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Non-energy Use and CO_2 Emissions: NEAT Results for Korea*

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Abstract — Carbon accounting is a key issue in the discussions on global warming/CO_2 mitigation. This paper applies both the IPCC Approach and the NEAT (Non-Energy use Emission Accounting Tables) model, a bottom-up approach, to estimate the potential CO_2 emissions (carbon storage) originating from the non-energy use as to assess the actual CO_2 emissions (carbon release) from the use of fossil fuels in Korea. The current Korean carbon accounting seems to overestimate the potential CO_2 emissions and with it to underestimate the actual CO_2 emissions. The estimation shows that the potential CO_2 emissions calculated according to the IPCC Approach are lower than those calculated using the NEAT model. This is because the IPCC default storage fraction for naphtha seems to be low for the Korean petrochemical production structure, on the one hand and because the IPCC Approach does not consider the trade with short life petrochemical products, on the other hand. This paper shows that a bottom-up approach like the NEAT model can contribute to overcome some of limitations of the IPCC guidelines, especially by considering the international trade with short life petrochemical products and by estimating the storage fractions of fossil fuels used as feedstocks for the country in consideration. This paper emphasizes the importance of accurate energy statistics for carbon accounting.

1. Introduction

The petrochemical industry uses a large amount of fossil fuels also as feedstocks for the manufacture of synthetic organic materials and products. Carbon embedded in short life materials like detergents and solvent is completely dissolved in CO_2 shortly after their use. However, carbon is stored in long life materials like bulk plastics for several hundreds years or more in natural environment unless they are burned. As such carbon storages do not adversely affect global warming/ climate change, they should be taken out from the annual national CO_2 emission accounting.

The non-energy use, predominantly feedstock consumption, is very important for many countries. It amounted to about 12 percent of fossil fuel consumption in Western Europe. These percentages were higher in Korea and the Netherlands with about 16 and 20 percent respectively (Patel *et al.*, 1999). Thus, it is important to estimate exactly the potential CO_2 emissions (carbon storage) originating from the non-energy use. These estimates can have importance in discussions on CO_2 emissions[1]. For instance, if carbon taxes are introduced, underestimation of the potential CO_2 emissions will adversely affect the petrochemical industry. On the other side, overestimation of the potential CO_2 emissions will mean wrong incentives for this industry.

Moreover, estimation of the potential CO_2 emissions originating from the non-energy use will gain importance in the discussion on relocation of bulk chemical industries from industrialized countries to developing countries within the framework of the flexible mechanisms. Another important question for countries with a large petrochemical industry like the Netherlands and Korea is how to treat the international trade with short life petrochemical products.

This paper tries to calculate the potential CO_2 emissions from the non-energy use as to assess the actual CO_2 emissions from the use of fossil fuels in Korea. First, accounting methods for carbon storage are discussed (Chapters II and V). Chapter III gives a brief overview of the Korean petrochemical industry. Chapters IV and VI estimate the potential CO_2 emissions

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[1] CO_2 emissions mean actual CO_2 emissions.

from the non-energy use in Korea by using the IPCC Reference Approach and the NEAT model, a material flow analysis, respectively. At the end some conclusions will be drawn.

2. Accounting Approaches for Carbon Storage

There are two basic approaches for carbon accounting: top-down and bottom-up approaches. A top-down approach estimates the potential CO_2 emissions (carbon storage) based on non-energy use statistics being a part of the national energy balances. Such an estimation method is proposed in the IPCC guidelines as an optional calculating step within the reporting framework (IPCC *et al.*, 1995). A bottom-up approach traces carbon storage in petrochemical processes and flows based on material flow analysis (MFA). It has been developed to overcome limitations of the IPCC guidelines (Gielen, 1997; Patel *et al.*, 1999; Gielen *et al.*, 1999).

2-1. The IPCC Approach

The IPCC guidelines indicate that storage of fossil carbon in synthetic organic materials and products should be taken into account. They make a distinction between carbon storage in products over long periods and short-term release of carbon. Only long-term storage originating from the non-energy use (potential CO_2 emissions) should be subtracted from annual national CO_2 emissions due to the use of fossil fuels. Hence, emissions from short-life (less than 20 years in general) materials and incineration of long-life materials do not belong to the potential CO_2 emissions. They are considered as actual CO_2 emissions or carbon release.

According to the IPCC guidelines the potential CO_2 emissions can be calculated while multiplying the non-energy use of fuels Q_{NEU} (given as lower heating value in GJ) by the respective storage fraction P and the emission factor EF (kg CO_2/GJ) as follows:

$$E_{IPCC}^{potential} = \sum_i \{Q_{NEU,i} * P_i * EF_i\} \qquad (1)$$

with i indicating the type of fuel (Gielen, 1997; Patel *et al.*, 1999). The IPCC guidelines provide default values for P_i as given in Table 6. Alternatively, the actual CO_2 emissions can be calculated as the difference between the total emissions and the potential emissions of fuels with the following formula:

$$E_{IPCC}^{actual} = \sum_i \{Q_{NEU,i} * (1-P_i) * EF_i\} \qquad (2)$$

Limitations of the calculation under the IPCC Reference Approach can be summarized as follows (Gielen, 1997; Patel *et al.*, 1999):

- The default values for the storage fraction P reflect an average mix of processes/products and an average mode of process operation, which might not hold for the country in consideration. For instance, the storage fraction 0.75 for naphtha is rather low for countries like Korea, which produces a lot of long life products like plastics.
- Default values of storage fractions P and emission factors EF are not given for all types of fuels.
- The Reference Approach does not consider actual emissions caused by the trade with short life petrochemicals. This can have consequences to the results of countries with large net imports and net exports.
- The Reference Approach is based on non-energy use data from the energy statistics. While these data are well-suited for energy accounting, they are less suited for carbon accounting.

To overcome these limitations a material flow analysis can be applied.

2-2. Material Flow Analysis

A material flow analysis estimates potential CO_2 emissions by tracing carbon flows from basic chemical production (e.g. steamcracking of either refinery products or natural gas fractions) to chemical products like polyvinylchloride PVC, polypropylene and polystyrene within a country's organic/petrochemical complex. Carbon flows are the sum of links between petrochemicals or the sum of processes. The major links are indicated by annual material flows in CO_2 equivalents. These flows can be calculated using the chemical formulae of the materials. As material yields in chemical processes are above 95 percent, production losses are neglected. Required are data on production and international trade of major basic chemicals, intermediates and products as listed in Table 4.

There are two principles/approaches to estimate actual and potential CO_2 emissions: "national boundary" prin-

Table 1. Estimation of potential CO_2 emissions in the Netherlands and Germany, according to the IPCC Approach and material flow analysis (in Mt CO_2).

	IPCC Approach	Producer principle	National boundary principle
The Netherlands (1992)[1)]	15.1	17.4	19.5
Germany (1989)[2)]	37.0	36.1	39.2

[1)] Gielen, 1997.

[2)] Patel *et al.*, 1999.

ciple (consumption based) and "producer" principle (production based). Both approaches differ in the treatment of international intermediate and short life material flows. The national boundary approach allocates these material flows to the potential emissions of the exporting country and to the actual emissions of the importing country. According to the producer approach emissions from short life materials are attributed to the actual emissions of the producer of these materials. This implies that for intermediate exports, the application in either short or long life materials abroad must be quantified. Gielen and Patel estimated the potential CO_2 emissions for the Netherlands and Germany respectively, as shown in Table 1.

This paper calculates the potential CO_2 emissions originating from the non-energy use applying both the IPCC Approach and a spreadsheet model NEAT (Non-Energy use Emission Accounting Tables) as to assess the actual CO_2 emissions (carbon release) from the use of fossil fuels in Korea.

3. The Korean Petrochemical Industry

The Korean petrochemical industry had grown rapidly in the period 1988 to 1996. Table 2 shows that the production capacities for ethylene, propylene, benzene, xylene, styrene monomer, high density polyethylene HDPE, terephthalic acid TPA increased by more than five times. For instance, the number of naphtha crackers went from two in 1988 to ten in 1996 up. As a result, the naphtha cracking capacities increased from 0.505 Mt (million tonnes) to 4.34 Mt. In com-

Table 2. Capacity trend of Korean petrochemical plants for 1988~1998 (in kilotonnes).

	1988	1990	1992	1996	April 1998
Ethylene	505	1,155	3,255	4,340	4,920
Propylene	268	625	1,895	2,602	3,282
Benzene	309	558	1,241	1,633	2,281
Toluene	292	418	751	1,195	1,411
Xylene	338	758	1,527	2,286	2,286
P-xylene	160	560	560	1,400	3,200
Styrene monomer	230	675	1,135	1,645	2,170
HDPE	280	743	1,173	1,503	1,583
Polypropylene	660	805	1,310	2,105	2,435
Polystyrene	373	787	925	1,036	1,042
PVC	530	610	710	1,045	1,255
TPC	500	1,160	1,210	3,110	4,250
Carbon black	205	250	340	530	530

Source: Korea Petrochemical Industry Association, *Petrochemical Annual* 1998 & 1999, Seoul.

Table 3. Korean trade with major petrochemicals in 1996 (in million $).

Exports		Imports	
Polypropylene	725	P-xylene	456
HDPE	494	Ethylene glycol	379
LDPE	433	Caprolactam	353
ABS	352	Acrylonitrile	175
Styrene momomer SM	311	Styrene momomer SM	152
Polystyrene	303	Vinylchloride monmer VCM	146
TPA	235	Xylene	184
P-xylene	183	Methanol	117
Toluene	182		
PVC	155		

Source: Korea Petrochemical Industry Association, *Petrochemical Annual* 1998 & 1999, Seoul.

Table 4. Korean petrochemical production and trade, 1996.

	Storage [t CO_2/t]	Product [Mt/yr]	Imports [Mt/yr]	Exports [Mt/yr]
Ammonia	0.000	0.735	0.540	0.000
Benzene	3.385	1.429	0.276	0.097
Bitumen	3.143	1.967	0.000	0.264
Butadiene	3.259	0.597	0.005	0.190
Other C4	3.143	0.703	0.000	0.000
Carbon black	3.667	0.350	0.008	0.056
Ethylene	3.143	3.979	0.081	0.299
Lubricants	3.143	0.897	0.062	0.015
Methanol	1.375	0.000	0.801	0.000
Pitch	3.385	0.196	0.000	0.195
Propylene	3.143	2.536	0.115	0.235
Toluene	3.348	1.044	0.005	0.695
Xylenes (o-,m-,p-,mixed xylene)	3.321	2.038	0.612	0.419
o-xylene	3.321	0.236	0.051	0.038
p-xylene	3.321	1.428	0.334	0.631
Acetic acid	1.467	0.198	0.046	0.048
Acetone	2.276	0.069	0.016	0.018
Acrylic acid	1.833	0.055	0.030	0.000
Acrylonitrile	2.491	0.100	0.223	0.012
Aniline	2.839	0.004	0.007	0.000
Bisphenol A	2.895	0.032	0.031	0.003
Butanol	2.378	0.018	0.016	0.029
Caprolactam	2.336	0.111	0.000	0.223
Cumene	3.300	0.089	0.068	0.000
Cyclohexane	3.143	0.166	0.000	0.048
Cyclohexanone	2.694	0.110	0.002	0.000
Dimethylterephthalate	2.268	0.124	0.027	0.017
Ethanol	1.913	0.033	0.000	0.000
Ethylbenzene	3.321	1.904	0.000	0.000
Ethylenedichloride	0.907	0.355	0.137	0.304
Ethylene glycol	1.419	0.371	0.061	0.014
Ethylene oxide	2.000	0.052	0.025	0.000
Formaldehyde	1.467	0.000	0.250	0.000
I-Propanol	2.200	0.035	0.000	0.010
MTBE	2.500	0.430	0.077	0.150
Octanol	2.708	0.138	0.011	0.098
Phenol	2.809	0.112	0.006	0.037
Phthalic anhydride PSA	2.378	0.254	0.007	0.072
Propylene oxide	2.276	0.137	0.019	0.012
Styrene	3.385	1.656	0.302	0.625
Terephthalic acid TPA	2.120	2.435	0.039	0.385
Toluenediisocyanate TDI	2.276	0.059	0.030	0.002
Vinylchloride monomer VCM	1.408	0.703	0.301	0.000
ABS	3.259	0.536	0.010	0.286
BR	3.259	0.137	0.060	0.005
EPDM	3.143	0.041	0.000	0.009
Epoxy resin	2.789	0.060	0.000	0.012
Melamineformaldehyde resin	1.248	0.018	0.012	0.000
Phenolic resin	2.920	0.100	0.018	0.000
Polyethylene PE	3.143	2.596	0.044	1.166
Polyethyleneterephthalate PET	2.292	2.118	0.018	0.132
Polypropylene PP	3.143	1.737	0.016	0.934
Polystyrene PS	3.385	0.923	0.021	0.394
Polyvinylchloride PVC	1.408	0.996	0.072	0.229
SBR	3.342	0.214	0.018	0.083

Sources : - Korea Petrochemical Industry Association, *Petrochemical Annual* 1998 & 1999, Seoul;
- Chemical Research Institute, *Chemical Annual*, 1997, 1998, 1999;
- Own survey results.

parison, the USA (23.344 Mt), Japan (7.115 Mt), the former Soviet Union (5.5 Mt) and Germany (4.475 Mt) had higher cracking capacities than Korea in 1996.

The Korean petrochemical industry uses almost exclusively naphtha as feedstocks for its high severity naphtha cracker in which about 35 percent of the production is ethylene. Korea is a net exporter of petrochemicals in the amount of US $ 1 billion. Korea exported these products in the amount of $ 5.4 billion in 1996. Exported petrochemicals were polypropylene, HDPE, low density polyethylene LDPE, acrylonitrile butadiene styrene ABS, styrene monomer SM, polystyrene, TPA etc. Imported petrochemicals had a value of $ 4.4 billion in 1996. Major importing chemicals were P-xylene, ethylene glycol, caprolactam, acrylonitrile etc., as shown in Table 3.

The Korean petrochemical industry produced in 1996 petrochemicals in the amount of US $ 16.773 billion which corresponded to 37.6 percent and 9.2 percent of the production in the chemical industry and in the manufacturing industry respectively. However, it was relatively less value added intensive and less manpower intensive. Its contribution to the manufacturing industry's value added and employment were 2.8 percent and 1 percent respectively.

4. Potential CO_2 Emissions in Korea According to the IPCC Approach

To estimate potential CO_2 emissions according to the IPCC Approach we should know exactly how much fossil fuels are used for feedstocks for the manufacture of petrochemicals, that is to know the non-energy use of fossil fuels. The Korean energy balances list naphtha, asphalt/bitumen and solvent as non-energy use. However, the Korean petrochemical industry uses also LPG, kerosene and coal tars as feedstocks. LPG, mostly butane, is required to produce synthetic gas, which is in turn needed by some petrochemical firms for the production of maleic anhydride MA. Kerosene is raw material for the production of normal paraffin. And coal tars are converted to carbon black.

On top of this, the Korean energy balances do not reveal the use of feedstocks as fuel or how much energy is recovered/recycled in the production process. For instance a naphtha steamcracker produces apart from basic chemicals such as ethylene, propylene, toluene and styrene hydrogen, methane, propane, fuel oil and mixed C_4 which can be used all or partly as fuel. Thus, it is necessary to make a correction for that part of the non-energy use, which is used as fuel.

A recent study (Patel *et al.*, 1999) shows that the non-energy use is differently defined in national energy statistics. According to the Dutch energy balances the net values for the non-energy requirement (Q_{NEU}) are equal to the difference between the gross non-energy use (Q_{TF}) on one side and the coproduced fuels used within basic chemical production (Q_E) and consumed outside the basic chemical production (Q_F) on the other side. But the German non-energy figures $Q_{NEU,FRG}$ include Q_E, while the Italian ones $Q_{NEU,IT}$ include Q_F. As German and Italian non-energy statistics include some part of fuels coproduced in the chemical process, Patel's study corrects the net values for the non-energy requirements for Germany and Italy by subtracting coproduced fuels within basic chemical production (Q_E) and consumed fuels outside the basic chemical production (Q_F) from the original net values for the non-energy requirements respectively. After correction the non-energy uses for Germany and Italy are considerably lower than before. For Germany, the total non-energy use reduces by 9 percent (for the year 1989) and for Italy by 32 percent (for the year 1992).

As the Korean energy balances give only information on gross values of naphtha, bitumen/asphalt and solvent, there is a need to improve the Korean non-energy use statistics. First, those feedstocks, which are not listed in the Korean energy balances should be collected. The Korea Oil Statistics published by the Korea National Oil Corporation contains information on petroleum products used by the petrochemical industry as feedstocks as shown in Table 6. In the case of coal tars, information on their consumption and imports was gathered from the sole producer of carbon black in Korea. As can be calculated with information given in Table 6, feedstocks not listed in the Korean energy balances, coal tars, lubricants, kerosene and LPG corresponded to 74.2 PJ in energy contents (11.1% of the non-energy use of 668 PJ) and 3.3 Mt in CO_2 equivalents (8.6% of the potential CO_2 emissions) for 1996. With these data the list of non-energy use statistics is complete but not in the net values as required to estimate properly the potential CO_2 emissions.

First, as the naphtha consumption figure in the non-energy use part of the Korean Energy Balances includes the backflows from the petrochemical sector to the refinery sector, the backflows of 84.567 PJ should be subtracted from the naphtha consumption of 752.271 PJ. Thus, the net deliveries of naphtha from the refining sector to the petrochemical sector should be 667.704 PJ.

Second, as to calculate the net values for the non-energy requirements, we should know about the coproduction of fuels, which are used in the production processes. Naphtha steamcracking processes represent major activities of the Korean petrochemical industry. Naphtha amounted to 81.7 percent of the non-energy use in energy contents in 1996. If bitumen and lubricants are excluded, the percentage rises to 95 percent. As well known, bitumen is not used as feedstocks. It is solely used as asphalt for road construction. Lubricants are required predominantly in the transportation sector and as short life chemicals not relevant for carbon storage.

Thus, we can assess the lion's part of the coproduction of fuels in basic chemical production by surveying fuels coproduced in naphtha steamcracking processes. The survey covered five of eight Korean ethylene producers having together more than 70 percent of the production capacities. As shown in Table 5, the survey results reveal that all of methane and fuel oil coproduced are used as energy. Other energy carriers such as hydrogen, propane and mixed C_4 are used both as feedstocks and fuels. Two producers use hydrogen only as feedstocks. And two producers use part of their production of mixed C_4 as fuels.

The coproduction of fuels per tonne of naphtha by 5 ethylene producers ranged from 8.682 GJ to 10.924 GJ with an average of 9.317 GJ. Assuming 44 GJ/t as energy content per tonne of naphtha, the average of the coproduction of fuels in the amount of 9.317 GJ/t represents 21.1 percent of the energy content per tonne of naphtha. In other words, Korean ethylene producers used 21.1 percent of naphtha on average as fuels. This survey result is very close to 22.3 percent, which was assessed as fuel use ratio for the Korean naphtha crackers in 1996 by the Korea Petrochemical Industry Association (Personal communications from the industry). Thus, we can subtract 22.3 percent from the naphtha consumption in Korea as to calculate approximately the net values of the non-energy use requirements for Korea.

After correction the non-energy use for 1996 decreases by 10.1 percent from 742.7 PJ to 668 PJ. At the same time the potential CO_2 emissions decrease by 20.2 percent from 47.3 Mt to 37.7 Mt, as shown in Table 6. Once the potential CO_2 emissions (37.7 Mt) from the non-energy use of fossil fuels are calculated, it is easy to assess the CO_2 emissions (425.6 Mt) by subtracting these from the carbon content of the total national fossil fuel use (463.3 Mt) as shown in Table 7. According to the IPCC Approach, carbon release and carbon storage from the fossil fuel use in

Table 5. Coproduction of fuels in Korean naphtha cracking processes: survey results.

	LHV GJ/t	Producer 1		Producer 2		Producer 3		Producer 4		Producer 5	
		T[1]	GJ[2]	T	GJ	t	GJ	t	GJ	T	GJ
Hydrogen	100.5	0.012	1.206	0.016	1.608	0.016	1.608	-	-	-	-
Methane	47.5	0.146	6.935	0.120	5.700	0.160	7.600	0.140	6.650	0.159	7.553
Propane	45.6	0.009	0.410	0.008	0.365	0.010	0.456	-	-	0.009	0.410
Fuel oil	42.0	0.010	0.420	0.016	0.672	0.030	1.260	0.031	1.302	0.019	0.798
Mixed C_4	45.6	-	-	0.020	0.912	-	-	0.021	0.730	-	-
Total			8.971 (20.4)[3]		9.257 (21.0)		10.924 (24.8)		8.682 (19.7)		8.761 (19.9)

[1] Production per tonne of naphtha.

[2] Production in energy contents.

[3] Share of coproduction of fuels per tonne of naphtha having an energy content of 44 GJ/t.

Source: Personal communications from 5 of 8 Korean ethylene producers having together more than 70 percent of the production capacities.

Table 6. Estimation of carbon storage and release in products after correction of coproduction of fuels, according to IPCC, Korea, 1996.

Energy carriers	Non-energy use [Mtoe]	Non-energy use [PJ]	Storage fraction [%]	Emission factor [Mt CO_2/PJ]	Carbon storage [Mt CO_2]	Carbon release [Mt CO_2]
Bitumen/asphalt*	1.7052	71.392	100	0.0807	5.759	0.000
Coal tars	0.1505	6.301	75	0.0876	0.414	0.138
Lubricants	1.0110	42.328	50	0.0733	1.552	1.552
Kerosene	0.1879	7.867	70	0.0719	0.396	0.170
Solvent*	0.0865	3.622	70	0.0693	0.176	0.075
Naphtha*	12.392[1]	518.806[2]	75	0.0733	28.534[3]	9.511[4]
LPG	0.4225	17.689	80	0.0631	0.892	0.223
Total (corrected)		**668.005**			**37.723**	**11.669**
Total (energy balances)		742.718			47.291	13.860

*Listed in the Korean energy balances.

[1] Uncorrected naphtha consumption was 15.948 toe (excluding backflows of 2.020 toe).

[2] Uncorrected naphtha consumption was 667.704 PJ (excluding backflows of 84.567 PJ).

[3] Uncorrected carbon storage was 41.356 Mt CO_2 eq.

[4] Uncorrected carbon release was 13.785 Mt CO_2 eq.

[5] 1 Mtoe = 41.86728 PJ.

Sources: Korea National Oil Corporation, Korea Energy Economics Institute and personal communications from the petrochemical industry.

Korea for 1996 were 425.6 Mt CO_2 and 37.7 Mt CO_2 respectively.

The change (correction) in the Korean non-energy statistics implies that the potential CO_2 emissions decrease by 9.6 Mt from 47.3 Mt to 37.7 Mt. Thus, the adoption of the proposed non-energy statistics results in an increase of Korea's CO_2 emissions by 9.6 Mt from 416 Mt to 425.6 Mt.

5. NEAT Model Structure

The NEAT model consists of four sheets, input

Table 7. Total national fossil fuel use and CO_2 emissions in Korea, 1996.

Energy carriers	Consumption [PJ]	Carbon emissions factor [Mt CO_2/PJ]	Carbon content [Mt CO_2]	Carbon stored [Mt CO_2]	CO_2 emissions [Mt CO_2]
Gasoline	375.514	0.0693	26.023		26.023
Jet kerosene	103.274	0.0715	7.384		7.384
Other kerosene	426.565	0.0719	30.656	0.396	30.260
Diesel oil	1055.757	0.0737	77.809		77.809
Fuel oil	1106.248	0.0774	85.587		85.587
LPG	287.802	0.0631	18.151	0.892	17.258
Naphtha	752.267	0.0733	55.166	28.534	26.632
Bitumen	71.391	0.0807	5.759	5.759	0
Lubricants	0	0.0733	0	1.552	-1.552
Solvent	3.623	0.0693	0.251	0.176	0.075
Liquide fuels total	**4182.441**		**306.786**	**37.309**	**269.477**
Anthracite	107.195	0.0983	10.534		10.534
Bituminous coal	1240.922	0.0946	117.391	0.414	116.977
Solide fuel total	**1348.116**		**127.925**	**0.414**	**127.511**
Natural gas	509.515	0.0561	28.584		28.584
Total fossil fuels	**6040.073**		**463.295**	**37.723**	**425.571**

- 1 PJ : 10^{12} J = 0.023885 Mtoe; 1 Mtoe = 41.86728 PJ.
- 1 Mt = 10^6 t

data, materials balances, energy/materials conversion coefficients, and CO_2 balances for the whole petrochemical industry.[2]

5-1. Input Data

The input data sheet in turn consists of the following elements:

- Production data for petrochemical products
- International trade data: imports and exports
- Petrochemical energy use and non-energy use
- Characterization of the chemical composition of petrochemical compound, based on composition data
- Conversion of petrochemical mass flows into CO_2 equivalents
- Conversion of energy flows into CO_2 equivalents

5-2. Material Balances

In order to generate a complete overview of the carbon balance of the petrochemical industry, two types of balances must be applied:

- a production/consumption balance for individual products in the petrochemical complex
- input/output balances of individual production processes

Fortunately a limited number of conversion routes are the basis of the petrochemical industry. The conversion efficiencies of these processes are generally similar all over the world for cost-efficiency reasons and for environmental reasons.

The balance of individual products is important because many petrochemical products are used by the industry as intermediates for the production of other petrochemicals. The whole network of petrochemical processes must be considered for proper balancing. The best approach is to eliminate any residual use of petrochemicals in the balance, because the long life/short life balance of these residual applications is not clear. Where such residual applications remain, an expert estimate is required.

A balance has been developed for the following intermediates:

- acetic acid
- acetone
- acrylic acid
- acrylonitrile
- aniline
- benzene
- bisphenol A
- butadiene
- butenes
- cumene
- cyclohexane
- cyclohexanone
- dimethylterephthalate
- ethylene
- ethylene glycol
- ethylene oxide
- formaldehyde
- methanol
- phenol
- phthalic anhyride
- propylene
- propylene oxide
- styrene
- vinylchloride monomer
- xylenes

Moreover, a mass balance has been developed for the petrochemical steamcrackers. These crackers constitute the most important primary step in the petrochemical production complex. Because the product mix depends on the feedstock type, different cracker types with differing feedstocks are separately analyzed and subsequently aggregated.

The data regarding petrochemical production routes and the selection of important applications of intermediates have been based on (Weissermel *et al.*, 1994). This source suggests that a limited number of production routes are applied for a given product. This allows the generation of materials balances for processes (input-output relations from process data) and materials balances for products:

Production = Consumption + Exports − Imports

Storage and losses between production and consumption have been neglected in the analysis.

6. Potential CO_2 Emissions in Korea According to the NEAT Model

To run this model, it is essential to have production

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[2] Adapted from Gielen *et al.*, 1999.

Table 8. Estimates for short life and long life for residual applications.

	Product	Quantity involved	Long life [%]	Short life [%]
Basic chemicals	Benzene	Other	50	50
	Bitumen	Total	100	0
	Butadiene	Other	100	0
	Other C4	Other	30	70
	Carbon black	Total	100	0
	Ethylene	Other	50	50
	Lubricants	Total	67	33
	Methanol	Other	50	50
	Pitch	Total	20	80
	Propylene	Other	0	100
	Toluene	Other	0	100
	Xylenes (o-,m-,p-,mixed xylene)	Other	0	100
	o-xylene	Other	0	100
	p-xylene	Other	0	100
Intermediates	Acetic acid	Total	35	65
	Acetone	Total	60	40
	Acrylic acid	Other	100	0
	Acrylonitrile	Other	100	0
	Aniline	Total	80	20
	Bisphenol A	Total	100	0
	Butanol	Total	0	100
	Caprolactam	Other	100	0
	Cumene	Other	100	0
	Cyclohexane	Other	0	100
	Cyclohexanone	Other	0	100
	Dimethylterephthalate	Other	100	0
	Ethanol	Total	0	100
	Ethylbenzene	Other	100	0
	Ethylenedichloride	Other	0	100
	Ethylene glycol	Other	0	100
	Ethylene oxide	Other	0	100
	Formaldehyde	Other	0	100
	I-Propanol	Other	0	100
	MTBE	Total	0	100
	Octanol	Total	50	50
	Phenol	Other	0	100
	Phthalic anhydride PSA	Total	0	100
	Propylene oxide	Other	0	100
	Styrene	Other	100	0
	Terephthalic acid TPA	Other	100	0
	TDI	Other	100	0
	Vinylchloride monomer VCM	Other	100	0
Products	ABS	Total	100	0
	BR	Total	100	0
	EPDM	Total	100	0
	Epoxy resin	Total	100	0
	Melamineformaldehyde resin	Total	100	0
	Phenolic resin	Total	100	0
	Polyethylene PE	Total	100	0
	Polyethyleneterephthalate PET	Total	100	0
	Polypropylene PP	Total	100	0
	Polystyrene PS	Total	100	0
	Polyvinylchloride PVC	Total	100	0
	SBR	Total	100	0

Source: Gielen *et al.*, 1999.

Table 9. NEAT model results for Korea, 1996.

	Product	Production of long life products [Mt CO_2 eq.]	Net exports of short life products [Mt CO_2 eq.]	Net carbon storage [Mt CO_2 eq.]
Basic chemicals	Benzene	-0.327	-0.303	-0.630
	Bitumen	6.181	0.000	6.181
	Butadiene	1.009	0.000	1.009
	Other C4	0.405	0.000	0.405
	Carbon black	1.282	0.000	1.282
	Ethylene	0.521	0.344	0.865
	Lubricants	1.888	0.099	1.987
	Methanol	-0.208	0.551	0.342
	Pitch	0.133	-0.132	0.001
	Propylene	0.000	0.377	0.377
	Toluene	0.000	2.311	2.311
	Xylenes (o-,m-,p-,mixed xylene)	0.000	0.000	0.000
	o-xylene	0.000	-0.043	-0.043
	p-xylene	0.000	0.987	0.987
Intermediates	Acetic acid	0.102	0.001	0.103
	Acetone	0.074	0.003	0.077
	Acrylic acid	0.010	0.000	0.101
	Acrylonitrile	-0.590	0.000	-0.590
	Aniline	0.010	-0.004	0.006
	Bisphenol A	-0.016	0.000	-0.016
	Butanol	0.000	0.031	0.031
	Caprolactam	0.520	0.000	0.520
	Cumene	0.033	0.000	0.033
	Cyclohexane	0.000	0.150	0.150
	Cyclohexanone	0.000	-0.005	-0.005
	Dimethylterephthalate	-0.143	0.000	-0.143
	Ethanol	0.000	0.000	0.000
	Ethylbenzene	0.719	0.000	0.719
	Ethylenedichloride	0.000	0.152	0.152
	Ethylene glycol	0.000	-0.834	-0.834
	Ethylene oxide	0.000	-0.050	-0.050
	Formaldehyde	0.000	-0.367	-0.367
	I-Propanol	0.000	0.022	0.022
	MTBE	0.000	0.183	0.183
	Octanol	0.187	0.117	0.304
	Phenol	0.000	0.087	0.087
	Phthalic anhydride PSA	0.000	0.154	0.154
	Propylene oxide	0.000	-0.014	-0.014
	Styrene	1.289	0.000	1.289
	Terephthalic acid TPA	0.733	0.000	0.733
	TDI	-0.064	0.000	-0.064
	Vinylchloride monomer VCM	-0.333	0.000	-0.333
Products	ABS	1.746	0.000	1.746
	BR	0.445	0.000	0.445
	EPDM	0.127	0.000	0.127
	Epoxy resin	0.167	0.000	0.167
	Melamineformaldehyde resin	0.022	0.000	0.022
	Phenolic resin	0.292	0.000	0.292
	Polyethylene PE	8.157	0.000	8.157
	Polyethyleneterephthalate PET	4.854	0.000	4.854
	Polypropylene PP	5.459	0.000	5.459
	Polystyrene PS	3.123	0.000	3.123
	Polyvinylchloride PVC	1.403	0.000	1.403
	SBR	0.714	0.000	0.714
	TOTAL	**40.016**	**3.818**	**43.834**

data and international trade data on basic chemicals, intermediates and products as listed in Table 4. In Korea, the Korea Petrochemical Industry Association and the Chemical Research Institute regularly publish in their annuals data on production and international trade of major petrochemicals. But they do not collect and publish information on pitch, acrylic acid, aniline, bisphenol A, cyclohexanone, ethylene oxide, epoxy resin, melamine resin, polyethyleneterephthalate PET etc. In these cases information was gathered directly from petrochemical producers. However, information on some petrochemicals is still missing.

One important task of a bottom-up approach such as the NEAT model is the treatment of the use of intermediates in the category "others" in Table 8. This category includes all types of applications, which have not been elaborated (in some case the total application of products of minor importance "total"). These estimates are based on more detailed data regarding applications. Depending on the application for the production of end products (plastics and elastomeres long life, others short life), the production has been allocated to the categories short life and long life. Data represent Western European averages (Gielen *et al.*, 1999, p. 7). Bitumen, carbon black, cumene, styrene and PET belong to long life materials. Benzene, ethylene, acetic acid and acetone are used for long life as well as short life purpose.

As shown in Tables 9 and 10, the production of long life petrochemical products resulted in the potential CO_2 emissions 40.016 Mt CO_2 for 1996, which are bigger than those assessed according to the IPCC Approach, 37.723 Mt CO_2. This would mean that the IPCC default storage fraction 0.75 for naphtha should not be adequate to assess the CO_2 emissions in Korea. As one percent of the naphtha consumption in the Korean petrochemical sector in terms of carbon storage is equivalent to 0.285 Mt CO_2, the difference (2.293 Mt CO_2) between the potential CO_2 emissions assessed by the NEAT model and according to the IPCC Approach will corresponds to about 8 percent. As a result, the storage fraction for naphtha should be about 0.83 (0.75 + 0.08). In the case of Japan, 0.80 is used as the storage fraction for naphtha (Gielen *et al.*, 2002, p. 14). In fact, Table 11 shows that Korea produced relatively more long life petrochemical products than Germany or Japan.

Furthermore, the NEAT model results show that Korea was a net exporter of short life petrochemical products in the amount of 3.818 Mt CO_2, which

Table 10. Comparison of estimates according to IPCC Approach and NEAT model in Mt.

		Potential CO_2 emissions from non-energy use	Actual CO_2 emissions from use of fossil fuels	Total use of fossil fuels in CO_2
IPCC Approach[1)]	Statistics uncorrected	47.291	416.004	463.295
	Statistics corrected	37.723	425.571	463.295
NEAT model[2)]	Without trade	40.016	423.279	463.295
	With trade	43.834	419.461	463.295

[1)] Tables 6 and 7.
[2)] Table 9.

Table 11. Production of selective long life petrochemicals in Germany, Japan & Korea.

		Germany	Japan	Korea
Terephthalic acid TPA	Mt/year	0.147	1.560	2.435
Polyethylene PE	Mt/year	1.938	3.310	2.596
Polyethyleneterephthalate PET	Mt/year	0.655	1.360	2.118
Polypropylene PP	Mt/year	0.764	2.730	1.737
Polystyrene PS	Mt/year	0.957	1.504	0.923
Polyvinylchloride	Mt/year	1.235	2.510	0.996
Naphtha use	PJ/year	419.6	1435.0	518.8

Source: - Patel, M (2001), "Feedstock-related CO_2 Emissions in the petrochemical sector in Germany".
- Gielen *et al.* (2002), "Carbon Accounting for Japanese Petrochemicals".

should be considered as potential CO_2 emissions or carbon storage. Thus, the total potential CO_2 emissions amounted to 43.834 Mt CO_2 for 1996.

As the NEAT model considers the trade with short life petrochemical products, the potential CO_2 emissions assessed with the NEAT model are by 6.1 Mt CO_2 higher than those assessed according to the IPCC Approach using the corrected non-energy use statistics. In sum, Korea emitted 419.5 Mt CO_2 against 425.6 Mt CO_2 (the IPCC Approach) from the use of fossil fuels in 1996. However, the potential CO_2 emissions assessed with the NEAT model is by 3.457 Mt CO_2 lower than those assessed according to the IPCC Approach using the uncorrected (official) non-energy use statistics.

As a result, Korea emitted 419.5 Mt CO_2 against 425.6 Mt CO_2 (the IPCC Approach using the corrected non-energy use statistics) and 416.0 Mt CO_2 (the IPCC Approach using the uncorrected data) from the use of fossil fuels in 1996. Thus, the current Korean carbon accounting seems to overestimate the potential CO_2 emissions and with it to underestimate the actual CO_2 emissions by 6.1 Mt CO_2 to 9.6 Mt CO_2.

7. Conclusions

This paper has estimated the potential CO_2 emissions (carbon storage) originating from the non-energy use by applying both the IPCC Approach and the NEAT model, a bottom-up approach, as to assess the actual CO_2 emissions (carbon release) from the use of fossil fuels in Korea. The potential CO_2 emissions 47.291 Mt (million tonnes) CO_2 calculated according to the IPCC Approach by using the uncorrected non-energy use statistics is by 9.568 Mt CO_2 higher than those assessed according to the IPCC Approach by using the corrected non-energy use statistics and by 3.457 Mt CO_2 higher than those assessed with the NEAT model. Thus, the current Korean carbon accounting seems to overestimate the potential CO_2 emissions and with it to underestimate the actual CO_2 emissions.

Moreover, the estimation has shown that the potential CO_2 emissions calculated according to the IPCC Approach are by 6.1 Mt CO_2 lower than those calculated using the NEAT model. On the one hand, this is because the IPCC storage fraction 0.75 for naphtha seems to be low for the Korean petrochemical production structure. The fact that the potential CO_2 emissions with 37.723 Mt CO_2 assessed according to the IPCC Approach were by 2.293 Mt CO_2 lower than those assessed by the NEAT model with 40.016 Mt CO_2, indicates that the storage fraction for naphtha should be raised from 0.75 (IPCC default fraction) to 0.83.

On the other side, this is because the IPCC Approach does not consider the trade with short life petrochemical products. The consideration of such a trade is very important in the carbon accounting for large net petrochemical exporters like Korea which exported 3.8 Mt CO_2 in net values.

Furthermore, this study has shown that the current Korean non-energy use statistics is not adequate for carbon accounting. First, it does not list all fossil fuels used in the petrochemical sector as feestocks. Lubricants, LPG, kerosene and coal tars are also used as feedstocks in Korea. Second, the consumption of naphtha, the major feedstock, is not given in net values in the non-energy use part of the Korean Energy Balances. External backflows, e.g. backflows from the petrochemical sector to the refinery sector, as well as the internal backflows, e.g. the use of fuel by-products like methane, fuel oil and mixed C_4 produced in the naphtha cracking process are substantial. For the year 1996, the external backflows 84.567 PJ and internal backflows 148.898 PJ amounted to around 35 percent of the net deliveries of naphtha from the refinery sector to the petrochemical sector. These backflows have to be subtracted from the gross deliveries of naphtha from the refinery sector to the petrochemical sector. The balance should be the share of the basic chemicals in the naphtha cracking process, which is about 65 percent.

In conclusion, this paper has shown that a bottom-up approach like the NEAT model can contribute to overcome some of limitations of the IPCC guidelines, especially by considering the international trade with short life petrochemical products and by estimating the storage fractions of fossil fuels used as feedstocks for the country in consideration. This paper has made plain once more the importance of accurate energy statistics, in this case, non-energy use statistics. The energy statistics should be adequate for carbon accounting.

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