The Climate Impact of the Book Industry and Its Carbon Footprint

One of the key measures of the sustainability and improvement in environmental performance of an industry is its carbon footprint. The analysis in this report calculates the total known impact of the book industry to assess the footprint. To judge performance of the book industry in the United States, we calculate the total emissions attributable to all books produced, through every step of the process, where we have reliable information, and divide by the total number of books that reach consumers (i.e., books sold). The total carbon footprint for the industry's 4.15 billion books produced is 12.4 million metric tons CO_2 equivalent. For each book sold in the United States in 2006, 8.85 pounds of greenhouse gases in CO_2 equivalent were released.

A carbon footprint measures the overall greenhouse gas (GHG) emissions or removals of an industry, a business, a person, or an activity. It is called a *carbon* footprint for two reasons: the end result of the method measures all GHG impacts in terms of carbon dioxide equivalents, and carbon dioxide is the most prominent greenhouse gas. Emissions constitute any flow, or flux, of greenhouse gases to the atmosphere from a terrestrial source. Carbon removals, also known as sequestration, are the fluxes from the atmosphere primarily to forests and the oceans. There is also storage of carbon in products that moves carbon from forests to books, which is accounted for in this analysis. Greenhouse gases that are relevant to the book industry are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases differ in their potential to warm the atmosphere, known as Global Warming Potential. The carbon footprint presented here is reported, as is done in other industries, in carbon dioxide (CO_2) equivalents.[9]

[9]The United States is not a signatory to the Kyoto Protocol to the United Nations Framework Convention on Climate Change. However, the methodology of the Kyoto Protocol is the international standard for measuring greenhouse gas emissions and removals and the most sound science for achieving reductions. The Kyoto Protocol requires signatories in industrialized nations, where the vast majority of emissions occur, to reduce emissions of greenhouse gases against a baseline year of 1990. Industrialized countries have the option to not account for emissions from land-use change and forestry. Effectively, this has meant that countries with net removals of greenhouse gases from land-use change and forestry (such as the United States) account for the sector in their target totals, while those that have net emissions do not (such as Canada). The Protocol also allows for some emissions reductions action in developing countries under the rules of Clean Development Mechanism as offsets that can be counted toward emissions reduction targets in industrialized countries.

In terms of our carbon footprint analysis for the book industry, the most important factor of the Kyoto Protocol is to understand the baseline for measuring emissions. The baseline is measured as the total emissions in a single year, 1990, and targets for reduction measured against that year. The baseline does not take into account any projections into the future or speculation, however well founded, about what emissions may be under different scenarios. The baseline is simply the net of the actual, observed emissions or removals in 1990. An actual, observed baseline as adopted removes gamesmanship and speculation from the process.

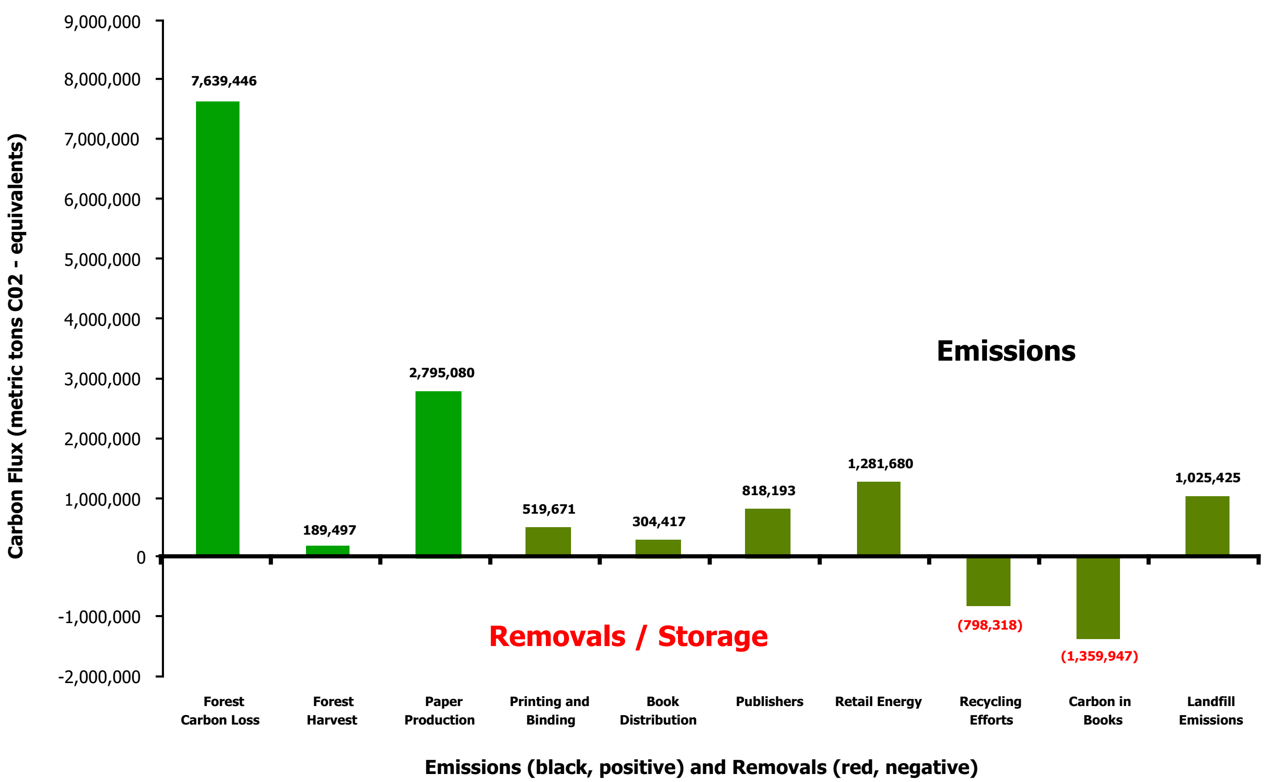
The carbon footprint for the book industry should include measurements of as much of the flux to and from the atmosphere as possible to quantify the impact of the industry and to help it understand how to reduce any negative impact. The book industry needs to determine where the real impacts are to know where action can be taken in the short and long terms to reduce its carbon footprint.

The information gathered through our book industry survey allows us to make some estimates of the carbon footprint of the average book. We have added some industry averages to our survey information where information is lacking. Figure 24 shows the emissions and removals in the book production process, indicating where the greatest emissions occur and where the book industry can take action efficiently to reduce its overall impact. The methodology for calculating the emissions and removals in each segment is detailed below.

Figure 24 also shows the climate impacts of the book industry at various stages of production, sale, and disposal or recycling. Each stage is detailed in the text following the chart. This assessment, while preliminary, allows us to understand where the greatest impacts are in the industry and effectively address the major impacts. Recommendations based on this analysis can be found at the end of the report in the recommendations section.

The entire figure is given in carbon dioxide equivalents. Green bars are carbon from forests through books, while brown bars are emissions from nonforest fiber sources and waste. Detailed descriptions of the estimates given here and how they were derived follow in the text. This is a summary:

FIGURE 24 Carbon Footprint for the U.S. Book Industry, 2006.



- **Forest Carbon Loss.** The amount of carbon (in CO_2-equivalent) taken from the forest and delivered to the pulp/paper mill. In national accounting of greenhouse gases, this is recorded in the Land-use, Land-use Change, and Forestry sections rather than under energy to avoid double-counting. There is a great deal of debate about how to account for changes in forest and plantation carbon; details of our analysis of the importance of this emissions source are found in a later chapter. Source: Wood use is from Environmental Defense/The Paper Calculator. This carbon is offset by carbon stored in books, unsold books returned for pulping, and energy recovery.
- **Recycling Efforts.** Books that are recycled each year. Source: U.S. EPA for 2006 book recycling data.
- **Carbon in Books.** Carbon storage for books in CO_2-equivalent based on total paper used for books minus books recycled and books incinerated.
- **Fiber Harvest and Transport.** Virgin fiber collection. This includes:[10] harvesting of trees, transporting of logs (or chips) to the mill, debarking and chipping, and waste collection and transport. Source: Environmental Defense/The Paper Calculator.
- **Paper Production.** Greenhouse gas emissions from the paper-making process only at the mill. Source: Environmental Defense/The Paper Calculator.
- **Printing and Binding.** Energy emissions from the printing and binding process as derived from the survey results.
- **Book Distribution.** Transportation emissions from the shipment of books and energy used in book storage as derived from the survey results. Calculated using data from publishers and estimating the total number of miles by air, ship, and truck emissions per mile, and the share of books in any transport; and electricity and natural gas emissions in warehouses.
- **Publishers.** Building energy, office paper use, and company transport as derived from the survey results.
- **Retail Energy.** Retail building emissions as derived from the survey results and extrapolated for the industry using a standard coefficient for emissions per kWh.
- **Landfill Emissions.** Methane (CH_4) emissions from landfills for book paper. Based on estimated book paper entering landfills from U.S. EPA.
- **Energy Recovery (not shown in figure).** Energy derived from the incineration of book paper after disposal, based on an estimated 110,000 metric tons of books incinerated and standard coefficients.
- **Recycling Emissions (not shown in figure).** Constituting only 5% of the total fiber furnish, recycling emissions make up only 0.2% of the total process for books. This includes "material collection; transport; preprocessing at material recovery facilities (MRFs); residuals management and disposal; and transport of processed recovered material to the remanufacturing site." Source: Environmental Defense/The Paper Calculator.

[10]Paper Task Force, White Paper 3. www.environmentaldefense.org/pdf.cfm?ContentID=1618&FileName=WP3%2Epdf

Opposing Views

It should be noted that within the environmental committee established for the purposes of this report, there was one opposing view related to the carbon footprint model that was developed. As can be seen in Figure 24, the largest CO_2 emissions connected to the book industry stem from the loss of carbon in the forest from trees harvested to make paper. The opposing perspective maintains that the model does not account for regrowth for forests after they are harvested and as such is flawed.

Forest carbon storage from regrowth was not calculated because, according to data sources cited in this report, any carbon storage from replanted trees is counterbalanced or negated by the fact that trees that are left standing would continue to sequester carbon. This important issue will be further researched in future reports. To learn more about this opposing view, go to www.malloy.com/carbonanalysis.

Net Carbon Emissions by Segment

FOREST CARBON LOSS CARBON FOOTPRINT

For this study, we estimate carbon loss in forests using the content of carbon in the wood used in paper production. According to our estimates of the different grades of paper, the Environmental Defense Paper Calculator estimates total wood use at 4.2 million metric tons. The estimates of carbon content in paper and wood are taken from the International Applied Systems Analysis and two studies by Tellus and Alter.[11] The total carbon content of wood entering the pulp mills for book paper production is 2.1 million metric tons, and the CO_2 equivalent of that wood is 7.6 million metric tons.[12] Part of the carbon from forests and plantations is stored in products or recycled; a portion is used as an energy source when books are incinerated; and another portion is lost in the paper-making process when it is burned for energy or lost through decay. We have tracked the carbon taken from forests either to storage as carbon or to its release to the atmosphere as carbon dioxide.

This study was unable to estimate several other emissions from forests that are likely to be significant, but for which data was limited or not available:

- Amount of burned slash and decay, post-harvest. Emissions would include CO_2, CH_4, and N_2O from combustion of organic matter.
- Emissions from the use of chemicals and fertilizers in forest management.

In addition, there are a number of variables with regard to the dynamics of forest growth that we do not consider in this analysis. The U.S. EPA developed methodology to calculate the savings of forest carbon through source reduction (i.e., using less paper) and recycling. A memorandum detailing this methodology states:

> When paper products are source reduced or recycled, trees that would otherwise be harvested are left standing. In the short term, this results

[11]Kubeczko, Klaus. “Austrian Carbon Database: Production and Waste. Materials Flow Based on Carbon Accounting for 1990.” International Institute for Applied Systems Analysis. www.iiasa.ac.at/Publications/Documents/IR-01-028.pdf. Alter, H., et al. (1974). “Chemical Analyses of the Organic Portions of Household Refuse: The Effect of Certain Elements on Incineration and Resource Recovery,” Solid Wastes Management 64 (12): 706-712. Tellus Institute, Assessing the Impacts of Production and Disposal of Packaging and Public Policy Measures to Alter Its Mix, prepared for the Council of State Governments, the U.S. Environmental Protection Agency, and the New Jersey Department of Environmental Protection and Energy, May 1992, Report #4, “Impacts of Production and Disposal of Packaging Materials: Methods and Case Studies,” Chapter 2.

[12]To calculate carbon dioxide equivalents from carbon we multiply by the standard coefficient 3.6667. www.iuep.org/RFP2006/commonconversionfactors.php

> in a larger amount of carbon remaining sequestered—in effect, resulting in "negative emissions"—because the standing trees continue to store carbon, whereas paper production and use tends to release carbon. . . . Working with U.S. Forest Service staff, who generated outputs from Forest Service models, we estimated that recovering one metric ton of paper results in incremental forest carbon sequestration of 0.81 metric tons of carbon equivalent (MTCE). This estimate includes changes in carbon storage in trees and understory, and excludes changes in the forest floor and soil.

This finding of additional carbon stored in forests helps us understand that forests that are harvested for paper store less carbon than forests that are not harvested. This finding is also supported by the recent agreement in Bali by the signatory nations of the United Nations Framework Convention on Climate Change, which agreed to study and include mechanisms to avoid deforestation in future negotiations over international climate change policy. Although the focus of the negotiations is on deforestation in tropical countries, the implication for forestry in industrialized countries is similar: logging forests reduces carbon storage in forests, and leaving forests standing helps combat climate change. As a result of these findings, we track the carbon that is stored in paper (books) in this report. The remainder is emitted to the atmosphere as carbon dioxide when it is used to make energy for the paper-making process.

Different analyses account for forest carbon in different ways. Some advocates for the paper industry believe that growth in all forests should be credited to the forest products or paper industry. This analysis ignores the growth that would occur in forests if there was no harvest and the reduced total carbon storage and absorption that the paper industry affects negatively. There are a number of different factors that we cannot take into account in this carbon footprint analysis due to the complexity of the data, as well as the speculative nature of the dynamics of land-use decisions:

- Changes in the rate of forest carbon accumulation between harvested and nonharvested forests. Most moderately aged forests accumulate carbon at a faster rate than very young forests or plantations.[13] Harvesting thus causes a slowing of carbon accumulation in many forests.
- The difference between total forest growth and net forest growth in harvested in nonharvested forests.

Here are some of the factors we cannot consider in this analysis:

- Gross carbon accumulation in forests or net carbon accumulation in forests. Including either is speculative in a number of ways, although some estimates would be possible.
- The different carbon-storage rates under different management regimes. More sustainable forest-management techniques tend to store more carbon, since sustainable forestry leaves more trees and dead wood in the forests as well as encourages growth rates that are faster than harvest rates.

For this analysis and carbon footprint, we believe that using the forest carbon removed from forests is the most straightforward means of accounting for forest carbon emitted to the atmosphere, balanced by carbon stored in books.

[13]Carbon accumulation or forest growth is largely a function of photosynthesis and thus leaf area, which is how trees change carbon dioxide in the atmosphere into carbon in the trees themselves and oxygen.

FIBER TRANSPORT AND HARVEST CARBON FOOTPRINT

Environmental Defense's Paper Calculator accounts for the transport and harvest of fiber for virgin fiber. It includes harvesting of trees and transport of logs (or chips) to the mill, debarking, and chipping.

The Fiber Transport and Harvest segment thus accounts for all transport and harvesting emissions, but not for impacts in the forests from slash burning and decay, road building (which can contribute to permanent loss in the system as long as the forest is under management), and the reduction in storage potential from management.

RECYCLED FIBER COLLECTION AND MANAGEMENT CARBON FOOTPRINT

Given the 5% average use of the post-consumer recycled content in book papers, the total recycled collection system for the book industry was small—approximately 0.2% of the total emissions, as calculated in Environmental Defense's Paper Calculator. The Paper Task Force considers the following in its estimate of recycling emissions:

> For the recycled fiber-based system, we have examined: used paper collection, transport of the recovered paper to a material recovery facility (MRF), processing of the material at the MRF, transport of processed recovered material to the manufacturing site, manufacturing of pulp and paper using recovered fiber, and disposal of residuals from MRF operations and paper manufacturing.

The emissions resulting from the collection of recycled fiber were so small compared to other segments that we did not include them in the chart. It should be noted that all participating mills were asked to provide data related to total number of miles required to transport recycled fiber versus virgin fiber to the mill. A lack of substantive responses prevented any further analysis beyond the averages determined by Environmental Defense's Paper Calculator.

PAPER PRODUCTION CARBON FOOTPRINT

The Paper Calculator accounts for all energy use and other emissions in the paper production system itself. Energy use is reported as "purchased energy" in the output from the calculator. However, energy used at paper mills (and considered in the Paper Calculator) includes the on-site use of fossil fuels such as oil and coal, the burning of tires, and also some renewable sources such as wind and hydro power. Energy from biomass (black liquor—a byproduct of chemical pulping of trees and parts of trees) is not accounted for in the Paper Calculator, nor is it recorded in national greenhouse-gas reporting as energy use, but it is accounted for in the changes in forest carbon levels. This report separates these two elements as well. Paper production accounted for 2.8 million metric tons of CO_2 equivalent greenhouse gases. This analysis assumes a 60/40 split between freesheet and groundwood content in book paper, and thus 59% of the total impact estimated by the Paper Calculator (which excludes a number of impacts from the book industry as a whole).

PRINTING AND BINDING CARBON FOOTPRINT

To properly assess the carbon footprint for the book printing segment of book production, we should consider:

- Emissions from the energy consumed in printing facilities
- Emissions from the energy consumed for material inputs for the book-printing process such as inks, packaging, print plates, glues, and cover materials
- Emissions from delivery transport for inputs, as listed above and for paper

The surveys provided some significant information for these inputs and energy consumption from printers.

The five printers that provided sufficient information to answer the question purchased electricity averaged at 0.22 kilowatt hours per book. Total electricity used for printing and binding books at printers was extrapolated to the entire industry at 848,650 Megawatt hours (MWh). Additional, natural gas for heating dryers at printing facilities add 14,219 MWh of energy consumption.

The survey results did not present sufficient information for the following inputs to calculate the carbon footprint:

- Industry-wide, coated book covers averaged 0.39 square feet per book and paper-backed cloth averaged 0.01 square feet per book.
- Glues and adhesive consumption was 0.01 pounds per book.
- Aluminum printing-plate consumption was 0.01 pounds of plates per book.
- Packaging cartons were 0.03 pounds per book. Packaging cartons were reported to be corrugated cardboard ranging between 7% and 100% recycled.

DISTRIBUTION OF BOOKS CARBON FOOTPRINT

Our estimate of the emissions from the distribution of books from printers to warehouses and retail outlets was based on limited data from the surveys. This estimate includes data for transportation and storage of books. Transport of books by truck constituted 54% of the total impact of distribution. We took the total number of miles shipped by truck provided by three companies and divided by the number of books those companies shipped. That gives us a per-book coefficient (not miles shipped for a book) that we can apply to the total number of books produced and shipped by the entire industry. The result found that shipments of books by truck totaled just over 210 million miles. Emissions factors used for trucking were taken from the Climate Trust. Average fuel economies were taken from the Energy Information Agency and *Fleet Maintenance* magazine. We assumed that light delivery vehicles and heavy trucks both constituted 50% of transportation miles by truck.

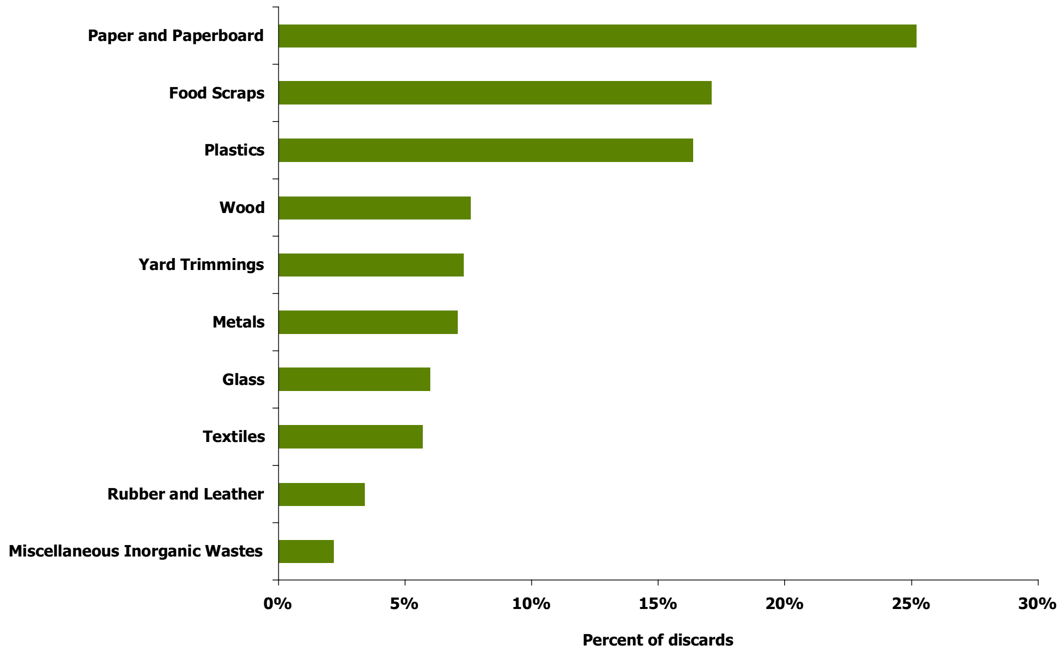
We calculated a per-book coefficient for air and water shipments from one company that provided us with detailed information on this aspect. With air and water shipments, total shipments of books totaled 1.25 billion miles. Air and ship miles and emissions factors were based on the calculations of one publisher only, but account for 4% of the total emissions for this segment. Distribution of paper to printers and pulp to paper manufacturers was not included due to a lack of data and should be included in future studies.

Energy used in the storage of books was calculated from four distributors. Total energy use for gas and grid electricity amounted to approximately 200 million kilowatt hours, or 128,000 metric tons of CO_2 equivalent emissions. Natural gas emissions are less than 10% of the total emissions from energy use for storage.

LANDFILL EMISSIONS CARBON FOOTPRINT

When paper, wood, and other organic materials enter a landfill, they begin to emit methane as they break down in what are known as anaerobic conditions (i.e., lacking oxygen). Landfill emissions are the largest portion (34%) of the United States' total emissions of methane—a greenhouse gas with a Global Warming Potential (GWP) 21 times that of carbon dioxide. According to the U.S. Environmental Protection Agency (EPA), paper is the largest contributor to municipal waste and landfills, where it comprises 26% of the content of landfills, and a much larger proportion of organic materials that create methane (see Figure 25). The

FIGURE 25 Municipal Waste.



Source: U.S. Environmental Protection Agency, 2005.

World Resources Institute states that methane from landfills constitutes 55% of emissions from the waste stream in the United States.

We calculated landfill emissions for the book industry differently from the Paper Calculator, since fewer books enter the Municipal Solid Waste stream than the average for paper. According to the U.S. EPA, books accounted for 762,000 metric tons of paper in Municipal Solid Waste. We assumed that for Municipal Solid Waste, 80% is landfilled, 20% incinerated. Emissions from the landfilled portion (610,000 tons) are based on the 3,364.1 lbs. of CO_2 equivalent emissions per short ton of books entering landfills.

PUBLISHERS' CARBON FOOTPRINT

This analysis includes three elements for which enough information was available to make an estimate: energy use in publishers' offices, internal office paper use by publishers, and publisher business travel. Publisher business travel was based on data given in the surveys, while office energy and paper use were national averages based on the number of employees as given by the U.S. Department of Energy and General Services Administration. The total emissions for the publishing segment of books accounted for 6.56% of the total impact, or 818,000 metric tons of CO_2 equivalent.

CARBON STORAGE IN BOOKS

Harvested wood products store carbon in the products themselves until they either break down or are incinerated. The U.S. Forest Service Forest Products Laboratory estimates the half-life of paper products to be approximately one year.[14] From their

[14]www.fpl.fs.fed.us/documnts/pdf2004/fpl_2004_skog001.pdf

calculations, it is estimated that 55.8 teragrams (one million metric tons) of carbon are stored annually in wood products. The storage includes both accumulations of carbon and loss to the atmosphere annually. Of that amount, one quarter is paper products. This includes paper that is "stored" in landfills as it slowly decays into methane.

Our estimate for the carbon stored in books begins with the total carbon dioxide equivalent of books produced in 2006 (2.4 million metric tons) minus books recycled (800,000 metric tons) and books incinerated (224,000 metric tons), or 1.4 million metric tons of CO_2 equivalent.

RETAIL EMISSIONS CARBON FOOTPRINT

Retail outlets use energy for lighting, air conditioning, and heating. Retail sales account for nearly 60% of all book sales.[15,16] Although our sample from the survey is small, retail energy use from the grid, also called "purchased electricity," is largely responsible for the result in this analysis. Emissions from online or direct-to-consumer sales and most storage was not included in this analysis due to a lack of information about the entire impact, and therefore this segment should be considered only as a preliminary result that requires further research. The results from this study are derived from the electricity consumption in kilowatt hours multiplied by the EPA's estimate for carbon release through the grid nationally.

The average of energy consumption per book in retail sales was 1.089 kilowatt hours per book (accounting for the amount of each retail location dedicated to book sales), for a total of approximately 2 billion kilowatt hours. The number was derived by taking total kilowatt hours per book from our survey, multiplied by the factor for portion of retail space devoted to books, and multiplied by the factor for retail sales of books as a percentage of total books.

Carbon Footprint—Methodology

OVERALL METHODOLOGY

The carbon footprint starts from estimates of the weight and volume of books and paper used to produce books. BISG reported in 2007 that the number of books sold in the United States in 2006 was 3,098,000,000, or approximately 10.3 books per U.S. resident. The surveys provided limited data on the return rate of unsold books. We have used a conservative return rate of 25%. That brings the total number of books produced for the U.S. market to 4.15 billion. The carbon footprint of the average book for this report is based on the total production process of the book industry (the total number of books produced, sold, and unsold) divided by the number of books that reach the consumer (i.e., sold). Responses in the survey allow us to estimate the average book weight at 0.89 pounds.[17] The total tonnage of books (in metric tons) from these estimates is 1,634,000. This estimate is approximately 90,000 tons less than the RISI estimate for book-paper usage in 2005 (1.72 million metric tons). Other estimates of the total tonnage for book paper have been lower than the estimate derived by the methodology adopted here.

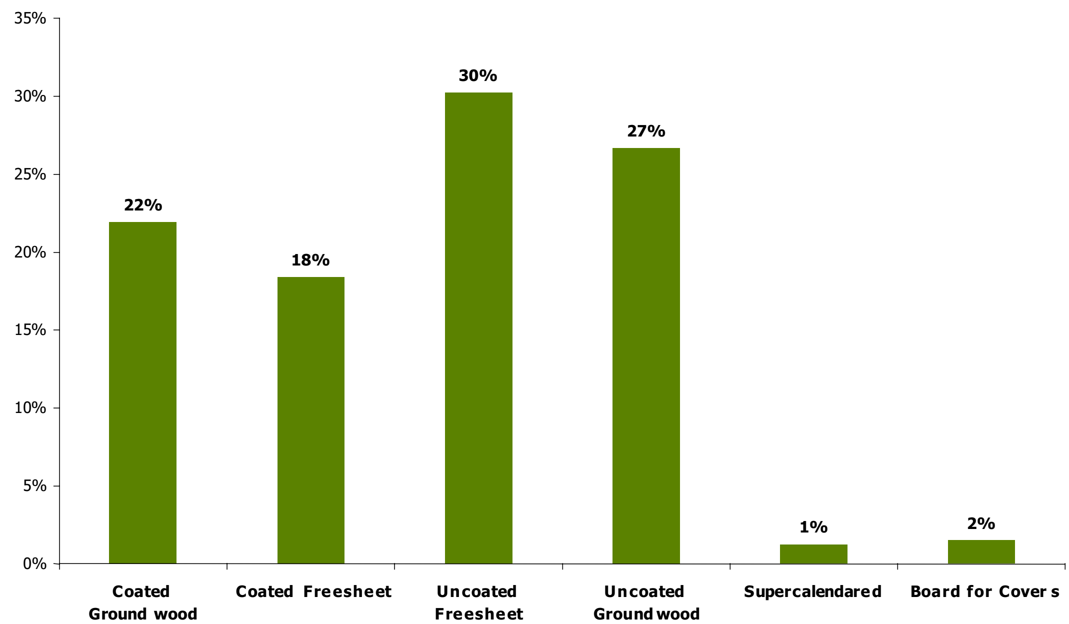
Environmental Defense's Paper Calculator, developed under the Paper Task Force, remains one of the best sources for determining the greenhouse gas emissions and other paper production impacts for certain segments of the paper industry at large. This study uses the Paper Calculator for the esti-

[15]www.nytimes.com/2007/06/17/technology/17ecom.html?_r=1&oref=slogin

[16]Book Industry TRENDS 2007. Book Industry Study Group.

[17]We used six average book weights from publishers to establish the average book weight. More data points would allow us to determine the average weight of a book more exactly.

FIGURE 26 Paper Grades Used in Book Papers. For this report, coated grades 1, 2, and 3 are considered freesheet, 4 and 5 are considered groundwood.



Sources: Published industry data and book industry survey responses.

mate of the emissions in paper production (purchased and produced energy only), harvesting of virgin fiber, methane releases from landfills, and other emissions or removals. We assumed a 60/40 split between freesheet and groundwood content for virgin fiber and 5% post-consumer average in all paper. The resulting Paper Calculator estimate breakdown is:

- paper production, 59%
- virgin fiber harvest and transport, 4%
- methane release from landfills, 40%
- recycling fiber collection, 0.2%
- energy recovery through incineration,–3%

The Paper Calculator does not report on biomass used in the paper-making process for energy as emissions. However, the total wood use is estimated accurately, which helps us determine the carbon taken from forests and accounts for this energy source.

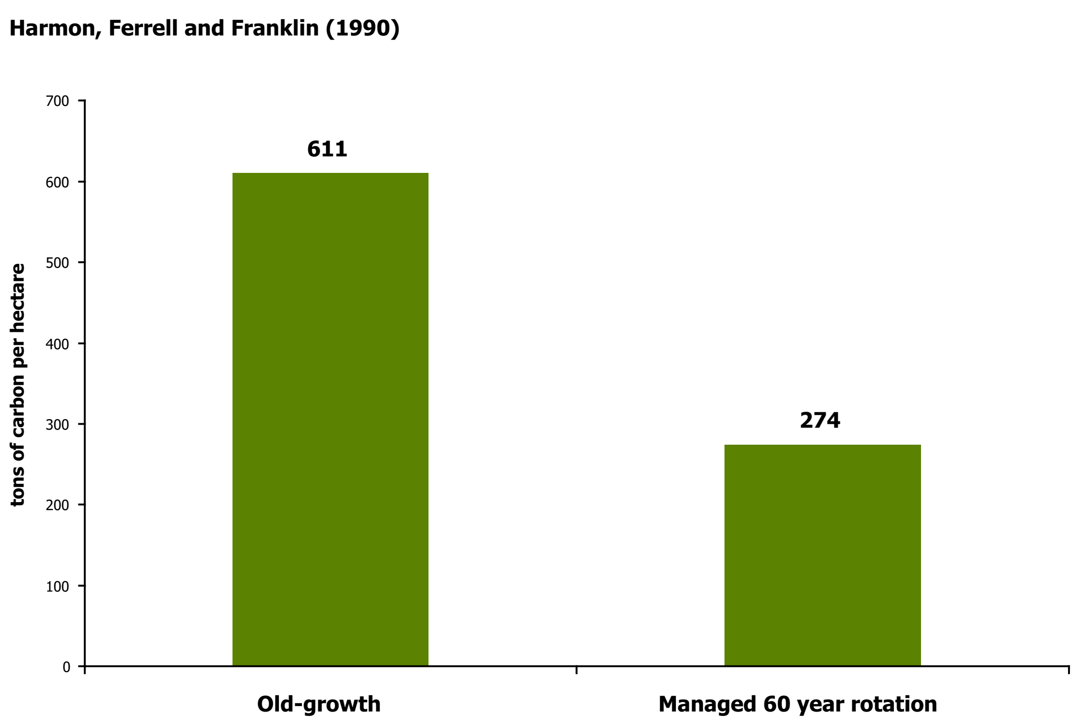
One of the survey respondents made the following observation: "A very positive attribute of the printed book is the fact that it is made from a renewable resource which draws CO_2 from the atmosphere and captures it in the final product. However, claiming this as a positive attribute assumes that there is adequate assurance that this resource (trees) is, in fact, being renewed. FSC and SFI chain of custody certification provides that assurance." Clearly, some of the paper (and the carbon it contains) that becomes books is stored in the final product for a certain period. The storage of carbon in books is dealt with below and included in the production segment analysis. According to the baseline rules described above, however, we must also determine whether the biomass used as an energy source in paper production or other loss or decay of carbon from biomass removed from forests is in fact recaptured in the trees, or if this carbon (or a portion of it) is in the atmosphere as CO_2.

FOREST MANAGEMENT AND CARBON LOSS IN PAPER-MAKING—CHANGES IN FOREST AGE AND MANAGEMENT AND RELATED CARBON STORAGE

Several studies have measured the amount of carbon stored in forests under different management regimes. Some of these studies include the carbon that accumulates in products or landfills. Figures 27 to 29 demonstrate the results.

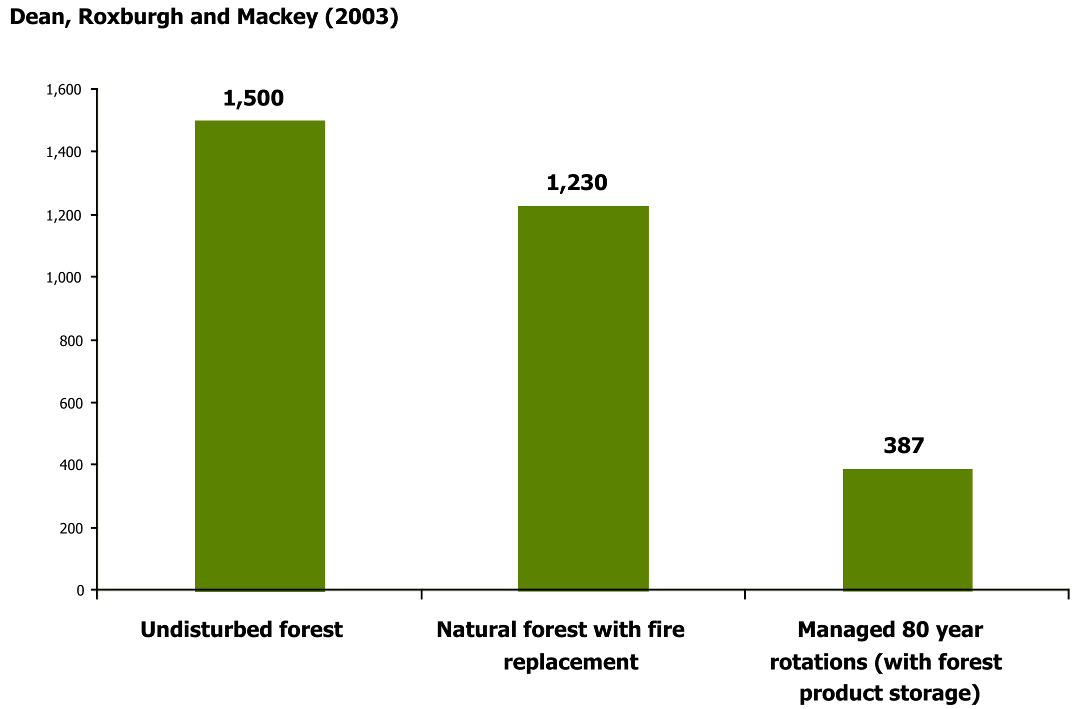
All three studies demonstrate that natural or undisturbed forests contain more carbon over time on average than forests managed for forest products. These studies include assessments that take into account the accumulation of carbon in forest products. We must also consider that paper has a lower lifetime in useful products than most wood products used in construction and other uses. Fig-

FIGURE 27 Storage of carbon in an old-growth forest in the Pacific Northwest compared to a managed 60-year rotation forest. All forests can vary in their carbon storage over time due to natural factors, but the average storage across the landscape is the important factor when making decisions about management regimes and their relationship to protecting against climate change. Managed forests in this context store less than half the carbon of natural forests.



Source: Harmon, Mark E., William K. Ferrell, and Jerry F. Franklin. "Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests." *Science* 9 February 1990: Vol. 247, no. 4943, pp 699–702.

FIGURE 28 Three different scenarios measured in Australia. Undisturbed forests store the greatest amount of carbon even when natural fires are permitted. Forests managed for wood products and paper contain less than a third of the carbon of undisturbed forests in this study, including storage in forest products.

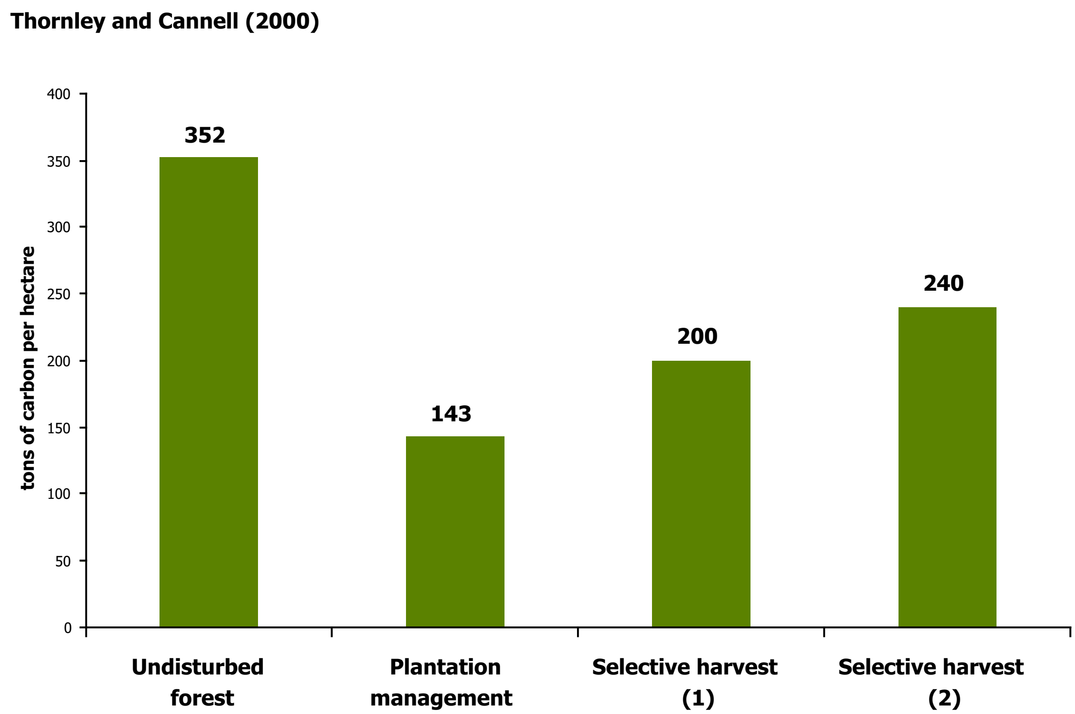


Source: Dean, Christopher, Stephen Roxburgh and Brendan Mackey. "Growth Modelling of *Eucalyptus regnans* for Carbon Accounting at the Landscape Level." In *Modelling Forest Systems,* edited by A. Amaro, D. Reed, and P. Soares. CAB International 2003.

ure 30 demonstrates a hypothetical forest's carbon-storage trajectory. The two areas, gray and brown, together indicate the amount of carbon that is stored on site in an old-growth forest over the course of 100 years. The top line shows the forest varying in carbon storage over time, sometimes gaining carbon, and at other times losing carbon due to disturbance. The brown area alone indicates the carbon stored when the forest is harvested on a 40-year rotation basis. The initial harvest causes a sharp decrease in carbon storage, which is recaptured over time. The gray area alone, then, indicates the amount of carbon lost to harvest in forests.

Let's consider the case of a second-growth forest that is already under a harvest-management system (see Figure 31). A system of regular harvest will maintain a relatively steady state of carbon in the forests and plantations under consideration and we could assume an average for this area of forests. However, without harvesting, the forest has the potential for significant regrowth over time. It is important to note that these forests will recover the biomass (and therefore the carbon) on the scale of many decades and centuries, much longer than the rotation age of forests managed for industrial uses. That is,

FIGURE 29 Analysis under four different scenarios of a northern European forest. While undisturbed forests again proved the most effective in storing carbon, different regimes of selective harvest showed the potential for increased average storage while allowing for forest product harvest. Currently, however, the vast majority of management for wood and paper products is in plantation management and clear-cutting. Scenarios 1 and 2 are the range of 10% and 20% of biomass removed each year. Plantation management was modeled on a 60-year clearcut and replanting management strategy.



Source: Thornley, J. H. M., and M. G. R. Cannell. "Managing Forests for Wood Yield and Carbon Storage: A Theoretical Study." *Tree Physiology* 20, 477–484. August 24, 1999.

forests would continue to capture carbon from the atmosphere whether or not the forests are harvested, in most cases.

These figures, and the data in the studies that underlie them, demonstrate quite clearly that only a portion of the carbon is stored in the forest over time on average. Over larger areas dedicated to the harvest of wood for paper, the total carbon storage is reduced on a large scale. The question we must ask from this is, Where is the carbon? The answer is rather straightforward. After accounting for the storage in products, any remaining carbon was released to the atmosphere as carbon dioxide when it was used as an energy source for the pulp and paper mills themselves, or lost to decay and other release.

FIGURE 30 Carbon Loss from Old-Growth or Mature Natural Forest Logging (model).

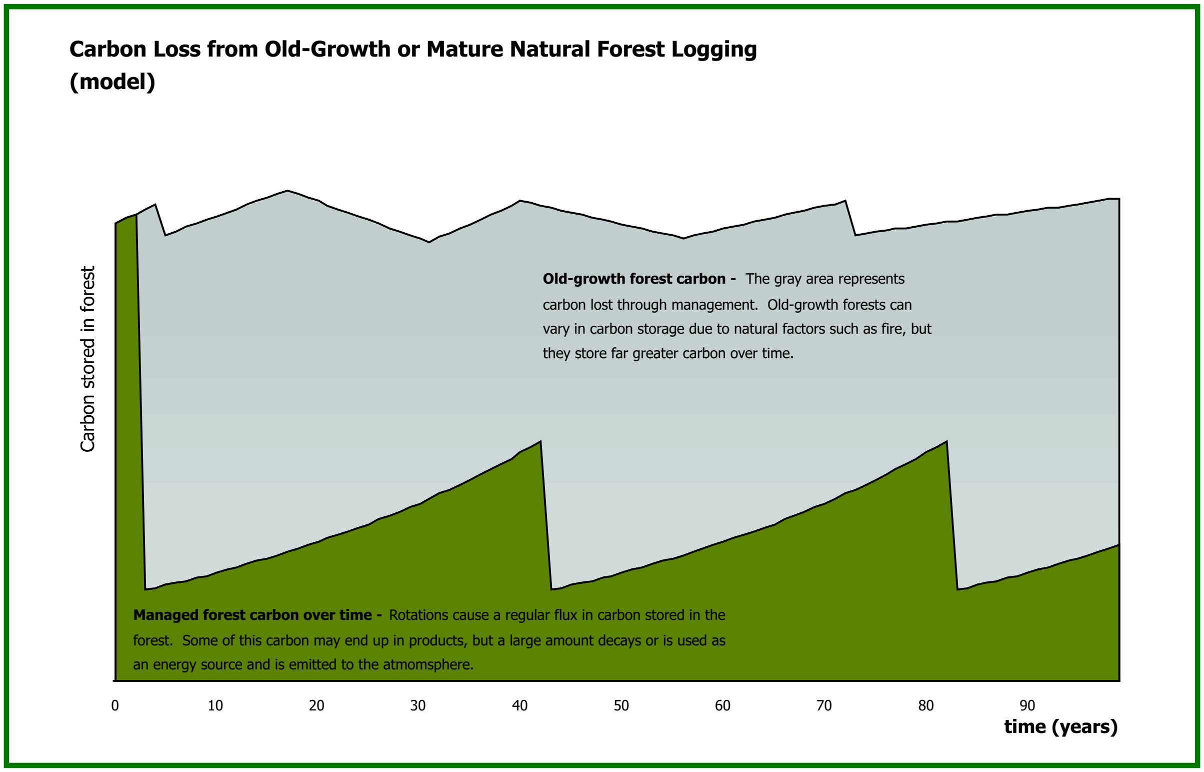


FIGURE 31 Carbon Storage in a Managed Forest (model).