ISSN 0258-6150

FAO FORESTRY PAPER

159

# Impact of the global forest industry on atmospheric greenhouse gases

***Cover photos:***
Natural and planted forest (Veracel/N. Souza); paper industry (Bahia Specialty Cellulose)

# Impact of the global forest industry on atmospheric greenhouse gases

FAO
FORESTRY
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159

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**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS**
Rome, 2010

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ISBN 978-92-5-106560-0

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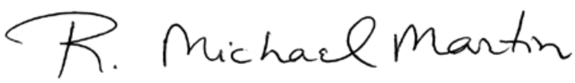
# Foreword

FAO and the International Council of Forest and Paper Associations (ICFPA) commissioned this study at the request of the forty-ninth session of the Advisory Committee on Pulp and Wood Products (ACPWP), held in Backubung, South Africa in June 2008. It outlines the global roundwood production, pulp and paper, and wood processing industry's contribution to climate change mitigation and aims to raise the industry's profile in international negotiations on global warming.

Over the years, climate change has become a priority issue for the global environment. Recently, the focus of the global climate change agenda has started to shift from carbon sequestration to low carbon emission products and technologies, in which forest industries should play a crucial role. Stable demand for forest products is one of the most important factors in avoiding forest land-use change and maintaining stable forest cover to withstand global warming.

FAO does not necessarily share or support all of the statements in this report. However, we think it is an important attempt to present the climate profile of modern forest management and industries impartially, based on solid facts and figures. We hope that the report will open avenues for further clarification, discussion, findings and solutions.



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# Acknowledgements

FAO wishes to thank the author and all contributors and reviewers of this study, particularly:

- Teresa Presas, President of the International Council of Forest and Paper Associations (ICFPA) and Managing Director of the Confederation of European Paper Industries (CEPI);
- Bernard De Galembert, Forest and Research Director, Confederation of European Paper Industries (CEPI);
- Susan Braatz, Rikiya Konishi, Andrea Perlis and Simmone Rose, FAO;
- the Advisory Committee on Pulp and Wood Products (ACPWP);
- the Confederation of European Paper Industries (CEPI);
- the International Council of Forest and Paper Associations (ICFPA);
- the National Council for Air and Stream Improvement (NCASI).

# Acronyms and abbreviations

| | |
|---|---|
| **ACEEE** | American Council for an Energy-Efficient Economy |
| **ACPWP** | Advisory Committee on Pulp and Wood Products |
| **BSI** | British Standards Institution |
| **CEPI** | Confederation of European Paper Industries |
| **CHP** | combined heat and power |
| **$CO_2$** | carbon dioxide |
| **CoC** | chain-of-custody certificate |
| **EJ** | exajoule |
| **EU** | European Union |
| **FICAT** | Forest Industry Carbon Assessment Tool |
| **FSC** | Forest Stewardship Council |
| **GDP** | gross domestic product |
| **Gha** | gigahectare |
| **GJ** | gigajoule |
| **Gt** | gigatonne |
| **GW** | gigawatt |
| **HWP** | harvested wood product |
| **ICFPA** | International Council of Forest and Paper Associations |
| **IEA** | International Energy Agency |
| **IFC** | International Finance Corporation |
| **IIED** | International Institute for Environment and Development |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **ICFPA** | International Council of Forest and Paper Associations |
| **LHV** | lower heating value |
| **MCF** | methane correction factor |
| **MW** | megawatt |
| **NCASI** | National Council for Air and Stream Improvement |
| **OECD** | Organisation for Economic Co-operation and Development |
| **PAS** | Publicly Available Specification |
| **PEFC** | Programme for the Endorsement of Forest Certification schemes |
| **PPP** | purchasing power parity |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **USEPA** | United States Environmental Protection Agency |
| **WBCSD** | World Business Council for Sustainable Development |
| **WRI** | World Resources Institute |

# Summary

This book examines the influence of the forest products (roundwood, processed wood products and pulp and paper) value chain on atmospheric greenhouse gases. Forests managed for natural conservation, for protection of soil and water resources or for non-wood forest products may also have a considerable role in the global carbon balance, but these are beyond the scope of this publication.

Many forest owners and forest product companies engage in practices that will increase forest ecosystem carbon stocks or help avoid their decline, chiefly the establishment of planted forests on areas that were not previously forested, adherence to sustainable management practices in production forests and, increasingly, participation in chain-of-custody programmes.

Experiences in North America and the European Union (EU) suggest the effectiveness of sustainable management of production forests. These regions contain most of the world's certified forests, and their forest carbon stocks are generally stable or increasing, even though these areas also account for 69 percent of global industrial roundwood production. National-level statistics do not necessarily reflect the carbon stocks on land used for wood production, but some countries can provide information specific to production forests. In the United States of America, for instance, government statistics demonstrate that carbon stocks are stable on industrial timberland, the areas most likely to be used for wood production.

Total greenhouse gas emissions from the forest products value chain are estimated to be 890 million tonnes of carbon dioxide ($CO_2$) equivalent per year, not counting the sequestration accomplished in the value chain. However, the forest products value chain also accomplishes large net removals of $CO_2$ from the atmosphere, because a portion of the $CO_2$ it removes from the atmosphere is stored as carbon for long periods in forests, products in use and products in landfills. In 2007, the net sequestration of $CO_2$ from the atmosphere into the forest products industry value chain was 424 million tonnes of $CO_2$ equivalent, enough to offset 86 percent of the greenhouse gas emissions associated with manufacturing forest products, and almost half of the value chain's total emissions. When sequestration is taken into account, net greenhouse gas emissions from the forest products value chain decline to 467 million tonnes of $CO_2$ equivalent per year.

Between 2002 and 2007, the direct emissions intensity (direct greenhouse gas emissions per tonne of product) of pulp and paper mills declined by 13 percent, while that from wood product facilities fell by 16 percent. The methods used to characterize other aspects of the global profile were too different from earlier methods to allow similar comparisons over time.

The pulp and paper sector and wood products sector are closely connected through wood flows, ownership of facilities and land, and economics. As a result, their carbon footprints are intimately connected, and attempts to influence one sector will likely have an impact on the other. When looked at separately, however, the pulp and paper sector is generally characterized by higher emissions and less sequestration than the wood products sector.

Several aspects of the forest industry's activities are not adequately captured by looking at only the emissions and sequestration accomplished in the value chain. For example, the use of wood-based building materials avoids emissions of 483 million tonnes of $CO_2$ equivalent a year, via substitution effects. In addition, by displacing fossil fuels, the burning of used products at the end of the life cycle avoids the emission of more than 25 million tonnes of $CO_2$ equivalent per year, which could be increased to

135 million tonnes per year by diverting material from landfills. The Intergovernmental Panel on Climate Change (IPCC) estimates that forest biomass-derived energy could reduce global emissions by between 400 million and 4.4 billion tonnes of $CO_2$ equivalent per year, a goal that the forest products industry can help society to reach through its forest biotechnology research and forest biomass infrastructure. The market for wood encourages landowners to keep land under forest, helping to avoid large-scale losses of carbon to the atmosphere via land-use change.

IPCC has stated that "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit." The analysis contained in the present report gives strong support to IPCC's assertion that sustainable management of production forests represents an important mitigation option over the long term.

# 1. Introduction

## OVERVIEW OF THE GLOBAL FOREST PRODUCTS INDUSTRY

### Economic importance

In 2006, the forest industry – in this book taken to include roundwood production, pulp and paper, and wood processing – contributed approximately US$468 billion to the global economy, or 1 percent of the total (Figure 1). Although between 1990 and 2006 the industry's contribution to the global economy grew by about 10 percent in absolute terms, it became relatively less important owing to the much faster growth of other sectors over the same period. The industry's economic contribution varies among regions and nations. In Latin America, for instance, it represents about 2 percent of the economy, twice the global average (FAO, 2009).

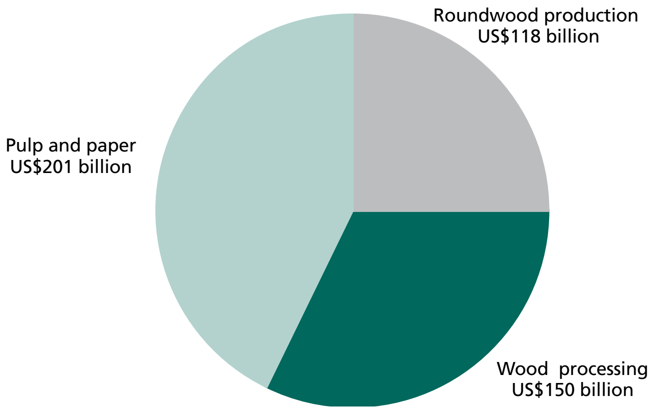
In 2006, the forest products sector was estimated to employ 13.7 million people, divided among roundwood production (almost 3.9 million), pulp and paper manufacturing (4.4 million) and wood processing (5.5 million) (FAO, 2009).

### Forest products

In 2007, approximately 3.6 billion cubic metres of roundwood (wood in its natural state as felled, with or without bark [FAO, 2008]) was removed from the world's forests, of which 1.7 billion cubic metres was industrial roundwood and the rest fuelwood (FAO, 2007). Most of this wood is converted into products or burned for energy in industrial boilers, and the forest industry is becoming increasingly efficient at using it. The combined output of sawnwood, wood-based panels and paper and paperboard increased by 30 percent between 1990 and 2005, while industrial roundwood production remained essentially unchanged (Figure 2).

The industry's products serve a wide range of society's needs. Sawnwood and engineered wood products are used in structures that provide shelter and comfort (e.g. housing and furniture), facilitate transportation (e.g. railroad sleepers), and serve a broad range of other functions. Paper and paperboard products transmit written material, protect packaged goods, and fulfil a range of personal hygiene needs. Wood-

FIGURE 1
**Economic impact of the global forest products industry (2006)**

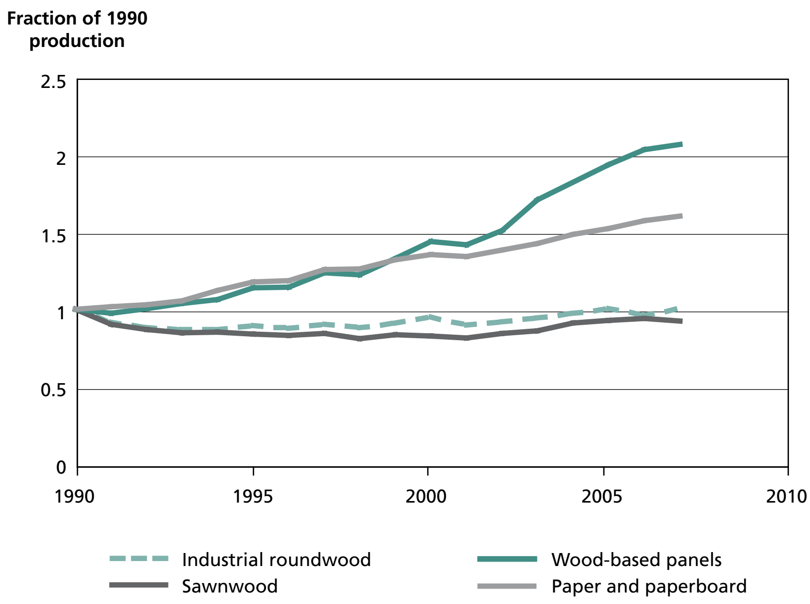



**Note:** Data are subject to rounding.
*Source:* FAO, 2009.

derived materials can be found in products as diverse as liquid crystal display (LCD) computer screens and ice cream.

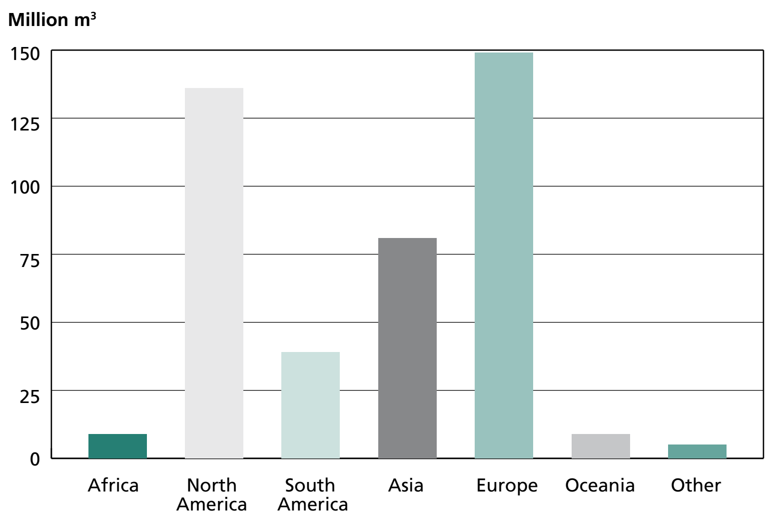
The industry's products are often divided into three major groups: sawnwood, wood panels, and paper and paperboard. Most sawnwood production is in North America and Europe, although the fastest growth is in Asia and South America (Figure 3). Between 2000 and 2007, sawnwood production grew by 27 percent in South America and by 32 percent in Asia, compared with 12 percent globally (FAO, 2007).

FIGURE 2
**Trends in production of forest products, as fractions of 1990 production**



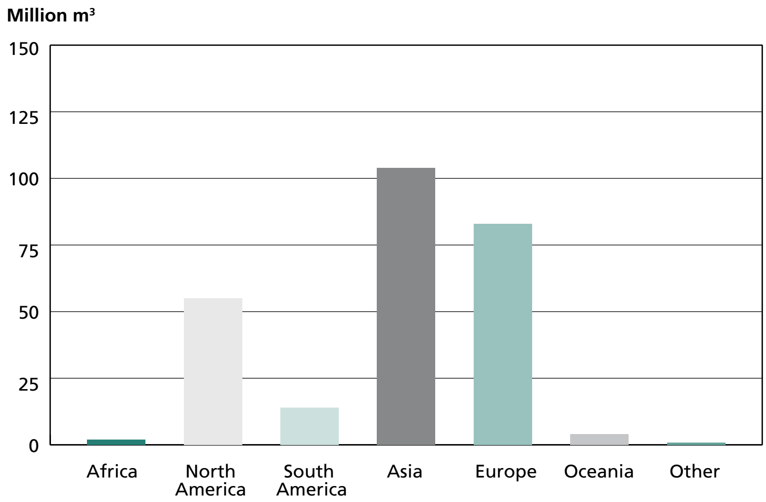

*Source:* Based on National Council for Air and Stream Improvement (NCASI) analysis of data from FAO, 2007.

FIGURE 3
**Global production of sawnwood, 2007**



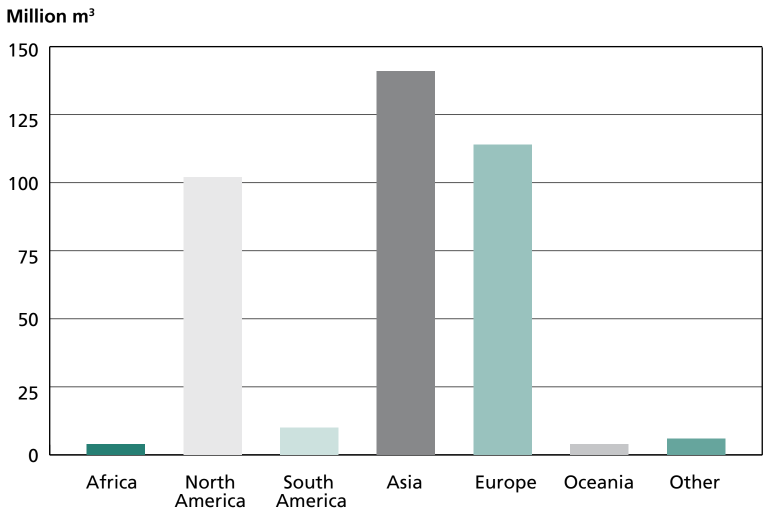

*Source:* FAO, 2007.

FIGURE 4
**Global production of wood-based panels, 2007**




*Source:* FAO, 2007.

FIGURE 5
**Global production of paper and paperboard, 2007**




*Source:* FAO, 2007.

Asian production of wood panels and of paper and paperboard already exceeds that of either North America or Europe, as do the growth rates for these product categories (Figures 4 and 5). Between 2000 and 2007, Asian production of wood panels and pulp and paperboard increased by 115 and 50 percent, respectively, while global production grew by 44 and 18 percent (FAO, 2007).

## Fibre supply

Globally, the recovered fibre utilization rate in 2007 was just over 50 percent (calculated by dividing the consumption of recovered paper by the production of paper and paperboard, using data from FAO, 2007). The remaining fibre needed for paper and paperboard production is primarily harvested from forests. The fibre used in wood products is essentially all harvested from forests.

Removals of roundwood from forests are fairly evenly distributed among the world's regions, but removals in Africa and Asia are dominated by non-industrial uses, mainly as woodfuel for cooking and heating (Figure 6). Globally, 53 percent of harvested roundwood is for woodfuel, primarily in Africa and Asia (FAO, 2007). In contrast, most industrial roundwood is harvested in North America and Europe. Between 2000 and 2007, growth rates in industrial roundwood production were highest in South America, at 18 percent, and Europe, at 19 percent, compared with 6 percent growth globally.

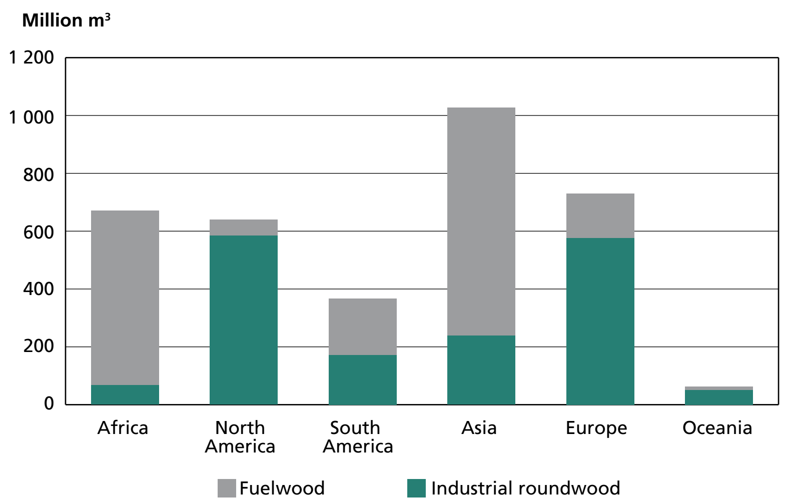
## Forest certification

In 2008, more than 300 million hectares, or almost 8 percent of the world's forests and 13 percent of those managed for timber production, had been certified by independent third parties (FAO, 2009; UNECE/FAO, 2008). By 2000, 89 percent of forests in industrialized countries were being managed "according to a formal or informal management plan" (FAO, 2001). Perhaps more relevant, it has been estimated that in recent years, approximately one-quarter of global industrial roundwood has come from certified forests (FAO, 2009). The area of certified forest is growing by about 10 percent per year (ITTO, 2008).

In developed countries that are major wood producers, the levels of certification are very high, and 90 percent of certified forests are located in North America and Europe (ITTO, 2008). In Europe, 86 percent of forests owned by companies are certified, while 87 percent of pulp production and 63 percent of paper and paperboard production are chain-of-custody-certified (CEPI, 2008). In North America, 36 percent of all forests (public and private) are certified (ITTO, 2008), and participation in sustainable forest management certification programmes is mandatory for membership in the major industry associations of Canada and the United States of America (i.e. the Forest Products Association of Canada and the American Forest and Paper Association).

Forest certification is not extensive in developing countries, with less than 2 percent of forest in Asia, Africa and Latin America being certified. However, this overall figure covers important differences among countries and ownerships. For instance, 82 percent of certified forests in the tropics are owned by the private forest sector, and most are in large management units (ITTO, 2008). In 2007, forest product companies representing nearly half of global annual sales of forest, paper and packaging products agreed "progressively and systematically [to] introduce credible forest certification in the forests [they] own, lease or manage" (WBCSD, 2007a).

FIGURE 6
**Global production of roundwood, 2007**




*Source:* FAO, 2007.

## FOREST INDUSTRY AND THE GLOBAL CARBON CYCLE

The connections between climate change concerns and the product value chain are perhaps more complex in the forest industry than in any other industry. The forests that supply the industry's raw material remove carbon dioxide ($CO_2$) from the atmosphere and store the carbon not only in trees, but also below ground in soil and root systems. The carbon is also ultimately stored in the forest products. Forests and their carbon sequestration potential are affected by management practices, climate and the rise in atmospheric $CO_2$.

Most of the forest industry's manufacturing facilities use fossil fuels, which generate greenhouse gases when burned. However, the industry also uses much energy from woody biomass. This is preferable to burning fossil fuels because the $CO_2$ released when wood is burned is part of a natural cycle and is offset by growing trees. The forest products industry is a leader in using co-generation, also known as combined heat and power (CHP), to produce electricity. CHP systems use fuels far more efficiently than conventional electricity generation systems do, so smaller amounts of fuel are required and fewer greenhouse gases emitted.

The forest industry's products compete with products that have different greenhouse gas and carbon attributes. As a result, market forces that cause product substitutions can have important implications for greenhouse gases and carbon. The end-of-life management options for forest products, which include recycling, landfilling and burning for energy, have important but complex greenhouse gas and carbon implications.

To help understand these complex connections, the Confederation of European Paper Industries (CEPI) has developed a carbon footprint framework of ten elements that cover the complete life cycle of forest products (CEPI, 2007). This report addresses all of these elements, but for simplification it condenses them into six:

- carbon sequestration and storage in forests and forest products;
- manufacturing-related emissions – essentially Scope 1 and 2 emissions as defined in the Corporate Accounting and Reporting Standard of the World Resources Institute (WRI)/World Business Council for Sustainable Development (WBCSD) Greenouse Gas Protocol, which was developed as a multi-stakeholder initiative and is arguably the most widely recognized corporate accounting standard for greenhouse gas emissions, covering accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol;
- other emissions associated with the cradle-to-gate portion of the value chain (encompassing all activities, direct and ancillary, starting in the forest, such as seedling development, planting or regeneration, forest management and harvesting, and extending to the manufacture of a finished product) – upstream emissions, mostly Scope 3;
- emissions from product transport and use – essentially downstream Scope 3 emissions not including end-of-life emissions;
- emissions associated with end-of-life management – Scope 3;
- emissions avoided elsewhere in society owing to activities of the forest products industry:
  - recycling, which avoids landfill methane emissions;
  - use of non-recyclable discarded products for energy, which avoids methane emissions and displaces fossil fuel;
  - exports of electricity and steam with low greenhouse gas-intensity, which displaces the electricity and steam produced with fossil fuels;
  - use of wood-based building materials, which displaces more greenhouse gas intensive building materials.

# 2. The role of forests in sequestering and storing carbon

## CARBON IN THE WORLD'S FORESTS

The world's forests store and cycle enormous quantities of carbon. FAO (2006a) estimates that they store 283 gigatonnes (Gt) of carbon in their biomass alone, and that this plus the carbon stored in dead wood, litter and soil is more than the carbon in the atmosphere (estimated by the Intergovernmental Panel on Climate Change [IPCC, 2007b] as 762 Gt). The total annual turnover of carbon between global forests and the atmosphere (as characterized by gross primary production) is in the range of 55 to 85 Gt per year (from data in IPCC, 2000; Sabine *et al.*, 2004; Field, 1998; Zhang, 2009). The amount of atmospheric carbon transformed into forest biomass, which is essentially equal to net primary production, has been estimated at 25 to 30 Gt per year (Field, 1998; Sabine *et al.*, 2004). In comparison, the amounts of carbon removed from global forests in industrial roundwood are small, at approximately 0.42 Gt per year (estimated from data in FAO, 2007).

Atmospheric levels of $CO_2$ are directly affected by changes in forest area, net gains or losses in carbon on forested land, and gains or losses in off-site stocks of carbon in products. At the global level, forested area continues to decline, largely owing to continued deforestation in the tropics (although the rates of tropical deforestation are "uncertain and hotly debated" [IPCC, 2007b]). Between 1990 and 2000, forested area declined by 0.22 percent per year, slowing to 0.18 percent per year between 2000 and 2005. Even at this diminished rate, more than 7.3 million hectares of forest were being lost per year (FAO, 2009). This loss of forested area is associated with transfers of carbon to the atmosphere, which for the 1990s were estimated to average 1.6 Gt per year, ranging from 0.5 to 2.7 Gt. This represented about 20 percent of global carbon emissions in this period (IPCC, 2007a).

For areas that remain in forest, it is difficult to determine how the amounts of carbon are changing at the global level. Attempts to develop global carbon budgets have found a large unexplained uptake of carbon by the terrestrial ecosystem (IPCC, 2007a). This residual land sink is not well understood, but explanations have been proposed, including continuing accumulation of carbon in undisturbed tropical forests, and in forest regrowth in other areas such as abandoned agricultural lands and managed forests (IPCC, 2007a). The residual land sink is large, but impossible to determine accurately. In the 1990s, it was estimated to average 2.6 Gt carbon per year, ranging from 0.9 to 4.3 Gt per year (IPCC, 2007a).

In summary, the world's forests have important effects on the levels of $CO_2$ in the atmosphere. Enormous amounts of carbon are stored by forests and cycled between forests and the atmosphere. Losses of forested area, mostly owing to deforestation in the tropics, are causing transfers of 0.5 to 2.7 Gt carbon to the atmosphere every year. At the same time, annual net removals of 0.9 to 4.3 Gt carbon from the atmosphere are accomplished via a poorly understood residual land sink. Gains in the amounts of carbon in existing forests are often cited as a possible explanation for this sink. Compared with the amounts of carbon converted annually into forest biomass, the amounts removed in industrial roundwood are relatively small, representing less than 2 percent of net primary production in forests.

## EFFECTS OF THE FOREST PRODUCTS INDUSTRY ON FOREST ECOSYSTEM CARBON

To understand the forest industry's impact on global forest ecosystem carbon stocks, it is necessary to consider the industry's relation to deforestation, the establishment of planted forests (via afforestation or reforestation) and the sustainable management of production forests.

### Deforestation

The causes of deforestation are multiple, complex and vary from location to location. Although deforestation at the global scale is "mainly due to conversion of forests to agricultural land…" (FAO, 2006a), the underlying causes are less well understood. The most significant underlying factors contributing to deforestation are often identified as high population density and low per capita income (e.g. Uusivuori, 2002; Kauppi, 2006), but this view may obscure the complexity of the problem.

The Scenarios Working Group of the Millennium Ecosystem Assessment (2005) reported that "Ten years of research within the international programme on land use and land cover change of [the International Global-Biosphere Programme] concluded that neither population nor poverty alone constituted the sole and major underlying causes of land cover change worldwide". The working group cited a meta-analysis of 152 case studies, which concluded that "The multiple factors intervening in tropical deforestation … make it particularly difficult to develop generic and widely applicable policies that best attempt to control the process. Many land-use policies are underlain by simplifications on the drivers of change…. From the results of the meta-analysis it is clear that any universal policy or global attempt to control deforestation (e.g. through poverty alleviation) is doomed to failure."

Attempts to characterize the forest products industry's role in deforestation are also greatly complicated by the diversity of the industry, which comprises all people and entities involved in the forest products value chain. This broad definition captures both legal and illegal activities, sustainable and unsustainable management practices, and all sizes of entities; it is impossible to generalize about the role of such a broadly defined industry.

It is possible, however, to gain insights into the potential role of large corporate forest owners in deforestation. As already noted, 82 percent of certified forests in the tropics are owned by the private forest sector, and are mostly in large management units (ITTO, 2008). In addition to the 2007 agreement among forest product companies mentioned at the end of the last chapter, the global forest products industry has also denounced non-sustainable and illegal harvesting of wood and, through the International Council of Forest and Paper Associations (ICFPA), has "committed to a global expansion of third-party certification of sustainable forest management practices – where companies commit to externally developed standards and their performance is audited against these standards" (ICFPA, 2005).

In the developing world, however, much managed forest is not certified, and some forest product companies rely on wood from these sources. This makes it more difficult to address concerns that corporate forest product entities may be contributing to deforestation by purchasing wood from landowners who are less committed to sustainable forest management practices. Attempts to address such concerns have led to a rapid increase in the use of chain-of-custody certificates (CoCs). In the year from May 2007 to May 2008 the number of CoCs issued by the Programme for the Endorsement of Forest Certification schemes (PEFC) and the Forest Stewardship Council (FSC) (the two largest certification programmes) grew by almost 50 percent. However, extending chain-of-custody to the world's uncertified forests is seen as a "…major challenge, especially in the tropical regions" (UNECE/FAO, 2008). Increasing attention to traceability is also clear in the sustainable procurement tools and initiatives being applied to forest products. A recent review of 22 such tools and initiatives revealed that more than 80 percent address traceability and legality, while 30 percent also specifically address forest conversion (WBCSD/WRI, 2007).

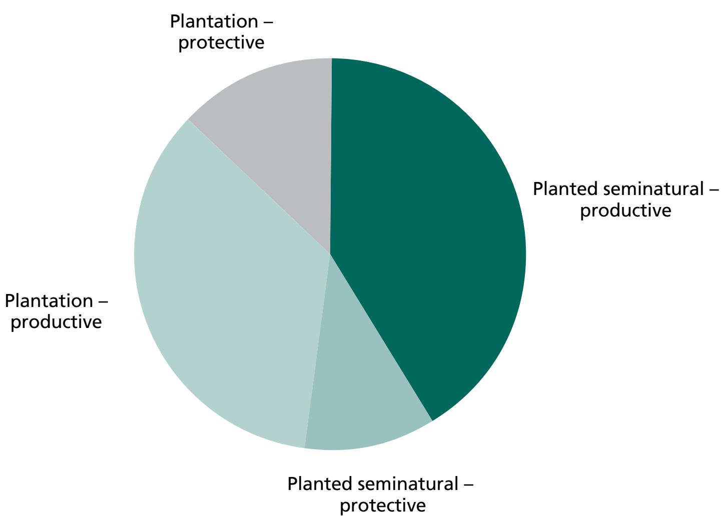
Given the complexity of deforestation, it is not possible to calculate how much global loss of forest area can be attributed to specific causes. It is also impossible to quantify the potential role of corporations that own forests or manufacture forest products, although empirical evidence suggests that large corporate producers of wood are already involved in sustainable forest management activities that would be expected to combat deforestation. Large corporate users of wood are also increasingly engaged in programmes that help to ensure that wood is sourced from sustainably managed forests.

## Planted and assisted forests

In 2005, total planted forests covered 271 million hectares, or 6.9 percent of global forested area. This does not include an additional 128 million hectares of "assisted" semi-natural forest, which is a major wood source in some regions, but is not considered planted forest by FAO. In the planted forest estate of 2005, 141 million hectares were in plantations and 130 million hectares in planted semi-natural forest (Figure 7). Between 2000 and 2005, total planted forest area grew by 1.9 percent. About three-quarters of planted forest is primarily for production rather than protection purposes. Among the predominant, large-scale end-uses of productive planted forests, sawlogs and pulpwood/fibre represent about 75 percent of those specified by reporting countries (and about 65 percent when unspecified outputs are included in the total) (Figure 8).

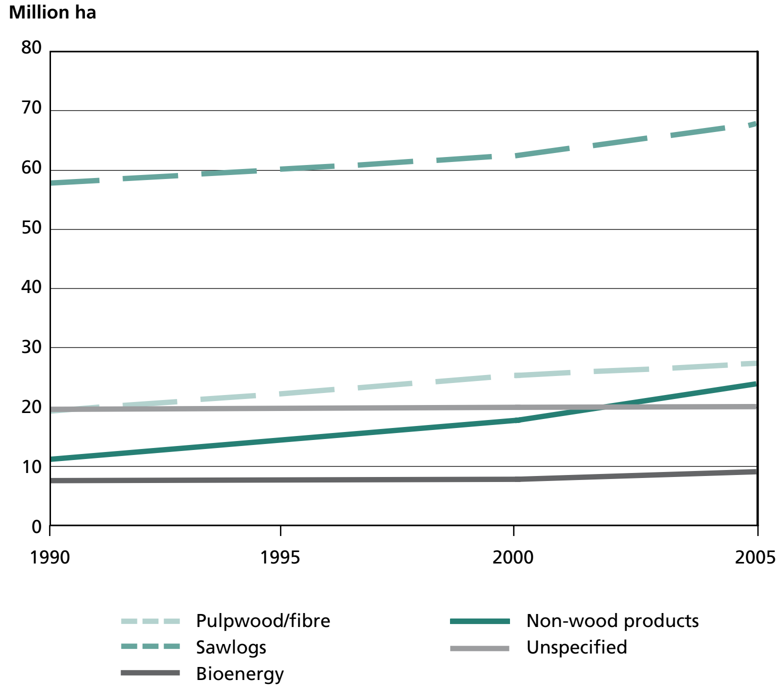
The global forest products industry is increasingly reliant on planted forests for raw material. In 2000, fast-growing plantations had the potential to supply 259 million cubic metres of high-value timber (i.e. "logs to be sawn, sliced or peeled") per year, representing 27 percent of all high-value wood production (FAO, 2005). Although accounting for only 5 percent of global forest cover in 2000, forest plantations supplied about 35 percent of global roundwood, and this figure was expected to increase to 44 percent by 2020 (FAO, 2001). Clearly, planted forests are increasingly important sources of wood for the forest products industry. It is therefore important to understand their impact on forest carbon stocks.

FIGURE 7
**Types of planted forests, 2005**




*Source:* FAO, 2006b.

FIGURE 8
**Uses of planted forests**




*Source:* FAO, 2006b.

Planted forests are often established by converting non-forested land into forest, via afforestation. In some cases, however, planted forests and assisted semi-natural forests are established on forested land that has not previously been managed for wood production, via forest conversion. Afforestation almost always increases land-based carbon stocks, while forest conversion often, although not always, decreases forest carbon stocks.

Few recent data are available for characterizing accurately the types of land converted to planted or assisted semi-natural forest. Between 1990 and 2000, plantations were established via afforestation at approximately the same rate as they were via forest conversion (1.6 million hectares and 1.5 million hectares per year, respectively) (FAO, 2001). The carbon-related impacts of these activities cannot be calculated with certainty at the global level. In general, afforestation significantly increases above-ground carbon stocks and often also increases those below ground, although losses in soil carbon have also been reported. Forest conversion often results in decreases in forest carbon stocks, although increases are possible in some situations. In spite of these uncertainties, based on the types of impacts on carbon stocks that would commonly be expected, it is reasonable to assume that from 1990 to 2000, the carbon gains from the 1.6 million hectares per year of afforestation would have approximately offset the losses associated with forest conversion of 1.5 million hectares per year (Miner and Perez-Garcia, 2007a).

Among global forest product companies, afforestation appears to be a far more common approach for establishing forest plantations than forest conversion. According to information from ten major forest product companies, 90 percent of the plantation area that they established between 2000 and 2006 was on previously non-forested land, and only 5 percent on converted forest land that had not been used for wood production (WBCSD, 2007b). Although this information is not adequate for characterizing the industry's overall practices, with 23 percent of 2006 sales from the top 100 forest, paper and packaging industry companies (PwC, 2007), these ten companies represent a large enough share of global sales to suggest that the net carbon-related effects of plantation establishment among major companies are often positive.

It is even more difficult to estimate the carbon-related impacts of converting natural forests – which are influenced primarily by natural disturbances – to forests that FAO classifies as assisted semi-natural forests. Some such conversions result in forests that closely resemble the original forest, with very little impact on carbon stocks; in other cases, the replacement forest may have very different carbon stocks from those of the forest before conversion. Modelling of these conversion practices in Canada, for example, found widely varying carbon impacts, depending on the type of forest involved (Kurz, 1998).

Current information is clearly insufficient to allow accurate estimates of the carbon-related impacts resulting from the global forest products industry's establishment of planted and assisted forests. There is evidence suggesting that global forest product companies are far more likely to develop plantations on non-forested than forested land, implying that the carbon impacts from plantation establishment are likely to be positive. However, the carbon-related impacts of converting forests from natural disturbance regimes to managed, assisted semi-natural forest are not known at the global level.

Although global estimates remain problematic, some individual companies have adequate information on the forests that they have established (or converted), so reasonable estimates of the carbon-related impacts associated with these activities are possible.

### Sustainable management of production forests

A major objective of all sustainable management programmes in production forests is to achieve a long-term balance between harvesting and regrowth. The operational guidelines of PEFC, the world's largest certification programme, stipulate that "forest management practices should safeguard the quantity and quality of the forest resources in the medium and long term by balancing harvesting and growth rates" (PEFC, 2007a, 2007b; MCPFE, 1998). A key principle of the FSC Standard, the second largest certification programme, is that "the rate of harvest of forest products shall not exceed levels which can be permanently sustained" (FSC, 2002). Although certification programmes are not always explicit about the connections between sustainable forest management and carbon, the practical effect of maintaining a balance between harvesting and regrowth is to achieve stable long-term carbon stocks in managed forests.

Insights into the benefits of sustainable forest management can be gained by examining forest carbon stocks in the regions with the most certified forest. As already noted, 90 percent of certified forests are in North America and Europe (ITTO, 2008), and forest carbon stocks are continuing to grow in the United States and the European Union (EU-27) countries (USEPA, 2009; MCPFE, 2007). Although this finding does not necessarily reflect what is happening in forests used for wood production, evidence of the effects of sustainable forest management on carbon stocks can be derived from the subset of United States forests comprising industry-owned timberland, where carbon stocks are essentially stable (Heath *et al.*, 2010).

Empirical evidence therefore appears to support the existence of a link between sustainable forest management and stable or increasing forest carbon stocks in production forests.

### Efforts by forest products industry to limit losses of forest ecosystem carbon

For the variety of reasons explained in the previous paragraphs, it is not possible to quantify the global forest products industry's effect on forest ecosystem carbon stocks. However, evidence suggests that corporate forest owners and forest product companies commonly engage in practices that help avoid the loss of forest ecosystem carbon. Key among these practices are:

- the establishment of planted forests, primarily on non-forested areas;
- adherence to sustainable forest management practices (and increasingly chain-of-custody programmes).

The effectiveness of sustainable forest management practices in maintaining carbon stocks in production forests is clear from experiences in North America and the EU. These regions contain most of the world's certified forests and have generally stable or increasing forest carbon stocks, even though they also account for more than 55 percent of global industrial roundwood production (FAO, 2007).

# 3. Carbon in forest products

The industrial roundwood removed every year from global forests contains approximately 420 million tonnes of carbon (data from FAO, 2007, assuming densities of coniferous and non-coniferous roundwood of 0.45 and 0.56 tonnes per cubic metres, respectively, and a carbon content of 50 percent). Much of this carbon is returned to the atmosphere relatively quickly, often via use of the roundwood as a source of biomass energy. However, a significant fraction of the carbon in industrial roundwood is stored in products for periods ranging from months to centuries.

If all the carbon removed from the atmosphere by forests was quickly returned to the atmosphere, the net impact of this cycle on atmospheric $CO_2$ would be zero. However, because some of the carbon is stored in products, the biomass carbon cycle can be a net sink for atmospheric $CO_2$. For this to happen, the amounts of carbon returned to the atmosphere from the product carbon pool over a given period must be less than the amounts of carbon added to the pool. It is only the net growth in stored carbon that affects the atmosphere. If the amounts of stored carbon are constant, the carbon stored in the product pool has no effect on atmospheric $CO_2$.

Until recently, IPCC's national greenhouse gas accounting guidelines defaulted to the assumption of zero growth in the product carbon pool (this is mathematically equivalent to assuming the carbon in harvested wood is oxidized instantaneously). However, countries have the option of including the effects of carbon stored in products, and several countries have been estimating these effects (e.g. USEPA, 2009; Australia Department of Climate Change, 2009). In 2006, IPCC updated its guidelines for national greenhouse gas inventories (IPCC, 2006). Instead of assuming zero growth in the harvested wood products carbon pool as the recommended default approach, the updated guidelines provide countries with various approaches for calculating the impacts of carbon stored in harvested wood products. (The implications of different accounting approaches on national inventory results are discussed in Annex 2.)

The global pool of carbon stored in forest products is estimated to be growing by 150 million tonnes (±50 percent) per year (Miner and Perez-Garcia, 2007b). This is equivalent to removing 540 million tonnes (±50 percent) of $CO_2$ from the atmosphere every year. The growth in the pool attributable to United States and Canadian production alone is more than 35 million tonnes of carbon per year (USEPA, 2009; Environment Canada, 2009). Growth in the carbon pool stored in products is due to:

- the long times over which many forest products remain in use;
- the growth in annual demand for forest products;
- the very long storage time for a fraction of the carbon in products in landfills.

The importance of carbon in products is acknowledged in a range of activities beyond national greenhouse gas inventories. For instance, in the British Standards Institution's (BSI) Publicly Available Specification (PAS) 2050, on the carbon footprint, the forest products footprint is credited with the weighted average amount of carbon stored over a 100-year period (BSI, 2008). Using IPCC's first order model and half-lives for the time-in-use of forest products (two years for paper and 30 years for wood products) (IPCC, 2006), the 100-year weighted average of carbon storage in paper is 2.9 percent of the original biomass carbon, while the storage in wood products is 39 percent of the original carbon. Using typical biomass carbon contents, these translate into carbon storage benefits (equivalent to net removals from the atmosphere) of approximately 50 kg of $CO_2$ equivalent per tonne of paper and 700 kg of $CO_2$ equivalent per tonne of wood products. Additional storage is accomplished in anaerobic landfills.

In this study, the global benefits of carbon storage in forest products in use have been estimated using the PAS 2050 method, FAO production statistics (FAO, 2007) and the IPCC default factors described above. Additional details are provided in Annex 1. The carbon storage benefits of products in use were determined to be 20 million and 243 million tonnes of $CO_2$ equivalent per year for paper and wood products, respectively, totalling 263 million tonnes of $CO_2$ equivalent per year, based on 2007 production. This is reasonably close to the 200 million tonnes of $CO_2$ equivalent per year estimated by an earlier study using a different approach (Miner and Perez-Garcia, 2007b).

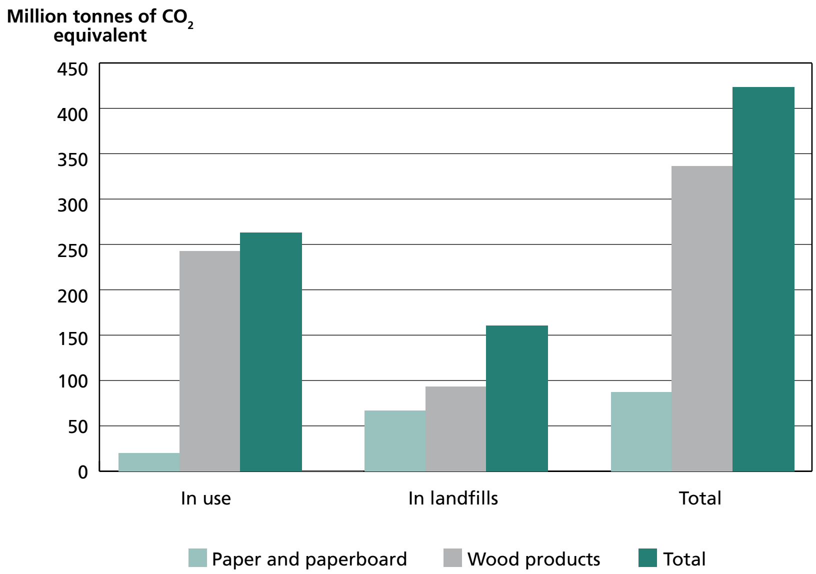
To estimate carbon storage in landfills, the amounts not remaining in use were assumed to pass to end-of-life management. The amounts of paper recovered at the end of the life cycle were estimated from FAO statistics (FAO, 2007), and it was assumed that 30 percent of wood was recovered. The amounts remaining in the waste stream and sent to landfills were estimated using IPCC waste management statistics (IPCC, 2006). Landfill design and operating practices were described using IPCC approaches and factors (IPCC, 2006) and were assigned to the countries accounting for 90 percent of consumption according to national per capita gross domestic product (GDP) groupings (World Bank, 2009). (One exception was the assumed loss of carbon from products under landfill conditions. IPCC's default assumption is 50 percent loss for all forest products, but other data suggest that while 50 percent may be a reasonable average for paper products, a 20 percent loss is a more appropriate assumption for wood products [USEPA, 2006; IFC, 2009].)

Details of the calculations are described in Annex 1. The results indicate that in 2007 the carbon storage benefits of products in landfills were approximately 67 million tonnes of $CO_2$ equivalent per year for paper and paperboard, and 94 million tonnes of $CO_2$ equivalent per year for wood products, resulting in a total of 161 million tonnes of $CO_2$ equivalent per year for all forest products. This is less than the 340 million tonnes of $CO_2$ equivalent per year estimated in an earlier study using a different approach (Miner and Perez-Garcia, 2007b). Most of the difference can be attributed to different assumptions about landfill design and operation; this study assumed that a lower fraction of waste goes to anaerobic landfills, especially in developing and least-developed countries. This results in reduced landfill carbon storage, because biomass carbon is stored in landfills only under anaerobic conditions. The difference between the two estimates highlights the uncertainties associated with attempting to characterize the effect of end-of-life management on the carbon footprint of forest products.

The fate of the degradable fraction of carbon in landfills (the fraction that is not stored) is also very important to the life cycle profile of forest products. Of particular relevance is the generation and release of methane attributable to the decomposition of forest products in anaerobic landfills. Landfill methane emissions are examined in detail later in this report. Based on the current analysis, it appears that the global methane emissions (adjusted for global warming potential) associated with paper products in landfills are larger than the offsetting carbon storage benefits. Other studies have shown that this balance varies greatly by grade of paper, depending on the non-degradable fraction of the paper (USEPA, 2006), with some grades of paper having carbon storage attributes similar to those of wood products; however, the differences among paper grades are not explored in the current analysis. For wood products, the inverse appears to be true: i.e. globally, the carbon storage associated with the non-degradable fraction of wood products seems to be greater than the impact of the methane emissions associated with the degradation of wood products in landfills. However, the uncertainties involved in estimating end-of-life impacts are too large to allow precise definition of the net balance between landfill-related emissions and carbon storage at the global level.

It is important to understand that the pulp and paper and wood product sectors are closely connected via wood flows, the ownership of facilities and land, and economics.

FIGURE 9
**Growth in global stocks of stored carbon**
**(estimated long-term storage of carbon in products sold in 2007)**




For instance, manufacturing residuals (e.g. sawdust and chips) from wood product manufacturing represent a major source of fibre for pulp production. In the United States, for example, residuals from forests and manufacturing provide 15 percent of the virgin fibre used for pulp (AF&PA, 2007). Wood product facilities earn substantial income from sales of these residuals to pulp mills. Through these connections, the carbon footprints of the two sectors are closely connected, and attempts to influence one sector will likely have impacts on the other.

The carbon storage benefits of forest products are summarized in Figure 9. Although there are uncertainties associated with these estimates, it is clear that growth in the product carbon pool represents an important part of the footprint of forest products. The methods used in this study indicate that this growth in carbon storage is equivalent to removing 424 million tonnes of $CO_2$ from the atmosphere per year.

# 4. Manufacturing-related emissions

The manufacturing of forest products often results in the release of greenhouse gases from manufacturing facilities (usually Scope 1 emissions) and from electricity producers selling electricity to manufacturers (Scope 2 emissions).

## DIRECT EMISSIONS FROM PRIMARY MANUFACTURING

Emissions from manufacturing of pulp, paper, paperboard and wood products are greatly influenced by the industry's reliance on biomass for energy. Biomass provides almost 50 percent of the fuel energy used by the pulp and paper industry and more than 60 percent of the fuel energy used by the wood products industry (IEA, 2006) – far more than in any other industry sector (Table 1).

A study from 2002 estimated the emissions from fossil fuel combustion at pulp and paper mills to be approximately 205 million tonnes of $CO_2$ equivalent, based on data from national trade associations from around the world (Miner and Perez-Garcia, 2007b). This estimate has been updated for the present report, again using data from national trade associations (via a survey distributed by ICFPA), but including a more robust method for estimating emissions from China. The details are explained in Annex 1. Most of the data obtained were for 2006/2007. Using these data, global emissions from fossil fuel use in the paper and paperboard sector were estimated to be approximately 202 million tonnes of $CO_2$ equivalent. From IEA energy data and corresponding FAO production data, the emissions of nitrous oxide and of methane from burning biomass were estimated to be approximately 5 million tonnes of $CO_2$ equivalent per year, bringing the total greenhouse gas emissions from pulp, paper and paperboard production to 207 million tonnes of $CO_2$ equivalent a year, which is essentially the same as estimated for 2002. Between 2002 and 2006/2007, however, global production of paper and paperboard increased from 331 million to 384 million tonnes.

Given the uncertainties in estimating global emissions, it is useful to examine some of the better documented national statistics to see whether the trend revealed at the global level is evident in national-level data. Information from the major trade associations in the United States, Europe and Japan, where more than half of the world's paper and

TABLE 1
**Industrial reliance on biomass energy**

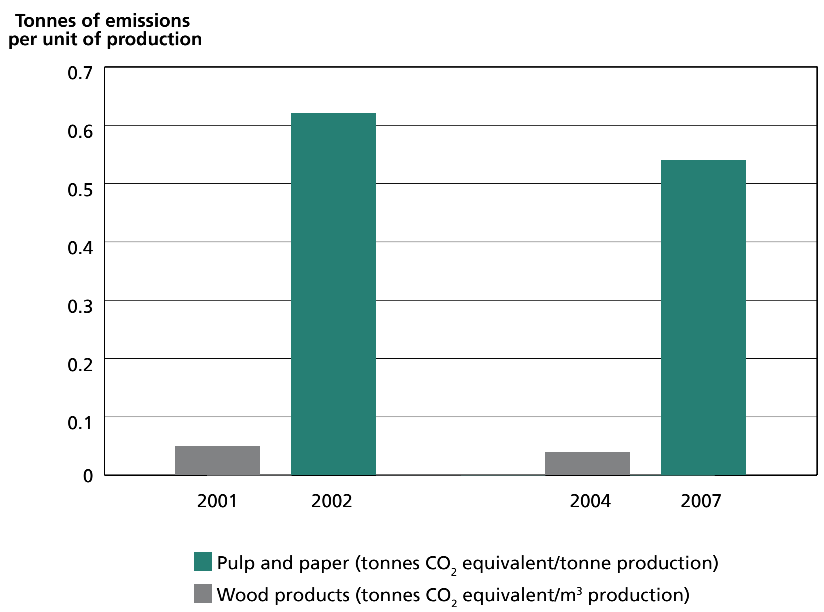
| Sector | % of fuel energy from biomass |
|---|---|
| Iron and steel | 0.0 |
| Chemicals and petrochemicals | 0.2 |
| Non-ferrous metals | 0.3 |
| Non-metallic minerals | 1.0 |
| Transport equipment | 0.1 |
| Machinery | 0.1 |
| Mining and quarrying | 0.0 |
| Food and tobacco | 8.3 |
| Paper, pulp and print | 48.0 |
| Wood and wood products | 61.1 |
| Construction | 0.5 |
| Textiles and leather | 0.8 |

*Source:* Based on data from IEA, 2006.

paperboard are produced, were examined to determine the greenhouse gas intensity of the industries in these countries over the same four to five-year period. The data indicate that the industries in all three regions reduced emissions intensity by 14 to 15 percent between 2002 and 2006/2007. The data sources cited here indicate that at the global level, the greenhouse gas intensity of the paper and paperboard sector in 2002 was 0.62 tonnes of $CO_2$ equivalent per cubic metre of production, dropping to 0.54 tonnes in 2007, an improvement of 13 percent, which is consistent with the regional-level improvements.

The emissions from wood products manufacturing are less well documented. In a survey of ICFPA members, only four countries provided wood product emissions data, representing only 19 percent of global production. Because of the small and non-representative character of the data, IEA fuel consumption data and corresponding FAO country data were used to estimate global emissions from the wood products sector (IEA, 2006; FAO, 2007). This yielded an estimate of 24.5 million tonnes of $CO_2$ equivalent from fossil fuel combustion. The same sources yielded an estimate of 1.1 million tonnes of $CO_2$ equivalent in methane and nitrous oxide from biomass combustion at wood product facilities, indicating total greenhouse gas emissions from wood products manufacturing of 25.6 million tonnes of $CO_2$ equivalent per year. This is approximately the same as an earlier estimate of 2001 emissions (26 million tonnes of $CO_2$ equivalent per year) derived from the same sources (Miner and Perez-Garcia, 2007b). Over the four years from 2001 to 2004, global production of sawnwood and wood-based panels increased by 17 percent (FAO, 2007), suggesting that the improvement in greenhouse gas intensity of wood products manufacturing was at least as rapid as that of pulp and paper production. The data sources cited here indicate that the greenhouse gas intensity of the wood products sector in 2001 was 0.046 tonnes of $CO_2$ equivalent per cubic metre of production, dropping to 0.039 tonnes in 2004, an improvement of 16 percent (Figure 10).

FIGURE 10
**Greenhouse gas intensity of forest products manufacturing**



## DIRECT EMISSIONS FROM FINAL PRODUCT MANUFACTURING

Paper, paperboard, wood and panels are made into a wide range of products. It is therefore not feasible to calculate the emissions associated with the manufacturing step of converting these intermediate products into all of the final products that are made from them. However, a large number of life cycle studies calculate the emissions related to conversion of intermediate forest products into final products. This literature, and expert judgements, can be used to estimate global emissions from final product manufacturing.

Some products require very little processing to convert them from intermediate to final products. For example, the process of converting rolls of uncoated freesheet into reams of office paper involves only cutting and packaging, with a small amount of printing required on the packaging. Tissue and paper towel converting operations consist mainly of cutting, folding and placing in printed packages. Converting sawnwood into pallets results in almost no emissions of greenhouse gases, but other products involve much more final processing. Corrugated containers, for instance, require cutting, folding, corrugating, gluing and printing. The production of magazines containing a large number of high-quality images can result in significant emissions of greenhouse gases, owing not only to the printing operations but also to upstream emissions associated with ink manufacturing (Table 2).

The large range in emissions documented in these studies clearly demonstrates that any estimate of global emissions from final manufacturing is very uncertain. In this study, it is assumed that final manufacturing emissions are equal to 20 percent of emissions from primary and intermediate product manufacturing, and that the emissions are equally divided between those related to combustion of fossil fuel and those associated with purchased electricity consumption. This value is larger than those estimated in earlier studies (e.g. Miner and Perez-Garcia, 2007b) owing to a judgement that these earlier assessments underestimated the effects of printing, which is widely used on paper and paperboard products. However, it is also possible that this figure of 20 percent of upstream production-related emissions overstates the emissions from converting activities for the overall forest products industry, because almost half of the industry's output is in wood products, and the final manufacturing processes for wood products (e.g. house building) generally produce emissions that are much less than 20 percent of the accumulated embodied emissions in the construction materials (e.g. Cole, 1999). The range of uncertainty around estimates of emissions from final manufacturing is therefore large.

TABLE 2
**Selected studies examining the greenhouse gas emissions from final product manufacturing**

| Final product | % contribution of final product manufacturing | Contribution *(kg $CO_2$/tonne product)* | Reference |
|---|---|---|---|
| Magazine production | 3% to 7% of emissions from paper manufacturing | 12 to 135 (averaging 55) | Gower *et al.*, 2006 |
| Magazine production and distribution | 37% of emissions from paper manufacturing | 611 | Wegner, 2009 |
| Multi-layer corrugated board | 14% of cradle-to-gate emissions from manufacturing multi-layer corrugated board | 67.6 kg | FEFCO, 2006 |
| Wood-framed houses | Construction activities, not including worker transport, are less than 10% of the total embodied emissions | ? | Cole, 1999 |
| Printed graphic papers | 8% of emissions from pulp and paper manufacturing | 76 per tonne of paper consumed | Tiedemann, 2001 |
| Newspapers and magazines | 42% to 100% of emissions from pulp and paper manufacturing | 300 to 500 per tonne of product printed | Axel Springer Verlag, Stora and Canfor, 1998 |

Twenty percent of total direct and indirect emissions from purchased electricity (described later in this report) for the forest products sector is 77.4 million tonnes of $CO_2$ equivalent per year. The direct emissions from converting are estimated by halving this, to derive 38.7 million tonnes of $CO_2$ equivalent per year, which is significantly larger than an earlier estimate of 12 million tonnes (Miner and Perez-Garcia, 2007b), for the reasons explained in the previous paragraph.

## DIRECT EMISSIONS FROM MANAGEMENT OF MILL WASTES

Under anaerobic conditions, mill liquid and solid wastes can degrade to a mixture of $CO_2$ and methane. Estimates of these emissions are highly uncertain owing to a lack of information on global waste management practices and incomplete scientific understanding of the factors that influence methane generation. Based on the following calculations, however, it is clear that these emissions are small.

When considering the methane emissions from mill wastes placed in landfills, the following assumptions can be made. For pulp and paper mill landfills, it can be assumed that:

- mill solid waste going to anaerobic landfills is equal to 4 percent of production (a value between those of the European and the United States paper industries [CEPI, 2008; AF&PA, 2008]);
- waste is 25 percent biomass carbon (value based on NCASI testing [Heath *et al.*, 2010]);
- 50 percent of the biomass carbon in mill solid wastes can degrade under anaerobic conditions to gas containing equal amounts (by volume) of methane and $CO_2$ (the IPCC default for paper products);
- none of the landfills have systems for capturing methane, so the only destruction is a 10 percent oxidation that occurs in the upper layers of the landfill via natural processes (the IPCC default assumption).

Under these circumstances, ultimate emissions from the pulp and paper mill wastes placed in landfills in 2007 are expected to be approximately 24 million tonnes of $CO_2$ equivalent.

For wood product mill landfills, it can be assumed that:

- the mill solid waste going to anaerobic landfills is equal to only 1 percent of production, because most of the waste from wood product plants has high value as fuel and is burned rather than discarded (an assumption with large uncertainty, especially in developing countries where mill solid waste is sometimes disposed of in piles instead of being sent to landfills or burned);
- the waste is 25 percent biomass carbon, based on awareness that material placed in landfills is often unusable as fuel owing to contamination with soil, rocks and other debris;
- 50 percent of the biomass carbon in mill solid wastes can degrade under anaerobic conditions to gas containing equal amounts (by volume) of methane and $CO_2$ (the IPCC default for paper products, which is likely to overstate the degradation of wood waste);
- none of the landfills have systems for capturing methane, so the only destruction is a 10 percent oxidation that occurs in the upper layers of the landfill via natural processes (the IPCC default assumption).

Under these circumstances, ultimate emissions from the wood product mill wastes placed in landfills in 2007 are expected to be approximately 2 million tonnes of $CO_2$ equivalent.

Adding the mill landfill-related emissions from the pulp and paper and wood products sectors yields an estimate of total global methane emissions from mill landfills of 26 million tonnes of $CO_2$ equivalent per year. This is somewhat larger than the amounts estimated in an earlier profile of the global industry (20 million tonnes of $CO_2$ equivalent per year) (Miner and Perez-Garcia, 2007b). However, the earlier estimate was of current emissions from industry landfills, considering the rate at which all past wastes decompose, whereas the updated estimate is a projection of ultimate emissions from waste placed in landfills in 2007. In any event, the estimates of methane emissions from mill wastes are highly uncertain owing to uncertainties regarding the amounts of waste generated and the methods used to manage this waste.

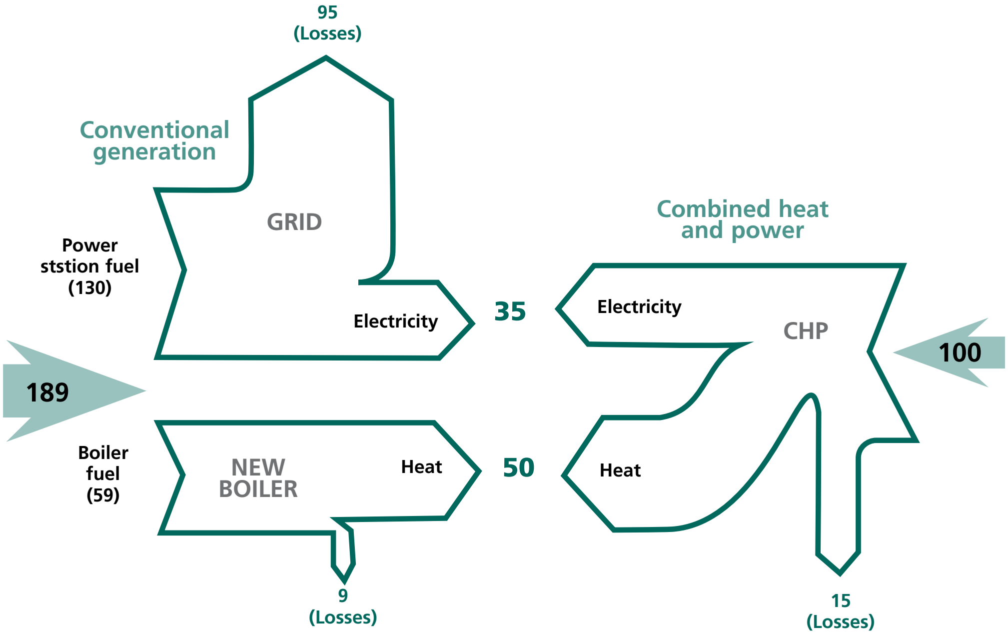
It is also possible to generate methane where wastewater is treated under anaerobic conditions. Only a small amount of wastewater in the pulp and paper industry is treated in anaerobic treatment systems. Although many aerated wastewater treatment systems have anaerobic zones, studies indicate that these emissions are very small relative to other emissions from the forest products industry, amounting to 400 000 tonnes of $CO_2$ equivalent for the 93 million tonnes of paper and paperboard produced in the United States (Heath *et al.*, 2010). Almost no wastewater is generated in wood products manufacturing. Extrapolated to global production of paper and paperboard (384 million tonnes in 2007), the United States estimate of emissions yields a global estimate of 1.7 million tonnes of $CO_2$ equivalent per year.

The total emissions from managing mill wastes generated in 2007 are therefore approximately 28 million tonnes of $CO_2$ equivalent, with most of these being ultimate methane releases from pulp and paper waste placed in landfills.

## EMISSIONS ASSOCIATED WITH PURCHASED ELECTRICITY

Both pulp and paper mills and wood product manufacturing facilities use electricity. A significant fraction of the electricity used at pulp and paper mills is self-generated. Almost all of this self-generated electricity is produced in CHP systems (e.g. CEPI, 2008; AF&PA, 2008). In the most common CHP systems, the steam used by the mill for pulp and paper production is first passed through a turbine where it produces electricity. Some CHP systems also produce hot water or steam for district heating. The CHP process extracts far more usable energy from fuel than separate electricity and steam production systems do. Typical CHP system requires about 50 percent less fuel energy than separate systems producing the same amount of usable energy (ACEEE, 1999) (Figure 11).

FIGURE 11
**Comparison of conventional and CHP generation systems**




*Source:* ACEEE, 1999.

IEA's analysis of the pulp and paper industry in several countries found that CHP systems were supplying 20 to 60 percent of the electricity requirements for the industry (IEA, 2007c). This is especially significant considering that most of the fuel used in pulp and paper mill CHP systems is biomass, primarily pulping liquors that are burned to recover pulping chemicals as well as generating steam and electricity. In some situations, chemical pulp mills can generate enough energy from biomass to become net exporters of biomass-based electricity to the electricity grid.

In spite of the extensive reliance on biomass-driven CHP systems, most pulp and paper mills must purchase electricity. The emissions associated with these purchases (Scope 2 emissions under the WRI/WBCSD Greenhouse Gas Protocol) were estimated by first determining how much electricity is typically purchased. Information from the pulp and paper associations in Europe, the United States and Japan was examined to calculate the average electricity purchases per tonne of production in each of these regions. These regional estimates ranged from 0.44 to 0.59 MW per tonne, averaging 0.5 MW per tonne. Given the large amounts of production represented by these three regions, it seems reasonable to model the industry's purchased electricity requirements on the average value for the three regions, 0.5 MW per tonne. National-level purchased electricity requirements were then estimated from FAO production statistics (FAO, 2007). Countries that cumulatively represent 91 percent of global production were selected, with the remaining 9 percent treated as a separate group. The emissions associated with these purchases were then calculated using country-specific electricity emission factors published by IEA (2007a). The detailed calculations are shown in Annex 1.

This approach produced an estimate of 106 million tonnes of $CO_2$ associated with the global pulp and paper industry's electricity purchases in 2007. This estimate is significantly smaller than an earlier estimate of 140 million tonnes of $CO_2$, primarily because it relies on country-level factors to estimate emissions from purchased electricity, whereas the earlier study did not attempt to provide this level of resolution for the many countries where industry associations lacked Scope 2 emissions estimates of their own (Miner and Perez-Garcia, 2007b).

Owing to a scarcity of information, it is more difficult to estimate global emissions related to purchased electricity used at wood products facilities. Purchased electricity factors were developed for sawnwood and wood-based panels from several sources, mostly focused on North American and European facilities (NCASI, 2008; ecoinvent, 2008; USDOE, 2009). For sawnwood, the factors from these three sources ranged from 0.07 to 0.09 MW per cubic metre, so a value of 0.08 MW per cubic metre was used in the calculations. For wood panels, the values varied widely, depending on the type of panel, and ranging from 0.1 to 0.35 MW per cubic metre. A weighted average factor of 0.2 MW per cubic metre was derived, based on the global production of each panel type according to FAO data (FAO, 2007). National-level production data were obtained for the same countries used for pulp and paper, in this case representing 85 percent of sawnwood and 89 percent of wood-based panel production. The results were extrapolated to global production, and the same national-level electricity factors were used as for the pulp and paper sector.

This approach produced an estimate of 48.8 million tonnes of $CO_2$ associated with the global wood product sector's electricity purchases in 2007. This estimate is approximately the same as an earlier estimate of 40 million tonnes of $CO_2$ per year (Miner and Perez-Garcia, 2007b).

Emissions associated with electricity purchases by final manufacturing operations (i.e. converting plants) were estimated at 38.7 million tonnes of $CO_2$ equivalent per year, as described previously.

Combined, the pulp and paper and wood products sectors, including converting, are responsible for Scope 2 emissions of approximately 193 million tonnes of $CO_2$ per year. This is approximately the same as an earlier estimate of 180 million tonnes, developed using different methods, as explained previously (Miner and Perez-Garcia, 2007b).

# 5. Other cradle-to-gate emissions from the forest products value chain

The cradle-to-gate portion of the forest products value chain includes several other sources of emissions. Because most of these sources of emissions are not owned or controlled by forest product companies (and because they are not due to purchases of electricity or steam), these emissions are mostly Scope 3, as defined under the WRI/WBCSD Greenhouse Gas Protocol.

## EMISSIONS ASSOCIATED WITH WOOD PRODUCTION

In addition to transport-related emissions (examined elsewhere in this report), there are several other potential sources of greenhouse gas emissions related to the production of wood: at a minimum, fossil fuel is used in thinning and harvesting operations; as forest management becomes more intensive, the opportunities for greenhouse gas impacts often increase; the use of fire as a forest management tool releases methane and nitrous oxide; the production of herbicides, pesticides and fertilizers requires energy, so is associated with upstream greenhouse gas emissions; and nitrogen-containing fertilizer can release nitrous oxide after application.

The International Finance Corporation (IFC, 2009) has developed generic factors representing different management intensities for use in its Forest Industry Carbon Assessment Tool (FICAT) (Table 3). These factors do not address all situations and are not appropriate for some practices. Nonetheless, they can be used for estimating global emissions from forest management. It was assumed that half of industrial roundwood was produced under Category 1 management, and that the remaining 50 percent was divided evenly among the other three categories. Industrial roundwood production in 2007 was obtained from FAO (FAO, 2007). From this, it was estimated that forest management activities result in emissions of 36.9 million tonnes of $CO_2$ equivalent per year.

## UPSTREAM EMISSIONS ASSOCIATED WITH NON-WOOD INPUTS AND FOSSIL FUELS

Although most of the raw material mass used in forest products manufacturing is wood fibre, other raw materials are also often used. These materials and fossil fuels are associated with their own upstream emissions. It is not universally accepted that these upstream emissions should be considered part of the forest products value chain, but they are included in this study for completeness. Earlier studies of the global forest products sector have not included these emissions (e.g. Miner and Perez-Garcia, 2007b; Subak, 1999).

TABLE 3
**Greenhouse gas emission factors associated with forest management**

| Category | Management practice | Tonne $CO_2$ equivalent/m$^3$ harvested |
|---|---|---|
| 1 | Only harvesting and thinning | 0.015 |
| 2 | Harvesting plus burning for site preparation or undergrowth control | 0.024 |
| 3 | Harvesting plus fertilizer and herbicide use on the land | 0.026 |
| 4 | Harvesting plus burning, fertilizer and herbicide use | 0.035 |

*Source:* NCASI, 2009.

To estimate the upstream emissions associated with chemicals and additives, the FICAT factors were used (IFC, 2009). These factors reflect generic "recipes" for the chemicals and additives used to produce different forest products, and data from several life cycle databases. Factors for the major grades of paper tracked by FAO range from 30 to 200 kg of $CO_2$ per tonne of product. The FICAT factors suggest that a reasonable value for wood panels is 200 kg of $CO_2$ per tonne of product, equivalent to 50 to 200 kg of $CO_2$ per cubic metre of product, depending on the type of wood panel. Sawnwood was assumed to have no upstream emissions associated with chemicals and additives (although this is not the case for preservative-treated wood). These factors were applied to the FAO production statistics for the respective products (FAO, 2007). Details of the calculations are explained in Annex 1.

The results of the calculations indicate that the upstream emissions associated with chemicals and additives used in the pulp and paper and wood products sectors are 34.9 and 22.4 million tonnes of $CO_2$ equivalent per year, respectively, based on 2007 production. In total, these upstream emissions equal 57.3 million tonnes of $CO_2$ equivalent per year.

The upstream emissions associated with fossil fuels used in the global forest products sector can be estimated using:

- IEA energy consumption data for Organisation for Economic Co-operation and Development (OECD) countries (IEA, 2006);
- FAO production statistics to extrapolate the IEA data to the rest of the globe (FAO, 2007);
- upstream emission factors from the United States life cycle database, modified for IFC's FICAT (USDOE, 2009; IFC, 2009).

The results of the calculations, described in more detail in Annex 1, indicate that the upstream emissions associated with fossil fuel use in the pulp and paper sector totalled 30.5 million tonnes of $CO_2$ equivalent in 2004, and those from the wood products sector 4.6 million tonnes of $CO_2$ equivalent per year. Together, the upstream emissions associated with fossil fuels used by the forest products sector in 2004 therefore totalled 35.1 million tonnes of $CO_2$ equivalent (Table 4).

## EMISSIONS ASSOCIATED WITH TRANSPORTING RAW MATERIALS AND FUELS

The forest products value chain involves the shipment of large amounts of raw materials and products, both domestically and internationally. To estimate the emissions associated with the international transport of fibrous raw materials and products, FAO data were obtained for exporting countries representing 80 percent of global exports of each of industrial roundwood, sawnwood, wood-based panels, paper and paperboard, and recovered paper. For these countries, FAO data were also used to identify the major export destinations for each material (FAO, 2007). One-way transport distances and modes were approximated for each pairing of an exporting country and a major importing destination. The emissions associated with transport were estimated using emission factors from the WRI/WBCSD Greenhouse Gas Protocol calculation tools, as presented in documentation for the FICAT model (IFC, 2009), and then extrapolated

TABLE 4
**Upstream emissions associated with fossil fuels and chemical inputs in manufacturing**

| Product | Upstream emissions *(tonnes $CO_2$ equivalent/year)* | | |
|---|---|---|---|
| | Chemicals | Fossil fuels | Total |
| Paper and paperboard | 34.9 | 30.5 | 65.4 |
| Wood products | 22.4 | 4.6 | 27 |
| **Total** | **57.3** | **35.1** | **92.4** |

to account for the remaining 20 percent of the material exported by countries not included in the calculations.

For each of the materials identified, the difference between global production and global exports was assumed to be transported domestically. This amounted to approximately 75 percent of the total production mass of the materials. The transport distances were assumed to be 100 km for industrial roundwood and 500 km for all other materials. Domestic transport was assumed to be by land.

Because land-based transport uses a combination of truck and train carriers, two sets of calculations were made. One assumed that most international and domestic land-based transport was by diesel truck, and the other that it was by diesel train. The average of these two values was used in the final estimates. To account for the transport of non-fibrous raw materials and fuels, the emissions associated with transport of fibrous raw materials were increased by 15 percent; various sources of information suggest that such an adjustment should be adequate (e.g. Diesen, 1998; Lofgren, 2005; Kline, 2004). In addition, it was assumed that the emissions associated with discarded paper are equal to half those associated with transporting recovered fibre. The detailed calculations are shown in Annex 1.

Cradle-to-gate emissions for transport of fibrous raw materials, non-fibrous raw materials and fuels are estimated to be 21 million tonnes of $CO_2$ equivalent per year (Table 5). Of this, approximately 40 percent is related to domestic and 60 percent to international shipping. Emissions related to gate-to-customer (i.e. product) transport are 26.7 million tonnes of $CO_2$ equivalent per year, with about 43 percent of these occurring domestically and 57 percent being associated with international shipments of products. Cradle-to-gate emissions are lower than gate-to-customer emissions because, although the quantities of products are smaller than those of raw materials, the shipping distances for fibrous raw materials are typically much shorter than those for finished products. Another 3.6 million tonnes of $CO_2$ equivalent per year are assumed to be associated with transport of used paper to the end of the life cycle (half of the emissions associated with transporting product to customers).

In total, transport-related emissions are estimated to be 51.2 million tonnes of $CO_2$ equivalent per year, of which approximately 60 percent is associated with international trade.

An earlier study combined fibre procurement emissions with transport-related emissions and estimated the total of these to be 70 million tonnes of $CO_2$ equivalent per

TABLE 5
**Transport-related emissions in the forest products industry value chain**

| Material | Emissions[a] *(million tonnes $CO_2$ equivalent/year)* | | |
|---|---|---|---|
| | International trade | Domestic consumption | Total |
| Industrial roundwood | 3.55 | 3.46 | 7.00 |
| Market pulp | 4.08 | Not estimated | 4.08 |
| Recovered paper | 3.89 | 3.28 | 7.17 |
| **Total cradle-to-gate associated with fibre** | **11.50** | **6.74** | **18.30** |
| **Total cradle-to-gate extrapolated to include non-fibrous raw materials and fuels** | **13.20** | **7.75** | **21.00** |
| Sawnwood | 4.47 | 3.54 | 8.01 |
| Wood-based panels | 3.45 | 1.98 | 5.44 |
| Pulp and paper | 7.30 | 5.92 | 13.20 |
| **Total gate-to-consumer** | **15.20** | **11.40** | **26.70** |
| Consumer-to-grave (assumed to equal transport for recovered fibre) | 1.94 | 1.64 | 3.58 |
| **Total cradle-to-grave** | **30.40** | **20.80** | **51.20** |

[a] Inconsistencies may reflect rounding.

year (Miner and Perez-Garcia, 2007b). The current study estimates forest management-related emissions to be 36.9 million tonnes of $CO_2$ per year. Adding this to the transport-related emissions estimated previously (51.2 million tonnes per year) yields a total of 88.1 million tonnes of $CO_2$ equivalent per year, which is close to the earlier estimate derived using different methods.

# 6. Emissions from the gate-to-grave portion of the value chain

## TRANSPORT OF PRODUCTS TO CONSUMERS

As already noted, gate-to-customer (i.e. product) transport-related emissions are estimated to be 26.7 million tonnes of $CO_2$ equivalent per year, of which about 43 percent occurs domestically and 57 percent is associated with international shipments of products.

## EMISSIONS ASSOCIATED WITH PRODUCT USE

Forest products are sometimes used as a component in final products that consume energy, and therefore release greenhouse gases (e.g. wood used in home construction). However, it is seldom the wood-derived component that consumes the energy or releases greenhouse gases. Although it may sometimes be possible to allocate a portion of a final product's energy consumption to the wood-derived components it contains, this is seldom done, is often inappropriate, and is not possible for a global profile.

One type of forest product that is responsible for releasing greenhouse gases during use is the wood-derived fuels that are sold by the forest products industry for use elsewhere. When burned, these fuels release small amounts of methane and nitrous oxide. Significant quantities of wood-derived fuel by-products are sold by forest products companies, but almost all of these are used elsewhere in the forest products industry, so the emissions are included in the manufacturing-related emissions. Wood from industry-owned forests is increasingly being used for energy in other industries, especially for electricity production. However, the emissions of methane and nitrous oxide from all of the biomass burned in the forest products industry amount to only about 6 million tonnes of $CO_2$ equivalent per year (as calculated previously). The emissions associated with burning wood from industry-owned forests at sources outside the forest products industry are therefore small enough to be ignored in this study.

## EMISSIONS ASSOCIATED WITH TRANSPORTING USED PRODUCTS TO THE END OF THE LIFE CYCLE

The emissions generated by transporting used products to the end of the life cycle are assumed to be half of those associated with transporting products from mills to customers, or 3.58 million tonnes of $CO_2$ equivalent per year.

## EMISSIONS ASSOCIATED WITH THE END OF THE LIFE CYCLE

After use, most forest products are recovered for recycling, burned for energy, or sent to landfills. Emissions associated with recycling are included in the manufacturing and transport elements of the footprint. The emissions associated with burning used products for energy are small, consisting only of the methane and nitrous oxide formed in the combustion process. Using the calculations associated with estimating carbon storage in forest products, and assuming that used forest products are burned if they are not recovered or sent to landfills, it is estimated that the burning of used products at the end of the life cycle releases about 3.0 million tonnes of $CO_2$ equivalent per year. The calculations are shown in Annex 1.

The emissions of methane, a potent greenhouse gas, from used forest products in landfills are far more significant. To estimate these, it is first necessary to calculate the carbon stored in products in use and in landfills. These calculations identify the quantities of used products disposed in landfills that have the potential to generate methane (because the landfills are partly or completely anaerobic). The calculations employ the IPCC approach, in which the carbon in forest products located in anaerobic zones is partly stored, with the remainder decomposing into a mixture (50/50 by volume) of methane and biogenic $CO_2$. Ten percent of the methane is assumed to oxidize as it migrates through the landfill. In addition, some landfills capture and burn the methane that they generate.

The fraction of waste under anaerobic conditions and the fraction of methane captured and burned are two very important variables in methane emission calculations, but few data on national practices are available, especially in developing countries. Most landfills in developed countries are designed to minimize the intrusion of water and oxygen, so are largely anaerobic. In developing countries, landfills tend to be shallow and unmanaged, allowing more oxygen and water to enter. IPCC divides landfills into five categories: managed-anaerobic, managed-semi-aerobic, unmanaged-shallow, unmanaged-deep, and uncategorized. A factor is assigned to each type of landfill, reflecting the extent of anaerobic conditions within it (IPCC, 2006). For this study, the landfill types for each major consuming country were based on 2008 per capita GDP (based on purchasing power parity [PPP]) published by the World Bank (World Bank, 2009). It was assumed that countries with per capita GDP of more than US$30 000 were using landfills of the two most anaerobic types (managed anaerobic and unmanaged deep). Countries with per capita GDP of less than US$10 000 were assumed to be using unmanaged shallow landfills, and the remaining countries were assumed to be using a combination of deep and shallow unmanaged landfills.

The values selected for capturing and burning methane were also based on per capita GDP. It was assumed that countries with per capita GDP of more than US$30 000 were capturing and burning 40 percent of the methane from decomposing forest products; those with per capita GDP of less than US$10 000 were assumed to be capturing none; and the remaining countries were assumed to be capturing and burning 10 percent. Details of the calculations are shown in Annex 1.

Based on the results of these calculations, products manufactured in 2007 and disposed of in landfills (rather than being recovered or burned for energy) are expected eventually to release 235 million tonnes of $CO_2$ equivalent per year in methane. About 75 percent of this (176 million tonnes of $CO_2$ equivalent per year) is due to the decomposition of paper and paper products, while the remainder is associated with wood products. This estimate is similar to that developed in an earlier study (250 million tonnes of $CO_2$ equivalent per year), although the estimates were developed using different approaches (Miner and Perez-Garcia, 2007b).

# 7. Emissions avoided elsewhere in society owing to forest industry activities

The elements of the industry's emissions profile already discussed involve movements of greenhouse gases to or from the atmosphere in the course of a year. They occur within the industry's value chain and require no assumptions about alternative scenarios. However, the industry's activities also influence societal emissions of greenhouse gases in other ways. These impacts often occur outside the industry's value chain, and measuring them usually requires assumptions about the emissions that would occur in the absence of the industry's activities.

Grouped under the general heading of "avoided emissions", these impacts, although important, are generally understood to be more uncertain than those that occur within the industry's value chain, because they require assumptions about what would occur in the absence of industry activity. In addition, their occurrence outside the industry's value chain gives rise to questions about the extent to which they should be used to offset emissions that occur within the value chain.

Nonetheless, it is important to understand the types of societal impacts that are associated with various activities of the forest products industry. This review examines five types of impacts, some quantitatively and some qualitatively:

- the methane emissions that would occur if the paper that is now recovered for recycling was sent to landfills;
- the fossil fuel-related emissions that would occur if the used products now being burned for energy were instead burned without energy recovery;
- the increased emissions from electricity producers that would occur if the forest products industry was not exporting low greenhouse gas intensity fuel to the grid;
- the avoided emissions (and opportunities for reducing societal emissions) associated with using wood-based building materials instead of non-wood materials;
- the importance of a market for wood as a means of encouraging landowners to keep land in forest.

### METHANE EMISSIONS THAT WOULD OCCUR IF RECOVERED PAPER PRODUCTS WERE SENT TO LANDFILLS

One greenhouse gas related impact of recycling can be illustrated by estimating the methane emissions from landfills that would be associated with sending to landfills the paper that is currently recovered. This calculation is useful for understanding the importance of recycling, but the resulting value should not be viewed as an estimate of avoided emissions because the scenario being modelled (i.e. sending all used paper to landfills) is not likely to occur.

In addition, the calculation highlights only one aspect of the relationship between recycling and societal greenhouse gas emissions. Recycling has extremely complex effects on greenhouse gas emissions and carbon sequestration. Among the factors that have to be considered in estimating avoided emissions attributable to recycling are:

- the methane from landfills that is avoided;
- the carbon storage in landfills that is avoided;
- the biomass energy that is precluded (i.e. recycled used products are not available for biomass energy);

- the difference in greenhouse gas intensity between virgin and recycled manufacturing;
- the differences in processing and transport requirements between virgin and recycled fibre;
- the impact of increased use of recovered fibre on forest carbon.

In the calculations of methane emissions associated with paper in landfills (Annex 1), it is estimated that globally the amounts of paper being recovered are about 1.7 times the amounts going to landfills. Accordingly, the additional methane that would be released if recovered paper were sent to landfills should be 1.7 times the amount estimated for the paper currently going to landfills, or approximately 300 million tonnes of $CO_2$ equivalent per year. For all of the reasons noted above, however, the estimated impact of recycling on avoided landfill emissions should be regarded as illustrating the importance of recycling, and not as an estimate of avoided emissions.

## BENEFITS OF BURNING NON-RECYCLABLE DISCARDED PRODUCTS AT THE END OF THE LIFE CYCLE

Although IPCC and FAO data can be used to estimate the amounts of recovered forest products removed from the waste stream and the amounts of non-recovered material going to landfills, the methods used to manage the remaining used forest products are less well documented. For this study, it was assumed that in countries with per capita GDP of more than US$30 000 half of non-recovered forest products not going to landfills were being burned for energy. The remaining material in these countries, and all such material from other countries, was assumed to be going to other end-of-life systems (composting, burning without energy recovery, etc.). This approach yields an estimated 40 million tonnes of used forest products produced in 2007 that will be burned for energy, about evenly divided between paper and wood products. Assuming that this material has a heat content of 15.6 GJ per tonne (lower heating value, LHV) and that it displaces natural gas, and considering the differences in the combustion efficiencies for the different types of fuels, it is estimated that the use of this material as a source of fuel is currently avoiding the emission of 25.8 million tonnes of $CO_2$ equivalent per year. This does not include situations where methane gas from decomposing forest products is captured from landfills and used as a source of biomass energy, displacing fossil fuels.

The magnitude of this number reveals the opportunity for reducing societal greenhouse gas emissions by diverting material from landfills to biomass energy applications. If the products made in 2007 that are expected to go to landfills were instead burned as a source of biomass energy to displace natural gas, the expected global benefit would be a reduction in greenhouse gas emissions of 135 million tonnes of $CO_2$ equivalent per year (not considering the impacts on landfill methane emissions, or the offsetting impacts of burning landfill methane as biomass energy and of carbon storage).

## IMPACTS OF THE FOREST INDUSTRY'S EXPORTS OF LOW GREENHOUSE GAS INTENSITY ELECTRICITY AND STEAM

Pulp and paper making requires large amounts of steam. This steam is often used to produce electricity before being used in the pulp and paper making process (i.e. mills commonly use CHP systems). In some cases, the amount of electricity generated exceeds the mill's demands, so the excess can be exported for societal use. For example, IEA indicates that modern market pulp mills generate an excess of 2 GJ of electricity per tonne of pulp (IEA, 2007c). The greenhouse gas intensity of this exported electricity is usually very low, both because it is generated in CHP systems and because biomass is often a large portion of the fuel used to produce it.

The societal greenhouse gas benefits of exported electricity vary greatly, depending on the greenhouse gas intensities of the exported electricity and of the electricity that is assumed to be displaced from the grid. Using IEA's estimate of 2 GJ of exported electricity per tonne of pulp, a 500 000 tonne per year pulp mill producing biomass-based electricity might accomplish avoided emissions of only 1 500 tonnes of $CO_2$ equivalent per year in Norway, but more than 200 000 tonnes of $CO_2$ equivalent per year in China, based on national average electricity emission factors (IEA, 2007a).

Owing to a lack of information about the amounts of electricity exported by the forest industry in countries around the world, it is not possible to derive a global estimate of the emissions avoided by these exports. However, it is clear that exports of low greenhouse gas intensity electricity can have large benefits, particularly where they displace high greenhouse gas intensity electricity.

## SOCIETAL BENEFITS OF USING WOOD-BASED BUILDING MATERIALS INSTEAD OF MORE GREENHOUSE GAS INTENSIVE ALTERNATIVES

In commerce, many different products can often fulfil the same function. If the impacts of these different choices on greenhouse gas emissions vary, societal emissions are affected when one product substitutes another. Forest products compete with other types of products in many situations, so there are an enormous number of potential substitution effects involving the forest products industry. It is therefore not possible to characterize substitution effects for the global industry, as there are too many potential product substitutions to examine. In recent decades, however, one substitution effect that is important to a large segment of the forest products industry has been examined in detail. This is the use of wood-based building materials as substitutes for non-wood alternatives, primarily concrete and steel. The substitution effect for housing construction has been especially well studied.

The findings of these studies have been varied, partly because of the different assumptions they make regarding effects on forest carbon and what happens to used products at the end of the life cycle (e.g. Upton, 2008; Gustavsson, 2006; Petersen, 2005). However, the overall conclusion of these studies has been remarkably consistent: in comparisons of housing structures designed to have similar energy demands for heating and cooling, wood-based materials have almost always been found to have lower life cycle greenhouse gas emissions than other materials. Reviews of this literature can be found in Upton (2008) and Sathre (2008), for example.

The energy required to heat and cool residential structures usually generates far more emissions than are generated from producing construction materials, transporting them and assembling the structure (although Nassen [2007] supplies evidence that many studies may be underestimating the importance of these pre-occupancy emissions). Because of the importance of heating and cooling-related emissions, comparisons of building materials must be based on structures with similar thermal performances. Many building codes help to ensure that houses built of different construction materials have similar thermal performances.

The literature suggests that differences in thermal performance may give rise to an exception to the general finding that wood-based building systems result in lower life cycle greenhouse gas emissions. This exception arises in climates where thermal mass is important to a structure's thermal performance. Such situations are generally limited to arid regions where there is a large difference between day- and night-time temperatures and where the human comfort zone lies midway between the two (Upton, 2008). In these situations, it may be difficult for wood-based structures to match the thermal performance of construction materials with high thermal mass, such as concrete. However, the literature suggests that in most temperate, tropical and cold climates, wood-based construction systems will have lower life cycle greenhouse gas emissions.

Sathre (2008) recently reviewed 48 North American and European studies of the substitution effects associated with using wood-based building materials in place of alternatives. Data from 20 of these studies were used in a meta-analysis to develop an average factor describing substitution effects for wood-based building products. This analysis revealed that:

> "The calculated displacement factors ranged from a low of -2.3 to a high of 15.0 [tonnes of carbon of emission reduction per tonne of carbon in wood product], with most lying in the range of 1.0 to 3.0. The average displacement factor value was 2.0, meaning that for each tonne of carbon in wood products substituted for non-wood products, an average greenhouse gas emission reduction of approximately 2 tonnes of carbon can be expected. In other units, this value corresponds to roughly 3.7 tonnes of $CO_2$ equivalent emission reduction per tonne of dry wood used. This average number can be viewed as a reasonable estimate of the greenhouse gas mitigation efficiency of wood product use, over a range of product substitutes and analytical methodologies."

Applying this average substitution factor to housing construction in the United States in 2006, McKeever (2009) suggests that the use of wood in housing in the United States avoided the emission of 135 million tonnes of $CO_2$ equivalent per year. In the United States, wood-based housing accounts for more than 90 percent of total housing, but this share is lower in many other countries (Eriksson, 2009), implying significant opportunities for expanding the benefits of using wood in house construction. Based on information from several decades ago suggesting that approximately 40 percent of global wood products were used for housing construction (FAO, 1971), a global substitution effect of 483 million tonnes of $CO_2$ equivalent can be estimated for 2007.

## THE VALUE OF MARKETS FOR WOOD AS AN INCENTIVE FOR KEEPING LAND IN FOREST

In many places in the world, landowners have the opportunity to convert forest to other uses, to improve the economic returns from their land. Where these conversion pressures exist, the value of harvested wood can help to keep land in forest. This indirect effect of the forest industry's activities is very important. For instance, if only 1 percent per year of industry-owned timberland in the United States was converted to non-forest uses, the result would be a transfer of carbon to the atmosphere equal to 90 million tonnes of $CO_2$ equivalent per year, not including the soil carbon impacts (based on carbon data in Heath *et al.,* 2010). Although it is impossible to calculate precisely the role of wood markets in keeping land in forest, the effect is clearly important.

# 8. The global forest industry's overall carbon and greenhouse gas profile

This chapter assembles the calculations discussed in the previous chapters to outline the global forest products industry's overall carbon and greenhouse gas profile. Manufacturing-related emissions dominate the forest industry's profile, amounting to approximately 490 million tonnes of $CO_2$ equivalent per year, or 55 percent of all emissions occurring throughout the value chain (Figure 12, Table 6). Of the manufacturing-related emissions, 55 percent are due to fuel combustion at forest products manufacturing facilities. Emissions related to purchased electricity account for 39 percent of manufacturing emissions, and the balance is attributable to methane releases from waste treatment and disposal operations at manufacturing plants.

Other large emissions occur at the end of the life cycle, where methane emissions total 235 million tonnes of $CO_2$ equivalent per year and emissions associated with burning used products amount to 3 million tonnes of $CO_2$ equivalent per year, for a total of 238 million tonnes. If additions to carbon stocks in landfills are considered as offsetting these emissions, the net end-of-life emissions are reduced to 77 million tonnes of $CO_2$ equivalent per year, of which 74 million tonnes are associated with used products in landfills.

Total emissions from the forest products value chain are estimated to be 890 million tonnes of $CO_2$ equivalent per year, before correcting for the sequestration accomplished in the value chain.

The forest products value chain accomplishes large removals of $CO_2$ from the atmosphere and stores a portion of these for long periods in products in use and in landfills. Evidence suggests that the total sequestration of $CO_2$ from the atmosphere associated with the products manufactured in 2007 will be 424 million tonnes of $CO_2$

FIGURE 12
**Greenhouse gas emissions for the global forest products sector**

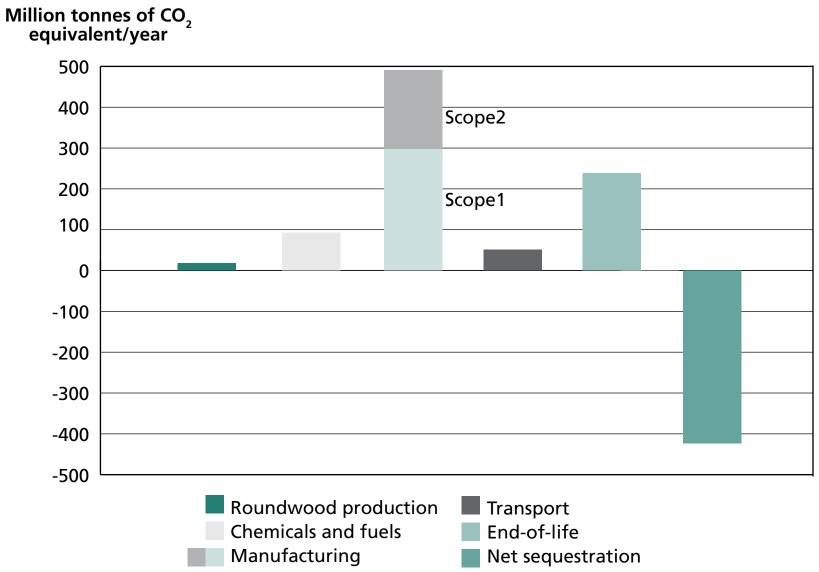


TABLE 6
**Estimated emissions and sequestration in the global forest products industry value chain, circa 2006/2007**

| Process | Emissions *(million tonnes $CO_2$ equivalent/ year)* |
|---|---|
| Direct emissions from manufacturing (Scope 1) | |
| Fuel combustion: pulp and paper | 207.0 |
| Fuel combustion: wood products | 25.6 |
| Fuel combustion: converting | 38.7 |
| Methane from manufacturing waste | 26.2 |
| **Total** | **297** |
| **Emissions associated with electricity purchases (Scope 2)** | |
| Pulp and paper | 106.0 |
| Wood products | 48.8 |
| Converting | 38.7 |
| **Total** | **193** |
| **Wood production** | **18.2** |
| **Upstream emissions associated with chemicals and fossil fuels** | |
| Non-fibre inputs: pulp and paper | 34.9 |
| Non-fibre inputs: wood products | 22.4 |
| Fossil fuels: pulp and paper | 30.5 |
| Fossil fuels: wood products | 4.6 |
| **Total** | **92.4** |
| **Transport** | |
| Cradle-to-gate | 21.0 |
| Gate-to-consumer | 26.7 |
| Consumer-to-grave | 3.6 |
| **Total** | **51.2** |
| **Product use** | |
| Emissions | 0 |
| Effect of additions to carbon stocks in paper products in use | -20 |
| Effect of additions to carbon stocks in wood products in use | -243 |
| **Total** | **-263** |
| **End-of-life** | |
| Burning used products | 3.0 |
| Paper-derived methane | 176.0 |
| Effect of additions to carbon stocks in paper products in landfills | -67.0 |
| Wood-derived methane | 58.6 |
| Effect of additions to carbon stocks in wood products in landfills | -93.6 |
| **Total** | **77.1** |

**Note:** Data are subject to rounding.
Total cradle-to-gate emissions = 622 million tonnes of $CO_2$ equivalent per year (not considering sequestration).
Total cradle-to-grave emissions = 890 million tonnes of $CO_2$ equivalent per year (not considering sequestration).
Value chain sequestration = net uptake of 424 million tonnes of $CO_2$ equivalent per year, based on estimates of the accumulation of carbon stocks in product pools and an assumption that globally, regeneration and regrowth are keeping carbon stocks stable in the forests the industry relies on.
Net value chain emissions, cradle-to-grave = 467 million tonnes of $CO_2$ equivalent per year.

equivalent, enough to offset 86 percent of the emissions associated with manufacturing and almost half of total value chain emissions.

When sequestration is considered, the emissions from the forest products value chain are estimated to be 467 million tonnes of $CO_2$ equivalent per year.

When examined separately, the pulp and paper sector's profile is different from that of the wood products sector. The paper products value chain emissions, after adjusting for carbon sequestration, appear to be between 500 and 600 million tonnes of $CO_2$ equivalent per year, while the wood products value chain appears to accomplish net sequestration of approximately 100 million tonnes of $CO_2$ equivalent per year. However, separating the wood products and paper sectors overlooks the extent to which they are connected via economics and physical flows. For instance, in many regions, by-products from wood product operations comprise a sizeable fraction of the fibre input for pulp and paper production.

The general features of this profile are similar to those of an earlier global profile by Miner and Perez-Garcia (2007b) and generally consistent with an earlier study by the International Institute for Environment and Development (IIED) (Subak, 1999). After correcting for sequestration, however, the net emissions are larger in this study. The first cause of this increase is that the present study uses a far smaller estimate of carbon storage in landfills, based on a more refined method for identifying regions that are unlikely to have the types of landfills that store carbon. The second major cause of this study's higher net emissions is the inclusion of several categories of emissions that were not previously included (e.g. upstream emissions associated with fossil fuels and non-fibre inputs in manufacturing). Each of these changes increased net emissions by approximately 100 million tonnes of $CO_2$ equivalent per year compared with the earlier study.

The indirect benefits occurring elsewhere in society and attributable to the forest products value chain are summarized in Table 7. Although the uncertainty associated with these estimates is large, the effects are clearly significant and in many cases could be expanded.

TABLE 7
**Summary of selected avoided emissions associated with the forest products value chain**

| Avoided emission | Global impacts (for illustrative purposes) *(million tonnes $CO_2$ equivalent/year)* | Comments |
|---|---|---|
| **Due to recycling**<br>Net releases of greenhouse gases from landfills that would occur if paper recovered in 2007 went into landfills instead (emissions minus carbon storage) | 300 | Recovery and reuse of used fibre has many more effects on greenhouse gases than avoided methane from landfills |
| **Due to burning used products**<br>Emissions from fossil fuel (natural gas) combustion that do not occur because forest products are used as a source of biomass energy | 25.8 | If the products made in 2007 that are expected to be sent to landfill were instead burned for energy, the expected global benefit would be a reduction in greenhouse gas emissions of at least 135 million tonnes of $CO_2$ equivalent per year |
| **Due to exports of electricity**<br>Emissions from electricity production that do not occur because of exports of low-emissions-intensity electricity from pulp, paper and paperboard mills | Not possible to develop a global estimate | Highly variable, depending on source of displaced electricity. Biomass-based electricity exported from a single mill can avoid the generation of several hundred thousand tonnes of $CO_2$ per year from coal-based electricity generation |
| **Due to substituting wood for non-wood materials in housing construction**<br>Net benefit of using wood-based systems for housing construction in 2007 | 483 | Estimated benefits depend on many factors, including assumptions about forest carbon stocks' response and end-of-life practices. Where wood-based construction is not common, there are large opportunities for increasing these benefits |
| **Due to providing a reason for keeping land in forest**<br>Carbon not lost to the atmosphere because land is kept in forest to supply the forest products industry | Not possible to develop a global estimate | Although an estimate is not possible, the impact is significant: If only 1% per year of industry-owned timberland in the United States was converted to non-forest uses, the result would be a transfer of carbon to the atmosphere equal to 90 million tonnes of $CO_2$ equivalent per year, not including soil carbon impacts |

# 9. The potential for forest-based materials to displace fossil fuels

Currently, biomass supplies 10.6 percent of global energy demand. However, developing countries rely far more on biomass for energy, with some using it to meet 50 to 90 percent of their energy demand, mostly for cooking and space heating (FAO, 2008; IEA, 2007b). Industry uses biomass to meet about 10 percent of its energy requirements globally, but almost all of this use is concentrated in the forest products industry, with the wood products and pulp and paper sectors deriving 61 and 48 percent, respectively, of their energy needs from biomass (IEA, 2006). In 2000, the global capacity for generating electricity from biomass was 40 GW, representing just over 1 percent of global generation capacity (FAO, 2008; IEA, 2002). Biofuels account for only about 1.5 percent of transport fuel use worldwide (IEA, 2007b), implying that there are significant opportunities for increasing the use of biomass for energy, especially outside the forest products industry.

IEA (2007b) estimates that by 2050, an additional 40 to 1 100 EJ of biomass energy could be available globally, with the likely range being 200 to 400 EJ (Table 8). This would be approximately four to eight times the current global use of biomass energy, estimated at 45 ± 10 EJ.

TABLE 8
**Potential biomass supply in 2050**

| Biomass category | Main assumptions and remarks | Energy potential from biomass by 2050 *(EJ)* |
|---|---|---|
| Energy farming on current agricultural land | Potential land surplus: 0–4 Gha (average: 1–2 Gha). A large surplus requires structural adaptation towards more efficient agricultural production systems. If this is not feasible, the bioenergy potential could be reduced to zero. On average, higher yields are likely from better soil quality: 8–12 dry tonnes per hectare per year is assumed. | 0–700 (average: 100–300) |
| Biomass production on marginal lands | Globally, a maximum of 1.7 Gha could be involved. Low productivity of 2–5 dry tonnes per hectare per year. The net supplies could be low owing to poor economics or competition with food production. | <60–110 |
| Residues from agriculture | Potential depends on yield-to-product ratios, the total agricultural land and the type of production system. Extensive production systems require reuse of residues for maintaining soil fertility. Intensive systems allow higher utilization rates of residues. | 15–70 |
| Forest residues | The sustainable energy potential of the world's forests is unclear – some natural forests are protected. Low value: includes limitations related to logistics and strict standards for removals of forest material. High value: technical potential. Figures include processing residues. | 30–150 |
| Dung | Use of dried dung. Low estimate based on current global use. High estimate: technical potential. Utilization (collection) in the longer term is uncertain. | 5–55 |
| Organic wastes | Estimated from literature values. Strongly dependent on economic development, consumption and the use of biomaterials. Figures include the organic fraction of municipal solid waste and waste wood. Higher values possible from more intensive use of biomaterials. | 5–50 |
| Combined potential | Most pessimistic scenario: no land available for energy farming; utilization of residues only. Most optimistic scenario: intensive agriculture concentrated on better-quality soils. In between: average potential in a world aiming for large-scale deployment of bioenergy. | 40–1 100 (average: 200–400) |

*Source:* IEA, 2007b.

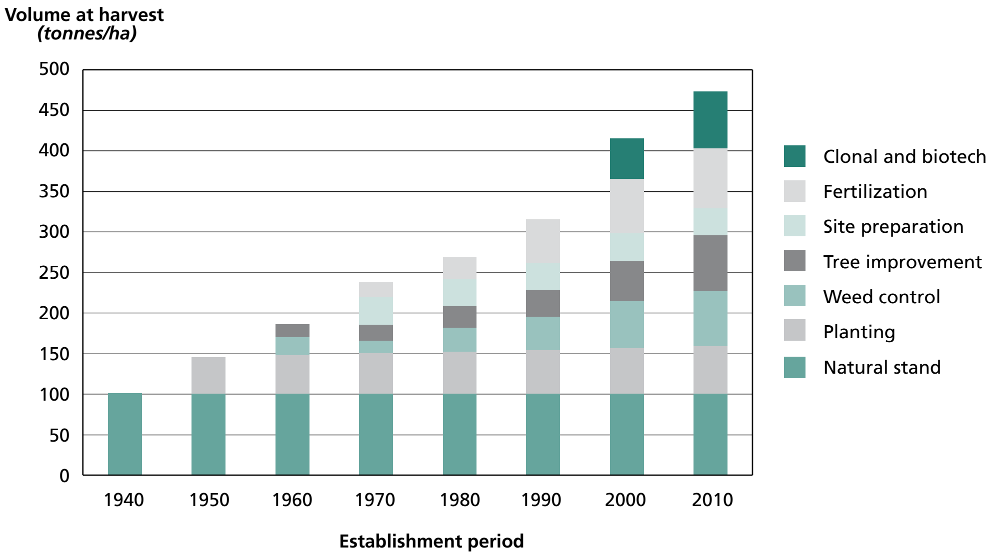
IEA estimates that forest residues, including processing residues, are capable of providing 30 to 150 EJ of additional biomass energy by 2050. IPCC estimates that biomass from forestry can contribute 12 to 74 EJ per year to energy consumption, with a mitigation potential equal to about 0.4 to 4.4 billion tonnes of $CO_2$ per year. With total global biomass energy consumption currently at 45 EJ, both of these estimates suggest the likelihood of a major increase in the demand for forest-derived biomass.

This has significant implications for companies owning forest and/or using wood. For forest owners, biomass energy provides an important new market and additional incentives for enhancing forest productivity and recovering unused biomass. For wood users, it represents competition for raw material. For instance, it has been estimated that 380 million cubic metres of wood will be needed to meet the EU's renewable energy commitments, an amount equal to the total currently used by the European forest products industry (de Galembert, 2008).

It is clear that meeting the need for additional forest biomass will require continued improvements in technologies for improving forest productivity. Figure 13 shows the productivity improvements in pine plantations in the southeastern United States as an example. With continued investment in forest productivity research, such gains can continue.

The efficient use of biomass to replace fossil fuels is an important component of efforts to reduce the accumulation of atmospheric $CO_2$. At present, approximately half of harvested wood is used for energy in low-efficiency heating or cooking applications in developing countries. Improving the efficiency of wood use in these applications will be important but challenging (FAO, 2008; 2007b). Also important will be the development of new technologies that use biomass efficiently in industrial and commercial applications. A number of biomass-conversion technologies are currently under study or being commercially deployed (IEA, 2007b; FAO, 2008).

FIGURE 13
**Factors in increased pine plantation productivity in the southeastern United States**




*Rauscher*, 2004.

# 10. IPCC's findings regarding the mitigation potential of forests

In the section on mitigation in IPCC's Fourth Assessment Report, the value of forests in climate change mitigation was summarized as follows:

> "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit." (IPCC, 2007b)

(In this mitigation report, IPCC's discussion of sustainable forest management generally refers to management practices in forests used for production of wood or non-wood forest products.)

The basis for this important summary statement warrants closer examination. This chapter examines the scientific bases for the disaggregated components of the statement.

### "IN THE LONG TERM…"

The processes that govern the cycling of carbon between the atmosphere and the biosphere operate over time scales ranging from seconds to centuries. Forest-based mitigation activities designed to achieve short-term benefits may, therefore, not be helpful in the medium to long term. One important reason for this is that there are limits to the amount of carbon that can be stored in the forest: i.e. the benefit saturates. The saturation point and the time it takes to reach it depend on many factors, including the starting conditions, the type of forest and the growing conditions (e.g. Marland, 1997).

In the short term, maximum atmospheric $CO_2$ reductions may sometimes be accomplished by preservation, allowing carbon to accumulate in forests. At some point, however, the accumulation of carbon in the forest saturates and the net removals of $CO_2$ from the atmosphere cease. In the long term, using sustainably produced forest biomass as a substitute for carbon-intensive products and fossil fuels provides greater permanent reductions in atmospheric $CO_2$ than preservation does. The time required for long-term effects to become more important than short-term ones is highly variable. The optimum approach in a particular situation depends not only on the forest's response to various management strategies, but also on the size of the substitution effect (e.g. Marland, 1997; Schlamadinger, 1996).

### "…A SUSTAINABLE FOREST MANAGEMENT STRATEGY…"

Sustainable forest management is at the heart of forest-based mitigation activities in production forests. The value of forests in climate change mitigation is primarily related to their ability to remove and store carbon from the atmosphere, and this ability is a function of the health of the forest. This report's earlier discussion of the role of sustainable forest management bears repeating here.

The core objective of all sustainable management programmes in production forests is to achieve a long-term balance between harvesting and regrowth. The operational guidelines for PEFC stipulate that "forest management practices should safeguard the quantity and quality of the forest resources in the medium and long term by balancing harvesting and growth rates" (PEFC, 2007a; 2007b; MCPFE, 1998). A key principle of the FSC Standard is that "the rate of harvest of forest products shall not exceed levels which can be permanently sustained" (FSC, 2002). Although certification programmes are not always explicit about the connections between sustainable management and carbon in production forests, the practical effect of maintaining a balance between harvesting and regrowth is to keep long-term carbon stocks stable in managed forests.

The benefits of sustainable management of production forests are clear when examining the forest carbon stocks in the regions with the largest amounts of certified forest. For example, in industry-owned timberland in the United States, forest carbon stocks are essentially stable (Heath *et al.*, 2010). In Canada, there is very large year-to-year variability in forest carbon stocks, due primarily to fires and insect damage. As a result, forest carbon stocks drop in some years. On average, however, forest carbon stocks in Canada's managed forest grew during the period 1990 to 2005 (NRC, 2007). The empirical evidence therefore supports the conceptual link between sustainable forest management and stable or increasing forest carbon stocks.

### "…AIMED AT MAINTAINING OR INCREASING FOREST CARBON STOCKS…"

The net benefits of any forest-based mitigation activity reflect both the impacts in the forest and the carbon storage and substitution effects accomplished elsewhere. If the mitigation activity reduces forest carbon stocks, this reduction must be netted against any benefits that the activity may accomplish. If the activity increases forest carbon stocks, the increase can be added to the activity's other carbon benefits.

As already noted, sustainable management activities in production forests are a critical element in maintaining forest carbon stocks. In addition to the benefits of regeneration and regrowth, such management can reduce the risk of catastrophic carbon losses due to fire (e.g. Lippke, 2008).

Where sustainable forest management involves converting forest type, the impact on forest carbon stocks (positive or negative) should be accounted for when assessing the overall benefits of forest-based mitigation activities (e.g. Kurz, 1998).

### "…WHILE PRODUCING AN ANNUAL SUSTAINED YIELD OF TIMBER, FIBRE OR ENERGY FROM THE FOREST…"

The wood removed from sustainably managed forests can have various carbon-related benefits. Only part of the carbon removed from the atmosphere in the forest is returned to the atmosphere, because some of it remains stored in forest products. Some forest products, notably wood-based building materials and biomass burned for energy, can reduce society's use of fossil fuels. The ability to produce these benefits continuously, via sustainable forest management, is a key feature of forest-based mitigation.

The benefits are significant. As estimated previously, the use of wood-based building materials may be avoiding global greenhouse gas emissions of 483 million tonnes of $CO_2$ equivalent per year, via substitution effects. During use, the long-term storage of carbon in these wood-based building materials is equivalent to removing an additional 243 million tonnes of $CO_2$ from the atmosphere per year. Burning used products at the end of the life cycle avoids the emission of more than 25 million tonnes of $CO_2$ equivalent per year, with an opportunity to increase this to 135 million tonnes by diverting material from landfills. IPCC estimates that forest biomass-derived energy could reduce global emissions by 400 million to 4.4 billion tonnes of $CO_2$ equivalent per year. These benefits can occur and continue only if forests are used to produce "an annual sustained yield of timber, fibre or energy".

### "…WILL GENERATE THE LARGEST SUSTAINED MITIGATION BENEFIT."

For climate change mitigation, the optimal use of any plot of forest land depends on the specific conditions that apply to that land and the products it produces. Nonetheless, the greatest long-term benefits are obtained when forest carbon stocks are maintained or increased while the forest continues to produce products that directly or indirectly reduce societal greenhouse gas emissions.

The scientific justification for IPCC's summary statement is sound, and has been reaffirmed by a body of research stretching back to at least the mid-1990s (Marland, 1997; Schlamadinger, 1996).

# 11. Key findings

In 2006, the forest industry (roundwood production, pulp and paper, and wood processing) contributed approximately US$468 billion annually to the global economy – approximately 1 percent of global economic activity – and provided employment for 13.7 million people.

In 2007, approximately 3.6 billion cubic metres of roundwood were removed from the world's forests. Over one-half (53 percent) of this was used as fuelwood, 90 percent of which is used in developing countries, primarily for heating and cooking. The remaining 47 percent of roundwood harvests were for industrial purposes. Sixty-nine percent of the harvesting of industrial roundwood takes place in North America and Europe. Global production of wood and paper products amounts to approximately 710 million tonnes per year, about 54 percent of which is paper and paperboard products.

Certification of sustainable forest management is widespread in the developed world and growing in the developing world. By 2008, almost 8 percent of the world's forests and 13 percent of the world's managed forests had been third-party certified. Approximately one-quarter of global industrial roundwood comes from certified forests, most of which are located in North America and Europe. The amount of certified forest is growing globally by about 10 percent per year. Certification is less common in developing countries. Less than 2 percent of forest in Asia, Africa and Latin America is certified. Eighty-two percent of certified forests in the tropics are privately owned, and most of these are in large management units.

In addition to wood, the forest products industry uses large amounts of recovered fibre. Approximately 50 percent of the paper and paperboard produced globally is recovered, and most of this is recycled to make paper and paperboard.

This study has characterized the complex connections between the forest products industry value chain and the global carbon cycle. These connections include:

- carbon sequestration and storage in forests and forest products;
- emissions from forest products manufacturing operations;
- emissions that occur upstream of manufacturing;
- emissions from product transport and use;
- emissions associated with end-of-life management;
- emissions avoided elsewhere in society because of forest industry activities.

Although it is not possible to quantify the effect of the forest products industry's activities on global forest ecosystem carbon stocks, the evidence suggests that in many places corporate forest owners and forest product companies are engaged in practices that will increase forest ecosystem carbon stocks or help avoid their declines. Key among these practices are the establishment of planted forests, primarily on areas that were not previously forested, and adherence to sustainable management practices in production forests (and increasingly, chain-of-custody programmes). Experiences in North America and the European Union, the regions with most of the world's certified forests, offer insights into the effectiveness of sustainable management of production forests. Even though these regions account for more than two-thirds of the world's global industrial roundwood production, their forest carbon stocks are generally stable or increasing.

Sustainable forest management is key to maintaining forest carbon stocks. Although maintenance of carbon stocks is not addressed directly in the main programmes for certifying sustainable forest management, it is inherent in their requirements. The operational guidelines for PEFC, the largest certification programme, stipulate that "forest management practices should safeguard the quantity and quality of the forest resources in the medium and long term by balancing harvesting and growth rates…". A key principle of the FSC Standard, the second largest certification programme, is that "the rate of harvest of forest products shall not exceed levels which can be permanently sustained".

Total greenhouse gas emissions from the forest products value chain are estimated to be 890 million tonnes $CO_2$ equivalent per year, not considering the sequestration accomplished in the value chain. Of these, 33 percent are from manufacturing facilities, 22 percent are associated with purchased electricity, 10 percent are related to production of non-fibre inputs to manufacturing, 2 percent are related to wood production, 6 percent are transport related and 27 percent are associated with the end of the product's life, almost entirely methane emissions from landfills receiving used products.

The forest products value chain accomplishes large net removals of $CO_2$ from the atmosphere as a result of uptake in forests and storage in forests, products in use and products in landfills. Net sequestration of $CO_2$ from the atmosphere into the forest products industry value chain in 2007 was 424 million tonnes $CO_2$ equivalent, enough to offset 86 percent of the greenhouse gas emissions associated with manufacturing of forest products and almost one-half of the total emissions of the value chain. After considering sequestration, the net greenhouse gas emissions from the forest products value chain are 467 million tonnes $CO_2$ equivalent per year.

Between 2002 and 2007, the direct emissions intensity (direct greenhouse gas emissions per tonne of product) of pulp and paper mills was reduced by 13 percent. Over the same period, the direct emissions intensity from wood product facilities fell by 16 percent. The emissions intensity of the forest industry would be higher if biomass fuels were not used so extensively – they comprise over one-half of the fuel used by the industry.

The pulp and paper and wood products sectors are closely connected via wood flows, ownership of facilities and land, and economics. As a result, the carbon footprints of these sectors are also closely connected, and attempts to influence one sector are likely to have impact on the other. Looked at separately, however, the pulp and paper sector is generally characterized by higher emissions and less sequestration than the wood products sector.

A number of aspects of the forest industry's activities are not adequately captured by looking only at the emissions and sequestration accomplished in the value chain. On an annual basis, the use of wood-based building materials avoids, via substitution effects, emissions of 483 million tonnes of $CO_2$ equivalent per year. Also, by displacing fossil fuels, burning used products at the end of the life cycle avoids the emission of over 25 million tonnes of $CO_2$ equivalent per year. These avoided emissions could be increased to 135 million tonnes $CO_2$ equivalent per year by diverting material from landfills. IPCC estimates that energy derived from forest biomass could reduce global emissions by 400 million to 4.4 billion tonnes $CO_2$ equivalent per year. The industry can help society reach this goal through its forest biotechnology research and its forest biomass infrastructure. The market for wood gives landowners a reason to keep land in forest, helping to avoid large-scale losses of carbon to the atmosphere via land use change.

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# Annex 1
# Calculations

## CARBON STORAGE IN PAPER PRODUCTS IN USE AND IN LANDFILLS

The amount of paper stored in paper products was calculated using the PAS 2050 approach in which the footprint of forest products is credited with the weighted average amount of carbon stored over a 100-year period (BSI, 2008). Using IPCC's first order model, and half-lives for the time-in-use of forest products (two years for paper) (IPCC, 2006), the 100-year weighted average for the carbon storage in paper is 2.885 percent of the original biomass carbon.

The countries responsible for 90 percent of global paper and paperboard consumption were identified by adding each country's imports to its production, and subtracting its exports (FAO, 2007) (Table A-1).

Each country's consumption was multiplied by 2.885 percent to determine the amount remaining in use (Table A-2) , which also shows the amounts going to landfill in each country. These estimates were calculated by subtracting the amount remaining in use from each country's consumption, and assuming that the remainder was recycled or sent for end-of-life management. The amounts of paper recovered for recycling were taken from FAOSTAT (FAO, 2007) and subtracted from these remainders, to yield estimates of the amounts destined for end-of-life management at solid waste disposal sites or landfills. This was assumed to be the same as the fraction of municipal solid waste destined for landfills in each country, as reported in IPCC's 2006 national inventory guidelines (IPCC, 2006).

To estimate the amount of carbon stored in landfills, the quantities going to landfill were multiplied by the carbon content, assumed to be 50 percent. Carbon storage was assumed to be limited to the non-degradable fraction of the carbon. Because biomass carbon in forest products is non-degradable only under anaerobic conditions, it was necessary to calculate the fraction of waste in each country that was disposed in anaerobic conditions. In general, highly engineered landfills in developed countries are more anaerobic than unmanaged landfills in developing countries. IPCC's methane correction factors (MCFs) give an estimate of the fractions of waste held under anaerobic conditions in a number of different landfill types (Table A-3).

Based on the values in Table A-3, it was assumed that countries with per capita GDP (on a purchasing power parity [PPP] basis) of more than US$30 000 would have an MCF value of 0.9; those with per capita GDP of less than US$10 000 would have an MCF of 0.4; and those with per capita GDP of between US$10 000 and US$30 000 would have an MCF of 0.6. From this, the amount of carbon in disposed paper and paperboard products destined for anaerobic landfills was estimated for each country.

To estimate the fraction of non-degradable anaerobic carbon, the IPCC default value of 50 percent was used (IPCC, 2006). The amount of non-degradable carbon was then converted to $CO_2$ equivalent (Table A-4).

Note that data in the tables are subject to rounding, which results in some minor inconsistencies.

TABLE A-1
**Countries responsible for 90 percent of paper and paperboard consumption**

| Country | Per capita GDP (PPP basis) *(US$)* | Production 2007 *('000 tonnes)* | Imports 2007 *('000 tonnes)* | Exports 2007 *('000 tonnes)* | Consumption 2007 *('000 tonnes)* | % of global consumption |
|---|---|---|---|---|---|---|
| Argentina | 14 020 | 1 545 | 872 | 155 | 2 262 | 0.6 |
| Australia | 34 040 | 3 192 | 1 490 | 684 | 3 998 | 1.0 |
| Austria | 37 680 | 5 199 | 1 328 | 4 268 | 2 259 | 0.6 |
| Belgium | 34 760 | 1 897 | 3 957 | 3 298 | 2 556 | 0.7 |
| Brazil | 10 070 | 5 836 | 1 046 | 2 590 | 4 293 | 1.1 |
| Canada | 36 220 | 18 113 | 2 839 | 13 131 | 7 821 | 2.0 |
| China | 6 020 | 78 026 | 7 820 | 7 253 | 78 594 | 20.5 |
| France | 34 400 | 9 871 | 6 360 | 5 098 | 11 133 | 2.9 |
| Germany | 35 940 | 23 172 | 9 376 | 11 028 | 21 519 | 5.6 |
| India | 2 960 | 4 183 | 1 381 | 299 | 5 265 | 1.4 |
| Indonesia | 3 830 | 7 223 | 385 | 3 718 | 3 890 | 1.0 |
| Italy | 30 250 | 10 112 | 5 295 | 3 513 | 11 894 | 3.1 |
| Japan | 35 220 | 28 930 | 1 664 | 1 667 | 28 927 | 7.6 |
| Korea, Republic of | 28 120 | 10 932 | 844 | 3 066 | 8 710 | 2.3 |
| Malaysia | 13 740 | 1 062 | 2 228 | 275 | 3 015 | 0.8 |
| Mexico | 14 270 | 5 594 | 3 335 | 386 | 8 543 | 2.2 |
| Netherlands | 41 670 | 3 224 | 3 519 | 3 106 | 3 637 | 1.0 |
| Poland | 17 310 | 2 992 | 2 838 | 1 553 | 4 277 | 1.1 |
| Russian Federation | 15 630 | 7 559 | 1 462 | 2 512 | 6 509 | 1.7 |
| South Africa | 9 780 | 3 033 | 527 | 944 | 2 616 | 0.7 |
| Spain | 31 130 | 6 714 | 5 878 | 2 737 | 9 855 | 2.6 |
| Sweden | 38 180 | 11 902 | 1 056 | 10 649 | 2 309 | 0.6 |
| Switzerland | 46 460 | 1 536 | 958 | 761 | 1 733 | 0.5 |
| Thailand | 5 990 | 4 484 | 751 | 984 | 4 251 | 1.1 |
| Turkey | 13 770 | 1 643 | 2 495 | 196 | 3 942 | 1.0 |
| United Kingdom | 36 130 | 5 284 | 7 883 | 970 | 12 197 | 3.2 |
| United States | 46 970 | 83 826 | 14 964 | 10 972 | 87 818 | 22.9 |
| Viet Nam | 2 700 | 1 309 | 648 | 24 | 1 933 | 0.5 |

*Sources:* World Bank, 2009 (GDP); FAO, 2007.

TABLE A-2
**Calculation of the carbon in paper remaining in use and in discards to landfills**

| Country | % waste sent to landfill after recovery 2000 (from IPCC, 2006) | Remaining in use[a] *('000 tonnes)* | Recovered paper *('000 tonnes)* | Discards[b] *('000 tonnes)* | Discards to landfill *('000 tonnes)* |
|---|---|---|---|---|---|
| Argentina | 59 | 65 | 943 | 1 253 | 739 |
| Australia | 100 | 115 | 3 032 | 851 | 851 |
| Austria | 30 | 65 | 1 539 | 655 | 196 |
| Belgium | 17 | 74 | 2 295 | 187 | 32 |
| Brazil | 80 | 124 | 3 642 | 527 | 421 |
| Canada | 71 | 226 | 2 851 | 4 744 | 3 368 |
| China | 97 | 2 268 | 31 324 | 45 002 | 43 652 |
| France | 43 | 321 | 5 947 | 4 865 | 2 092 |
| Germany | 30 | 621 | 15 746 | 5 153 | 1 546 |
| India | 70 | 152 | 850 | 4 263 | 2 984 |
| Indonesia | 80 | 112 | 1 163 | 2 615 | 2 092 |
| Italy | 70 | 343 | 5 580 | 5 971 | 4 180 |
| Japan | 25 | 835 | 22 837 | 5 255 | 1 314 |
| Korea, Republic of | 42 | 251 | 7 998 | 461 | 193 |
| Malaysia | 70 | 87 | 1 112 | 1 816 | 1 271 |
| Mexico | 49 | 247 | 4 302 | 3 995 | 1 957 |
| Netherlands | 11 | 105 | 2 307 | 1 225 | 135 |
| Poland | 98 | 123 | 1 550 | 2 603 | 2 551 |
| Russian Federation | 71 | 188 | 2 100 | 4 221 | 2 997 |
| South Africa | 90 | 75 | 923 | 1 617 | 1 456 |
| Spain | 68 | 284 | 5 678 | 3 893 | 2 647 |
| Sweden | 23 | 67 | 1 598 | 644 | 148 |
| Switzerland | 100 | 50 | 1 324 | 359 | 359 |
| Thailand | 80 | 123 | 1 708 | 2 421 | 1 936 |
| Turkey | 99 | 114 | 1 016 | 2 812 | 2 784 |
| United Kingdom | 82 | 352 | 8 617 | 3 228 | 2 647 |
| United States | 55 | 2 534 | 46 431 | 38 853 | 21 369 |
| Viet Nam | 60 | 56 | 77 | 1 800 | 1 080 |
| **Total from above** | | **9 976** | | | **106 999** |
| **Extrapolated to global consumption** | | **11 042** | | | **118 426** |
| **Converted to tonnes of $CO_2$ equivalent, assuming 50% carbon** | | **20 243** | | | |

[a] Fraction remaining in use = 0.02885.
[b] Consumption minus recovered minus remaining in use.

TABLE A-3
**IPCC's methane correction factors**

| Type of site | MCF | Comments |
|---|---|---|
| Managed: anaerobic | 1.0 | |
| Managed: semi-aerobic | 0.5 | |
| Unmanaged: deep (> 5 m) | 0.8 | Also applies to sites with a high water table |
| Unmanaged: shallow (< 5 m) | 0.4 | |
| Uncategorized solid waste disposal sites | 0.6 | |

*Source:* IPCC, 2006.

TABLE A-4
**Calculation of carbon stored in paper and paperboard products in landfills**

| Country | Carbon to landfills[a] *('000 tonnes)* | IPCC MCF (fraction anaerobic) | Carbon in anaerobic zones of landfills *('000 tonnes)* | Carbon remaining after degradation[b] *('000 tonnes)* | Carbon storage *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|
| Argentina | 370 | 0.6 | 222 | 111 | 407 |
| Australia | 425 | 0.9 | 383 | 191 | 702 |
| Austria | 98 | 0.9 | 88 | 44 | 162 |
| Belgium | 16 | 0.9 | 14 | 7 | 26 |
| Brazil | 211 | 0.6 | 126 | 63 | 232 |
| Canada | 1 684 | 0.9 | 1 516 | 758 | 2 779 |
| China | 21 826 | 0.4 | 8 730 | 4 365 | 16 006 |
| France | 1 046 | 0.9 | 941 | 471 | 1 726 |
| Germany | 773 | 0.9 | 696 | 348 | 1 275 |
| India | 1 492 | 0.4 | 597 | 298 | 1 094 |
| Indonesia | 1 046 | 0.4 | 418 | 209 | 767 |
| Italy | 2 090 | 0.9 | 1 881 | 940 | 3 448 |
| Japan | 657 | 0.9 | 591 | 296 | 1 084 |
| Korea, Republic of | 97 | 0.6 | 58 | 29 | 106 |
| Malaysia | 635 | 0.6 | 381 | 191 | 699 |
| Mexico | 979 | 0.6 | 587 | 294 | 1 077 |
| Netherlands | 67 | 0.9 | 61 | 30 | 111 |
| Poland | 1 276 | 0.6 | 765 | 383 | 1 403 |
| Russian Federation | 1 499 | 0.6 | 899 | 450 | 1 648 |
| South Africa | 728 | 0.4 | 291 | 146 | 534 |
| Spain | 1 323 | 0.9 | 1 191 | 596 | 2 184 |
| Sweden | 74 | 0.9 | 67 | 33 | 122 |
| Switzerland | 179 | 0.9 | 161 | 81 | 296 |
| Thailand | 968 | 0.4 | 387 | 194 | 710 |
| Turkey | 1 392 | 0.6 | 835 | 418 | 1 531 |
| United Kingdom | 1 324 | 0.9 | 1 191 | 596 | 2 184 |
| United States | 10 685 | 0.9 | 9 616 | 4 808 | 17 630 |
| Viet Nam | 540 | 0.4 | 216 | 108 | 396 |
| **Total from above** | | | | | **60 339** |
| **Extrapolated to world** | | | | | **67 043** |

[a] Carbon content = 50 percent.
[b] Assuming 50 percent of carbon in anaerobic zones is non-degradable under anaerobic conditions.

## CARBON STORAGE IN WOOD PRODUCTS IN USE AND IN LANDFILLS

The amount of carbon stored in wood products in use was also calculated using the PAS 2050 approach, which credits the footprint of forest products with the weighted average amount of carbon stored over a 100-year period (BSI, 2008). Using IPCC's first order model and half-lives for the time-in-use of forest products (30 years for wood products) (IPCC, 2006), the 100-year weighted average for the carbon storage in wood products is 38.987 percent of the original biomass carbon.

The countries responsible for 90 percent of global wood product consumption (Table A-5) were identified by adding each country's imports to its production, and subtracting its exports (FAO, 2007). Cubic metres were converted to tonnes using separate conversion factors for sawnwood and wood panels. Both factors represent weighted average conversion factors, which for sawnwood were weighted by the global production of coniferous and non-coniferous wood, and for panels by the global production of veneer, plywood, particleboard and fibreboard.

The consumption of each country was multiplied by 39.987 percent to determine the amount remaining in use (Table A-6). The amount going to landfill in each country was estimated by subtracting the amount remaining in use from each country's consumption, and the remainder was assumed to be recycled or sent to end-of-life management (landfills). It was assumed that 30 percent of this wood was recovered for recycling, and the rest was destined for end-of-life management. For each country, the fraction of discarded wood (after recovery for recycling) destined for landfills was assumed to be the same as the fraction of municipal solid waste destined for landfills, as reported in IPCC's 2006 national inventory guidelines (IPCC, 2006).

To estimate the amount of carbon stored in landfills, the quantities going to landfill were multiplied by the carbon content, assumed to be 50 percent. Carbon storage was assumed to be limited to the non-degradable fraction of the carbon. Because biomass carbon in forest products is non-degradable only under anaerobic conditions, it was necessary to calculate the fraction of waste in each country that was disposed in anaerobic conditions. In general, highly engineered landfills in developed countries are more anaerobic than unmanaged landfills in developing countries. IPCC's MCFs give an estimate of the fractions of waste held under anaerobic conditions in a number of different landfill types, as shown in Table A-3.

Again, it was assumed that countries with per capita GDP of more than US$30 000 would have an MCF value of 0.9; those with per capita GDP of less than US$10 000 would have an MCF of 0.4; and those with per capita GDP of between US$10 000 and US$30 000 would have an MCF of 0.6. From this, the amount of carbon in discarded wood products destined for anaerobic landfills was estimated for each country.

To estimate the non-degradable fraction of the anaerobic carbon, it was necessary to know the fraction of carbon in wood products that does not degrade under anaerobic environments. The IPCC default value is 50 percent (IPCC, 2006), but information from other sources indicates that this value significantly overstates the degradation of wood products in anaerobic landfills. Studies by Barlaz (summarized in USEPA, 2006; IFC, 2009) suggest that 80 percent of the biomass carbon in wood products will not degrade under anaerobic conditions, and this figure was used for the calculations in Table A-6. The amount of non-degradable carbon was then converted into $CO_2$ equivalent (Table A-7).

TABLE A-5
**Countries accounting for 90 percent of global wood products consumption**

| Country | Sawnwood | | | | | Wood-based panels | | | | | Total wood products | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Production 2007 ('000 m³) | Imports ('000 m³) | Exports ('000 m³) | Consumption[a] ('000 m³) | Consumption[a] ('000 tonnes) | Production 2007 ('000 m³) | Imports ('000 m³) | Exports ('000 m³) | Consumption[b] ('000 m³) | Consumption[b] ('000 tonnes) | Consumption ('000 tonnes) | % of global consumption |
| Argentina | 2 103 | 101 | 237 | 1 967 | 942 | 1 333 | 110 | 303 | 1 140 | 566 | 1 508 | 0.4 |
| Australia | 5 064 | 575 | 377 | 5 262 | 2 520 | 1 788 | 545 | 441 | 1 892 | 940 | 3 460 | 1.0 |
| Austria | 11 262 | 1 707 | 7 842 | 5 127 | 2 455 | 3 716 | 883 | 3 584 | 1 015 | 504 | 2 959 | 0.9 |
| Belgium | 1 555 | 2 275 | 1 203 | 2 627 | 1 258 | 2 552 | 1 865 | 2 887 | 1 530 | 760 | 2 018 | 0.6 |
| Brazil | 24 414 | 145 | 3 167 | 21 392 | 10 243 | 8 680 | 437 | 3 770 | 5 347 | 2 657 | 12 900 | 3.8 |
| Canada | 52 284 | 1 635 | 33 184 | 20 736 | 9 929 | 14 645 | 2 846 | 10 686 | 6 805 | 3 381 | 13 310 | 3.9 |
| Chile | 8 340 | 35 | 3 642 | 4 733 | 2 266 | 2 482 | 133 | 1 448 | 1 167 | 580 | 2 846 | 0.8 |
| China | 29 202 | 8 131 | 973 | 36 360 | 17 411 | 70 955 | 4 200 | 15 166 | 59 988 | 29 806 | 47 216 | 13.9 |
| Czech Republic | 5 454 | 513 | 1 708 | 4 259 | 2 039 | 1 716 | 723 | 1 238 | 1 201 | 597 | 2 636 | 0.8 |
| Denmark | 300 | 2 201 | 143 | 2 357 | 1 129 | 343 | 1 609 | 161 | 1 791 | 890 | 2 019 | 0.6 |
| Egypt | 2 | 1 911 | 0 | 1 913 | 916 | 56 | 260 | 1 | 315 | 157 | 1 073 | 0.3 |
| Estonia | 1 750 | 824 | 709 | 1 866 | 893 | 402 | 277 | 306 | 373 | 185 | 1 079 | 0.3 |
| Finland | 12 477 | 626 | 7 081 | 6 023 | 2 884 | 1 995 | 401 | 1 543 | 853 | 424 | 3 308 | 1.0 |
| France | 10 190 | 4 497 | 1 399 | 13 288 | 6 363 | 6 709 | 2 450 | 3 761 | 5 398 | 2 682 | 9 045 | 2.7 |
| Germany | 25 170 | 4 222 | 9 565 | 19 827 | 9 494 | 18 185 | 4 114 | 6 313 | 15 986 | 7 943 | 17 437 | 5.1 |
| Greece | 108 | 928 | 14 | 1 023 | 490 | 918 | 367 | 71 | 1 214 | 603 | 1 093 | 0.3 |
| India | 14 789 | 122 | 15 | 14 896 | 7 133 | 2 554 | 257 | 63 | 2 748 | 1 365 | 8 498 | 2.5 |
| Iran, Islamic Republic of | 52 | 909 | 0 | 961 | 460 | 795 | 658 | 7 | 1 446 | 718 | 1 178 | 0.3 |
| Italy | 1 700 | 8 031 | 435 | 9 296 | 4 451 | 5 701 | 2 945 | 1 502 | 7 144 | 3 550 | 8 001 | 2.4 |
| Japan | 11 632 | 7 354 | 29 | 18 957 | 9 077 | 5 313 | 4 641 | 40 | 9 914 | 4 926 | 14 003 | 4.1 |
| Korea, Republic of | 4 366 | 966 | 19 | 5 313 | 2 544 | 3 706 | 2 786 | 53 | 6 439 | 3 199 | 5 743 | 1.7 |
| Malaysia | 5 122 | 1 005 | 2 078 | 4 049 | 1 939 | 7 719 | 367 | 7 087 | 999 | 496 | 2 435 | 0.7 |
| Mexico | 2 687 | 4 974 | 64 | 7 597 | 3 638 | 547 | 1 085 | 94 | 1 538 | 764 | 4 401 | 1.3 |
| Netherlands | 271 | 3 434 | 601 | 3 104 | 1 486 | 15 | 1 886 | 405 | 1 496 | 743 | 2 230 | 0.7 |
| New Zealand | 4 280 | 52 | 1 781 | 2 551 | 1 222 | 2 203 | 63 | 906 | 1 360 | 676 | 1 897 | 0.6 |
| Norway | 2 402 | 1 173 | 387 | 3 187 | 1 526 | 613 | 278 | 177 | 715 | 355 | 1 881 | 0.6 |
| Pakistan | 1 313 | 225 | 0 | 1 538 | 736 | 481 | 172 | 0 | 653 | 324 | 1 061 | 0.3 |
| Poland | 3 304 | 805 | 625 | 3 484 | 1 668 | 8 534 | 1 717 | 2 275 | 7 977 | 3 963 | 5 632 | 1.7 |
| Romania | 4 143 | 47 | 2 384 | 1 806 | 865 | 1 263 | 1 047 | 866 | 1 444 | 718 | 1 582 | 0.5 |
| Russian Federation | 23 200 | 18 | 17 277 | 5 941 | 2 845 | 9 813 | 1 660 | 2 493 | 8 980 | 4 462 | 7 307 | 2.2 |
| Saudi Arabia | 0 | 1 807 | 0 | 1 807 | 865 | 0 | 705 | 0 | 705 | 350 | 1 216 | 0.4 |
| Slovakia | 2 781 | 257 | 1 235 | 1 803 | 863 | 844 | 539 | 456 | 927 | 461 | 1 324 | 0.4 |
| South Africa | 2 091 | 535 | 79 | 2 548 | 1 220 | 786 | 345 | 73 | 1 058 | 526 | 1 746 | 0.5 |
| Spain | 3 332 | 4 015 | 138 | 7 209 | 3 452 | 5 390 | 1 625 | 1 736 | 5 279 | 2 623 | 6 075 | 1.8 |
| Sweden | 18 600 | 409 | 11 347 | 7 662 | 3 669 | 928 | 1 222 | 961 | 1 188 | 590 | 4 259 | 1.3 |
| Switzerland | 1 541 | 425 | 347 | 1 620 | 776 | 1 086 | 628 | 829 | 885 | 440 | 1 216 | 0.4 |
| Turkey | 6 599 | 634 | 76 | 7 157 | 3 427 | 5 459 | 1 102 | 842 | 5 719 | 2 842 | 6 269 | 1.9 |
| Ukraine | 2 525 | 10 | 1 474 | 1 062 | 508 | 2 029 | 676 | 491 | 2 214 | 1 100 | 1 608 | 0.5 |
| United Kingdom | 3 146 | 8 403 | 337 | 11 212 | 5 369 | 3 549 | 3 891 | 512 | 6 928 | 3 442 | 8 811 | 2.6 |
| United States | 84 363 | 32 213 | 4 381 | 112 195 | 53 724 | 41 091 | 16 213 | 2 226 | 55 078 | 27 366 | 81 090 | 23.9 |
| Viet Nam | 3 150 | 563 | 129 | 3 583 | 1 716 | 559 | 488 | 33 | 1 013 | 503 | 2 219 | 0.7 |

[a] Factor for conversion of sawnwood from cubic metres to tonnes = 0.47884.
[b] Factor for conversion of panels from cubic metres to tonnes = 0.496864.

TABLE A-6
**Calculation of carbon stored in wood products in use and in discards to landfills**

| Country | Per capita GDP PPP 2008 *(US$)* | Consumption 2007 *(tonnes)* | % municipal solid waste sent to landfill after recovery 2000[a] | Remaining in use[b] *(tonnes)* | Recovered wood waste 2007[c] | Discards[d] | Discards to landfill |
|---|---|---|---|---|---|---|---|
| Argentina | 14 020 | 1 508 | 59 | 588 | 276 | 644 | 380 |
| Australia | 34 040 | 3 460 | 100 | 1 349 | 633 | 1 478 | 1 478 |
| Austria | 37 680 | 2 959 | 30 | 1 154 | 542 | 1 264 | 379 |
| Belgium | 34 760 | 2 018 | 17 | 787 | 369 | 862 | 147 |
| Brazil | 10 070 | 12 900 | 80 | 5 029 | 2 361 | 5 509 | 4 408 |
| Canada | 36 220 | 13 310 | 71 | 5 189 | 2 436 | 5 685 | 4 036 |
| Chile | 13 270 | 2 846 | 40 | 1 110 | 521 | 1 216 | 486 |
| China | 6 020 | 47 216 | 97 | 18 408 | 8 642 | 20 166 | 19 561 |
| Czech Republic | 22 790 | 2 636 | 75 | 1 028 | 483 | 1 126 | 844 |
| Denmark | 37 280 | 2 019 | 10 | 787 | 369 | 862 | 86 |
| Egypt | 5 460 | 1 073 | 70 | 418 | 196 | 458 | 321 |
| Estonia | 19 280 | 1 079 | 98 | 421 | 197 | 461 | 452 |
| Finland | 35 660 | 3 308 | 61 | 1 290 | 605 | 1 413 | 862 |
| France | 34 400 | 9 045 | 43 | 3 526 | 1 656 | 3 863 | 1 661 |
| Germany | 35 940 | 17 437 | 30 | 6 798 | 3 192 | 7 447 | 2 234 |
| Greece | 28 470 | 1 093 | 91 | 426 | 200 | 467 | 425 |
| India | 2 960 | 8 498 | 70 | 3 313 | 1 555 | 3 629 | 2 541 |
| Iran, Islamic Republic of | 10 840 | 1 178 | 100 | 459 | 216 | 503 | 503 |
| Italy | 30 250 | 8 001 | 70 | 3 119 | 1 465 | 3 417 | 2 392 |
| Japan | 35 220 | 14 003 | 25 | 5 459 | 2 563 | 5 981 | 1 495 |
| Korea, Republic of | 28 120 | 5 743 | 42 | 2 239 | 1 051 | 2 453 | 1 030 |
| Malaysia | 13 740 | 2 435 | 70 | 949 | 446 | 1 040 | 728 |
| Mexico | 14 270 | 4 401 | 49 | 1 716 | 806 | 1 880 | 921 |
| Netherlands | 41 670 | 2 230 | 11 | 869 | 408 | 952 | 105 |
| New Zealand | 25 090 | 1 897 | 70 | 740 | 347 | 810 | 567 |
| Norway | 58 500 | 1 881 | 55 | 733 | 344 | 803 | 442 |
| Pakistan | 2 700 | 1 061 | 100 | 414 | 194 | 453 | 453 |
| Poland | 17 310 | 5 632 | 98 | 2 196 | 1 031 | 2 405 | 2 357 |
| Romania | 13 500 | 1 582 | 1 | 617 | 290 | 676 | 7 |
| Russian Federation | 15 630 | 7 307 | 71 | 2 849 | 1 337 | 3 121 | 2 216 |
| Saudi Arabia | 22 950 | 1 216 | 100 | 474 | 223 | 519 | 519 |
| Slovakia | 21 300 | 1 324 | 100 | 516 | 242 | 565 | 565 |
| South Africa | 9 780 | 1 746 | 90 | 681 | 320 | 746 | 671 |
| Spain | 31 130 | 6 075 | 68 | 2 369 | 1 112 | 2 595 | 1 764 |
| Sweden | 38 180 | 4 259 | 23 | 1 661 | 780 | 1 819 | 418 |
| Switzerland | 46 460 | 1 216 | 100 | 474 | 222 | 519 | 519 |
| Turkey | 13 770 | 6 269 | 99 | 2 444 | 1 147 | 2 677 | 2 651 |
| Ukraine | 7 210 | 1 608 | 90 | 627 | 294 | 687 | 618 |
| United Kingdom | 36 130 | 8 811 | 82 | 3 435 | 1 613 | 3 763 | 3 086 |
| United States | 46 970 | 81 090 | 55 | 31 614 | 14 843 | 34 633 | 19 048 |
| Viet Nam | 2 700 | 2 219 | 60 | 865 | 406 | 948 | 569 |
| **Total product from above** | | | | **119 140** | **Total from above** | | **83 945** |
| **Extrapolated to world** | | | | **132 378** | **Extrapolated to world** | | **93 026** |
| **Converted to tonnes of $CO_2$ equivalent, assuming 50% carbon** | | | | **242 693** | | | |

[a] From IPCC, 2006.
[b] Fraction remaining in use = 0.38987.
[c] Fraction assumed diverted from disposal = 0.30.
[d] Consumption minus recovered minus remaining in use.

TABLE A-7
**Calculation of carbon stored in wood products in landfills**

| Country | Discards to landfills *('000 tonnes)* | Carbon to landfills[a] *('000 tonnes)* | IPCC MCF (fraction anaerobic) | Carbon in anaerobic zones of landfills *('000 tonnes)* | Carbon remaining after degradation[b] *('000 tonnes)* | Carbon storage *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|---|
| Argentina | 380 | 190 | 0.6 | 114 | 91 | 334 |
| Australia | 1 478 | 739 | 0.9 | 665 | 532 | 1 950 |
| Austria | 379 | 190 | 0.9 | 171 | 137 | 501 |
| Belgium | 147 | 73 | 0.9 | 66 | 53 | 193 |
| Brazil | 4 408 | 2 204 | 0.6 | 1 322 | 1 058 | 3 879 |
| Canada | 4 036 | 2 018 | 0.9 | 1 816 | 1 453 | 5 328 |
| Chile | 486 | 243 | 0.6 | 146 | 117 | 428 |
| China | 19 561 | 9 780 | 0.4 | 3 912 | 3 130 | 11 476 |
| Czech Republic | 844 | 422 | 0.6 | 253 | 203 | 743 |
| Denmark | 86 | 43 | 0.9 | 39 | 31 | 114 |
| Egypt | 321 | 160 | 0.4 | 64 | 51 | 188 |
| Estonia | 452 | 226 | 0.6 | 135 | 108 | 397 |
| Finland | 862 | 431 | 0.9 | 388 | 310 | 1 138 |
| France | 1 661 | 831 | 0.9 | 747 | 598 | 2 193 |
| Germany | 2 234 | 1 117 | 0.9 | 1 005 | 804 | 2 949 |
| Greece | 425 | 212 | 0.6 | 127 | 102 | 374 |
| India | 2 541 | 1 270 | 0.4 | 508 | 406 | 1 490 |
| Iran, Islamic Republic of | 503 | 252 | 0.6 | 151 | 121 | 443 |
| Italy | 2 392 | 1 196 | 0.9 | 1 076 | 861 | 3 157 |
| Japan | 1 495 | 748 | 0.9 | 673 | 538 | 1 974 |
| Korea, Republic of | 1 030 | 515 | 0.6 | 309 | 247 | 907 |
| Malaysia | 728 | 364 | 0.6 | 218 | 175 | 641 |
| Mexico | 921 | 461 | 0.6 | 276 | 221 | 811 |
| Netherlands | 105 | 52 | 0.9 | 47 | 38 | 138 |
| New Zealand | 567 | 284 | 0.6 | 170 | 136 | 499 |
| Norway | 442 | 221 | 0.9 | 199 | 159 | 583 |
| Pakistan | 453 | 226 | 0.4 | 91 | 72 | 266 |
| Poland | 2 357 | 1 179 | 0.6 | 707 | 566 | 2 074 |
| Romania | 7 | 3 | 0.6 | 2 | 2 | 6 |
| Russian Federation | 2 216 | 1 108 | 0.6 | 665 | 532 | 1 950 |
| Saudi Arabia | 519 | 260 | 0.6 | 156 | 125 | 457 |
| Slovakia | 565 | 283 | 0.6 | 170 | 136 | 498 |
| South Africa | 671 | 336 | 0.4 | 134 | 107 | 394 |
| Spain | 1 764 | 882 | 0.9 | 794 | 635 | 2 329 |
| Sweden | 418 | 209 | 0.9 | 188 | 151 | 552 |
| Switzerland | 519 | 260 | 0.9 | 234 | 187 | 685 |
| Turkey | 2 651 | 1 325 | 0.6 | 795 | 636 | 2 333 |
| Ukraine | 618 | 309 | 0.4 | 124 | 99 | 363 |
| United Kingdom | 3 086 | 1 543 | 0.9 | 1 389 | 1 111 | 4 073 |
| United States | 19 048 | 9 524 | 0.9 | 8 572 | 6 857 | 25 143 |
| Viet Nam | 569 | 284 | 0.4 | 114 | 91 | 334 |
| **Total from above** | | | | | | **84 283** |
| **Extrapolated to world** | | | | | | **93 648** |

[a] Assuming carbon content of discards is 50 percent.
[b] Assuming 80 percent of carbon in anaerobic zones is non-degradable under anaerobic conditions.

## EMISSIONS FROM MANUFACTURING

An NCASI survey of ICFPA member associations provided emissions data for 2008 or the most recent estimates available. Information was obtained from countries representing 64 percent of global paper and paperboard production. The remaining countries, except China, were assumed to have the average emissions intensity (emissions per tonne of production) of these countries.

Because China is a very large producer of paper and paperboard, a more refined approach was used to estimate emissions from Chinese paper and paperboard producers. IEA has published information that allows the structure and emissions intensity of the Chinese paper industry to be compared with those of other countries (IEA, 2007b). This analysis indicates that the United States and China are reasonably similar with respect to both the weighted average expectation for best-available technology (which accounts for the structural differences among the industries in different countries) and the energy efficiency indicator for heat. Both the Chinese and United States industries also rely more heavily on coal than the industries in many other countries do. Emissions from the Chinese industry were therefore estimated by assuming that Chinese production had the same greenhouse gas intensity as United States production (rather than assuming the greenhouse gas intensity for the global industry).

To check the resulting global estimate, a separate estimate was developed using IEA energy consumption data for 2004 and extrapolating accepted emission factors from OECD production to global production, using FAO statistics (IEA, 2006; FAO, 2007). This yielded an estimate of approximately 180 million tonnes of $CO_2$ per year, which would be expected to be somewhat lower than other estimates because IEA allocates some fuel use at pulp and paper mills to electricity generation in the transformation sector (IEA, 2006). Because of this, and because the data collected for this report were both more extensive than the IEA OECD data (representing 80 percent of global production if China is included, rather than 71 percent) and more representative (in terms of representing both developing and developed countries), the estimate developed here is felt to be more robust. This estimate is 202 million tonnes of $CO_2$ per year from fossil fuel combustion at pulp and paper mills, plus 5 million tonnes of $CO_2$ equivalent in methane and nitrous oxide from all fuel combustion, including biomass.

Wood product emissions data were provided by four countries, representing only 19 percent of global production. As this sample was too small to be representative, IEA fuel consumption data and FAO data from OECD countries in the IEA dataset were used to develop the estimate of global emissions from the wood products sector (IEA, 2006; FAO, 2007). The IEA data were appropriate for this, because electricity is seldom generated at wood product facilities. This yielded an estimate of 24.5 million tonnes of $CO_2$ per year from fossil fuel combustion and another 1.1 million tonnes of $CO_2$ equivalent in methane and nitrous emissions from fossil fuel and biomass combustion. This is approximately the same as an earlier estimate of 2001 emissions (25 million tonnes of $CO_2$) derived from the same sources (Miner and Perez-Garcia, 2007b).

## EMISSIONS ASSOCIATED WITH PURCHASED ELECTRICITY

The emissions associated with purchased electricity (Scope 2 emissions under the WRI/WBCSD Greenhouse Gas Protocol) were estimated by first determining how much electricity is typically purchased. Information from pulp and paper associations in Europe, the United States and Japan was examined to calculate the electricity purchases per tonne of production in each of these regions. These estimates ranged from 0.44 to 0.59 MW per tonne, averaging 0.5 MW per tonne. Given the large proportion of global production that these three regions account for, it was felt reasonable to model the industry's purchased electricity requirements on the average value of these regions. National-level purchased electricity requirements were then estimated using FAO production statistics (FAO, 2007). The countries that together account for 91 percent of global production were selected, and those accounting for the remaining 9 percent were treated as a separate group. The emissions associated with electricity purchases were then calculated using country-specific electricity emission factors published by IEA (2007a) (Table A-8).

Owing to the scarcity of information, it is more difficult to estimate global emissions related to purchased electricity used at wood product facilities. Purchased electricity factors were developed for sawnwood and wood-based panels based on information from several sources (NCASI, 2008; ecoinvent, 2008; USDOE, 2009), referring mostly to North American and European facilities. For sawnwood, the factors from these three sources ranged from 0.07 to 0.09 MW per cubic metre, so a value of 0.08 MW per cubic metre was used in the calculations (Table A-9). For wood panels, the values varied dramatically, depending on the type of panel, and ranging from 0.1 to 0.35 MW per cubic metre. A weighted average factor of 0.2 MW per cubic metre was derived, based on FAO (2007) data for global production of each panel type (Table A-10). National-level production data were obtained for the same countries as were used for pulp and paper, in this case representing 85 percent of sawnwood and 89 percent of wood-based panel production. The results were extrapolated to the global level. The same national-level electricity factors were used as for the pulp and paper sector.

TABLE A-8
**Emissions associated with purchased electricity at paper and paperboard mills**[a]

| Country | Production (*'000 tonnes*) | $CO_2$ emissions | |
|---|---|---|---|
| | | Per MW (*kg*) | Total (*'000 tonnes*) |
| Australia | 3 192 | 873 | 1 393 |
| Austria | 5 199 | 225 | 585 |
| Belguim | 1 897 | 268 | 254 |
| Brazil | 5 836 | 84 | 245 |
| Canada | 18 113 | 199 | 1 802 |
| Chile | 1 344 | 357 | 240 |
| China | 78 026 | 788 | 30 742 |
| Czech Republic | 1 023 | 516 | 264 |
| Finland | 14 334 | 194 | 1 390 |
| France | 9 871 | 91 | 449 |
| Germany | 23 172 | 349 | 4 044 |
| India | 4 183 | 942 | 1 970 |
| Indonesia | 7 223 | 771 | 2 784 |
| Italy | 10 112 | 405 | 2 048 |
| Japan | 28 930 | 429 | 6 205 |
| Malaysia | 1 062 | 557 | 296 |
| Netherlands | 3 224 | 387 | 624 |
| New Zealand | 872 | 275 | 120 |
| Norway | 2 010 | 5.5 | 6 |
| Poland | 2 992 | 659 | 986 |
| Portugal | 1 644 | 498 | 409 |
| Russian Federation | 7 559 | 338 | 1 277 |
| South Africa | 3 033 | 848 | 1 286 |
| Spain | 6 714 | 394 | 1 323 |
| Sweden | 11 902 | 45 | 268 |
| Switzerland | 1 536 | 26 | 20 |
| Thailand | 4 484 | 531 | 1 191 |
| United Kingdom | 5 284 | 473 | 1 250 |
| United States | 83 826 | 573 | 24 016 |
| Uruguay | 90 000 | 103 | 5 |
| Rest of world | 34 916 | 501 | 8 747 |
| **World** | **383 603** | | |
| Coverage, % of world | 91% | **Total of above** | **96 238** |
| | | **Total extrapolated** | **105 875** |

[a] Assuming electricity purchased = 0.5 MW per tonne.

TABLE A-9
**Emissions associated with purchased electricity at timber mills**[a]

| Country | Production ('000 $m^3$) | $CO_2$ emissions | |
|---|---|---|---|
| | | Per MW (kg) | Total ('000 tonnes) |
| Australia | 5 064 | 873 | 354 |
| Austria | 11 262 | 268 | 241 |
| Belgium | 1 555 | 225 | 28 |
| Brazil | 24 414 | 84 | 164 |
| Canada | 52 284 | 199 | 832 |
| Chile | 8 340 | 357 | 238 |
| China | 29 202 | 788 | 1 841 |
| Czech Republic | 5 454 | 516 | 225 |
| Finland | 12 477 | 194 | 194 |
| France | 10 190 | 91 | 74 |
| Germany | 25 170 | 349 | 703 |
| India | 14 789 | 942 | 1 114 |
| Indonesia | 525 | 771 | 32 |
| Italy | 1 700 | 405 | 55 |
| Japan | 11 632 | 429 | 399 |
| Malaysia | 5 122 | 557 | 228 |
| Netherlands | 271 | 387 | 8 |
| New Zealand | 4 280 | 275 | 94 |
| Norway | 2 402 | 5.5 | 1 |
| Poland | 3 304 | 659 | 174 |
| Portugal | 1 010 | 498 | 40 |
| Russian Federation | 23 200 | 338 | 627 |
| South Africa | 2 091 | 848 | 142 |
| Spain | 3 332 | 394 | 105 |
| Sweden | 18 600 | 45 | 67 |
| Switzerland | 1 541 | 26 | 3 |
| Thailand | 288 | 531 | 12 |
| United Kingdom | 3 146 | 473 | 119 |
| United States | 84 363 | 573 | 3 867 |
| Uruguay | 308 | 103 | 3 |
| Rest of world | 63 725 | 501 | 2 554 |
| **World** | **431 042** | | |
| Coverage, % of world | 85% | **Total of above** | **14 541** |
| | | **Total extrapolated to world** | **17 064** |

[a] Assuming electricity purchased = 0.08 MW per cubic metre.

TABLE A-10
**Emissions associated with purchased electricity at panel plants**[a]

| Country | Production (*'000 m³*) | $CO_2$ emissions | |
|---|---|---|---|
| | | Per MW (*kg*) | Total (*'000 tonnes*) |
| Australia | 1 788 | 873 | 312 |
| Austria | 3 716 | 268 | 199 |
| Belgium | 2 552 | 225 | 115 |
| Brazil | 8 680 | 84 | 146 |
| Canada | 14 645 | 199 | 583 |
| Chile | 2 482 | 357 | 177 |
| China | 70 955 | 788 | 11 182 |
| Czech Republic | 1 716 | 516 | 177 |
| Finland | 1 995 | 194 | 77 |
| France | 6 709 | 91 | 122 |
| Germany | 18 185 | 349 | 1 269 |
| India | 2 554 | 942 | 481 |
| Indonesia | 4 305 | 771 | 664 |
| Italy | 5 701 | 405 | 462 |
| Japan | 5 313 | 429 | 456 |
| Malaysia | 7 719 | 557 | 860 |
| Netherlands | 15 | 387 | 1 |
| New Zealand | 2 203 | 275 | 121 |
| Norway | 613 | 5.5 | 1 |
| Poland | 8 534 | 659 | 1 125 |
| Portugal | 1 341 | 498 | 134 |
| Russian Federation | 9 813 | 338 | 663 |
| South Africa | 786 | 848 | 133 |
| Spain | 5 390 | 394 | 425 |
| Sweden | 928 | 45 | 8 |
| Switzerland | 1 086 | 26 | 6 |
| Thailand | 1 365 | 531 | 145 |
| United Kingdom | 3 549 | 473 | 336 |
| United States | 41 091 | 573 | 4 709 |
| Uruguay | 163 | 103 | 3 |
| Rest of world | 30 278 | 501 | 3 034 |
| **World** | **266 170** | | |
| Coverage, % of world | 89% | **Total of above** | **28 127** |
| | | **Total extrapolated to world** | **31 737** |

[a] Assuming electricity purchased = 0.2 MW per cubic metre.

## UPSTREAM EMISSIONS ASSOCIATED WITH NON-WOOD INPUTS AND FOSSIL FUELS

To estimate the upstream emissions associated with chemicals and additives, the factors in FICAT were used (IFC, 2009). These reflect generic "recipes" of chemicals and additives used to produce different forest products, and data from several life cycle databases. Sawnwood was assumed to have no upstream emissions associated with chemicals and additives (although this is not the case for preservative-treated wood). These factors were applied to FAO production statistics for the respective products (FAO, 2007) (Tables A-11 and A-12).

The upstream emissions associated with fossil fuel use in the global forest products sector were estimated using: IEA energy consumption data for OECD (IEA, 2006); FAO production statistics to extrapolate the IEA data to the rest of the world (FAO, 2007); and upstream emission factors from the United States life cycle database, modified for IFC's FICAT (USDOE, 2009; IFC, 2009) (Table A-13).

TABLE A-11
**Upstream emissions associated with chemicals used in producing paper and paperboard**

| FAO grade of paper and paperboard | Global production 2007 *('000 tonnes)* | % of global production | Upstream emission factor *(kg $CO_2$ equivalent/tonne)* | FICAT factors used to select the upstream emission factor | Upstream emissions *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|
| Household and sanitary paper | 26 278 | 7 | 200 | Midway between integrated and non-integrated uncoated freesheet | 5 256 |
| Newsprint | 38 096 | 10 | 75 | Newsprint: average of 100% and 0% de-inked pulp | 2 857 |
| Paper and paperboard not elsewhere specified | 19 603 | 5 | 100 | Selected factor is within the range for all grades. If anything, it may be biased high | 1 960 |
| Printing and writing paper | 113 635 | 30 | 165 | Average of coated freesheet, uncoated freesheet, coated mechanical and uncoated mechanical | 18 750 |
| Wrapping and packaging paper and board | 185 911 | 48 | 32.5 | Average of semi-chemical, recycled corrugating medium, recycled liner and kraft liner | 6 042 |
| **Total** | **383 523** | **100** | | | **34 865** |

TABLE A-12
**Upstream emissions associated with chemicals used in producing wood-based panels**

| FAO grade of wood- based panels | Global production 2007 *('000 m³)* | % of global production | Upstream emission factor *(kg $CO_2$ equivalent/tonne)* | FICAT factors used to select the upstream emission factor | Conversion factor for m³ to tonnes | 2007 global production *('000 tonnes)* | Upstream emissions *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|---|---|
| Hardboard | 9 716 | 4 | | MDF | 1.02 | 9 911 | 1 982 |
| Insulating board | 7 105 | 3 | 200 | MDF | 0.5 | 3 553 | 711 |
| Medium density fibreboard (MDF) | 55 573 | 21 | 200 | MDF | 0.5 | 27 786 | 5 557 |
| Particle board | 106 144 | 40 | 200 | Oriented strand board | 0.26 | 27 598 | 5 520 |
| Plywood | 76 127 | 29 | 200 | Plywood, outside | 0.48 | 36 541 | 7 308 |
| Veneer sheets | 11 505 | 4 | 200 | Plywood, outside | 0.59 | 6 788 | 1 358 |
| **Total** | **266 170** | **100** | | | | **Total upstream emissions** | **22 435** |

TABLE A-13
**Upstream emissions associated with fossil fuel use at forest products manufacturing facilities**

| Fuel | Fuel consumption *(terrajoules [LHV])* | | Upstream emission factor *(kg $CO_2$ equivalent/GJ [LHV])* | Upstream emissions *(tonnes $CO_2$ equivalent/year)* | |
|---|---|---|---|---|---|
| | OECD paper, pulp and print | OECD wood and wood products | | Paper, pulp and print | Wood and wood products |
| Other bitumen coal | 263 243 | 8 037 | 6.03 | 1 587 | 48 |
| Sub-bitumen coal | 22 813 | 67 | 6.03 | 138 | - |
| Lignite | 4 097 | | 6.03 | 25 | - |
| Peat | 15 880 | | 6.03 | 96 | - |
| Oven and gas coke | 801 | | 6.03 | 5 | - |
| Patented fuel and brown coal briquettes | 10 509 | | 6.03 | 63 | - |
| Liquefied petroleum gas and ethane | 16 590 | 4 503 | 12.83 | 213 | 58 |
| Kerosene | 3 043 | 269 | 12.89 | 39 | 3 |
| Gas and diesel | 99 312 | 99 356 | 12.89 | 1 280 | 1 281 |
| Heavy fuel oil | 391 250 | 14 187 | 12.83 | 5 020 | 182 |
| Petroleum coke | 2 170 | | 12.83 | 28 | - |
| Natural gas | 1 067 765 | 111 354 | 12.33 | 13 166 | 1 373 |
| Gas works | 23 | | 12.33 | - | - |
| Coke ovens | 829 | 842 | 6.03 | 5 | 5 |
| **Totals for OECD** | | | | **21 664** | **2 951** |
| Fraction of global production in OECD countries | | | | 0.71 | 0.64 |
| **Extrapolated totals for world** | | | | **30 513** | **4 611** |

## TRANSPORT-RELATED EMISSIONS

To estimate the emissions associated with the international transport of fibrous raw materials and products, FAO data were obtained for the countries representing 80 percent of exports of each of the following materials: industrial roundwood, sawnwood, wood-based panels, paper and paperboard, and recovered paper. FAO data were also used to identify the major export destinations for each material from these countries (FAO, 2007). One-way transport distances and modes were approximated for each pairing of exporting country and major importing destination. The emissions associated with this transport were estimated using emission factors from WRI/ WBCSD Greenhouse Gas Protocol calculation tools, as presented in documentation for IFC's FICAT model (IFC, 2009) and then extrapolated to account for the remaining 20 percent of exports from countries not included in the calculations.

Because most land-based shipping uses a combination of truck and train carriers, two sets of calculations were made: one assuming that most overland international transport was by diesel locomotive and the other assuming that overland international transport was by diesel truck. The average of these two values was used for the final estimates (Tables A-14 and A-15). To account for the transport of non-fibrous raw materials and fuels, the emissions associated with transporting fibrous raw materials were increased by 15 percent. Several sources of information suggest that this was an adequate adjustment (e.g. Diesen, 1998; Lofgren, 2005; Kline, 2004). In addition, it was assumed that the emissions associated with discarded paper are equal to half those associated with transporting recovered fibre.

TABLE A-14
**Final calculation of emissions associated with international transport**

| Factor | Emissions 2007 (*'000 tonnes CO2 equivalent*) | | |
|---|---|---|---|
| | Overland mostly by locomotive | Overland mostly by truck | Midpoint estimate between locomotive and truck |
| Industrial roundwood | 3 036 | 4 061 | 3 549 |
| Pulp | 3 508 | 4 652 | 4 080 |
| Recovered paper | 3 409 | 4 362 | 3 885 |
| **Cradle-to-gate fibre total** | | | **11 514** |
| **Add 15% for fuel/chemicals for cradle-to-gate total** | | | **13 241** |
| Sawnwood | 2 569 | 6 366 | 4 468 |
| Panels | 2 575 | 4 329 | 3 452 |
| Paper and paperboard | 4 242 | 10 353 | 7 298 |
| **Gate-to-consumer total** | | | **15 217** |
| **Post-consumer (half of recovered paper transport emissions)** | | | **1 943** |
| **Overall total** | | | **30 401** |

TABLE A-15
**Calculation of transport emissions related to domestic transport**

| Factor | Global domestic consumption[a] (*'000 tonnes*) | Distance (*km*) | Emissions 2007 (*'000 tonnes $CO_2$ equivalent*) | | |
|---|---|---|---|---|---|
| | | | Overland mostly by locomotive | Overland mostly by truck | Midpoint estimate between locomotive and truck |
| Industrial roundwood | 751 611 | 100 | 1 503 | 5 412 | 3 457 |
| Pulp | n.a.[b] | | 0 | 0 | 0 |
| Recovered paper | 142 781 | 500 | 1 428 | 5 140 | 3 284 |
| **Cradle-to-gate fibre total** | | | | | **6 741** |
| **Add 15% for fuel/chemicals for cradle-to-gate total** | | | | | **7 753** |
| Sawnwood | 154 047 | 500 | 1 540 | 5 546 | 3 543 |
| Panels | 86 246 | 500 | 862 | 3 105 | 1 984 |
| Paper and paperboard | 257 369 | 500 | 2 574 | 9 265 | 5 919 |
| **Gate-to-consumer total** | | | | | **11 446** |
| **Post-consumer (half of recovered paper transport emissions)** | | | | | **1 642** |
| **Overall total** | | | | | **20 841** |

[a] Global consumption minus global exports.
[b] n.a. = not available.

## END-OF-LIFE EMISSIONS

In the tables estimating the carbon stored in products, the amounts of product reaching the end of the life cycle and going to landfills were estimated. It was assumed that all products not recovered or sent to landfills are burned (Table A-16).

Estimates of methane emissions attributable to forest products in landfills (Tables A-17 and A-18) begin with the estimates shown for the carbon stored in landfills. For products in landfills, it is assumed that half of the degradable carbon under anaerobic conditions is converted into methane, and 10 percent of methane is assumed to oxidize naturally as it migrates through the upper layers of the landfill. Additional amounts can be captured and burned, but this depends on the use of landfill gas capture systems.

The fraction of methane captured and burned is an important variable in methane emission calculations, but there are few data on national practices, especially in developing countries. In this study, the values selected for capturing and burning methane were based on per capita GDP (PPP basis) published by the World Bank (2009). It was assumed that countries with per capita GDP greater than US$30 000 were capturing and burning 40 percent of the methane from decomposing forest products; countries with per capita GDP of less than US$10 000 were capturing none; and the remaining countries were capturing and burning 10 percent.

TABLE A-16
**Emissions from burning used products at the end of the life cycle, 2007**

| Product | Not landfilled or recycled *('000 tonnes per year)* | '000 GJ[a] | $CO_2$ equivalent[b] *('000 tonnes)* |
|---|---|---|---|
| Paper | 49 020 | 764 712 | 1 484 |
| Wood products | 51 609 | 805 100 | 1 562 |
| **Total** | **100 629** | **1 569 812** | **3 045** |

[a] Calculated based on 15.6 GJ per tonne (LHV), from IPPC, 2006.
[b] Calculated based on1.94 kg of $CO_2$ equivalent in $CH_4$ and $N_2O$ emissions per GJ (LHV), from IPPC, 2006.

TABLE A-17
**Methane emissions from paper and paperboard disposed of in landfills**

| Country | Per capita GDP PPP 2008 *(US$/year)* | C to methane *('000 tonnes/ year)* | Methane produced *('000 tonnes)* | Methane remaining[a] *('000 tonnes)* | Fraction captured and burned | Methane released *('000 tonnes)* | Methane released *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|---|---|
| Argentina | 14 020 | 55 | 74 | 67 | 0.1 | 60 | 1 258 |
| Australia | 34 040 | 96 | 128 | 115 | 0.4 | 69 | 1 447 |
| Austria | 37 680 | 22 | 29 | 27 | 0.4 | 16 | 334 |
| Belgium | 34 760 | 4 | 5 | 4 | 0.4 | 3 | 54 |
| Brazil | 10 070 | 32 | 42 | 38 | 0.1 | 34 | 717 |
| Canada | 36 220 | 379 | 505 | 455 | 0.4 | 273 | 5 730 |
| China | 6 020 | 2 183 | 2 910 | 2 619 | 0 | 2 619 | 55 001 |
| France | 34 400 | 235 | 314 | 282 | 0.4 | 169 | 3 558 |
| Germany | 35 940 | 174 | 232 | 209 | 0.4 | 125 | 2 629 |
| India | 2 960 | 149 | 199 | 179 | 0 | 179 | 3 760 |
| Indonesia | 3 830 | 105 | 139 | 126 | 0 | 126 | 2 636 |
| Italy | 30 250 | 470 | 627 | 564 | 0.4 | 339 | 7 109 |
| Japan | 35 220 | 148 | 197 | 177 | 0.4 | 106 | 2 235 |
| Korea, Republic of | 28 120 | 15 | 19 | 17 | 0.1 | 16 | 329 |
| Malaysia | 13 740 | 95 | 127 | 114 | 0.1 | 103 | 2 162 |
| Mexico | 14 270 | 147 | 196 | 176 | 0.1 | 159 | 3 329 |
| Netherlands | 41 670 | 15 | 20 | 18 | 0.4 | 11 | 229 |
| Poland | 17 310 | 191 | 255 | 230 | 0.1 | 207 | 4 340 |
| Russian Federation | 15 630 | 225 | 300 | 270 | 0.1 | 243 | 5 098 |
| South Africa | 9 780 | 73 | 97 | 87 | 0 | 87 | 1 834 |
| Spain | 31 130 | 298 | 397 | 357 | 0.4 | 214 | 4 502 |
| Sweden | 38 180 | 17 | 22 | 20 | 0.4 | 12 | 252 |
| Switzerland | 46 460 | 40 | 54 | 48 | 0.4 | 29 | 610 |
| Thailand | 5 990 | 97 | 129 | 116 | 0 | 116 | 2 440 |
| Turkey | 13 770 | 209 | 278 | 251 | 0.1 | 226 | 4 736 |
| United Kingdom | 36 130 | 298 | 397 | 357 | 0.4 | 214 | 4 503 |
| United States | 46 970 | 2 404 | 3 205 | 2 885 | 0.4 | 1 731 | 36 349 |
| Viet Nam | 2 700 | 54 | 72 | 65 | 0 | 65 | 1 361 |
| **Total** | | | | | | | **158 543** |
| **Extrapolated to world** | | | | | | | **176 159** |

[a] After 10 percent oxidized naturally.

TABLE A-18
**Methane emissions from wood products disposed of in landfills**

| Country | Per capita GDP PPP 2008 *(US$/year)* | C to methane *('000 tonnes/ year)* | Methane produced *('000 tonnes)* | Methane remaining[a] *('000 tonnes)* | Fraction captured and burned | Methane released *('000 tonnes)* | Methane released *('000 tonnes $CO_2$ equivalent)* |
|---|---|---|---|---|---|---|---|
| Argentina | 14 020 | 11 | 15 | 14 | 0.1 | 12 | 259 |
| Australia | 34 040 | 66 | 89 | 80 | 0.4 | 48 | 1 005 |
| Austria | 37 680 | 17 | 23 | 20 | 0.4 | 12 | 258 |
| Belgium | 34 760 | 7 | 9 | 8 | 0.4 | 5 | 100 |
| Brazil | 10 070 | 132 | 176 | 159 | 0.1 | 143 | 2 999 |
| Canada | 36 220 | 182 | 242 | 218 | 0.4 | 131 | 2 746 |
| Chile | 13 270 | 15 | 19 | 18 | 0.1 | 16 | 331 |
| China | 6 020 | 391 | 522 | 469 | 0 | 469 | 9 859 |
| Czech Republic | 22 790 | 25 | 34 | 30 | 0.1 | 27 | 575 |
| Denmark | 37 280 | 4 | 5 | 5 | 0.4 | 3 | 59 |
| Egypt | 5 460 | 6 | 9 | 8 | 0 | 8 | 162 |
| Estonia | 19 280 | 14 | 18 | 16 | 0.1 | 15 | 307 |
| Finland | 35 660 | 39 | 52 | 47 | 0.4 | 28 | 586 |
| France | 34 400 | 75 | 100 | 90 | 0.4 | 54 | 1 130 |
| Germany | 35 940 | 101 | 134 | 121 | 0.4 | 72 | 1 520 |
| Greece | 28 470 | 13 | 17 | 15 | 0.1 | 14 | 289 |
| India | 2 960 | 51 | 68 | 61 | 0 | 61 | 1 280 |
| Iran, Islamic Republic of | 10 840 | 15 | 20 | 18 | 0.1 | 16 | 342 |
| Italy | 30 250 | 108 | 144 | 129 | 0.4 | 78 | 1 628 |
| Japan | 35 220 | 67 | 90 | 81 | 0.4 | 48 | 1 017 |
| Korea, Republic of | 28 120 | 31 | 41 | 37 | 0.1 | 33 | 701 |
| Malaysia | 13 740 | 22 | 29 | 26 | 0.1 | 24 | 495 |
| Mexico | 14 270 | 28 | 37 | 33 | 0.1 | 30 | 627 |
| Netherlands | 41 670 | 5 | 6 | 6 | 0.4 | 3 | 71 |
| New Zealand | 25 090 | 17 | 23 | 20 | 0.1 | 18 | 386 |
| Norway | 58 500 | 20 | 27 | 24 | 0.4 | 14 | 301 |
| Pakistan | 2 700 | 9 | 12 | 11 | 0 | 11 | 228 |
| Poland | 17 310 | 71 | 94 | 85 | 0.1 | 76 | 1 604 |
| Romania | 13 500 | 0 | 0 | 0 | 0.1 | 0 | 5 |
| Russian Federation | 15 630 | 66 | 89 | 80 | 0.1 | 72 | 1 508 |
| Saudi Arabia | 22 950 | 16 | 21 | 19 | 0.1 | 17 | 353 |
| Slovakia | 21 300 | 17 | 23 | 20 | 0.1 | 18 | 385 |
| South Africa | 9 780 | 13 | 18 | 16 | 0 | 16 | 338 |
| Spain | 31 130 | 79 | 106 | 95 | 0.4 | 57 | 1 200 |
| Sweden | 38 180 | 19 | 25 | 23 | 0.4 | 14 | 285 |
| Switzerland | 46 460 | 23 | 31 | 28 | 0.4 | 17 | 353 |
| Turkey | 13 770 | 80 | 106 | 95 | 0.1 | 86 | 1 803 |
| Ukraine | 7 210 | 12 | 16 | 15 | 0 | 15 | 312 |
| United Kingdom | 36 130 | 139 | 185 | 167 | 0.4 | 100 | 2 099 |
| United States | 46 970 | 857 | 1 143 | 1 029 | 0.4 | 617 | 12 960 |
| Viet Nam | 2 700 | 11 | 15 | 14 | 0 | 14 | 287 |
| **Sum of above** | | | | | | | **52 753** |
| **Extrapolated to world** | | | | | | | **58 614** |

[a] After 10 percent oxidized naturally.

# Annex 2
# An overview of harvested wood products accounting in national greenhouse gas inventories

Currently, countries reporting greenhouse gas emissions under the Kyoto Protocol use IPCC's 1996 default accounting approach for carbon in harvested wood products (HWPs). This approach assumes that there is no growth in the carbon stored in HWPs. From the standpoint of the calculations, this is the same as assuming that carbon in biomass is emitted in the year the biomass is harvested. Although most countries reporting under the United Nations Framework Convention on Climate Change (UNFCCC) use the original IPCC default assumption, IPCC guidelines allow other approaches, and some countries use these. In 2006, IPCC revised the hierarchy of HWP accounting approaches so that the former default is now one of several equally favoured alternatives. However, the parties to UNFCCC have not yet adopted the 2006 guidelines for national inventory reporting. Since these were issued, a number of alternative accounting approaches have been suggested.

It is important to understand that in carbon accounting under UNFCCC or the Kyoto Protocol, HWPs include all biomass removed from the forest, and is not limited to manufactured products.

It is well documented that the stocks of carbon stored in HWPs are growing, in both products in use and in landfills. The assumption of no growth in stored carbon therefore overstates the transfers of $CO_2$ to the atmosphere from the forest products value chain. Based on the estimates in this report, the assumption of no growth in stored carbon is overstating global emissions from the forest products value chain by 424 million tonnes of $CO_2$ per year.

In spite of many years of discussion, it has not been possible to reach international consensus on which accounting approach, other than the original IPCC default, to use for national greenhouse gas inventories submitted under UNFCCC. The lack of consensus can be attributed to such concerns as:

- the sometimes significant differences between the greenhouse gas inventories of HWP importing countries and those of exporting countries;
- uncertainties associated with approaches that require assumptions about how exported products will be used and disposed of;
- perverse incentives that may be created;
- the implications of having some countries within the accounting framework and others outside it;
- the potential impacts on international trade;
- producers' concerns that the accounting approaches do not account for substitution effects.

Several recent proposals attempt to address some of these concerns by limiting the accounting to countries within the reporting framework, or to the HWPs produced and used domestically.

The lack of international consensus has resulted in IPCC recommending (in the 2006 revised guidelines) that countries report a series of parameter values in their national inventories, which can be used to calculate emissions according to any of the different approaches.

## THE MAJOR OPTIONS

Conceptually, the major HWP accounting options fall into three general categories:

- The original IPCC default: This assumes that there is zero growth in carbon stored in HWPs (mathematically equivalent to assuming instant oxidation of harvested biomass).
- The stock change approach: This calculates the net exchange of carbon with the atmosphere by adding up all the changes in amounts of stored biomass carbon within national boundaries. If the total amount of carbon stored in a country's forests and forest products has increased over time (and if the carbon in imports equals the carbon in exports), a corresponding amount of carbon must have been removed from the atmosphere.
- The atmospheric flow approach: This calculates the net exchange of biomass carbon with the atmosphere by adding up all the flows of carbon to and from the atmosphere at all points along the forest-based value chain within national boundaries. Carbon is removed from the atmosphere in the forest and is subsequently returned to the atmosphere both from the forest and from downstream points along the value chain that lie within national boundaries. If not all of the carbon is returned (and if the carbon in imports equals the carbon in exports), there has been a net removal of carbon from the atmosphere equal to the amount not returned.

At the global level, the stock change and atmospheric flow approaches give essentially the same results. The differences between them are important primarily for countries that are large net importers or exporters of HWPs. This is because, under stock change accounting, exported HWP represents the export of carbon storage, while in atmospheric flow accounting it represents the export of delayed emissions. As a result, large net importers of HWPs will have significantly larger HWP emissions using atmospheric flow accounting, while large net exporters will have larger emissions using stock change accounting. The differences for such countries can be more than 5 to 10 million tonnes of carbon a year. In Canada, for instance, annual emissions estimated using the atmospheric flow approach are 60 million tonnes of $CO_2$ lower than those estimated using the stock change approach, an amount equal to 8 percent of national emissions. In turn, annual emissions estimated using the stock change approach are 15 million tonnes of $CO_2$ lower than those estimated using the IPCC default approach (Environment Canada, 2009).

In addition to the old IPCC default, stock change accounting, and atmospheric flow accounting, the 2006 IPCC guidelines explain two other approaches:

- The production approach: This is based on stock change accounting, but it attributes the stock changes associated with carbon stored in HWPs to the country where the wood was harvested.
- The simple decay approach: This is based on atmospheric flow accounting, but it attributes delayed emissions associated with HWPs to the country where the wood was harvested.

In many cases, these approaches yield results that lie between those obtained with atmospheric flow and stock change accounting. It is important to understand that, at the global level and in most national inventories, the IPCC default approach, which does not acknowledge the accumulation of carbon in HWP pools, gives higher emissions than any of the alternatives that recognize this accumulation. There are exceptions, however. For instance, countries without domestic forest resources that import large amounts of forest products will calculate higher emissions under atmospheric flow accounting than under the IPCC default.

## CONCERNS ABOUT HWP ACCOUNTING

This section elaborates on the issues that have prevented global consensus on an approach to HWP carbon accounting.

***Concern: The greenhouse gas inventories of HWP importing and exporting countries sometimes differ significantly.***

There is no question that the selection of accounting approach will affect the national inventories of many countries, particularly those that are large net importers or large net exporters of HWP. This concern could be addressed by selecting an accounting approach that reduces the differences among countries and by adjusting national targets to reflect the effects of the selected accounting approach.

***Concern: The estimates are too uncertain for use in national inventories, especially when they are used to judge compliance against reduction targets.***

There are uncertainties in all the emissions estimates contained in national inventories. However, when discussing the uncertainties associated with HWP estimates, it is important to remember that these same HWP calculations are also used to estimate national emissions of landfill methane, when their results are used in further analyses that apply additional assumptions and involve additional uncertainty. For instance, the United States Environmental Protection Agency (USEPA) has estimated that the uncertainty in the estimates of growth in HWP stocks is -26 to +24 percent, while the uncertainty in methane emissions from landfills is -39 to +33 percent (USEPA, 2009). In spite of the uncertainty, the estimates of landfill methane emissions are readily accepted in national greenhouse gas inventories, suggesting that estimates of HWP-related carbon sequestration should also be accepted.

***Concern: Some of the approaches require assumptions about how exported products will be used and disposed of, creating uncertainties in the results.***

A number of the accounting approaches require the producing country (i.e. the country where the wood is grown) to calculate the carbon storage or emissions that will be attributable to the wood or forest products it exports to other countries. This requires information from the importing country regarding: how the wood or forest product will be used; the typical time in use for the imported products or for products made from the imported wood; the amounts of used products that are sent to landfill at the end of their life; and the design and operation of landfills typically receiving this material. Many countries do not have good-quality information on these topics. The IPCC 2006 guidelines contain default values for these parameters, but there is likely to be significant uncertainty associated with the use of these defaults. This concern is likely to diminish over time, as countries develop the national-level data needed to replace these defaults.

***Concern: Perverse incentives may be created.***

A wide range of perverse incentives are potentially related to HWP accounting practices. The following are some of the most important of these:

- The old IPCC default assumption credits the forest-related value chain only for carbon left in the forest and for biomass removed from the forest and used to reduce fossil fuel-related emissions. Fossil fuels can be displaced by biomass in many ways, but national authorities often incentivize only the direct burning of forest biomass for fuel. Thus, the current IPCC default has the practical effect of encouraging countries to promote policies that leave wood in the forest (foregoing substitution effects from wood products), except where wood is removed to be used as fuel. In either case, less wood becomes available for manufacturing forest products.

- A system that does not require reporting from all countries could encourage the overuse of forests in non-reporting countries and exports of the wood to reporting countries, where it could be used to reduce emissions. The emission reductions reported by the reporting country would be overstated if the exporting country had reduced its forest carbon stocks to produce the wood but was not required to report this.
- Because most HWP accounting approaches place a value on carbon stored in forest products, there is concern in some circles (and hope in others) that this would encourage more harvesting and increased production of forest products. This would depend on the national policies put in place for using the value of carbon stored in products to influence the decisions of landowners and producers. Some policies would allow landowners and producers to benefit directly from this value, while others would make the value irrelevant to landowners and producers. Ultimately, therefore, it is national policies and not carbon accounting approaches that dictate how the value of stored carbon is translated into incentives to increase or decrease the production of wood and forest products.
- Because landfills are responsible for much of the growth in carbon storage in the forest carbon value chain, there is concern that crediting this storage might somehow promote landfilling over other end-of-life management options for used forest products. This concern can be addressed by public policies that ensure that end-of-life management bears the responsibility for greenhouse gas emissions occurring at the end of the life cycle (e.g. methane from landfills) and that properly credit reductions in societal greenhouse gas emissions associated with other end-of-life management options (e.g. burning non-recyclable products for energy).
- There have been concerns that atmospheric flow accounting (and other flow-based approaches) could encourage national policies that do not differentiate between biomass-derived $CO_2$ emissions and fossil fuel-derived emissions. This concern arises because flow-based approaches focus on emissions of biomass-derived $CO_2$ in calculating national biomass carbon emissions/sequestration, and this is the same method used to track fossil fuel-related emissions. However, it should be remembered that these accounting approaches are only for estimating national-level emissions. National policies are designed to encourage activities that help the country to meet national emission targets. A national policy that did not differentiate between biomass $CO_2$ and fossil fuel $CO_2$ would increase national emissions, because many facilities using biomass for fuel would switch to fossil fuels, which deliver more usable energy per unit of carbon than biomass fuels. This suggests that such a national policy is unlikely.

***Concern: Having some countries within the accounting framework and others outside it could result in practices that cause global emissions to increase.***

The most likely unwanted consequence of this is that countries with emissions reduction targets will stop harvesting domestic forests to obtain the benefits of additional storage, while increasing imports of biomass from other countries, to obtain the carbon storage and fossil fuel displacement benefits. If an exporting country has no accounting responsibility for domestic forest carbon stocks, it might deplete these stocks in response to the strong market demand from countries within the accounting framework. Several accounting methods have been proposed to address this concern. In general, these account for HWPs only from wood harvested in countries within the accounting framework. Concerns with such proposals include the reductions in HWP benefits that would occur for some countries, relative to other approaches; and the difficulty of tracing all HWPs to the country where the wood was grown. Other proposals limit the accounting to HWPs associated with domestically grown wood. Although this simplifies the tracing difficulties, it also greatly reduces HWP benefits, not only for countries with limited domestic forest resources but also for HWP exporting countries with relatively small domestic markets.

***Concern: There will be effects on international trade in wood and forest products.***
Recognition of the carbon storage (and other) greenhouse gas related benefits associated with HWPs could have effects on the prices of wood and forest products. This would affect countries in different ways depending on: national policies for incentivizing HWP-related benefits; whether the country is inside or outside the HWP accounting framework; and the accounting approach used for HWPs. While international trade might be affected in many ways, it is reasonable to assume that the effects will primarily be related to national policies aimed at distributing the benefits (or costs) associated with HWPs (e.g. policies for transferring HWP-related impacts on greenhouse gas inventories to the forest products sector) or policies that address international trade concerns directly.

***Concern: None of the accounting approaches accounts for substitution effects.***
For many forest products, substitution effects have a greater impact than carbon storage benefits on long-term trends in atmospheric $CO_2$. There has therefore been interest in finding HWP accounting approaches that explicitly recognize substitution effects. This is difficult because it involves combining two different types of carbon accounting. HWP carbon accounting attempts to calculate carbon flows to/from the atmosphere as they occur, while substitution effects are based on a hypothetical alternative situation (e.g. "emissions would be X percent lower if we used Y percent more wood" or "emissions are X percent lower than they might otherwise be because we are using Y tonnes of wood per year"). The carbon accounting framework for HWPs is so different from that for substitution effects that it is difficult to envision a single accounting framework that would adequately address both.

## OUTLOOK

The global forest products sector supports adoption of a global HWP accounting framework that acknowledges the benefits of carbon stored in forest products (see, for instance, *Recommendations for government negotiators to effectively include harvested wood products (HWP) within the UN Framework Convention on Climate Change (UNFCCC),* endorsed by the Sustainable Forest Products Industry Working Group of WBCSD and ICFPA [WBCSD, 2009]). The original IPCC default approach does not do this. As a result, it greatly overstates the emissions from the forest products value chain. Unfortunately, various concerns prevent international consensus. A number of proposals under consideration attempt to address one or more of these concerns, but no approach can address all of them.

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FAO FORESTRY PAPER

# Impact of the global forest industry on atmospheric greenhouse gases

This publication examines the numerous and complex connections between the global forest products industry (taken here to include roundwood production, pulp and paper, and wood processing) and the global carbon cycle, with the objective of characterizing the carbon footprint of the sector. The study considers six types of industry impact: carbon sequestration and storage in forests and forest products; emissions from manufacturing facilities or from electricity producers supplying these facilities; other emissions attributable to product manufacturing; emissions from product transport and use; emissions associated with end-of-life management; and emissions avoided elsewhere in society owing to the forest products industry. The analysis finds that the industry's main sources of emissions are manufacturing (mostly because of fossil fuel consumption and electricity purchases) and disposal of used products in landfills. Globally, the impact of the industry on carbon in forests cannot be described quantitatively because of the lack of data in many parts of the world and the complexity of the industry's raw material supply chain. Data from some countries, however, suggest that sustainable forest management practices can be effective in keeping forest carbon stocks stable over time. Some of the carbon removed from the forest remains stored in forest products, providing significant benefits. Indirect greenhouse gas benefits resulting from the activities or products of the forest products industry, while difficult to measure, can be large and could be increased.

ISBN 978-92-5-106560-0 ISSN 0258-6150

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I1680E/1/06.10/1100