the overlap between the consensus supporting carbon and its potential to reshape supply chains in the paper and print industries. This will be done in two parts. We begin with a case study from the paper and print sector that explores the role of the supply chain in managing carbon. We follow with a framework grounded in our case study that explores how carbon will influence supply chains. The case study synthesizes results of interviews with six corporations along a supply chain in the paper and publishing industries. We explore the origins, evolution, and future directions of carbon management for supply chain actors. We also present a carbon footprint for the supply chain. We suggest that, in the future, a thorough understanding of carbon may become a central issue in supply chain design and business operations.

Background

There is a convergence around carbon. Many sectors of society, from corporations to non-governmental organizations (NGOs) to governments and international bodies, have embraced carbon management as central to addressing climate change. Governments have begun to regulate carbon emissions. Internationally, the Kyoto Protocol and subsequent processes are working towards binding international commitments for reducing carbon emissions (UNFCC 2009, Hede-

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gaard 2008). At the regional level, the European Union Emissions Trading Scheme is capping and monetizing carbon emissions. Nationally, Australia, Canada, and the United States are moving toward binding emissions targets. There are also regional and local initiatives to cap and trade carbon emissions — the Western Climate Initiative (WCI) and the Regional Greenhouse Gas Initiative (RGGI) are prominent examples.

The corporate world is also responding, treating carbon as both a risk and an opportunity. Growing consumer awareness, in addition to regulations, is shaping this response. Those who differentiate their products based on its carbon footprint may be rewarded. Insurance companies are including climate change in their long-term cost projections and designing incentives to reward climate change mitigation strategies (SwissRe 2008). Investors are adjusting their decisions to include climate change criteria (UN Principles for Responsible Investing 2009). Carbon also represents a possible source of savings, or perhaps revenue, for business. As carbon gains a price, business may be forced to pay; those that are able to emit less will spend less relative to their competition.

Civil society is active in shaping the response to climate change. Advocates are arguing to include REDD (Reduced Emissions from Deforestation and Degradation) schemes in a post-Kyoto global climate accord (IUCN 2008). Scientists are also central in this response, from the Intergovernmental Panel on Climate Change (IPCC), a body composed almost entirely of scientists and recipient of the Nobel Peace Prize for its efforts (IPCC, 2007) to the Stern Review (Stern, 2006), science is enjoying a prominent voice in discussions on climate change. The U.S. Climate Action Partnership (USCAP), a coalition of several major corporations (including Shell, General Electric, and ConocoPhillips), as well as four prominent NGOs (Environmental Defense, Natural Resources Defense Council, Pew Center on Global Climate Change, and World Resources Institute), have embraced carbon-oriented climate legislation.

Beyond the convergence of governments, corporations, and civil society, there is a strong theoretical grounding for the management and monetization of carbon. Typically, the producer of a good pays only the private costs associated with production. Public costs, like carbon, are not captured in the price. The evolution of carbon into a regulated pollutant is an example of internalizing a negative externality. Economic theory has established the "polluter pays principle," which has appeared in academic literature and policy for over 30 years. What is different now is the scale. Carbon is the largest attempt at internalization to date, and with a pollutant that is so ubiquitous and intangible, challenges arise. The specifics, means, and mechanisms, while well-grounded in theory, are less understood in practice.

Methodology

Our research measured the carbon footprint of a supply chain with a focus on describing the influence that carbon has on business-to-business relationships between supply chain partners. This chain oriented around the production of a major American magazine, which chose to remain anonymous. Using a case study approach (Yin 2009), we wanted to explore carbon not only as a quantifiable emission, but as a phenomenon that influences supply chain dynamics. We interviewed six corporations for this case study and investigated the origins, evolution, and future directions of carbon management in each company. In order to strengthen the internal validity of the case study, we shared our findings with all those interviewed and incorporated their feedback.

The steps in the supply chain were as follows. Catalyst Paper sourced fiber from Western Forest Products (WFP), which harvested trees on Vancouver Island, Canada. Residual fiber from WFP's operations was shipped to Catalyst's mill in Port Alberni by truck. After the paper was manufactured, it was shipped by truck and then on barges operated by the Washington Marine Group (WMG) to Catalyst's distribution center in Richmond, Canada. From here, it was shipped by Burlington Northern Santa Fe Railways (BNSF) to Quebecor World's printing plant in Merced, California, where it was printed and then distributed across North America.

The standard approach in quantifying carbon emissions is to conduct a life cycle assessment (LCA). LCAs of magazine products exist (Boguski 2010, Gower et al. 2006) and there is agreement that the paper manufacturing process is significant in the total footprint of a product. For example, Boguksi (2010) found that 79% of life cycle energy is accounted for by the cradle-to-gate (meaning from harvest in the forest to final product at the paper mill) for coated magazine paper. Gower et al. (2006) found that the paper manufacturing process accounts for 61% to 77% of total life cycle carbon emissions. Our approach to focus on the supply chain partners in direct contact with Catalyst Paper meant that we measured emissions that made up the bulk of the magazine's footprint. We therefore felt confident that our methods were in line with those employed in other LCAs, and chose not to prioritize the replication of LCAs that already exist.

Further, there are problems with LCA that we did not want to introduce into our analysis given our tandem focus on quantifying emissions and qualifying their influence on business relationships. Gadreault et al. (2007) reviewed 40 LCAs in the pulp and paper industry and found that sound methodologies for assessing land use and demonstrating the carbon storage advantages of paper were absent. They also noted that generalized coarse-level LCAs are not as robust as LCAs that rely on primary data and describe specific processes or products. Reap et al. (2008) took a broader view, and discussed unresolved problems in LCA methodologies. They found that, at each stage in the conduct of LCA there are several challenges. Most prominent in the context of a paper magazine were the problems of: local environmental uniqueness; spatial variation; time horizons; and data availability/quality. Summarizing these issues, Reap (2008, p.384) quotes Bare et al. (1999) in stating that it is hard to know "where to draw the line between sound science and modeling assumptions."

Pulp and paper LCAs, in sum, are not without problems. Notably, though, we opted to avoid the full LCA methodology not only because of these problems, but because we also had the advantage of a unique level of cooperation and accessibil-

Table 1. Supply Chain Emissions

Activity	Carbon Emissions ($C0_2$/ADt)	Percentage of Total
Harvesting, road-building, felling, transport to sawmills	55kg	12%
Sawmilling into dimensional and residual products	45kg	10%
Transport of chips to mill	8kg	2%
Paper manufacturing process	185kg	41%
Transportation to print facility	127kg	28%
Printing process	36kg	8%
Total	**456kg**	**100%**

ity to corporate executives, as well as primary data for several stages of the supply chain. We felt that a hybrid approach, quantifying what we could, while describing the qualitative influence of carbon, would lead to a more nuanced understanding of how carbon can influence a supply chain.

When we did quantify, we used the most granular data available. We tracked logs from specific logging operations to a specific mill, and along specific transport routes to a specific printer. We avoided generalized emissions factors in favor of specific data whenever possible. These data are expressed as greenhouse gas equivalent ($C0_2$) per air-dried tonne (ADt) in Table 1. Figure 1 shows the physical route of the supply chain. For a more detailed explanation of how we measured the emissions, please see "Appendix: Emission Factors Explained."

It should be noted that we did not include the distribution footprint for the product. We attempted to estimate this figure using several approaches, but each proved highly sensitive to assumptions made. Variables under consideration were: the average distance traveled by each copy of the magazine; the volume distributed by retail outlets compared to home-delivery; and the precise geography of distribution. Because actual data was not available, and the assumptions produced unacceptable variation in results, we omitted the distribution process from the supply chain footprint. This is an area where further research is warranted.

We also refrained from modeling the carbon emissions of the magazine after disposal by the consumer. Again, there was too much potential variation. Whether the magazine was recycled, incinerated, archived, or buried in a landfill strongly influenced our results. Since our study is distinct from a traditional LCA, we used data for specific facilities and processes rather than aggregate data. Our goal was to describe the carbon emissions of the supply chain stages examined, and to describe the relative emissions of those stages, not the entire life cycle of the magazine.

Figure 1. Map of Supply Chain Emissions
Note: Circles represent relative contribution to supply chain emissions, while numbers represent kilograms of $C0_2$ per air-dried tonne of paper.

The interviews were developed using qualitative methods for exploring complex and intricate phenomena that are difficult to express quantitatively (Cresswell 1998; Strauss and Corbin 1998; Yin 2009). Given the emergent nature of the topic at hand, this approach was deemed the most appropriate for providing a better understanding of carbon's potential to reshape supply chains. The following companies (five of which consented to be identified) and individuals participated in the interviews. We have separated the companies from the individuals interviewed to further protect anonymity.

Companies

- Anonymous Magazine Publisher
- Burlington Northern Santa Fe Railways
  Catalyst Paper Corporation
- Quebecor World Inc.
- Washington Marine Group
- Western Forest Products

Individuals

- Chief Executive Officer
- Chief Operating Officer
- Director, Environmental Affairs
- Director, Paper Procurement, Environmental Affairs
- General Director, Environmental
- Vice-President, Corporate Relations and Social Responsibility
- Vice President, Health, Safety and Environment
- Vice-President, Manufacturing

Data for this case study were collected through in-depth, semi-structured interviews. Participants received the interview questions in advance. Two researchers conducted each interview, either in person or via telephone. Each interview was recorded and transcribed. The interviews focused on three themes of interest in carbon management: origins; evolution; and future directions. We asked companies to identify how carbon manifested as a management priority, to describe the role that the supply chain played in shaping their perceptions of carbon, and to identify specific examples of interactions with external actors that shaped their carbon strategy. Given the elite status of those being interviewed, we adopted methods (Dexter 1970) that allowed the interviews to remain semi-structured, and responsive to the expertise and knowledge of those interviewed.

Upon completing the interviews, we supported our analysis with a review of existing literature around carbon and the supply chain. This review, influenced by qualitative methods developed by Glaser and Strauss (1967) and Strauss and Corbin (1998), led to the construction of a framework on efficient, responsible, and resilient supply chains. It is within the context of this framework that we discuss the interview results.

Throughout this paper, we use the term "carbon management" in an intentionally ambiguous way. It can mean the measurement of carbon emissions, or the acknowledgement that carbon is an important issue, or steps taken to control carbon emissions. In other words, its specific meaning varies depending on the context.

Results

We present the results of the interviews below, highlighting common themes and particular concerns of individual companies.

Origins and Evolution of Carbon Management

The interview process revealed three motives for managing carbon: as a performance metric in pursuing operational excellence; as a basis for product differentiation; or as a strategic priority to satisfy corporate commitments to environmental responsibility. The motivations of a company depended on three variables: the proximity of the corporation to the end consumer; the degree of compliance required by regulations; and the need to enhance the corporate brand. Despite these diverse motives, carbon provided an opportunity for cooperation and shared understanding between supply chain partners.

We classified motives for carbon management into two categories: internal and external. The only internal origin identified was the need to manage energy costs, and by extension, carbon. BNSF and Catalyst were both motivated by internal origins. BNSF, which spent approximately $4.6 billion on diesel fuel in 2008, saw carbon as an entry point for managing fuel costs. To them "not only does carbon make economic sense, we see it as an opportunity to differentiate ourselves from an environmental perspective." Catalyst, in a similar vein, wanted to reduce its energy use. To do so, "Catalyst invested heavily in the right equipment to turn waste into energy for their operations, and as they did, their reliance on fossil fuels decreased to almost zero." Catalyst then moved beyond operational benefits towards a more sophisticated marketing strategy. By controlling costs, it also produced a unique product; paper produced while emitting as little carbon as possible.

External origins took several forms, and were threefold in their origins: compliance with regulations; response to pressures from civil society; or relationships between supply chain partners. The latter was the most important in our case study. WMG cited a meeting with senior executives of Catalyst Paper as the origin of its carbon management. Catalyst, in trying to reduce its carbon footprint, engaged with WMG to maximize the use of fuel-efficient barges in moving its product. WMG cited this engagement as vital in its own consideration of carbon. WMG was not alone in crediting its relationship with Catalyst as an origin for its understanding of carbon. With the exception of BNSF, every interviewee had been actively engaged with Catalyst on carbon issues. Catalyst also helped connect its supply chain partners with World Wildlife Fund Canada, an NGO that assisted Catalyst in the measurement of its carbon emissions.

Two respondents, Catalyst and BNSF, also credited regulatory requirements as an important motive for managing carbon. In Canada, major emitters are already required to report their annual carbon footprint. The federal government in the United States has indicated that it may follow suit.

A company's position along the supply chain also affected carbon management. Upstream and downstream actors face different pressures. In our case study, upstream suppliers consume more energy than their downstream counterparts, but are less visible to consumers. As a result, they are more likely to undertake carbon management in order to derive cost savings or comply with regulations. Downstream suppliers, in contrast, use less energy and have fewer financial incentives to undertake carbon management. However, non-financial incentives do influence downstream actors. Quebecor World, for example, suggested that despite an economic downturn, there was a strong interest in sourcing environmentally preferable paper. To meet this demand, the company developed a database of carbon emissions for all of the paper products that it offers. Suppliers are requested to fill out comprehensive surveys that contain information on the carbon emissions of their products. Quebecor World receives an almost perfect response rate to this survey request.

We found that most supply chain actors in this case study were in the early stages of developing a carbon management policy. The evolution, therefore, was not fully understood because most, with the exception of Catalyst and BNSF, had only begun to develop their carbon management plans. All had begun to take the first steps to do so, but were still in the formative stages. Specific reduction targets were the exception rather than the norm. This speaks to the current regulatory uncertainty that exists in North America. National-level schemes are evolving, while regional initiatives, such as the WCI and RGGI, may have impacted some of the corporations interviewed, but were not significant regulatory priorities. British Columbia, Canada, proved an exception, as companies operating there (such as Catalyst, WFP, and WMG) are subject to a carbon tax on their fossil fuel use.

Future Directions of Carbon Management

When asked where they thought the future of carbon management lay, each respondent gave an answer specific to its own corporation and industry. The economic volatility at the time of the interviews (January through March 2009) influenced answers. It should be noted that four of the corporations interviewed were in the print industry (WFP, Catalyst, Quebecor World, and Anonymous Magazine); the particular hardships of this industry shaped interviewees' responses on future directions.

Respondents universally agreed that, in the future, carbon and sustainability will be considered more closely. They recognized carbon as a potential cost, risk, and opportunity. They also felt that the marketplace would increasingly demand information about carbon emissions. They suggested that the market was unwilling to pay significant premiums on carbon-light products (that is, products that are designed and manufactured with the goal of reducing carbon emissions). However, carbon-light products may be given preference if cost-competitive.

Interviewees identified the ability for carbon to create differentiated products. They described carbon's role in the marketplace as a three-step transition. The first step was simple differentiation. The second involved the marketplace rewarding carbon-light products with increased market share; further, they anticipated some scenarios where the market would pay a premium for carbon-light products. The final step depended on how the monetization of carbon plays out. If polluters are eventually forced to pay for emissions, carbon-light producers who currently only enjoy product differentiation may actually gain cost advantages. Respondents saw this as a medium- to long-term development, and felt that differentiation and market preference are priorities in the short-term.

It was suggested that carbon has the potential to change the value of existing industrial assets. This was particularly true for three companies — BNSF, Catalyst, and WFP. Their assets, and their economic value, would change in a low-carbon economy. Catalyst identified the possibility of using underutilized mills to produce electricity with biomass. WFP saw potential in recognizing solid wood products as sinks of carbon. Given that dimensional lumber can exist as a carbon sink in a home for decades and then be recycled, this has the potential to change the market and pricing of wood products. BNSF saw significant opportunities in the future for increased use of rail capacity, as the carbon benefits of shipping by rail may be enhanced by monetized carbon.

These same three firms also expressed concern about the specifics of carbon regulations. Catalyst moved early to reduce its carbon emissions. If allowances under a cap and trade system are calculated using an average of the previous 10 years of emissions, Catalyst could be in a position where further reductions in order to comply with shrinking allowances are almost impossible. In short, they could be punished for good behavior. BNSF also identified similar risks with cap and trade. WFP identified uncertainty around the measurement of carbon in forest products as risky. Harvested timber is converted to solid wood products that store carbon; pulp is converted to paper and can be recycled; and wood waste can be used to offset fossil fuel use. The methods and assumptions behind the measurement of these (and other) variables impacts the emissions associated with forest operations.

Discussion

Based on the interview results, we suggest a framework that explains how carbon will transform supply chains. We consider a three-step process, where: at first, efficient supply chains emerge due to carbon's equivalency with energy; next, environmentally responsible supply chains emerge; and finally, resilient supply chains develop as the risks of monetized carbon are mitigated.

Efficient Supply Chains

There are two ways in which carbon efficiency can transform supply chains. Corporations that are carbon-efficient may become preferred suppliers (a status achieved by Catalyst with Anonymous Magazine) and gain market share. Supply chains themselves may also reorient to minimize carbon emissions, as seen with Catalyst's use of barges and rail to reduce transportation carbon. These carbon-efficient supply chains will better adapt to the regulations and cost structures of a low-carbon economy. The carbon emissions associated with supply chains may influence where business is conducted. Supply chains may evolve to locate particularly energy-intensive processes (such as aluminum smelting or paper making) near low-carbon energy sources, such as hydroelectric power (used by Catalyst to reduce the carbon footprint of its paper). Conversely, processes using little energy may relocate closer to efficient transportation networks and major markets, minimizing emissions from transportation and distribution.

Responsible Supply Chains

As carbon emerges as a major component of sustainability, it may play a stronger role in corporate social responsibility (CSR) policies. The prevalence of the Carbon Disclosure Project (CDP 2009) indicates that corporations already understand this. How this will impact supply chains is less certain. If carbon continues to gain importance, products with large carbon footprints relative to their competition may fall out of

favor. Companies that demonstrate an understanding of their supply chain footprint, and steps taken (or at least plans) to reduce it, will benefit.

To achieve reliable and transparent management of carbon, third party auditing and verification will need to be more widespread. While costly, the outcomes of this monitoring may lead to stronger engagement between supply chain collaborators, a phenomenon shown in our case study. The potential to audit supply chains for carbon has several implications. These audits will provide a baseline measurement, and allow for improvements over time. Relationships between supply chain partners that developed around carbon may evolve to include other issues in sustainability. There are potential trickle-down effects if the demands of one customer change the behavior of a supplier. The supplier in this case study, responding to one customer's demand, is able to subsequently provide carbon-light products to all of its customers. Carbon management can therefore diffuse along the supply chain due to the requests of only one supply chain partner.

Resilient Supply Chains

Efficient and responsible supply chains build more resilient connections between supply chain collaborators. These connections, observed in our case study, suggest that, in the future, carbon will be considered closely in risk management. We identified three types of risk: regulatory risk; financial risk; and market access risk.

Regulatory risk involves government control of carbon. Businesses that anticipate this control are in a less risky position. Those that emit large amounts of carbon, but have not begun to adjust, are exposed. An illustrative example can be found in the American bond market, where analysts are projecting a premium on corporate bonds for new coal-fired power plants (Stevenson 2008), reflective of an anticipated cost of carbon. Regulatory risk also involves how regulations are deployed. Companies that have already made progress in reducing their footprints may be put in a difficult position, a danger identified by both Catalyst and BNSF. Good behavior already underway faces the risk of being punished by the definition and allocation of allowances.

Financial risk involves the ability of companies to secure capital in the long term. Investors have indicated that they will consider carbon in their investment decisions (Carbon Disclosure Project 2008). Their reasoning is simple: if a corporation emits a lot of carbon, they will be obligated to pay for these emissions. Some industries cannot avoid emissions, and investors may require the disclosure of emissions and the beginnings of a carbon management plan. In other circumstances, investors may prefer articulated targets and reduction strategies. In either scenario, carbon may emerge as an impediment to securing capital if emissions are not managed. Although no interviewees cited the specific connection between carbon and capital, sources such as the Carbon Disclosure Project (2008) and the UN Principles for Responsible Investing (2009) support the idea.

Market access risk has two components. Understanding carbon emissions may become mandatory for participating in supply chains as businesses seek to collaborate with partners who manage their carbon. Wal-Mart, for example, has initiated a process requiring all suppliers to measure and disclose their carbon footprints. Consumers may demand carbon labeling on products that they purchase. Although the appetite to pay a premium for sustainably produced goods is small (Manget et al. 2009), consumers have a preference for products that are cost-competitive, but also demonstrate an environmental commitment. Carbon, given its current prevalence, may emerge as an important criterion in consumer choice.

Implications for Businesses and Supply Chains

Through our interviews, it was clear that carbon is emerging as a common cause. Less clear is how this will induce change in purchasing decisions, design of supply chains, and perceptions of sustainability. Businesses trying to balance short-term costs, long-term profitability, and the maintenance of a corporate brand, have identified carbon as a means for progress on all three fronts. Supply chains composed of different actors facing different pressures have been able to align corporate strategies around a common variable.

Location matters if reducing carbon emissions is a priority. As our case study showed, printing contributes a small amount to the total footprint of a product and is best done close to markets and transportation hubs to reduce emissions. Papermaking contributes a large amount to the total footprint of a product and is best done where there are abundant supplies of renewable energy and efficient transportation networks. Focusing on the emissions of just one stage potentially ignores the biggest emitters and the best opportunities for emission reductions.

Supply chains will evolve to better reflect the carbon costs of transportation. Physical locations of supply chain stages may change, with low-energy operations relocating to reflect the carbon costs of transportation, and high-energy operations moving to reflect the carbon costs of energy bottlenecks in a supply chain. Regions with renewable energy bundles may become increasingly competitive, while regions reliant on carbon-heavy energy could find themselves at a disadvantage.

At present, when carbon is generally without a price, companies are finding that reducing their carbon footprint reduces their fuel costs. As carbon gains a price, these companies will find other benefits. Not only will they save on fuel, emissions will cost less. Some businesses already market a product on its carbon footprint, and if carbon awareness increases, these businesses stand to benefit. While current trends in carbon management are predominantly internal in orientation (steps to reduce employee travel, more efficient office lighting, etc.), there is a limited scope and diminishing returns from such efforts. More sophisticated policies to manage and reduce emissions will look at suppliers, logistics, and operations — in other words, the supply chain

Limitations

We acknowledge that there are limitations to the methods employed in this research. Any extrapolation from a specific case study to a more general population should be treated

with caution. That said, we did triangulate our interview findings to strengthen their validity and, in so doing, developed a framework that potentially extends beyond this case study. The concepts of carbon as a catalyst for deeper integration between supply chain partners, and carbon as a starting point for a transition from efficient to responsible to resilient supply chains has been validated for this case study of the paper and print sectors. However, we cannot infer that these patterns will hold true in all supply chains, although they are likely to manifest in some.

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Appendix: Emission Factors Explained

Harvesting, road-building felling, transport to sawmill

The data used here was based on a study by the Forest Engineering Research Institute of Canada (FERIC, 1997) that found that 6.9 l of diesel is used / m^3 harvested. This is equivalent to 18.5 kg CO_2, 0.000816 kg CH_4, and 0.000466 kg N_2O, which expressed in $C0_2$ equivalency, is 18.66 kg CO_2e / m^3 harvested wood converted to dimensional lumber.

The Western Forest Products Alberni Pacific Division generated 269,000 m^3 dimensional wood, 175,000 m^3 chips, 307,000 m^3 hog in 2008. The effective carbon footprint on all products is 18.66*269,000 / (269,000+175,000+307,000) = 6.7 kg CO_2e / m^3 chips. The final carbon footprint from harvest is 6.7*8.2 m^3 / Adt = 55 kg CO_2e / ADt.

Sawmilling fiber into dimensional and residual products

Based on WFP 2008 carbon footprint, APD scope I & II emissions = 5.5 kg CO_2e / m^3 chips. At 8.2 m^3 chips / ADt, sawmill carbon footprint on paper basis = 45 kg CO_2e / ADt.

Transport of chips to mills

Estimate average return trip of chip trucks between Western Forest Products operations and Catalyst's mill is 100 km. Using IPCC emission factor of 1.02 kg CO_2e / km from IPCC EF ID 19043, Carbon delivery of chips = 102 kg / truckload (at 3,500 ft^3 equals ~ 100 m^3) = 1.0 kg CO_2e / m^3. At 8.2 m^3 chips / ADt, carbon delivery footprint = 8 kg CO_2e / ADt.

Conversion of chips to paper at Catalyst

Based on Catalyst 2008 carbon footprint, Alberni scope I & II emissions = 185 kg CO_2e / ADt.

Transport of paper to Quebecor World in Merced

Based on supply chain logistics and recognized emissions factors, transport footprint = 127 kg $C0_2e$ / Adt.

Printing of paper at Quebecor World in Merced

Based on Heinz, 2006 study, surveyed printing facilities (Table 2) carbon footprint is 36 kg CO_2e / ADt.