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Paper Recycling of South Korea and its Effects on Greenhouse Gas Emission Reduction and Forest Conservation

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Abstract : The study evaluates the greenhouse gas (GHG) reduction potential of paper recycling by paper industry in South Korea and determines the positive impact on global warming by conserving the world's forests through decreasing pulp wood use. South Korea is one of the leading countries in the world that recycle papers with a collection rate of 71.8 percent and a recycling rate of 74.4 percent in 2005. Greenhouse gas emission reduction potential in terms of carbon dioxide (CO_2) equivalent from paper recycling was assessed scientifically by the use of Life Cycle Assessment (LCA). Three types of papers including newsprint, container-board, and white-board were used for assessment in this study. Results of this study indicate that CO_2 emission reduction potential of recycling paper varies according to its types and recycling rates. Greenhouse gas emission reduction factor of 0.74869 tCO_2 per ton of recycled paper was derived from this study. In applying this factor, it was found out that the South Korean paper industry reduced GHG emission of around 6,364,550 tCO_2 by recycling paper in 2005. With this, the country's paper industry could claim that by recycling in that particular year, approximately 23.8 million m^3 of woods were not harvested and thus 212,500 ha of world's forests were estimated to be saved in that particular year. Overall, it could be concluded that the Korean paper industry was able to reduce CO_2 emission and was able to conserve world's forests by its high rates of paper recycling.

Key words : *climate change, forest conservation, greenhouse gas, LCA, paper recycling*

Introduction

South Korea is the 5th largest importer and the 8th largest producer of pulp. Aside from these, it is the 12th largest exporter of paper and paperboard in the world in 2005. However, the country is also the 5th largest consumer (8.39 million ton) and the 8th largest importer (1.35 million ton) of recovered paper in the same year (FAO, 2007).

Nowadays, South Korea is one of the countries with high rates of paper recycling. The recycling of paper implies a reduction in demand for virgin pulp, which leads to the reduction of wood consumption and conservation of forests. Kyoto Protocol of the UNFCCC (United Nations Framework Convention on Climate Change) requires countries in Annex I to reduce greenhouse gas (GHG) emissions. As a result, South Korean paper industry has endeavored to reduce carbon dioxide (CO_2) emission by increasing paper recycling. In addition, the country is a net importer of wood pulp, industrial roundwood, and wood products, on which the paper industry depends for its raw materials for paper and paperboard.

The paper recycling rate (utilization rate) and the collection rate of the recovered paper in South Korea has increased from 34.9 percent in 1970 to 74.4 percent in 2005 and 28.6 percent in 1970 to 71.8 percent in 2005, respectively (Table 1). These figures placed South Korea in the group of the countries with the highest recycling rates including western European countries and Japan. According to Confederation of European Paper Industries (CEPI) (2006), the average utilization rate of the European 19 member countries was 47.6 percent and the collection rate was 62.6 percent in 2005. Among CEPI member countries, Denmark (108.1%), Spain (81.1%), and United Kingdom (74.7%) ranked high in the utilization rate of recovered paper.

This study was conducted to investigate the environmental impact of paper recycling on the global warming potential and to estimate the amount of CO_2 emission reductions at various recycling rates. Newsprints, container-boards, and white-boards, of which the current recycling rates are more than 80 percent, are subjects of the assessment in this study. Paper recycling can con-

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Table 1. Utilization and collection rate of recovered paper of South Korea (1970-2005). (unit: ton, %)

Year	Pulp (Domestic production +Imports)	Recovered paper		Paper consumption	Utilization rate of recovered paper[1)]	Collection rate of recovered paper[2)]
		Domestic collection	Imports			
1970	239,695	102,154	26,594	357,799	34.9	28.6
1975	325,250	208,756	179,786	646,573	54.5	32.3
1980	620,264	582,035	489,929	1,540,729	63.3	37.8
1985	834,611	817,139	701,320	2,275,819	64.5	36.0
1990	1,457,612	1,874,853	1,467,268	4,324,325	69.6	43.4
1995	2,218,158	3,661,974	1,283,349	6,423,738	69.0	53.2
2000	2,681,592	5,003,423	2,115,409	7,230,807	72.6	59.8
2001	2,786,568	5,250,937	1,956,781	7,522,073	72.1	61.6
2002	2,997,140	5,999,485	1,598,010	8,078,922	71.7	64.2
2003	2,950,104	6,610,658	1,330,938	8,234,659	72.9	66.3
2004	2,971,378	6,875,084	1,522,451	8,173,020	73.9	69.4
2005	2,930,562	7,085,813	1,415,102	8,352,983	74.4	71.8

Note: 1) Recovered paper Use (Domestic collection+Imports) / (Pulp+Recovered paper Use) × 100
2) Domestic collection / Paper use × 100
Source: Korea Paper Manufacturers' Association (2007)

tribute to the conservation of forests as the use of wood for paper raw materials decreases. The amount of forests saved by paper recycling of South Korean paper industry was also estimated.

In the analysis of GHG emission, a Life Cycle Assessment (LCA) methodology, a useful tool to evaluate environmental impact of a product or a system, was adopted. Many LCA studies have been conducted especially in Europe and North America. In general, results of previous studies indicate that in the whole life cycle of paper from raw material extraction to final disposal, paper recycling uses less embodied energy than other waste management options such as incineration or landfill, and that recycling has a positive impact on the environment (Villanueva and Wenzel, 2007). Waste Resources Action Programme compared environmental impacts of solid materials, such as paper, glass, plastic, and aluminum, according to three different waste management options of recycling, incineration, and landfill. Of the 63 scenarios compared, 46 scenarios showed that recycling is environmentally preferred than incineration or landfill (WRAP, 2006). Hokuetsu paper company in Japan estimated that deinking pulp (DIP) containing 70 percent of waste newsprint as raw material emits less CO_2 than the DIP containing 50 percent of waste newsprints in making 1 ton of newsprints. EPA WARM (Waste Reduction Model) showed that when recycling 1 ton of newsprints instead of landfills, 0.69 ton of carbon emission can be reduced while 0.81 ton for recycling corrugated paper (Friends of the earth, 2000).

In South Korea, LCA has been applied to only a few cases in pulp and paper products, such as pulp and paper packaging products (Park *et al.*, 2003), corrugated packaging papers (Jo *et al.*, 2001), and tissue papers (Kim *et al.*, 2001). However, most of these studies were not concentrated on impact of recycling to the global warming.

Materials and Methods

1. Life cycle assessment

A large number of methods and tools for describing environmental aspects have been developed for use in different types of decision context (Finnveden *et al.*, 2005). Life cycle assessment (LCA) is a tool to evaluate the environmental aspects and potential impacts throughout a product's life cycle which includes raw material acquisition, production, use, recycling and disposal (ISO 14040, 1997).

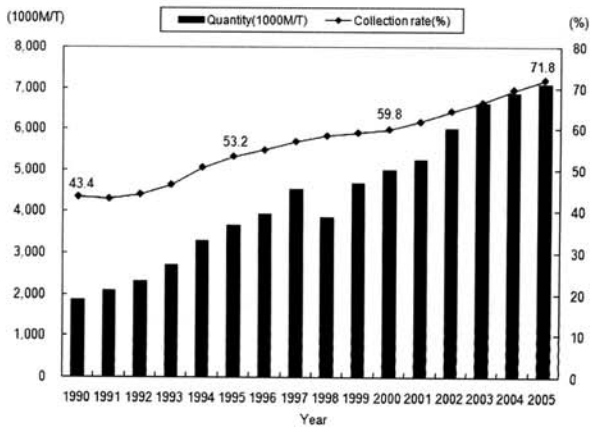

Figure 1. Wastepaper collection rate and quantity of South Korea.

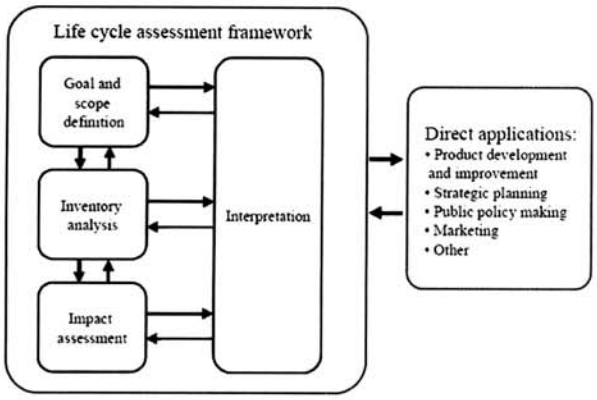

Figure 2. LCA framework (ISO 14040).

Life cycle assessment comprises four stages (Figure 2). In the impact assessment stage, among the environmental impact categories such as global warming, ozone depletion, acidification, and photochemical oxidant formation, only global warming potential (carbon dioxide and methane) was evaluated in this study. Since the UNCED in 1992, global warming problem has emerged as an important environmental issue, and it was recognized that forest can play a crucial role both in carbon sequestration and emission.

Many LCA studies on recycling papers have been implemented in Europe, the Unite States of America, and Japan. Environmental impacts including GHG emission potential according to different waste management options such as recycling, incineration, and landfill were incorporated. This study, however, mainly focused on the CO_2 emission reduction potential of paper recycling according to different recycling rates of three paper types, such as newsprints, container-boards, and white-boards.

2. Calculation of greenhouse gas emissions

The greenhouse gas (GHG) emission (in carbon dioxide equivalent) was calculated according to predetermined recycling rates in the process of pulp and paper production. The amount of reduced GHG emissions (kg-CO_2eq.) was computed per recycling 1 kg of paper. In this study, recycling is defined as the process of paper-making with used paper instead of disposing by landfill and incineration. In LCA, the functional unit, which is 1 kg of paper produced by recycling in this study, describes the entity analyzed.

The system boundary of this study is illustrated in Figure 3. It includes pulp production, sea transportation (container-board and white-board), paper production, pulp deinking process, and final disposal (incineration 50% and landfill 50%). Limitations of this study include the exclusion of forestry operations of wood production, use phase of paper, and road transportation in each stage. Dias *et al.* (2007) reported that in studying LCA, forestry stage plays a minor role, and according to Ecoinvent's (2006) database, carbon dioxide emission from fossil fuel use during forestry operation was around 1.5 kg~2.0 kg per $1m^3$ of industrial roundwood production, which accounts for only 0.1~0.3% of the paper life cycle stages. The emission in forestry stage can vary depending on tree species, site, and production techniques. Greenhouse gas emission in the use phase of paper is generally not included. In the case of transportation, overseas transportation by bulk ferry was only included. The road transportation has many uncertainties in both time and distance which contributes just less than 2 percent of the whole-cycle energy consumption (Tillman *et al.*, 1991). Frees *et al.* (2005) concluded that transportation in paper life cycle takes only 0.4 percent of the total energy use. Therefore, road transportation of paper distribution was not considered in this study.

South Korea imported a total of 2,503 thousand ton of pulp in 2005, of which 28.1 percent was from Canada, 26.9 percent from Indonesia, and 16.4 percent from the U.S. By pulp type, UKP (Unbleached Kraft Pulp) accounted for 228 thousand tonnes, SW-BKP (Softwood Bleached Kraft Pulp) 591 thousand tonnes, and HW-BKP (Hardwood Bleached Kraft Pulp) 1,482 thousand tonnes.. It was assumed that the raw material for white-board and container-board is UKP imported, and the raw material for newsprint is TMP (Thermo Mechanical Pulp) produced in South Korea. Consequently, sea transportation was not included in case of newsprints. Carbon dioxide emission factor of sea-transportation by bulk ferry, which is 3.93 gCO_2/tkm, and the distance of 8,135 km

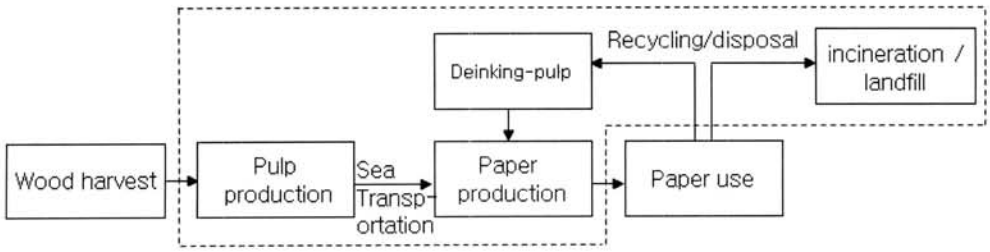

Figure 3. System boundary of the study.

(from the export port located in the west coast of Canada to import port of Incheon, South Korea) were adopted in this study (Michaelowa and Krause, 2000).

At the disposal stage of paper life cycle, it was assumed that a half is incinerated (without energy recovery) and the other half is landfilled.

Table 2. Production, shipment and inventory of paper and paperboard of South Korea in 2005.

	Paper Type	Production (ton)	Domestic Consumption (ton)	Exports[2)] (ton)	Inventories (ton)
Paper	Newsprint	1,587,845	1,037,070	554,966	68,506
	Printing and Writing paper	2,439,002	1,338,485	1,104,068	141,554
	Kraft paper	196,184	181,038	16,445	24,587
	Others[1)]	1,271,070	1,195,774	45,094	99,707
	Paper Total	5,494,101	3,752,367	1,720,573	334,354
Paper-board	Container-board	3,585,882	3,142,769	441,113	193,143
	White-board	1,194,363	506,497	687,287	58,914
	Others	275,060	270,076	5,071	13,759
	Paperboard Total	5,055,305	3,919,342	1,133,471	265,816
Paper and Paperboard Total		10,549,406	7,671,709	2,854,044	600,170

Note: 1) Household & Sanitary paper, Tissue paper, Other papers
2) Statistics of the export are totalled from the manufacturers' monthly reports
Source: Korea Paper Manufacturers' Association (2007)

Table 3. GHG emission inventory of pulp and paper production.

DB no.	Paper-process	Ecoinvent DB name	Unit	Input	Output(GHG emission)		
				Wood (m^3)	CO_2 (kg)[1)]	CH_4 (kg)	CO_2(*Eq.*) (kg)[2)]
E1	container-board production	Corrugated board base paper, kraftliner, at plant	kg	0.001312	1.415	9.63E-06	1.41520
E2	container-board pulp production (virgin, recycled)	Corrugated board fibre, at plant	kg	-	0.066	2.35E-06	0.06605
E3	newsprint production (no DIP-Deinking process included)	Paper, newsprint, 0% Dip, at plant	kg	0.002693	0.5069	5.87E-06	0.50702
E4	newsprint production (DIP included)	Paper, newsprint, Dip containing, at plant	kg	0.001084	0.434	8.75E-05	0.43584
E5	paper recycling (Deinking process excluded)	paper, recycling, no deinking, at plant	kg	-	0.51706	-	0.51706
E6	paper recycling (Deinking process included)	paper, recycling, with deinking, at plant	kg	-	1.16100	-	1.16100
E7	UKP production	Sulphate pulp, unbleached, at plant	kg	0.00363	0.2305	5.72E-06	0.23062
E8	BKP production	Sulphite pulp, bleached, at plant	kg	0.004234	0.1274	-	0.12740
E9	white-board production	Whitelined chipboard, WLC, at plant	kg	-	0.505	1.05E-05	0.50522
E10	SGP production	Stone groundwood pulp, SGW, at plant	kg	0.003175	1.33218	-	1.33218
E11	TMP production	Thermo-mechanical pulp, at plant	kg	0.003044	1.46455	-	1.46455
E12	newsprint-incineration	disposal, newsprint, 14.7% water, to municipal incineration	kg	-	1.48	6.38E-06	1.48013
E13	newsprint-sanitary landfill	disposal, newsprint, 14.7% water, to sanitary landfill	kg	-	0.00552	1.08E-05	0.00575
E14	container board-incineration	disposal, packaging cardboard, 19.6% water, to municipal incineration	kg	-	1.57	6.38E-06	1.57013
E15	container board-sanitary landfill	disposal, packaging cardboard, 19.6% water, to sanitary landfill	kg	-	0.0118	2.30E-05	0.01228

Note: 1) emissions from electricity, fossil fuel, chemicals, wood burning were included
2) kg CO_2+ kg CH_4*21(GWP conversion factor, IPCC)
Source: Ecoinvent (2006) : LCI Data v1.3

3. Life cycle inventory database analysis

Life Cycle Inventory (LCI) database was adopted from domestic and foreign database sources. Applicable domestic LCI database has not much been developed yet. As a result, a database combining Ecoinvent (2006) DB for pulp and paper and Korean National LCI DB for paper incineration and landfill was developed.

To implement life cycle inventory analysis, gathering input-output data is important. However, it is a difficult task. The National LCI database provides data for some types of pulp and paper, but not for newsprints, container-boards, and white-boards. An European LCI database, Ecoinvent (2006), was adopted in this study, which is one of the most frequently used LCI databases. The Ecoinvent database was combined with the National LCI database in this study. The Ecoinvent DB was used for pulp and paper production while the Korean DB was considered in paper disposal stage.

In the calculation of GHG emissions, methane was also included (mostly arises in landfill) in addition to CO_2. In this study, GHG emission amount (in kg CO_2) was calculated by adding methane (21 times) to carbon dioxide (Global warming potential of CH_4 is 21 times bigger than CO_2) (IPCC, 1996).

For the basic life cycle inventory data of paper production (kg), wood (m^3) input as a pulp raw material and carbon dioxide emission (kg) were calculated (Table 3). Ecoinvent (2006) DB was used for this calculation.

In the stage of paper disposal, the National LCI DB of paper waste management was applied (Table 4). An applicable GHG emission factor of disposal stage was obtained by assuming that incineration and landfill account 50% each, thus yielding an average value of 0.831 (1.1266 for database K2 and 0.54758 for database K3 in Table 4).

Results

1. GHG emissions of paper recycling at different recycling rates

At four different rates of recycling (100%, 80%, 60%, and 40%), greenhouse gas (GHG) emissions (in kg CO_2 equivalent) were calculated in the stages of production, recycling, and disposal per 1 kg of paper (functional unit of this LCA study). The GHG emission reduction potential of paper industry was estimated by setting an optimal recycling rate of each paper type.

Firstly, GHG emissions of virgin paper (made from virgin pulp) and recycled paper (made from recovered paper) were compared. In the production of recycled paper, deinking process was included, while in the production of virgin paper, pulp production process was

Table 4. GHG emission inventory of paper disposal in South Korea.

DB no.	Paper-process	Application at this study	Unit	Output(GHG emission)		
				CO_2 (kg)[1]	CH_4 (kg)	CO_2(*Eq.*) (kg)[2]
K1	paper production	-	kg	0.782	0.000223	0.78668
K2	paper incineration	applied	kg	1.126143	0.0000226	1.12662
K3	paper landfill	applied	kg	0.165461	0.018196	0.54758
K4	paper(general) recycling	-	kg	0.18138	0.00023	0.18621
K5	container-board recycling	-	kg	0.51452	0.00031782	0.52119

Note: 1) emissions from electricity, fossil fuel, chemicals, wood burning were included
2) kg CO_2 + kg CH_4*21(GWP conversion factor, IPCC)
Source: Ministry of Commerce, Industry and Energy (2003)

Table 5. GHG emission from production, recycling and disposal of newsprint in South Korea.

Newsprint (1 kg)		Paper-process	LCI DB	Wood (m^3) input	CO_2 (kg) output
Recycled Paper	paper production	Newsprint production (No DIP-Deinking process included)	E3	0.002693	0.50702
	paper recycling	Paper recycling (Deinking process excluded)	E5	-	0.51706
		Total		0.002693	1.02408
Virgin Paper	pulp production	TMP(Thermo Mechanical Pulp) production	E11	0.003044	1.46455
	paper production	Newsprint production (DIP included)	E4	0.001084	0.43584
	paper disposal	incineration : landfill = 1 : 1	K2, K3	-	0.83710
		Total		0.004128	2.73749

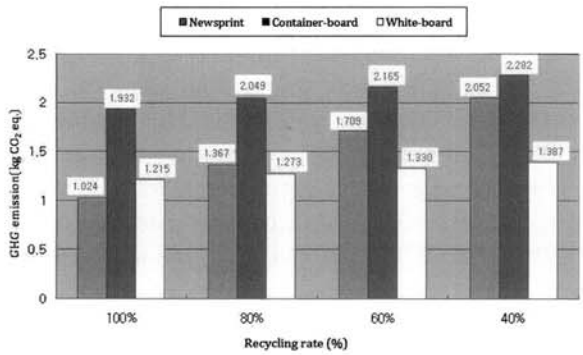

Figure 4. GHG emissions from 1 kg of paper recycling of newsprint, container-board and white-board at different recycling rates.

included. The GHG emissions from disposal stage were allocated only to virgin paper production assuming that the paper once used goes to landfill or incineration without recycling. The amount of GHG emission from 1 kg of paper disposal is 0.8371 $kgCO_2$ (average of 1.12662 $kgCO_2$ for K2 and 0.54758 $kgCO_2$ for K3) regardless of paper type (Table 4).

Tables 5 to 7 show the calculated GHG emissions of recycled paper (pulp is entirely from recycled paper) and virgin paper (pulp is 100% virgin paper) of newsprint, container-board, and white-board, respectively. The equation used for the computation of GHG emission at the recycling rate of X% is as follows:

$$[AX + B(100-X)]/100 \text{ (kg)} \quad (1)$$

Wherein: A is the emission from 100% recycled paper (in kilogram), and B is the emission from 100% virgin paper (in kilogram).

Figure 4 shows the GHG emissions from 1 kg of paper recycling of newsprint, container-board, and white-board at four different recycling rates (100%, 80%, 60%, and 40%). The four different recycling rates correspond to different amount of GHG emissions for each type of paper produced (Figure 4). As the recycling rate increases, the

Table 6. GHG emission from production, recycling and disposal of container-board.

Container-board (1 kg)		Paper-process	LCI DB	Wood (m^3) input	CO_2 (kg) output
Recycled Paperr	paper production	Container-board production	E1	0.001312	1.41520
	paper recycling	Paper recycling (Deinking process excluded)	E5	-	0.51706
		Total		0.001312	1.93226
Virgin Paper	pulp production	UKP(Unbleached Kraft Pulp) production	E7	0.003630	0.23062
	transportation	Sea transportation (bulk ship)	-	-	0.03170
	paper production	Container-board production	E1	0.001312	1.41520
	paper disposal	incineration : landfill = 1 : 1	K2, K3	-	0.83710
		Total		0.004942	2.51462

Table 7. GHG emission from production, recycling and disposal of white-board.

White-board (1 kg)		Paper-process	LCI DB	Wood(m^3) input	CO_2(kg) output
Recycled Paper	paper production	White-board(WLC) production	E9	-	0.50522
	paper recycling	Paper recycling (Deinking process excluded)	E5	-	0.51706
	deinking	Deinking process	E5, E6	-	0.19318*)
		Total		-	1.21546
Virgin Paper	pulp production	BKP(Bleached Kraft pulp) production	E8	0.004234	0.12740
	transportation	Sea transportation (bulk ship)	-	-	0.03170
	paper production	White-board(WLC) production	E9	-	0.50522
	paper disposal	incineration : landfill = 1 : 1	K2, K3	-	0.83710
		Total		0.004234	1.50142

*)Note: CO_2 emission from deinking process = 1.16100(E6) - 0.51706(E5) =0.64394 $kgCO_2$/1 kg paper
The portion of recycled paper which needs deinking process such as ONP and magazine paper is assumed to be 30% of the total recycled paper, so the CO_2 emission from White board deinking process is 0.64394×0.3=0.19318

GHG emissions decrease, but the decreasing rates are different according to paper types. When the recycling rate is 80 percent, 1 kg of newsprint emitted approximately 1.367 kg of CO_2 during paper production, recycling, and disposal. Likewise, container-board and white-board emitted 2.049 kg and 1.273 kg of CO_2, respectively. Container-board showed the largest GHG emissions among four recycling rates assessed in this study. This is because the consumption of energy (fossil fuel and electricity) in the production process of container-board is greater than that of newsprint or white-board. The GHG emission reduction effect from recycling showed the biggest in newsprint. When the recycling rate is increased from 40 percent to 100 percent, the amount of GHG emissions decreased to 1.028 kg (kg-CO_2eq.) in newsprint, 0.35 kg in container-board, and 0.172 kg in white-board. Therefore, newsprint had the greatest GHG emission reduction potential of recycling among the three types of papers in this study.

The GHG emissions from paper production were estimated. The quantities of paper production were 1,587,845 ton for newsprint, 3,585,882 ton for container-board, and 1,194,363 ton for white-board in 2005 (KPMA, 2007). To get the GHG emission, the quantity of production was multiplied by the corresponding emission factor from equation (1). Table 8 shows the GHG emissions of three kinds of paper at different recycling rates in 2005.

When the recycling rate of these papers was 90 percent, the total GHG emission was estimated to be 10,521,681 tCO_2. When the recycling rate was decreased to 80 percent, the emission was increased to 11,036,725 tCO_2. If the recycling rate was assumed to be 100 percent, the emission decreased to 10,006,636 tCO_2. But recycling 100% is only theoretical, and therefore not feasible in reality.

2. Effect of paper recycling on GHG emission reduction

1) Effect of paper recycling in production stage

From the LCI analysis of this study (Tables 5 to 7), the GHG emission reduction potential of paper recycling in three kinds of paper was determined (Table 9). Paper recycling here was defined as 1 ton of virgin paper substituted by 1 ton of recycled paper. The GHG emission

Table 8. South Korean GHG emissions from production of newsprint, container-board, and white-board at various recycling rate scenarios in 2005 (tCO_2/year).

Recycling rate (production in 2005)	100%	90%	80%	70%	60%
Newsprint (1,587,845ton)	1,626,080	1,898,143	2,170,206	2,442,269	2,714,332
Container-board (3,585,882ton)	6,928,856	7,137,684	7,346,511	7,555,339	7,764,166
White-board (1,194,363ton)	1,451,700	1,485854	1,520,008	1,554,162	1,588,316
Total (6,368,090ton)	10,006,636	10,521,681	11,036,725	11,551,770	12,066,814

Table 9. GHG emission reduction effect of recycled paper at current recycling rate in production of newsprint, container-board, and white-board.

Paper type (1 ton)	GHG emission (tCO_2)			GHG emission reduction (tCO_2) at current recycling rate
	Virgin Paper	100% Recycled Paper	Recycled Paper (recycling rate)	
Newsprint	2.73749	1.02408	1.06349 (97.7%)	1.67400 (97.7%)
Container-board	2.51462	1.93226	2.00389 (87.7%)	0.51073 (87.7%)
White-board	1.50142	1.21546	1.26407 (83.0%)	0.23735 (83.0%)

Table 10. Recovered paper and pulp input for the production of 1 ton of paper by type.

Paper Type (1 ton)	Paper production (ton)	Total pulp input (ton)	Recovered pulp input		Virgin pulp input		Recycling rate[3] (%)
			Quantity (ton)	Pulp material[1]	Quantity (ton)	Pulp material[2]	
Newsprint	1.000	1.309	1.279	ONP	0.030	wood	97.7
Container-board	1.000	1.092	0.958	OCC	0.134	UKP	87.7
White-board	1.000	0.917	0.761	OCC, ONP	0.156	BKP	83.0

Note: Data were collected from major paper manufacturers surveyed for this study (average value)

1) ONP: Old Newsprint, OCC: Old Corrugated Container

2) UKP: Unbleached Kraft Pulp, BKP: Bleached Kraft Pulp

3) Recycling rate(%) = Utilization rate of recovered paper = Recycled pulp input / Total pulp input

reduction potential of recycling 1 ton of newsprint, container-board, and white-board were estimated to be 1.71341 tCO_2, 0.58236 tCO_2, and 0.28596 tCO_2 respectively. To calculate the emission reduction potential of paper recycling, we assumed the average current recycling rates to be 97.7 percent (newsprint), 87.7 percent (container-board), and 83.0 percent (white-board) according to the sample survey of major paper manufacturers in South Korea (Table 10). At these recycling rates of three types of papers, the emission reduction potential of recycling 1 ton of newsprint, container-board, and white-board are 1.674 tCO_2, 0.51073 tCO_2, and 0.23735 tCO_2, respectively. In 2005, South Korea produced 1,587,845 ton of newsprint, 3,585,882 ton of container-board, and 1,194,363 ton of white-board (Table 2). The total reduced GHG emission from recycling of these three kinds of paper in 2005 is 4,772,953 tCO_2, which is the sum of emissions from producing newsprint (1.674×1,587,845 =2,658,053), container-board (0.51073×3,585,882=1,831,418), and white-board (0.23735×1,194,363=283,482).

South Korean paper industry has increased the recycling rate of paper and paperboard and thus contributed to sustainable use of forest resources. The Korean paper industry effectively reduced GHG emission by 4,772,953 tCO_2 in 2005 from recycling of newsprint, container-board, and white-board.

2) Effect of paper recycling in consumption stage

Korean paper industry used a total of 8,500,915 ton of recovered paper in 2005 [ONP (2,077,389 ton), OCC (5,074,770 ton), and others (1,348,756 ton)]. From Table 10, the amount of recovered paper as pulp input for the three types of papers can be roughly estimated, for example, newsprint (1,587,845×1.279=2,030,854 ton), container-board (3,585,882×0.958=3,435,278 ton), and white-board (1,194,363×0.761=908,910 ton). Total recycled paper input (ton) regardless of recycled paper type is 6,375,042 ton, which is 75.0 percent of the total recycled use in 2005. To know the GHG emission reduction effect of paper recycling, the GHG emission reduction factor of 0.74869 tCO_2 per ton of recycled paper consumed (from total GHG emission of 4,772,953 tCO_2 divided by 6,375,042 ton of total recycled paper used in the production of three paper types) was obtained. If we assume this figure to all recycled paper consumed (8,500,915 ton), a total of 6,364,550 tCO_2 of GHG emission would be reduced by paper recycling in South Korea in 2005.

3. Effect of forest conservation by paper recycling

Forests play a crucial role in regulating climate change by sequestering CO_2. Virgin paper needs more wood, which is pulp raw material, than recycled paper in the paper making process. So, if we use more recycled paper instead of virgin paper, the roundwood consumption would be reduced. This is an important environmental effect of paper recycling, by reducing forest harvest, forest conservation could be achieved and deforestation could be reduced.

In general, in the process of making 1 ton of paper, 4 m^3 of wood is required for chemical pulp and 3 m^3 of wood for mechanical pulp. This is because the pulp yield of mechanical pulp is higher than that of chemical pulp. Roughly, we assumed 3.5 m^3 of roundwood is required for making 1 ton of paper on the average, assuming that there is no difference in the amount of wood needed by species in paper making. When making recycled paper, about 20 percent of wood is assumed to be supplemented to maintain paper quality and to make

Table 11. Forest conservation effect of paper recycling of South Korea (2005).

Country[1)]	Forest area (1,000ha)	Growing stock (m^3/ha)	Saved forest area(ha)		Main species for pulpwood
			/1 ton of paper recycling[2)]	/total paper recycling of Korea (2005)[3)]	
South Korea	6,215	80	0.035	297,500	Pinus rigida
Canada	310,134	106	0.026	221,000	*Spruce* spp.
Indonesia	88,495	59	0.047	399,500	*Acacia* spp., *Eucalyptus* spp.
Unite States of America	303,089	116	0.024	204,000	Cottonwood, Poplar
Chile	16,121	117	0.024	204,000	Pinus radiata, *Eucalyptus* spp.
Brazil	477,698	170	0.016	136,000	*Eucalyptus* spp.
Russian Federation	808,790	100	0.028	238,000	*Spruce* spp.
World total	3,952,025	110	0.025	212,500	-

Note 1) Major pulp exporter of pulp to South Korea

2) Saved forest area(ha) by recycling 1 ton of paper (by countries) = 2.8 m^3(avoided wood consumption from 1 ton of paper recycling) / Growing stock (by countries) (m^3/ha)

3) Saved forest area(ha) by total paper recycling of Korea (by countries) = Saved forest area (ha) by recycling 1 ton of paper (by countries)×8,500,915 ton (Total paper recycling of Korea in 2005)

Source: Global Forest Resources Assessment (FAO, 2005)

up for pulp loss. Therefore, the reduced amount of wood harvest by recycling 1 ton of paper is 2.8 m^3, which is 80 percent of 3.5 m^3.

The effect of saving world's forests by region from paper recycling of Korea in 2005 is shown in Table 11. Estimated saved forest areas differ from countries where pulpwood is harvested. Korean paper industry could contribute to the reduction of wood harvest up to 23.8 million m^3 by recycling 8,500,915 ton of paper in 2005 (8,500,915 ton of recycled paper was assumed to be converted to the same amount of paper). From this estimation the Korean paper industry was able to save 297,500 ha of domestic forest in 2005. When applying the average world forest stock of 110m^3/ha (FAO, 2005), this figure is equivalent to saving 212,500 ha of world's forests in that particular year.

Discussion and Conclusion

Global warming is one of the most pressing environmental problems we have today. It calls for all nations and industries to address this issue by working on international climate change policies. Sustainable development cannot be accomplished without thinking of environmental soundness especially in reducing carbon dioxide emission and natural resource conservation.

Forests play an important role in the global carbon cycle. Forests can uptake and sequester CO_2 from the atmosphere for a long period. Therefore, afforestation, reforestation, and forest management were recognized as carbon sequestration activities under Article 3.3 of the Kyoto Protocol. Paper recycling can be a strategy with the potential to reduce harvest level of wood and promote greater carbon conservation, which is supported by the Intergovernmental Panel on Climate Change (IPCC).

Recycling effect of various waste materials has been analyzed in a number of studies over the last two decades. From a life cycle perspective, producing materials from recycled resources consumes less energy and causes less emission of GHG than from virgin resources. In most cases of paper and paperboard, total energy use of recycling is lower than that of incineration or landfill.. More energy may be saved from the recycling of mechanical pulp for newsprint than chemical pulp for paperboard (Finnveden and Ekvall, 1998). From the review of LCA studies of paper and paperboard, global warming potential (GWP) of recycling is in most cases lower than that of incineration or landfilling (Björklund and Finnveden, 2005).

Although this simplified LCA study was conducted with many assumptions and limitations, the results found that paper recycling can be a measure to reduce GHG emission by pulp and paper industry. Unlike other industries relying on fossil fuel based manufacturing processes, paper industry has rich opportunities for GHG reduction owing to the complexity of paper recycling and its dependency on renewable resources of wood. It can contribute to the national goal of reducing GHG emission by choosing best waste management option and natural resource management.

Further LCA studies of paper and paperboard, diversified in paper types (such as printing paper and wallpaper) and waste management options such as incineration (with and without energy recovery) and landfill (with or without biogas collection), are needed. This study was mainly focused on the carbon balance (category of global warming potential in LCA), but the other impact assessment categories such as acidification, resource depletion, ecosystem toxicity, and eutrophication are not included in the analysis, which are necessary for understanding the whole environmental impact of paper recycling.

Forests can sequester a great amount of carbon while still providing ecosystem services such as wildlife protection, biodiversity conservation, and water conservation. Deforestation is a major contributor to climate change. Recycling of paper can reduce wood consumption by using recycled pulp as a raw material instead of virgin pulp, and results in forest conservation. Besides, total energy required for life cycle of recycled paper is lower than that of virgin paper, and this avoids GHG emission eventually. In conclusion, paper recycling has a great potential of reducing GHG emission for climate change mitigation. Overall, it could be concluded that the Korean paper industry was able to reduce CO_2 emission and was able to conserve world's forests by its high rates of paper recycling.

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