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Paper Cycle

Sub-Study Series

20 The Paper Industry and Global Warming

Susan Subak, with Amelia Craighill, Michael Guthrie and Mick Kelly

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THE PAPER INDUSTRY AND GLOBAL WARMING

Susan Subak, with Amelia Craighill, Michael Guthrie and Mick Kelly
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Susan Subak is a Senior Research Associate at the Centre for Social and Economic Research on the Global Environment (CSERGE), based at the University of East Anglia at Norwich and University College, London, UK. Mick Kelly is a Senior Research Associate at the Climatic Research Unit and CSERGE. Amelia Craighill is a Research Associate at CSERGE and Michael Guthrie is an intern at CSERGE.

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THE PAPER INDUSTRY AND GLOBAL WARMING

Introduction

Global warming has the potential to put severe stress on many of the world's ecosystems. The resulting changes in temperature, sea-level and extreme storm events may significantly affect human welfare in a number of ways, through changes to agriculture, disease distribution, energy demand, flooding frequency, shore erosion, and other effects.

Acknowledging the risks of climate change, most of the world's countries have ratified the United Nations Framework Convention on Climate Change, which came into force in 1994. In doing so, all parties agreed to provide national communications detailing estimates of their sources and sinks of greenhouse gases, and industrialized countries agreed to aim to stabilize their emissions at 1990 levels by 2000.

The impact of the paper sector on global warming is an important consideration when assessing its sustainability. Fibre supply, paper production, transport and disposal encompass some of the most important source and sink categories of greenhouse gases: fossil fuel combustion, landfill and deforestation and afforestation. The figures below illustrate the emissions and offsets of greenhouse gases that occur during the paper cycle.

The Convention's inventory requirement calls for countries to publish estimates of greenhouse gas emissions at the national level only, not at the level of processes or industries. Therefore, the International Institute for Environment and Development commissioned the Centre for Social and Economic Research on the Global Environment (CSERGE), based at the University of East Anglia and University College, London, to assess the magnitude of the sources and sinks of greenhouse gases throughout the paper cycle.

Figure 1a Carbon Storage and Greenhouse Gas Emissions In Fibre Production and Paper Manufacture

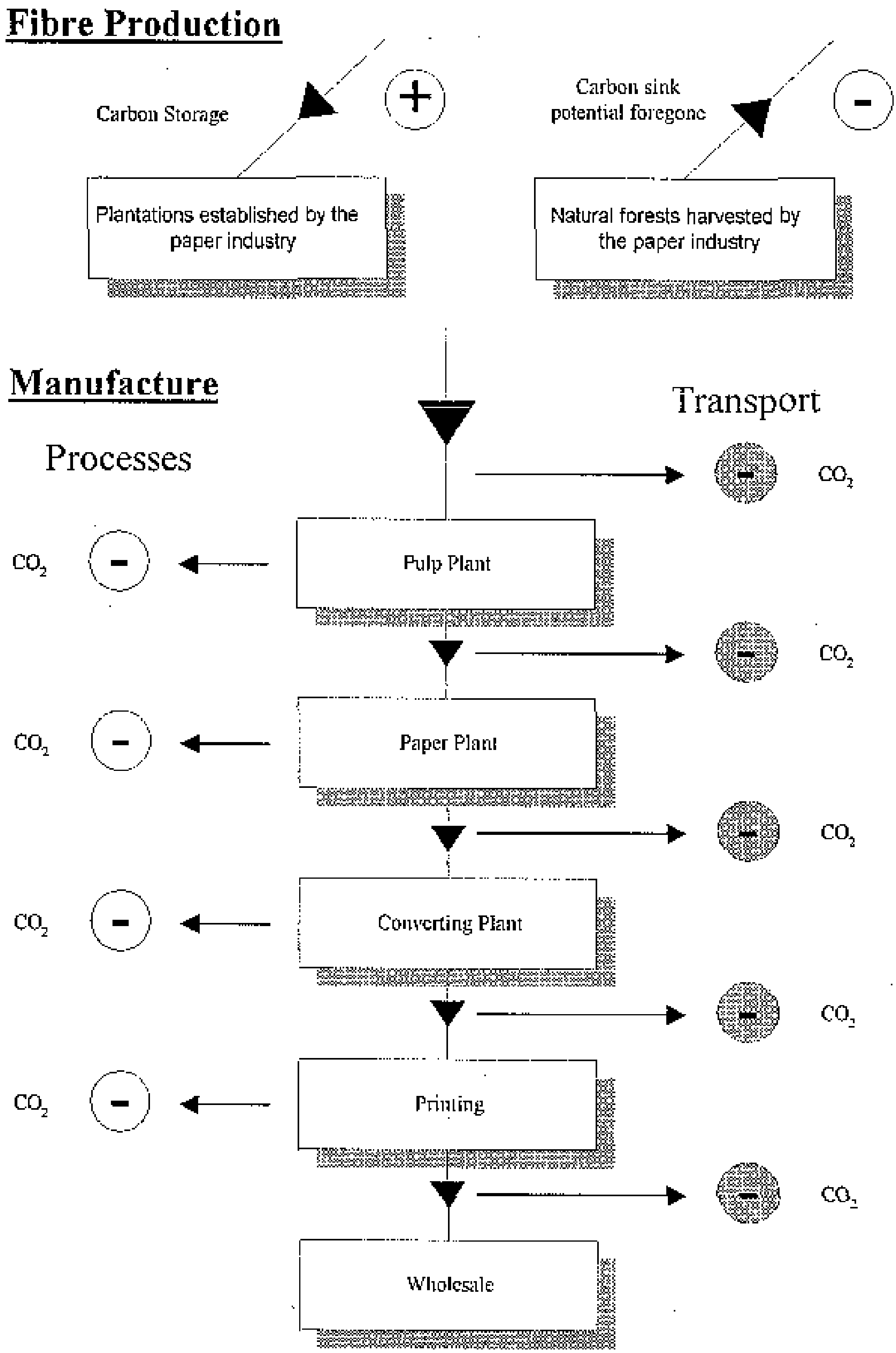
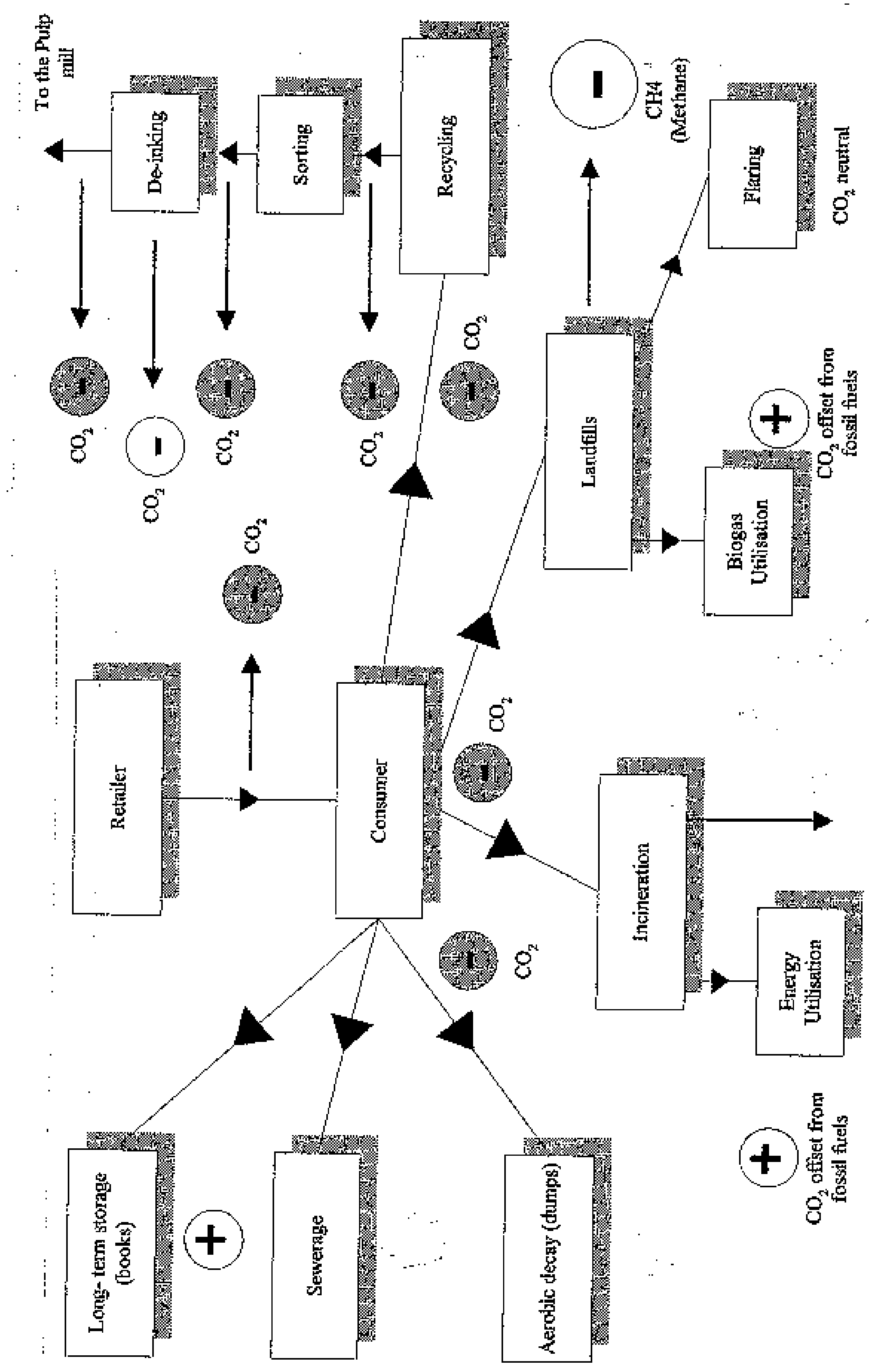


Figure 1b Greenhouse Gas Emissions and Mitigation from Paper Disposal



Greenhouse Gas Sources and Sinks Related to Paper Production and Disposal

Energy Use in Pulp and Paper Production and Manufacture

Carbon dioxide from fossil fuel combustion used in the production of pulp and paper proves to be the greatest source of greenhouse gas emissions in the paper cycle. Energy is consumed in many stages of the paper production cycle, but greenhouse gas emissions can be readily assessed given that fuel consumption for the pulp and paper industry is already published for most counties in the OECD/IEA (1993) international energy compendia. Carbon dioxide emissions from energy use in this industry in 1991 were estimated to be about 316 MT (million tonnes).

Carbon dioxide emissions from energy use in the pulp and paper industry were derived by applying country-specific carbon dioxide emissions factors by fueltype to the energy consumption data published by the OECD/IEA. The emissions factors were provided by the energy module of the Greenhouse Gas Scenario System (Von Hippel et al., 1993), and are weighted according to combustion devices in use in the industrial sector in individual countries.

Wood waste makes up a large proportion of the energy used by the pulp and paper industry. Although carbon dioxide is emitted when wood is burned, these emissions are not included in the above figure because this flux is temporary. Whether burning wood waste for fuel results in net carbon dioxide emissions depends on harvesting and plantation rates and forest management for fibre supply. The carbon dioxide flux related to biomass is accounted for in the estimates for carbon emissions and storage made later in the fibre supply section and is not estimated in this section in order to avoid double counting.

In some cases there is a small overlap in the OECD/IEA data between energy from peat consumption and energy from wood waste. The magnitude of this overlap is estimated to be a maximum of 29 MT of carbon dioxide. Therefore the lower bound of carbon dioxide emissions from fossil fuels used in manufacturing pulp and paper is estimated to be 287 MT. This represents about 1.3 per cent of annual carbon dioxide emissions from all fossil fuel combustion.

A variety of purchased fuels are used by pulp and paper companies. Worldwide, coal is the most common fuel source, used both directly at the mills and to generate electricity used by the industry. Coal has a high carbon intensity (carbon content relative to energy) and hence carbon dioxide intensity.

According to the OECD/IEA data, almost three quarters of the carbon dioxide emissions from energy use originate in just six regions -- the United States, China, CIS, Japan, Canada and Germany. The energy consumption figures published by the OECD/IEA are considered the most accurate of the greenhouse gas emissions-related activity data, with an accepted error range of 5 to 10 per cent in the national emissions estimates. This error range may be slightly higher for the industry breakdowns, since some countries may use somewhat different industrial classifications when they complete the energy use surveys (Ellis pers. comm. 1996).

CSERGE's estimate of carbon dioxide emissions from the industry is in keeping with the OECD's own estimate of global emissions from the pulp and paper industry of 1.2 per cent of global carbon dioxide emissions from all sources. While pulp and paper manufacturing is one of the largest industrial greenhouse gas emitters, it releases less than the steel industry and the chemicals industry, which are believed to account for 4.6 and 5.9 per cent of global carbon dioxide emissions respectively (IEA/OECD 1991). Pulp and paper accounts for over 4 per cent of estimated global energy consumption, but the industry's overall carbon intensity is relatively low because it satisfies a large proportion of its energy requirement from burning wood waste.

Although greenhouse gas emissions from energy used in the pulp and paper industry are dominated by carbon dioxide emissions, methane emissions related to fossil fuel use are also significant. On a molecule for molecule basis, methane has an estimated heat-trapping capability 24.5 times greater than carbon dioxide when considered over a 100-year time horizon (IPCC 1994).

Methane is emitted during coal production and from the distribution and transmission of natural gas used to supply fuel for paper manufacturing. Methane emissions from total energy production and distribution sources in all sectors are estimated to be about 90 MT methane each year worldwide (Watson *et al.* 1992). CSERGE assumed that methane emissions from energy used in paper manufacturing and recycling are proportionate to the industry's share of global carbon dioxide emissions from fossil fuel consumption -- about 1.4 per cent. This total was reduced by the amount of fossil fuel use offset by energy recaptured from paper disposed in landfills and incineration. Methane emissions from extraction are estimated to be only 1.5 MT, or 36 MT in carbon dioxide equivalent units.

Disposal – Landfills, Dumps and Incineration

Disposal of paper and paper products constitutes a major energy-related source of greenhouse gases – methane emissions from landfills -- and a minor offset of carbon dioxide emissions through the production of electricity from incinerators and landfills. Both the landfill emissions and the energy offset are quantified in detail in this study. Paper burned in incinerators is not treated as an emissions source because the carbon dioxide released represents only a temporary flux given that plantations are continually taking up carbon. Landfills are only of interest in the greenhouse gas emissions equation because they involve transforming what might be a temporary flux of carbon into emissions of the far more potent greenhouse gas – methane.

Two minor sources and sinks are not included in this research: storage of carbon in the form of books and other longer lived paper products and methane emitted from paper disposed of as sewage. Carbon storage through longer-term paper products is estimated to be about 10 per cent of paper product consumption. However, this storage is usually fairly short term in that most of these products eventually find their way into the disposal stream. Given that these paper products are offsetting shorter-term emissions from removals from managed forests, particularly at the milling stage, the longer-term storage in paper products is treated as neutral to the carbon cycle. An estimated 5 per cent of paper products is believed to be disposed of as sewage rather than as solid waste. Methane emissions from paper disposed of in this way are especially difficult to quantify. Paper destined for books or sewage is therefore removed from the solid waste stream category in this study and is not counted as a source or sink.

Landfills: Emissions Source

Although there are a number of disposal routes for paper, most paper is deposited eventually in landfills and becomes a major source of methane. Methane emissions from paper in landfills were estimated to be about 12 MT in 1993, making up about one quarter to one third of global methane emissions from landfills. In global warming equivalent terms, these methane emissions are almost as great as the heating effect of carbon dioxide released from fossil fuels combusted to make pulp and paper.

These numbers are more uncertain than the carbon dioxide emissions estimates from energy use. Estimates of global emissions of methane from waste disposal range from about 20 to 70 MT, compared with an uncertainty level of less than 10 per cent for carbon dioxide emissions related to fossil-fuel use.

In the case of paper, however, methane emissions from landfilled waste can be more accurately assessed than for solid waste as a whole because the amount of paper consumed is well known and the degradable organic content of paper is not nearly as variable as it is for the "wetter" food wastes. In addition, paper consumption by weight is recorded more precisely than consumption of "food", and paper is not actually "consumed" but is eventually disposed of in a similar form to when it was originally purchased. For the main parameters of waste disposal including landfill and incineration rates, CSERGE relied on waste disposal surveys published by the OECD and upon national communications.

Disposal-related emissions and offsets were calculated for the top paper-consuming countries. There are seventeen countries that can be identified as each consuming more than 1 per cent of the total world paper and board consumption. Together, these make up 85 per cent of world consumption, providing a reasonably large proportion of the disposal of paper worldwide. Much of the remainder is accounted for by the other Western European countries, so the assumptions used can be extrapolated.

Paper consumption and wastepaper recovery figures were taken from Pulp and Paper International (1995) for 1993, the latest year available. 'Wastepaper' is made up of both pre-consumer waste (including printers' offcuts but not mill broke) and post-consumer waste. 'Wastepaper recovery' is equal to the waste paper used in production, minus imports and plus exports of waste paper. In combination, these figures give the paper generated in each country that becomes municipal solid waste.

The amount of paper disposed of by aerobic decay, incineration (with and without energy recovery), sanitary landfills and open dumps has been calculated. The information on disposal routes was taken from OECD (1995) for France, Germany, Italy, the Netherlands, Spain, UK, CIS, Canada, United States, and Japan; for China, (Blakey 1995); for India, Anon. (1995); for Taiwan, RIET (1995); for

Australia, Morwood (1993), for Brazil, CEMPRE (1995), and for Mexico, personal communication, IIED (1996). No such information was available for Korea, so it was assumed that the situation there would be similar to Taiwan.

Much of the uncertainty in calculating methane generated from landfilled paper is related to the particular landfill conditions that can diminish methane generation potential. Given the wide variation in landfill sizes and conditions it is almost impossible for any country to supply exact methane emissions. CSERGE used the "default" factor of a 77 per cent release rate for degradable organic material in landfills, as used by the Intergovernmental Panel on Climate Change and others (IPCC/OECD 1994, Watt Committee on Energy 1994). This is similar to the original rate estimate published by the Max Planck Institute (Bingemer and Crutzen 1987).

Several countries have been assuming that a portion of the methane produced in landfills is oxidized and emitted as carbon dioxide, a process that limits final methane release. The highest methane oxidation rate suggested is 40-50 per cent (Orlich 1990), but countries that are considering oxidation are using lower estimates, based in part on limited but more recent testing. CSERGE's central estimate assumes a 10 percent methane oxidation rate, the level used by the United States (US EPA 1993). Oxidation rates of 0 to 20 per cent, the range used by most countries, would provide a range of methane emissions from paper of 11 to 13 MT.

The final methane flux will depend on whether the biogas is flared at the site, thereby being released as carbon dioxide, or if it is recovered for use as a medium-grade energy source. Figures on flaring and recapture rates for the UK have been taken from Bellingham *et al* (1994), and The Watt Committee on Energy (1994), and (Richards 1987) for France, Germany, Italy, the Netherlands, India, Australia and Brazil; for Canada, from their national communication, and for the US.

Recovered gas can be used in nearby residences or industry (within 3km), into a pipeline grid, electricity generation or steam production. Only sanitary landfills and large open dumps are suitable candidates for gas recovery. Small open dumps, common in rural areas of developing countries, are not suitable (Orlic and Kerr 1996). Wastes in open dumps generally decompose aerobically, producing no methane. There is evidence that some methane production occurs, but this amount has generally not been quantified (Orlic and Kerr 1996). Therefore, only methane arising from sanitary landfills has been calculated. Any methane arising from open dumps will be in addition to this figure, which thus represents a lower-bound estimate.

Given the long time lag in biogas emissions, calculations based on current paper consumption levels will tend to overestimate methane generation somewhat, since paper consumption is continually increasing. Most of the methane now being released in landfills is related to wastes disposed in the 1980s and earlier, rather than in recent years. Currently, there is not a practicable way to make this adjustment given the variation in lags for biogas production, although a new method is a priority of ongoing research coordinated by the climate change convention secretariat.

CSERGE "best guess" estimate of 12 MT methane from paper disposed in landfills can be compared with recent estimates of methane from landfills, as published in countries' 1994 and 1995 national communications to the Framework Convention. Nine of the major paper consuming countries have reported methane emissions from landfills for the year 1990, and their estimates sum to 19 MT. Our estimate of 8 MT from these nine countries suggests that paper represents about 40 percent of these industrialized countries' landfill emissions. This appears reasonable given the high degradable organic content of paper compared with other wastes; and appears conservative compared with the United States estimate that paper products contribute about half of wet solid waste disposed in landfills in recent years (US EPA 1993).

Fossil Fuel Offset from Incineration and Landfilling

A proportion of all solid waste is used to generate electricity. This offsets fossil fuel use, and therefore, carbon dioxide emissions. CSERGE estimated electricity produced from incinerated paper, and counted as a credit the carbon dioxide emissions avoided through burning paper. The proportion of municipal solid waste that is disposed of in incinerators by major paper-consuming countries with incineration facilities varies from a low of 5 per cent in Spain to a high of 74 per cent in Japan. Energy recovery is significant, with about half of the countries that rely on incineration reporting energy recovery capabilities for more than 75 per cent of incinerator capacity.

To calculate electricity generation from incineration, a standard energy content and incinerator efficiency estimate were used. The calorific value of paper (dry weight basis) is taken as 16.2 MJ/kg paper (Handbook of Environmental Engineering 1980), with an incinerator efficiency of 20 percent (RCEP 1993).

The energy content of the biogas was estimated to be 37.75 MJ/m^3 (Perry and Green 1984). The conversion efficiency for electricity generation was assumed to be 30 per cent (CSERGE *et al* 1993). The offsetting of carbon dioxide will vary to some extent according to the fuel mix for electricity. Carbon dioxide emissions offsets were calculated by assuming that the electricity generated was typical of the primary energy for electricity production in each country. Sources for electricity specific to each country were derived from the OECD/IEA energy balances.

It was assumed that all recaptured biogas from landfills was used to generate electricity, because it was not known what fraction was used directly as medium quality natural gas. This assumption will underestimate the amount of energy that is offset because energy is lost in the energy transformation process. On the other hand, this assumption will overestimate the carbon intensity of the energy produced because electricity generation involves coal combustion, which is more carbon intensive than natural gas.

Transport

As described in a previous substudy, transport is used at all stages of the paper cycle and involves a variety of vehicles: trucks, vans, trains, ships and occasionally aeroplanes. Energy used in the transport of particular products is not recorded for specific industries, as is energy requirement for manufacturing. The study completed by the Paper Industry Research Association (PIRA) (1996) for IIED assessed carbon dioxide emissions from transport for a representative case in Europe. Using the example of paper production, consumption and disposal in Germany based on fibre production in Scandinavia, the study concluded that carbon dioxide emissions from transport represents only about 2.5 per cent of emissions from paper production in Germany (see IIED Sub-Study No. 12 for more details).

In the PIRA study, energy expended on ocean shipping of fibres and pulpwood to Germany was negligible, given the relative proximity to Scandinavia. However, large quantities of pulpwood are transported on long distance trading routes i.e. South America and Japan, North America and Europe. Using bilateral trade tables of pulp, pulpwood, and wastepaper traded (United Nations 1992), the carbon dioxide intensity of ocean shipping, carbon dioxide emissions were calculated for the main international shipping routes. The carbon dioxide intensity of shipping fibre products between Scandinavia and Germany has been estimated at 0.038 t carbon dioxide/t pulp/km by PIRA (1996), which was applied to estimated km traveled between major national ports. Over half of estimated emissions are attributed to shipping between North America and Japan and between Chile and Japan. The use of PIRA's emission factor most likely overestimates carbon dioxide intensity in that a high proportion of the energy use is in start-up and docking. On the other hand, not all of the international trade was included in the shipping emissions estimate because the bilateral data tables are not a complete record of all trades. Moreover, a proportion of the bilateral trade will be by air plane, which is more energy-intensive than shipping. On balance, this estimate is likely to underestimate emissions from transport.

Carbon dioxide released from ocean ships carrying pulp and paper products is estimated to be at least 5 MT carbon dioxide, about 1.5 per cent of total carbon dioxide emissions from the pulp and paper industry. Adding the major shipping route emissions to PIRA's estimate of carbon dioxide from transport, yields a total estimate of 13 MT carbon dioxide from transport. CSERGE believes that this approach is still likely to underestimate carbon dioxide emissions from transport given the greater transport intensity and distances involved within North America relative to Europe.

Recycling

Recycled paper eventually joins virgin pulp for most of the steps involved in paper-manufacturing and distribution. From the limited life cycle analyses of paper recycling that have been completed to date, there is a difference of view as to whether recycling results in additional carbon dioxide emissions because of fossil-fuel intensive de-inking processes, or whether fossil fuel use is reduced overall because of savings in the pulping and other stages. Several of these studies are scenario specific, but most of them conclude that recycling requires additional fossil-fuel use, as summarized in Chapter 11 of IIED's main report and IIED Sub-Study No. 14. It is clear, however, that if recycling avoids a final fate of methane-intensive landfill disposal the recycling process reduces greenhouse gas emissions relative to a virgin paper - landfill disposal cycle.

On the other hand, for communities that have an option of incineration, disposal through incineration minimizes greenhouse gas emissions relative to recycling-landfilling. This is because the carbon dioxide emitted through incineration is a temporary flux only, given that growing plantations and forests are recycling the carbon dioxide. Incineration may also be viewed as a greenhouse gas-minimizing approach because energy recovered from incineration can replace carbon dioxide emissions from fossil-fuel use, as described above, although the offset potential is somewhat limited.

For this study, an attempt has been made to calculate emissions of carbon dioxide from recycling that is additional to energy use that applies to the paper manufacturing cycle. It is difficult to identify the energy requirements of paper recycling at each separate stage of the process. Johnson (1993) quotes requirements of 745 kWh electrical power and 4325 kWh coal-generated steam per tonne of recycled newsprint for mechanical sorting. Ogilvie (1992) gives a value of 25.1 GJ/t for primary paper production, and savings arising in production from the use of recovered wastepaper of 28 per cent - 70 per cent. White, Franke and Hindle (1995), quote the energy consumption from virgin paper as 22.7 GJ/t, and from recycled paper as 14.4 GJ/t (a saving of 37 per cent). These figures include energy use that in our study is included in the paper manufacturing stage.

The additional emissions are estimated to be only about 4 MT of carbon dioxide. This estimate excludes energy use after the pulp from recycled fibres joins virgin paper in the repulping, conversion and distribution phases, which should be captured in the main energy statistics for the pulp and paper industry.

Included in these emissions are carbon dioxide emitted in paper-sorting operations, which are often mechanized. White, Franke, and Hindle (1995) concluded that electrical energy for material reclamation facilities ranged from 22 to 27 kWh and involved small quantities of diesel and natural gas per tonne of waste paper in the three sites that they examined. The total energy required was 0.215 GJ/t materials recycled. Extrapolated to world paper consumption but adjusted by fuel mix for electricity generation, yields carbon dioxide emissions of somewhat less than 1 MT. In addition, carbon dioxide for transport related to recycling was considered. Using PIRA's estimates of carbon dioxide expended in transport to and from collection banks, conversion facilities and users, transport-related emissions are about 3 MT annually worldwide. This estimate is highly uncertain because of limited sampling and the wide variation in sorting operations in use.

Fibre Supply

The distribution of plantations and naturally regenerating forests to supply fibre for pulp production has been discussed in detail in Chapter 4 in IIED's main report. About 30 per cent of fibre for pulpwood is believed to be supplied from plantations, with the remaining from naturally regenerating forests. Original forests are thought to supply about 17 per cent of pulp. At least one quarter of fibre supplied for pulp production originates from wood waste from forests and plantations that are not classified as pulpwood producers. In terms of the carbon balance, fibre supply may be divided into three categories:

- plantations: harvests from tree plantations that were established on land that was previously in agriculture or non-forest use

- managed forests: harvests from "natural" forests on land that has been forested through much of this century and that is able to regenerate to its original biomass level

- converted forests: these forests which are converted from high biomass original forest to lower density secondary forests or plantations or other uses such as agriculture.

These three categories are treated differently in the carbon flux estimates.

Plantations

Plantations are treated as carbon credits if they were established on land that was not previously forested. This is believed to be the case for about 85 per cent of plantations that are harvested for pulp (Bass pers comm 1996). The carbon stored includes the fibre provided for the pulp and paper industry, plus the biomass and detritus that is not harvestable or recorded in the commercial harvest. Fibre production is converted to carbon storage as follows:

(a) pulp from plantations: 185 million m^3 (618 million m^3 x 30 per cent)

(b) conversion: 0.65 t dry matter/m^3 for deciduous trees, 0.45 t dry matter/m^3 for conifers (IPCC/OECD 1994)

(c) carbon density: 0.45 t carbon/t dry matter (IPCC/OECD 1994)

(d) expansion factor: 1.9 above-ground biomass/commercial biomass (IPCC/OECD 1994)

(e) percentage of plantations on land previously in agriculture: 85 per cent

net carbon storage = (a) x (b) x (c) x (d) x (e) = 249 MT carbon dioxide; 68 MT carbon

As mentioned in the fibre-supply substudy (IIED Sub-Study No. 2), only an estimated 30 per cent of fibre production for pulp and paper is believed to arise from these plantations, with the remainder sourced from naturally regenerating forests. Therefore, only a minority of fibre production may be considered as carbon storage or credited as net uptake in the carbon dioxide emissions balance. Net annual carbon storage will be the annual increase of biomass on the plantation and the annual increase of storage through harvested fibre and paper. Industrial plantations used for fibre production are believed to be increasing and the new establishment is estimated here based on other studies (Sedjo and Lyon 1995) to be in the order of 21 MT of carbon dioxide annually (6 MT carbon). In addition, some carbon is stored each year because the removal of fibre from plantations does not result in immediate emissions, but the paper products and fibre precursors moving through the cycle contribute to carbon storage. In the case of the fibre produced from plantations, each harvest is treated as an addition to carbon storage, and the plantations are assumed to replace harvested fibre through regrowth. These assumptions of equilibrium will overestimate the actual carbon strorage and in fact would represent an upper-bound estimate of carbon storage through fibre production from plantations.

Using this method, plantations are estimated to store an 270 million tonnes of carbon dioxide each year (74 MT carbon). A portion of this sink is attributed to new high-yielding plantation establishment in "emerging" regions. This is of the order of 600,000 hectares annually with a yield of 17.5 m^3/hectare/year or 7 t/ha carbon uptake each year (IIED Sub-Study No. 2 1995), for a total of 6 MT carbon storage. The area and yields of plantations and paper cannot be calculated precisely because insufficient surveys exist. The maintenance of these plantations involves some fossil fuel consumption for fertilizer manufacture that has not been quantified here. The estimate of 74 MT carbon storage through plantation establishment for pulpwood production appears to be reasonable given that total carbon sequestration from plantations in all developing regions is estimated to be about 210 MT per year (Subak *et al* 1993). Sedjo and Lyon (1995) state that the pulpwood share in total industrial wood production is now about 40 per cent when considering all regions.

Secondary Forest Regeneration

There is a debate as to whether "natural" managed forests, which supply an estimated 53 per cent of the fibre for pulp and paper, are a net source or sink for carbon dioxide when the entire forest-products cycle is taken into consideration. In theory, given a stable forest area, commercial harvesting of timber products can increase carbon storage if the harvested wood is converted to long-term uses such as construction materials. In this instance, houses, furniture, and so on, are extending the boundaries of the forest and, because the trees regrow on harvested land, net carbon storage is positive.

In the case of short-term forest products such as pulp and paper, however, the potential for net carbon storage is diminished. Carbon dioxide is released from burning and decaying wood at several stages in the paper production process and the resulting carbon flux may occur more rapidly than the cyclical uptake in the regenerating forest. Once the trees are cut, only about half of the biomass is used, with the remaining leaves, branches, and bark left to decay (Row 1995). Subsequently, only about half of the fibre supplied is recovered as paper and the residue is "digested" or used as fuel and so is emitted rapidly as carbon dioxide (Hartman *et al* 1976, Row 1995). While this woodfuel use serves to diminish the industry's requirement for fossil fuels, and in that respect decreases the total greenhouse gas emissions contribution of the pulp and paper industry, the scrap burning reduces the carbon stored in the paper cycle.

It is an open question as to whether the loss of biomass in harvest, processing, and disposal occurs more rapidly than biomass uptake in the regenerating forest. A recent study concluded that United States timberlands involve a net storage when wood-product storage is considered, but the study included all long-lived products, not just paper, in the analysis (Plantinga and Birdsey 1993). Given that the biomass replacement rate in the regenerating forests is many decades, while most biomass related to the paper cycle is lost within a few years, it is likely that net carbon storage related to these forests is depleted as a result of the pulp and paper industry. Nonetheless, in the absence of studies assessing the timing of biomass movement through different storage pools, these managed forests are treated as neutral in the carbon balance.

Old Growth Forest Depletion

An estimated 17 per cent of pulp fibre is believed to be harvested from original forests. Most of this area is coniferous forest from temperate regions of North America and the CIS. Harvests from these forests take a number of forms including conversion to agriculture, or transformation to plantations or to lower-density secondary forests. Because the conversions differ by region, it is especially difficult to quantify the impact of these harvests on the carbon balance. Assuming that average storage after harvest for pulp fibres will be at about half the original level (the upper bound estimate of storage after conversion, according to Harmon *et al*'s (1990) analysis of conversion of old growth American forests to plantations), emissions from forest conversion would stand at about 74 million tonnes carbon dioxide annually.

Soil Carbon

Most of the world's biotic carbon is stored in soils rather than above-ground. As logging perturbs soils to some degree, and plantation establishment involves some carbon accumulation, we would expect some soil flux related to fibre production. This flux is judged to be the most difficult to quantify, however, because of the wide variability in conditions leading to soil carbon flux. Of the fibre supply sources, the "mined" forests are likely to involve the highest carbon dioxide flux, because soil carbon is believed to decline by about 10 per cent (30 t C/ha) when primary evergreen and deciduous forests in temperate regions are converted to secondary forests (Schlesinger 1977).

This soil carbon loss, however, is a final rather than an annual value and, when averaged over a longer time horizon or a full rotation, may represent a relatively minor flux. The establishment of plantations on previously non-forested lands could result in accumulation of soil carbon over time, although international working groups on greenhouse gas emissions methods have declined to quantify this accumulation in the absence of additional research (IPCC/OECD 1994).

Overall Impact of the Paper Cycle on Global Warming

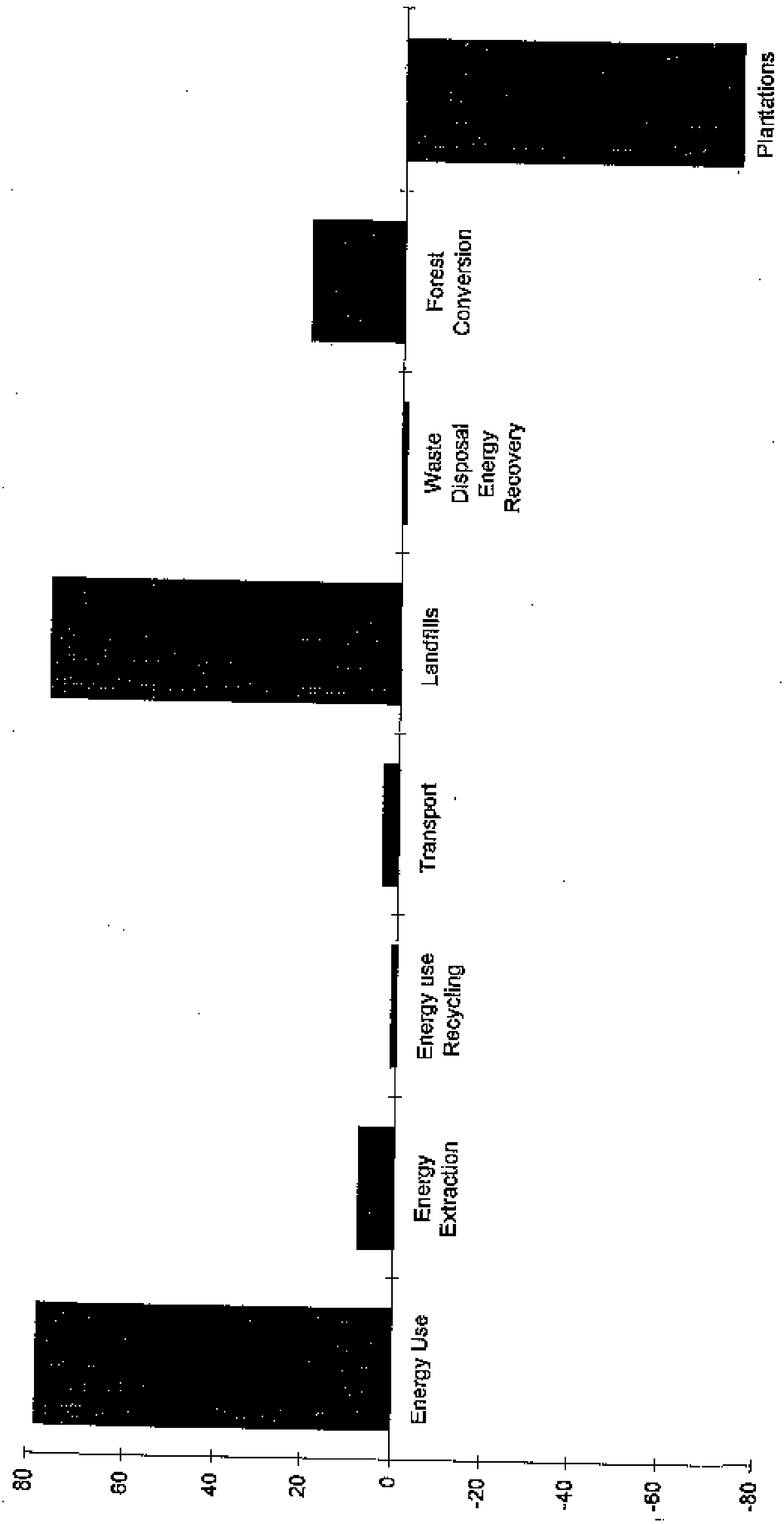
The pulp and paper industry is a significant emitter of greenhouse gases. While plantations maintained to supply fibre for pulp production store large amounts of carbon on land that previously was not forested, this carbon storage is insufficient to offset the even greater emissions from fossil fuel use in manufacture and from paper disposed in landfills. Despite the proportion of industrial plantations devoted to pulp production, plantations do not appear to be offsetting emissions from either energy use or landfills, let alone both of them, as shown in Figure 2. Production, consumption and disposal of paper products is estimated to contribute a net addition of about 450 million tonnes in carbon dioxide equivalent units each year, as indicated in Table 1. This sum represents the net emissions of carbon dioxide and methane by equivalent global warming potential integrated over a 100 year time horizon. This level is somewhat more than the carbon dioxide released each year from fossil fuel combustion in Canada, which is the ninth greatest carbon dioxide emitter from energy use. On a carbon equivalent basis (CO_2-C), i.e. considering only the carbon mass in carbon dioxide, net emissions are calculated to be 118 MT.

Table 1 Annual Emissions of Greenhouse Gases from the Paper Cycle

Sources	Annual gas Emissions (MT)	CO_2 Equivalents (MT)	CO_2-C Equivalents (MT)	Certainty
Energy Use (CO_2)	290	290	79	High
Energy Extraction (CH_4)	1	32	9	Medium
Energy Use Recycling (CO_2)	4	4	1	Medium- Low
Transport (CO_2)	29	29	8	Medium - Low
Landfills (CH_4)	12	278	76	Medium
Natural Forest Conversion (CO_2)	74	74	20	Low - Medium
Natural Forest Management (CO_2)	0	0	0	Low
Total Sources		707	193	
Sinks				
Waste Energy Recovery (CO_2)	-4	-4	-1	Medium
Plantations - Stable Harvest (CO_2)	-249	-249	- 68	Medium-High
Plantations - New Establishment (CO_2)	-21	-21	-6	Low -Medium
Total Sinks	**-274**	**-274**	**-75**	
Net Emissions Flux		433	118	

For this study, greenhouse gas emissions from 34 countries that are paper consumers, paper producers, or fibre suppliers were examined. More than one third of the countries appear to be net sinks for greenhouse gases, with the remainder net sources. The largest single emitter by a wide margin is the United States at 150 MT carbon dioxide equivalence, followed by Canada at 73 MT and China at 64 MT. Emissions from landfills dominate the U.S. and China total, whereas forest depletion is an important cause of Canada's emissions. Most developing countries that are fibre producers appear to be net sinks for these greenhouse gases as they do not have significant emissions from manufacturing or landfills. Brazil appears to sequester large amounts at 39 MT carbon dioxide equivalence, with South Africa a distant second at 15 MT and Chile at 9 MT. Led by Sweden and Finland, several European countries appear to be net sinks rather than sources of emissions related to the paper cycle.

Figure 2 Greenhouse Gas Emissions from the Paper Cycle - million tonnes equivalents per year (CO_2-C)



A breakdown of emissions by company and nation is beyond the scope of this project but would be of value in identifying the situations in which sinks in one country could be set against sources in another. Given the structure of the paper industry, there are opportunities for intra-industry 'joint implementation' arrangements, on a formal or informal basis, whereby credit can be gained for emissions offsets through the expansion of forest sinks. Joint implementation is the term used to describe bilateral arrangements whereby, on the grounds of cost effectiveness, one nation provides financial support for emission control measures in a second nation and, at some future time, will be in a position to claim credit against emissions reduction targets at home.

The Paper Industry and Future Global Warming

It seems likely that in the future the trend will be towards a moderate decrease in greenhouse gas emissions intensity at most stages of the paper cycle. The energy intensity of the pulp and paper industry has been declining by an average of 0.8 per cent each year per tonne of paper produced during the past two decades in OECD countries (IEA 1993). Carbon dioxide emissions from fossil fuel use would be expected to decrease at least commensurably. Plans to repair gas pipeline leaks and to recapture methane gas emitted in coal mining should reduce methane emissions related to fossil fuel used in the pulp and paper and other industries.

Most large industrialized countries project reductions in methane emissions from energy production by 2000. The aggregate reduction projected by one dozen of the largest energy-related methane emitters in the OECD is about 10 per cent by 2000 (INC 1994, INC 1995). Reductions in methane emissions from energy production should continue in industrialized countries on into the 21st century, as natural gas prices increase and industry is encouraged to adopt measures to reduce emissions.

In industrialized countries, methane emissions from landfills are expected to diminish at a faster rate than the projected increase in paper consumption. National communications to the Framework Convention on Climate Change from industrialized countries project that methane emissions from solid wastes will be reduced by about 20 per cent by 2000 (INC 1994, INC 1995). This projection is optimistic given the long lag time in methane generation in old landfills, and the currently modest rate of deployment of methane recapture technology. Nonetheless, there is a trend in many industrialized countries towards installing methane recovery technology at larger landfill sites, adopting mandatory recycling laws, and making increasing use of composting and incineration alternatives. All of these options will serve to reduce methane emissions from paper disposal as well as from other solid wastes.

In developing countries, paper consumption is projected to increase more rapidly than in industrialized countries, but changes in the methane intensity of paper disposal will depend on whether many regions shift from using open dumps, which release very little methane, to constructing sanitary landfills. Incineration may prove to be an attractive option in developing countries, if putrescibles become a diminishing share of the waste stream, as it has the potential to provide an inexpensive source of energy.

Trends in forest management related to fibre production have already been discussed in detail in earlier sections of this report. Plantations are expected to be established at a rate of up to 600,000 hectares per year in developing countries and China in the next few decades, enabling a doubling of pulpwood consumption by 2045 (IIED Sub-Study No. 2 1995). Some increase in wood yields is expected in this scenario. All management practices that increase average biomass levels on the ground serve as carbon sequestering measures.

Enhanced carbon storage, however, is not always compatible with other environmental goals such as species preservation. In addition, more intensive management of regenerating forests such as denser planting requires added fertilization that may have negative feedbacks on emissions by requiring fossil fuel inputs for nitrogenous fertilizer manufacture (Trexler 1991). Furthermore, the trend towards higher yield plantation and forest management may lead to increased soil carbon flux. Increasing plantation establishment on marginal but viable land, while reducing harvesting of old growth forests, would be a bonus in terms of carbon sequestration.

The general trend towards a modest decrease in the greenhouse gas emissions intensity of the paper industry is unlikely to lead to a situation of zero net emissions in the next few decades. Unless there is a wholesale switch from the use of fossil fuels in manufacturing -- towards renewables -- it is not likely that the paper industry could become a net zero emitter. While plantations may be established at an aggressive rate in the coming decades to meet heightened demand for fibre, afforestation will be matched by considerable growth in manufacturing, and in waste disposal -- the two major sources of greenhouse gas emissions. A simple scenario has been constructed based on assumptions of paper consumption, manufacturing efficiency and plantation establishment projected elsewhere in this report, along with projections of methane emissions from landfills published in national communications to the climate convention. As indicated in Table 2, if paper production matches current demand growth of 3.5 per cent annually, efficiency improves by only 0.8 per cent, and plantation establishment increases at 2.5 per cent, net greenhouse gas emissions will be similar or slightly below 1990 levels by 2010. This scenario is already assuming that landfill methane would be 20 per cent below 1990 levels. To achieve serious cuts in emissions, the industry would have to oversee a greater switch from fossil fuels to renewables, and establish and maintain a larger area of plantations.

Table 2 Projections of Greenhouse Gas Emissions from the Paper Cycle in 2010

	Fossil Fuel 3.5% growth 0.8%/yr efficiency improvement	**Landfills** 20% cut by 2010	**Plantations** 2.5% increase in establishment	**Depletion** decrease by 10%/yr	**Total** MT C eq.
1990	79	76	-64	20	111
1991	81	75	-66	18	109
1992	83	74	-67	16	107
1993	86	74	-69	15	105
1994	88	73	-71	13	103
1995	90	72	-72	12	102
1996	93	72	-74	11	101
1997	95	71	-76	10	100
1998	98	70	-78	9	99
1999	100	70	-80	8	98
2000	103	69	-82	7	97
2001	106	68	-84	6	96
2002	109	67	-86	6	96
2003	112	67	-88	5	95
2004	115	66	-90	5	95
2005	118	65	-93	4	95
2006	121	65	-95	4	94
2007	124	64	-97	3	94
2008	128	63	-100	3	94
2009	131	63	-102	3	94
2010	135	61	-105	2	93

Conclusions and Recommendations

Overall, like any other industry, the paper cycle contributes to the risks of global warming. While carbon is sequestered in plantations and carbon dioxide emissions are offset by energy recovery from incineration of paper and some landfills, these offsets do not compensate for the greenhouse gases released during manufacturing, transport, recycling, disposal in landfills, and deforestation.

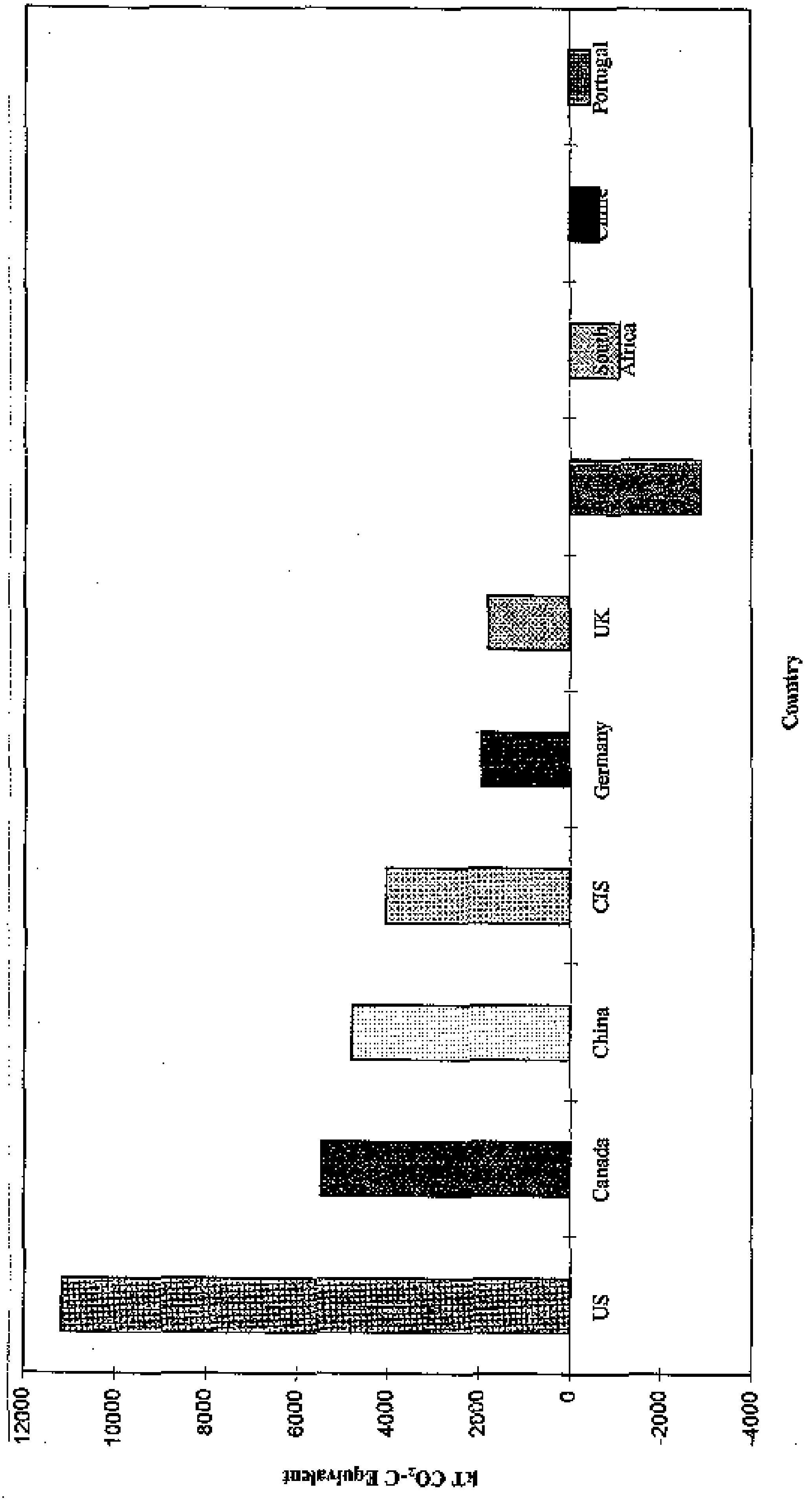
Estimation of emissions from the paper cycle is particularly complex given that greenhouse gases are released and taken up from so many sources. Greenhouse gas emissions from other major industries -- steel and chemicals -- are concentrated in fossil fuel use related to manufacture and are easier to quantify at 4.6 and 5.9 per cent of total carbon dioxide emissions (IEA/OECD 1991). The pulp and paper industry is a distant third at about 1.7 per cent of total carbon dioxide emissions, when methane emissions are considered as well, on a carbon dioxide equivalent basis. The greenhouse gas emissions intensity of the paper industry is comparable to that of chemicals considering that the paper industry's contribution to world GDP is 2.9 per cent of world value added from manufacturing compared to the chemical industry's at 8.4 per cent.

Greenhouse gas emissions could be reduced at all stages of the paper cycle. The carbon dioxide intensity of paper and pulp manufacturing could be reduced both by fuel switching, and by efficiency improvements. While Canada and the UK use natural gas for a high percentage of their fuel use in the paper industry, coal is used heavily in many regions. Switching from coal to natural gas and further reliance on woodwaste for fuel, could reduce carbon intensity. The Scandinavian countries are models as respects their use of woodwaste and wood liquors for fuel. Sweden, in particular, is likely to be a net zero emitter or a carbon sink, in part because fossil-fuel related emissions are so low.

Additional gains in reducing fossil-fuel intensity could be achieved by efficiency improvements. The IEA/OECD (1991) estimate that carbon dioxide emissions in the paper cycle could be reduced by 10 to 30 per cent if current manufacturing stock was replaced by the best available technology.

Landfills were found to be almost as great a source of greenhouse gas emissions as energy use in manufacturing. Although the pulp and paper industry have less control over the final fate of paper, advocacy of alternative waste disposal practices including recycling, composting, and incineration would serve to help reduce emissions from disposal. While currently the carbon dioxide intensity of recycling is relatively high, recycling still lowers emissions because it generally avoids contributing to methane emissions from landfilling. Incineration remains the best greenhouse gas minimizing strategy on the disposal side because it produces only negligible amounts of methane and can offset small amounts of

Figure 3 National Emissions from the Paper Cycle



While currently the pulp and paper industry is offsetting only a portion of their emissions from manufacture and disposal through the establishment of tree plantations, in theory the plantation area could be extended to offset emissions from the entire cycle. If the entire area of industrial plantations (not just plantations for fibre supply) now believed to be present worldwide -- 40 million hectares --was used for pulp production, the annual uptake needed would be 5.2 tonnes carbon per hectare each year to offset emissions quantified in this study. This uptake rate exceeds plausible scenarios of average high yield temperate and tropical plantations.

Put another way, at a moderately aggressive rate of carbon uptake of 2.5 tonnes per hectare each year (IIED Sub-Study No. 2 1995), about 76 million hectares of plantations would be needed to offset all current emissions. At current plantation establishment rates of 0.6 million hectares annually (Sedjo and Lyon 1995), complete offset of greenhouse gas emissions through plantations appears to be an elusive goal. To become a net zero emitter, the pulp and paper industry would need to pursue changes at all levels of the cycle -- the curtailment of timber extraction from original forests in the CIS, North America and some developing regions, as well as efficiency improvements in manufacture and alternative disposal routes to landfilling.

Unlike other industries relying only on fossil fuel-based manufacturing processes, the complexity of the paper cycle does provide rich opportunities for greenhouse gas emissions abatement. For the industry to capitalize on this key aspect of its activities and to enhance its sustainability, there are areas in which action should be taken. While the paper industry is unlikely to reach the goal of zero net emissions, there remains considerable scope for emissions reduction. A significant reduction strategy would take account of emissions at all stages of the paper cycle, and would involve the paper industry taking account of activities not generally considered within its sphere of responsibility, such as landfill management and alternatives to landfill disposal.

References

Anon. 1995. The emerging priority for disposal, use and recycling of MSW in India. *Wastes Management*, April.

Bass, S. 1996. International Institute for Environment and Development. Forestry Program. London. Personal Communication. March.

Bellingham, I.R., Milton, M.J.T., Woods, P.T., Passant, N.R., Poll, A.J., Couling, S., Marlowe, I.T., Woodfield, M., Garland, J. and Lee, D.S. 1994. The UK Methane Emissions Inventory: A Scoping Study on the Use of Ambient Measurements to Reduce Uncertainties. National Physical Laboratory Report DQM 98, NPL, Middlesex.

Bingemer, H.G. and Crutzen, P. 1987. The Production of Methane from Solid Wastes. *Journal of Geophysical Research* 92(D2):2181-2187.

Blakey, A. 1995. Solid Waste Management Opportunitites China. *Waste Age*.

CEMPRE News, Brazilian Recycling Commitment, No. 26, December 1995.

CSERGE, Warren Spring Laboratory and EFTEC. 1993. Externalities from Landfill and Incineration. HMSO, London.

Ellis, J. 1996. International Energy Agency. Organisation for Economic Cooperation and Development. Paris. Personal Communication. April.

G2S2. 1992. The Greenhouse Gas Scenario System computer tool. Energy Module including Fossil Fuel Share of Electricity Generation by Country.

Handbook of Environmental Engineering. 1980. Vol. 2, Human Press, New Jersey, USA..

Harmon, M.E., Ferrell, W.K., Franklin, J.F. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. *Science* Vol.247:699-702.

Hartman, D.A., Atkinson, W.A., Bryant, B.S., Woodfin, R.O. 1976. Conversion Factors the Pacific Northwest Forest Industry. Institute of Forest Resources, College of Forest Resources. University of Washington. Seattle.

IEA. 1992. *Energy Statistics and Balances of Non-OECD Countries: 1989-1990.* IEA/OECD. Paris.

IEA. 1993. *Energy Statistics of OECD Countries: 1990-1991.* IEA/OECD. Paris.

IEA/OECD. 1991. *Energy Efficiency and the Environment.* IEA/OECD. Paris.

IIED. 1996. Towards a Sustainable Paper Cycle. International Institute for Environment and Development, London , UK and World Business Council for Sustainable Development, Geneva, Switzerland.

INC. 1994. Matters Relating to Commitments: First Review of Information Communicated by Each Party Included in Annex 1 to the Convention. A/AC.2347/81.7. December. United Nations General Assembly. New York.

INC. 1995. Matters Relating to Commitments. First Review of Information Communicated by Each Party. FCCC/1995/Inf. 4. Berlin.

IPCC. 1994. *Report on Radiative Forcing of Climate*. Intergovernmental Panel on Climate Change. Geneva.

IPCC/OECD. 1994. Greenhouse Gas Inventory Reference Manual. IPCC Draft Guidelines for National Greenhouse Gas Inventories. Paris.

Johnson, C.J. 1993. A Lifecycle Assessment of Incinerating or Recycling Wastepaper. Unpublished MSc Thesis, Imperial College, London.

Morwood, R. 1993. Australian Waste Management - Towards 2000.

OECD. 1993. *OECD Environmental Data Compendium 1993*. Organisation for Economic Cooperation and Development. Paris.

OECD. 1995. *OECD Environmental Data Compendium 1995*. Organisation for Economic Cooperation and Development. Paris.

OECD/IEA. 1993. *World Energy Balances*. OECD/IEA. Paris.

Ogilvie, S.M. 1992. The Environmental Impacts of Recycling. Warren Spring Laboratory, Stevenage, Report no. LR 911 (MR).

Orlic, M., and Kerr, T. 1996. A Guide for Methane Mitigation Projects: Gas-to-Energy at Landfills and Open Dumps. U.S. EPA.

Orlich, J. 1990. Methane Emissions from Landfill Sites and Waste Water Lagoons. In: International Workshop on Methane Emissions from Natural Gas Systems, Coal Mining, and Waste Management Systems. April 9-13, 1990. Funded by the Environmental Agency of Japan, the U.S. Agency for International Development and the U.S. EPA.

Perry and Green. 1984. The Chemical Engineer's Handbook. 6th Edition, McGraw-Hill, New York.

Pira International. 1996. Life Cycle Assessment Study to Illustrate the Environmental Burdens of Transportation with the Paper Cycle. Prepared by Nicholas Turner for the International Institute for Environment and Development. January.

Plantinga, A.J., Birdsey, R.A. 1993. Carbon Fluxes Resulting from U.S. Private Timber Management. *Climatic Change* 23(1):37-54.

Pulp and Paper International. 1995. International Fact and Price Book.

Richards, K.M. 1987. Landfill Gas - A Global Review. ETSU, Harwell.

RIET. 1995. Business Opportunities in Waste Management in Eight Asian Countries. Regional Institute of Environmental Technology, Singapore, and INTEC GmbH, Bonn.

Row, C. 1995. Full-Cycle Carbon Capture from International Paper's Tropical Reforestation Project. An Analysis for the International Paper Company. Row Associates. Edgewood, MD, USA.

Royal Commission on Environmental Pollution, (RCEP). 1993. Incineration of Waste, 17th Report, HMSO, London.

Schlesinger, W.H. 1977. Carbon Balance in Terrestrial Detritus. *Annual Review of Ecology and Systematics* 8:51-81.

Sedjo, R., A., and Lyon, K.S. 1995. A Global Pulpwood Supply Model and Some Implications. A Report to the International Institute for Environment and Development (IIED Sub-Study No.2).

Subak, S., Raskin, P. and Von Hippel, D. 1993. National Greenhouse Gas Accounts: Current Anthropogenic Sources and Sinks. *Climatic Change* 25: 15-58.

Trexler, M.C. 1991. Minding the Carbon Store: Weighing U.S. Forestry Strategies to Slow Global Warming. World Resources Institute. Washington, DC.

UNIDO. 1993. 1992 Handbook of Industrial Statistics. UN Industrial Development Organisation. Vienna.

United Nations. 1992. *International Trade Statistics Yearbook*. Trade by Commodity. United Nations. New York.

U.S. EPA. 1993. Anthropogenic Methane Emissions in the United States: Estimates for 1990. Report to the Congress. Global Change Division. Office of Air and Radiation. Washington, DC.

Von Hippel, D., Raskin, P., Subak, S., and Stavisky, D. 1993. Estimating Greenhouse Gas Emissions from Energy: Two Approaches Compared. *Energy Policy* (March), 691-702.

Watson, R.T., Meira Filho, L.G., Sanhueza, E., Janestos, A. 1992. Sources and Sinks. *Climate Change 1992: The Supplementary Report*. Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Watt Committee on Energy. 1994. Methane Emissions. Watt Committee Report Number 28. A. Williams (Ed.). London.

White, P.R., Franke, M. and Hindle, P. 1995, Integrated Solid Waste Management: A Lifecycle Inventory, Blackie Academic and Professional, Glasgow.

ANNEX A

Tables A1 -A8

Country Tables by Emissions Sources

TABLE A1: CARBON DIOXIDE EMISSIONS (t C) FROM ENERGY USE IN THE PULP AND PAPER INDUSTRY

Country (a)	Coal	Other Solid Fuels	Oil	Gas	Electricity Emissions by source Coal	Oil	Gas	Total	Total less OSF
Australia	232,327	215,578	33,362	219,032	831,452	18,907	40,590	1,591,247	1,375,669
Austria	73,922	395,226	91,383	164,438	141,742	28,573	73,225	968,509	573,283
Belgium	21,121	0	67,296	37,461	138,574	7,878	31,773	304,102	304,102
Canada	84,482	0	1,631,940	1,504,676	2,149,878	228,330	123,543	5,722,850	5,722,850
Finland	0	1,461,139	75,276	530,695	874,679	74,433	228,532	3,244,754	1,783,615
France	94,855	0	359,417	556,522	251,633	53,983	5,309	1,321,720	1,321,720
Germany	655,349	71,859	658,863	582,257	2,618,133	78,065	185,929	4,850,455	4,778,596
Italy	0	0	251,858	706,127	243,215	629,882	152,825	1,983,887	1,983,887
Japan	1,245,698	0	1,092,142	0	982,044	1,526,765	1,757,249	6,603,898	6,603,898
Netherlands	0	0	8,412	268,469	242,432	24,086	210,176	753,576	753,576
New Zealand	0	203,601	0	0	13,092	1,092	21,709	239,494	35,893
Norway	0	347,320	50,472	0	3,033	0	0	400,825	53,505
Spain	31,681	526,968	298,928	285,174	403,395	59,173	4,730	1,610,050	1,083,082
Sweden	63,362	3,784,590	290,389	14,659	168,069	46,548	10,133	4,377,749	593,159
Switzerland	21,121	47,906	100,067	44,288	103	3,975	462	217,921	170,015
United Kingdom	422,414	0	217,746	399,839	1,272,236	132,718	11,156	2,456,109	2,456,109
United States (b)	7,496,595	0	0	0	16,400,067	930,136	2,150,595	26,977,413	26,977,413
Non-OECD									
Brazil	115,318	0	463,152	31,217	35,558	47,150	0	692,396	692,396
China	8,484,496	0	330,594	10,614	2,395,209	150,393	7,193	11,378,499	11,378,499
Mexico	0	0	446,260	358,125	36,421	245,205	30,207	1,116,218	1,116,218
South Korea	0	0	645,661	0	180,275	125,118	50,238	1,001,292	1,001,292
Taiwan	272,782	0	368,104	0	192,226	148,676	0	981,789	981,789
Former USSR	0	0	0	0	2,953,096	1,582,197	2,833,336	7,368,628	7,368,628
TOTAL	19,315,523	7,054,188	7,481,322	5,713,592	32,526,582	6,143,265	7,928,910	86,163,380	79,109,193

(a) Countries selected consumed energy in the pulp and paper industry in excess 0.35 mil TOE.
Sources: OECD/IEA, 1991. Non-OECD, 1990.
(b) Industry breakdown by fuel type was not provided.

TABLE A2: WASTE DISPOSAL ROUTES

Region	P&B Total Consumption kT	Wastepaper Recovery kT	Paper Waste Generated kT	Paper for Disposal kT (a)	Disposal Method: Open Dumps Aerobic %	Incin-eration %	Energy Recovery %	Land-filling %
France	8,924	3,217	5,707	4,851	16	38	72	46
Germany	15,380	8,564	6,816	5,794	6	17	68	77
Italy	7,392	2,243	5,149	4,377	6	8	33	86
Netherlands	3,170	1,740	1,430	1,216	20	33	93	48
Spain	4,784	1,760	3,024	2,570	19	5	78	76
UK	9,779	3,224	6,555	5,572	0	15	50	85
CIS	4,635	1,000	3,635	3,090	3	5	37	92
Canada	5,997	2,116	3,881	3,299	19	6	81	75
United States	81,856	32,450	49,406	41,995	14	16	76	70
China	20,426	4,661	15,765	13,400	50	0	0	50
India	2,780	375	2,405	2,044	85	5	10	10
Japan	28,059	14,386	13,673	11,622	0	71	80	29
Korea, Rep	5,603	2,518	3,085	2,622	58	0	0	50
Taiwan	4,248	2,286	1,962	1,668	58	1	0	42
Australia	2,793	1,035	1,758	1,494	2	0	0	98
Brazil	4,249	1,629	2,620	2,227	65	25	0	10
Mexico	3,387	1,278	2,109	1,793	79	0	0	21
Country Total	213,462	84,482	128,980	109,633				
WORLD TOTAL	250,270	95,692	154,578	131,381				

(a) Paper for disposal = 85% of paper waste (10% to long-tem storage, 5% to sewage)

Sources: Pulp and Paper International, 1995; OECD, 1995; Blakey, 1995; Anon, 1995; RIET, 1995; Morwood, 1995; CEMPRE, 1995; IIED (pers.comm.), 1996.

TABLE A3: LANDFILL PROCESSES

	Paper to to Landfill kT	D.O.C. (a) dry wt. %	Dissimil-ation rate %	Biogas Potential kT C	C as CH4 g CH4/g C	Methane Oxidation %	Methane Generation Potential kT
France	2,246	40	77	692	0.5	10%	415
Germany	4,473	40	77	1,378	0.5	10%	827
Italy	3,751	40	77	1,155	0.5	10%	693
Netherlands	577	40	77	178	0.5	10%	107
Spain	1,954	40	77	602	0.5	10%	361
UK	4,736	40	77	1,459	0.5	10%	875
CIS	2,855	40	77	879	0.5	10%	528
Canada	2,474	40	77	762	0.5	10%	457
United States	29,397	40	77	9,054	0.5	10%	5,432
China	6,700	40	77	2,064	0.5	10%	1,238
India	204	40	77	63	0.5	10%	38
Japan	3,370	40	77	1,038	0.5	10%	623
Korea, Rep	1,311	40	77	404	0.5	10%	242
Taiwan	695	40	77	214	0.5	10%	129
Australia	1,464	40	77	451	0.5	10%	271
Brazil	223	40	77	69	0.5	10%	41
Mexico	376	40	77	116	0.5	10%	70
	0						
Country Total	66,807			20,577			12,346
WORLD TOTAL	76,828			23,663			14,198

(a) Degradable Organic Carbon

Source: Bingemer and Crutzen, 1987.

TABLE A4:

GREENHOUSE GAS EMISSIONS FROM LANDFILLING

Methane Emissions from Landfills

	Methane Generation Potential kT	Methane Flared %	Recaptured for energy recovery %	Vented to atmosphere %	Atmospheric Methane Emissions kT CH4	National Communications Emissions kT CH4	% of Total Landfill CH4 from Nat. Com
France	415	0	0	100	415		
Germany	827	0	20	80	661	2,318	29%
Italy	693	0	1	99	686	1,526	45%
Netherlands	107	9	1	90	96	377	25%
Spain	361	0	0	100	361	470	77% (a)
UK	875	13	6	81	709	1,700	42%
CIS	528	0	0	100	528		
Canada	457	0	12	88	402	800	50%
United States	5,432	10	10	80	4,346	10,000	43%
China	1,238	0	0	100	1,238		
India	38	0	0	100	38		
Japan	623	15	20	65	405	446	91%
Korea, Rep	242	0	0	100	242		
Taiwan	129	0	0	100	129		
Australia	271	0	10	90	244	1,344	18%
Brazil	41	0	0	100	41		
Mexico	70	0	0	100	70		
	0						
Country Total	12,346				10,610		
WORLD TOTAL	14,198				12,202		

(a) Spain did not include landfill emissions in its methane total.

Sources: Bellingham et al, 1994; Williams, 1994.

TABLE A5: CO_2 EMISSIONS FROM BILATERAL SHIPPING (kT CO_2)

To \ From	USA	Canada	Chile	Germany	S. Africa	France	Argentina	NZ	Brazil
Japan	1,513	515	1,060		173			94	169
Finland	254		11				61		
Sweden	7		7						
USA		37	5	312		207			95
C. Europe	292	28	68						158
Canada				162		167			
S. Korea	74	82							23
TOTAL	2,065	579	1,151	312	173	207	61	94	423

Total: 5,676 kT CO_2

CO_2 intensity of ocean shipping: 0.038 t CO_2/t pulp/km

Sources: UN Trade Statistics Yearbook. Commodity Tables, 1992.
PIRA International, 1995.

TABLE A6: PLANTATIONS

Conversion Units:	
0.65 t dm/m3 deciduous	0.45 t C/ t dm
0.45 t dm/m3 conifers	1.9 expansion factor
	0.85 plantations on land previously in agriculture

Country	"New" Plantations 1000 m3 harvested Deciduous	Conifers	Carbon Storage (kT C) Deciduous	Conifers	Total
USA		58,663	0	17,053	17,053
Canada	0	8,315	0	2,719	2,719
Finland		6,110	0	1,998	1,998
Sweden		5,275	0	1,725	1,725
Japan	2,874	10,206	1,358	2,967	4,325
Kenya	35	230	17	75	92
S. Africa	4,330	4,250	2,045	1,390	3,435
China	2,985	1,700	1,410	556	1,966
India	4,370		2,064	0	2,064
Indonesia		2,000	0	654	654
Morocco	400		189	0	189
Korea R.	180	450	85	147	232
Malaysia		80	0	26	26
Philippines	90	95	43	31	74
Taiwan	270		128	0	128
Thailand	870		411	0	411
Turkey	110	300	52	98	150
Mexico		480	0	157	157
Argentina	1,095	1,280	517	419	936
Brazil	16,200	6,260	7,653	2,047	9,700
Chile	510	8,140	241	2,662	2,903
Colombia	480	275	227	90	317
Australia		2,225	0	728	728
New Zealand	185	4,770	87	1,560	1,647
Austria		1,165	0	381	381
Belgium		555	0	182	182
France	1,000		472	0	472
Germany		7,890	0	2,294	2,294
Italy	300	220	142	72	214
Czech Rep.	0	1,700	0	556	556
Portugal	3,700	215	1,748	70	1,818
Spain	2,335	470	1,103	154	1,257
Switzerland	0	700	0	229	229
UK	0	1,300	0	425	425
Poland		2,850	0	932	932
Romania		600	0	196	196
Slovakia	0	500	0	164	164
Total	42,319	139,269	19,991	42,757	62,748
WORLD TOTAL					67,768

Source: Wood Resources International, 1995.

TABLE A7: ORIGINAL FOREST

Conversion Units:			
conifer	0.45 t dm/ m3 biomass	1.9	expansion factor
mixed hard.	0.47 t dm/ m3	0.5	biomass loss after conversion
	0.45 t c /t dm		

	Original Forest		
	1000 m3	kT C	Type
China	1,360	262	conifer
India	475	95	mixed tropical hardwood
Indonesia	2,790	561	mixed. trop. hard
Japan	3,910	752	orig con and dec and mixed
Korea	65	13	mixed trop. hardwood
Malaysia	310	62	mixed trop hard
Philippines	130	26	mixed trop. hard
Taiwan	510	102	mixed trop. hard.
USA	2,685	517	conifer original
Canada	71,128	13,683	conifer original+hardwood
Mexico	65	13	mixed trop hard
Argentina	95	19	hardwood
Brazil	930	187	mixed trop hard
Australia	225	45	hardwood
Finland	1,200	231	conifer
Russia	19,750	3,799	conifer
Total	105,628	20,368	

Source: Wood Resources International, 1995.

TABLE A8: GRAND TOTALS

	Fossil Fuel Combustion kT C	Shipping kT C	Other Transport kT C	Recycling kT C	Fossil Fuel Extraction kT CH4	Methane Landfill kT CH4	Methane Total kT CO2 Eq.	Fossil Fuel Offset from Waste Management kT C Incineration	Landfills	Plantations kT C	New Plantations kT C	Depleted Original Forests kT C	Totals kT CO2 Eq.	Totals kT C Eq.
France	1,322	207	33	31	0.02	415	9,754	-13	0	-472			13,815	3,769
Germany	4,779	312	119	64	0.07	661	15,541	-35	-55	-2294			26,212	7,149
Italy	1,984		50	22	0.03	686	16,127	-6	-2	-214			22,850	6,232
Netherlands	754		19	19	0.01	96	2,257	-22	0				5,081	1,866
Spain	1,083		27	17	0.02	361	8,484	-3	0	-1257			7,995	2,180
UK	2,456		61	31	0.04	709	16,661	-21	-20	-425			24,294	6,626
CIS	7,369		184	10	0.11	528	12,401	-3	0			3,799	54,056	14,742
Canada	5,723	579	143	20	0.09	402	9,457	-3	6	-2,719		8,215	53,328	14,544
United States	26,977	2,095	674	317	0.40	4,346	102,141	-261	-179	-17,053		517	150,015	40,913
China	11,378		284	44	0.17	1,238	29,101	0	0	-1966	-492	262	63,975	17,448
India	0		0	4	0.00	38	29,097	-1	0	-2084	-516	95	19,998	5,454
Japan	6,604		165	143	0.10	405	9,516	-260	-11	-4325		752	20,691	5,643
Korea, Rep	1,001		25	24	0.02	242	5,694	0	0	-232	-58	13	8,530	2,326
Taiwan	982		25	22	0.01	129	3,020	0	0	-128	-32	102	6,580	1,794
Australia	1,376		34	10	0.02	244	5,724	0	-2	-728		45	8,384	2,287
Brazil	692	423	17	16	0.01	41	967	0	0	-9700	-2,425	187	-38,597	-10,526
Mexico	1,116		28	12	0.02	70	1,635	0	0	-157	-39	13	5,203	1,419
Chile		1,151								-2903	-726		-9,086	-2,478
Malaysia							0			-26	-7	62	-119	-33
Philippines							0			-74	-19	26	-243	-66
Indonesia							0			-354	-164	581	-942	-257
S. Africa		173								-3435	-859		-15,109	-4,121
Argentina		61								-936	-234		-4,066	-1,109
New Zealand	36	84	1		0.00		0			-1547			-5,559	-1,516
Switzerland	170		4		0.00		0			-229			-201	-55
Norway	54		1		0.00		0						203	55
Sweden	593		15		0.01		0			-1725			-4,096	-1,117
Austria	673		14		0.01		0			-361			757	206
Belgium	304		8		0.00		0			-182			475	130
Finland	1,784		45		0.03		1			-1988		231	263	72
Portugal							0			-1818			-6,666	-1,818
Poland							0			-932			-3,417	-932
Czech Rep.							0			-556			-2,039	-556
Country Total	79,110	5,066		825	1.19	10,810				-57,915	-5,569			
WORLD TOTAL	79,110	6,079	1,978	949	1.36	12,202	277,661	-627	-214	-61,480	-5,569	14,881	402,565	109,790