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

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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 a refined NEAT model, a bottom-up approach, to estimate carbon release (actual CO_2 emissions) and carbon storage (potential CO_2 emissions) originating from non-energy use in Korea. The estimates differ widely. The IPCC Approach estimates actual emissions of 15.5 Mt CO_2 and potential emissions of 45.2 Mt CO_2 for Korea, while the NEAT model shows actual emissions of 9.2 Mt CO_2 for both approaches and potential emissions ranging from 29 Mt CO_2 (consumption based) to 40.9 Mt CO_2 (production based) for 1996. The IPCC Approach results in much higher actual and potential CO_2 emissions than the NEAT model. This is because only bulk products and bulk intermediates are taken into account in the NEAT model, on the one side, and because the IPCC Approach does not consider actual emissions caused by traded short life materials and by intermediate imports and exports that are used for the production of short life materials, on the other side. Moreover, the results for carbon storage show that there is a large difference between the estimates calculated using the NEAT model. The carbon storage calculated according to the production based approach was much higher than the one calculated according to the consumption based approach, because Korea was a large net exporter of petrochemicals. This highlights the importance of international trade with intermediates and short life materials in the 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 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 13 and 20 percent respectively[10]. Thus, it is important to estimate exactly carbon storage (potential CO_2 emissions) and carbon release (actual CO_2 emissions) originating from non-energy use. These estimates can have importance in discussions on CO_2 emissions. For instance, if carbon taxes are introduced,

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[10] Patel et al., 1999.

underestimation of potential CO_2 emissions and with it overestimation of actual CO_2 emissions will adversely affect the petrochemical industry. On the other side, underestimation of actual CO_2 emissions will mean wrong incentives for this industry.

Moreover, estimation of CO_2 emissions originating from non-energy use will gain importance in the discussion on relocation of bulk chemical industries from industrialised 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 petrochemical intermediates and short life products.

This paper tries to calculate CO_2 emissions from non-energy use in Korea. First, accounting methods for carbon storage are discussed (Chapter 2). Chapter 3 gives a brief overview of the Korean petrochemical industry. Chapters 4 and 5 estimate actual and potential CO_2 emissions from non-energy use in Korea by using the IPCC Reference Approach and a refined NEAT model (material flow analysis) respectively. At the end some conclusions will be drawn.

2. Accounting approaches for carbon storage

There are two basic accounting approaches for carbon storage: top-down and bottom-up approaches. A top-down approach estimates carbon storage (potential CO_2 emissions) based on non-energy use statistics being a part of national energy balances. Such an estimation method is proposed in the IPCC guidelines as an optional calculating step within the reporting framework.[11] A bottom-up approach traces carbon storage in petrochemical processes and flows based on material flow analysis (MFA). It has been developed to overcome some of limitations of the IPCC guidelines.[12]

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 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 potential CO_2 emissions. They are considered as actual CO_2 emissions.

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

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

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[11] IPCC et al., 1995.

[12] Gielen, 1997; Patel et al., 1999; Gielen et al., 1999.

with i indicating the type of fuel.[13] The IPCC guidelines provide default values for P_i as given in Table 4. Alternatively, 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:[14]

- 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.
- 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 traded short life materials and by intermediate imports and exports that are used for the production of short life materials. 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 some of these limitations material flow analysis has been developed.

Material flow analysis

Material flow analysis estimates actual and 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 5.

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.

13 Gielen, 1997; Patel et al., 1999.

14 Gielen, 1997; Patel et al., 1999.

There are two principles/approaches to estimate actual and potential CO_2 emissions: "national boundary" principle (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 CO_2 emissions originating from non-energy use in Korea using both the IPCC Approach and a spreadsheet model NEAT (Non-Energy use Emission Accounting Tables) recently developed to estimate quickly emissions related to non-energy use.[15]

3. The Korean petrochemical industry

The Korean petrochemical industry grown rapidly in the period 1988 to 1996. Table 2 shows that the production capacities for ethylene, propylene, benzene, xylene, styrene monomor, 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 comparison, 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.

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 monmor	230	675	1,135	1,645	2,170
H D P E	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
P V C	530	610	710	1,045	1,255
T P C	500	1,160	1,210	3,110	4,250
Carbon black	205	250	340	530	530

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

[15] Gielen et al., 1999.

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. It exported them in the amount of $ 5.4 billion in 1996. Major exporting petrochemicals were polypropylene ($ 725 million), HDPE ($ 494 million), low density polyethylene LDPE ($ 433 million), acrylonitrile butadiene styrene ABS ($ 352 million), stylene monomor SM ($ 311 million), polystyrene ($ 303 million), TPA ($ 235 million), P-xylene ($ 183 million), toluene ($ 182 million) and PVC ($ 155 million). Imported petrochemicals had a value of $ 4.4 billion in 1996. Major importing chemicals were P-xylene ($ 456 million), ethylene glycole ($ 379 million), carprolactam ($ 353 million), acrylonitrile ($ 175 million), styrene monomor ($ 152 million), vinylchloride monomor VCM ($ 146 million), xylene ($ 184 million) and methanol ($117 million).

In CO_2 equivalents, Korea was net importer of intermediates (0.197 Mt) and net exporter of products (9.239 Mt).[16]

The Korean petrochemical industry produced in 1966 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. Actual and potential CO_2 emissions in Korea according to the IPCC Approach

To estimate actual and 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 bunker-C, LPG, kerosene and coal tars as feedstocks. Bunker-C is used to produce propylene at times of high demand for the latter which can not be met by the naphtha steamcracking process. 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 non-energy use which is used as fuel.

A recent study[17] shows that the non-energy use is differently defined in national energy statistics. According to the Dutch energy balances the net values for the

[16] Chapter 5 is referred for more information.

[17] Patel et al., 1999.

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 4. 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 4, feedstocks not listed in the Korean energy balances, coal tars, lubricants, kerosene, heavy fuel oil and LPG corresponded to 119.1 PJ in energy contents (14.5% of the non-energy use of 819.9 PJ) and 3.88 Mt in CO_2 equivalents (25.1% of the actual CO_2 emissions) for 1966. With these data the list of non-energy use statistics is complete but not in the net values as required to estimate properly the actual CO_2 emissions.

As to calculate the net values for the non-energy requirements, we should know about the coproduction of fuels in basic chemical production. Naphtha steamcracking processes represent major activities of the Korean petrochemical industry. Naphtha amounted to 76.2 percent of the non-energy use in energy contents in 1996. If bitumen and lubricants are excluded, the percentage rises to 88.5 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. The survey results show 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.

Table 3: Coproduction of fuels in Korean naphtha cracking processes: survey results

	LHV	Producer 1		Producer 2		Producer 3		Producer 4		Producer 5	
		t[1)]	GJ[2)]	t	GJ	t	GJ	t	GJ	t	GJ
Hydrogen	100	0.012	1.200	0.016	1.600	0.016	1.600	-	-	-	-
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			8.965 (20.4)[3)]		9.249 (21.0)		10.916 (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.

The coproduction of fuels per tonne of naphtha by 5 ethylene producers ranged from 8.682 GJ to 10.916 GJ with an average of 9.315 GJ. Assuming 44 GJ/t as energy content per tonne of naphtha, the average of the coproduction of fuels in the amount of 9.315 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. As a result, we can subtract 21 percent from naphtha consumption in Korea as to calculate approximately the net values of non-energy use requirements for Korea.

After correction the non-energy use for 1996 decreases by 16.8 percent from 985.9 PJ to 819.9 PJ. At the same time the actual and potential CO_2 emissions decrease by 16.4 percent from 18.5 Mt to 15.5 Mt and by 16.6 percent from 54.4 Mt to 45.2 Mt respectively, as shown in Table 4. In comparison, the actual and potential CO_2 emissions according to the actual Korean energy balances were 14.6 Mt and 49.5 Mt respectively. The change (correction) in the Korean non-energy statistics, however, implies that the actual CO_2 emissions increase from 15.5 Mt to 22.7 Mt since one has to add naphtha used as fuel (12.2 Mt) to the country's total and to subtract coal tars (0.6 Mt), lubricants (1.5 Mt), kerosene (0.3 Mt), heavy fuel oil (1.7 Mt) and LPG (0.8 Mt) used as feedstocks from the country's total. Thus, the adoption of the proposed non-energy statistics results in an increase of Korea's CO_2 emissions by 8.1 Mt (22.7 Mt - 14.6 Mt).

Table 4: Estimation of carbon storage in products after correction of coproduction of fuels, according to IPCC, Korea, 1996

Energy carriers	Non-energy Use [Mt]	LHV [PJ/Mt]	Non-energy use [PJ]	Storage fraction [%]	Emission factor [Mt CO_2/PJ]	Carbon storage [Mt CO_2]	Carbon release [Mt CO_2]
Bitumen/asphalt*	1.733	42	72.77	100	0.0807	5.87	0.00
Coal tars	0.228	43	9.80	75	0.0807	0.59	0.20
Lubricants	0.944	44	41.53	50	0.0733	1.52	1.52
Kerosene	0.172	44	7.57	50	0.0741	0.28	0.28
Sovent*	0.079	44	3.46	50	0.0741	0.13	0.13
Naphtha*	14.195[1)]	44	624.57[2)]	75	0.0733	34.34[3)]	11.45[4)]
Heavy fuel oil	1.043	42	43.82	50	0.0760	1.67	1.67
L P G	0.355	46	16.33	80	0.0631	0.82	0.21
Total(corrected)			**819.86**			**45.22**	**15.45**
Total(uncorrected)			985.88			54.35	18.49
Total(energy balances)			866.82			49.46	14.62

* Listed in the Korean energy balances.
1) Uncorrected naphtha consumption was 17.968 Mt.
2) Uncorrected naphtha consumption was 790.59 PJ.
3) Uncorrected carbon storage was 43.46 Mt CO_2 eq.
4) Uncorrected carbon release was 14.49 Mt CO_2 eq.
Sources: Korea National Oil Corporation, Korea Energy Economics Institute and personal communications from the petrochemical industry.

5. Actual and potential CO_2 emissions in Korea according to the NEAT model

The NEAT model consists of four sheets, import data, materials balances, energy/materials conversion coefficients, and CO_2 balances for the whole petrochemical industry. The input data sheet in turn consists of the following elements:

- Production data for petrochemical products
- International trend data: imports and exports
- Petrochemical energy use and non-energy use
- Characterisation 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

To run this model, it is essential to have production data and international trade data on basic chemicals, intermediates and products as listed in Table 5. 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.

Table 5: Estimates for short life and long life for residual applications

	Product	Quantity involved	Long life [%]	Short life [%]
Basic chemicals	Acetylene	Total	50	50
	Ammonia	Non relevant		
	Benzene	Other	50	50
	Bitumen	Total	100	0
	Butadiene	Other	100	0
	Butene	Other	100	0
	Carbon black	Total	100	0
	Ethylene	Other	50	50
	Lubricants	Total	0	100
	Methanol	Other	50	50
	Petroleum coke	Total	0	100
	Pitch	Total	100	0
	Propylene	Other	0	100
	Toluene	Total	0	100
	Waxes, paraffins	Total	0	100
	Xylenes (o-,m-,p-,mixed 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	0	100
	Cumene	Other	100	0
	Cyclohexane	Other	0	100
	Cyclohexanone	Other	0	100
	Dimethylterephthalate	Other	100	0
	Ethanol	Total	0	100
	Ethylbenzene	Not relevant ?		
	Ethylene glycol	Other	0	100
	Ethylene oxide	Other	0	100
	Formaldehyde	Other	0	100
	I-Propanol	Other	0	100
	MTBE	Not relevant		
	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
	Vinylchloride monomer VCM	Other	100	0
Products	ABS	Total	100	0
	Epoxy resin	Total	100	0
	Melamineformaldehyde resin	Total	0	100
	Other plastics	Total	100	0
	Phenolic resin	Total	0	100
	Polyacrylates	Total	100	0
	Polyacrylonitrile	Total	100	0
	Polyamide 6,66	Total	100	0
	Polycarbonate	Total	100	0
	Polyethylene PE	Total	100	0
	Polyethyleneterephthalate PET	Total	100	0
	Polypropylene PP	Total	100	0

Polystyrene PS	Total	100	0
Polyurethane PUR	Total	100	0
Polyvinylacetate	Total	100	0
Polyvinylchloride PVC	Total	100	0
SAN	Total	100	0
Saturated polyester	Total	100	0
SBR	Total	100	0
Unsaturated polyester/alkyd resin	Total	0	100
Urea formaldehyde resin UF	Total	0	100
Solvents	Total	0	100

Source: Gielen et al., 1999.

Table 6: Revised NEAT model results for Korea, 1996

	Production based		Consumption based	
	Storage	Release	Storage	Release
	[Mt CO_2 eq.]	[Mt CO_2 eq.]	[Mt CO_2 eq.]	[Mt CO_2 eq.]
Acetylene	0,0000	0,0000	0,0000	0,0000
Ammonia	0,0000	0,0000	0,0000	0,0000
Benzene	-0,3726	-0,3726	-0,0698	-0,0698
Bitumen	6.1820	0,0000	5.3523	0,0000
Butadiene	1,2739	0,0000	0.4135	0,0000
Butene	0.0000	0,0000	0.0000	0,0000
Carbon black	1,2833	0,0000	1,1092	0,0000
Ethylene	0,5261	0,5261	0,1825	0,1825
Lubricants	0,0000	2.8179	0,0000	2.9662
Methanol	-0,2811	-0,2811	0,2696	0,2696
Petroleum coke	0,0000	0,0000	0,0000	0,0000
Pitch	0,6634	0,0000	0,0047	0,0000
Propylene	0,0000	1.7148	0,0000	1.3373
Toluene	0,0000	2.9326	0,0000	0,9939
Waxes, paraffins	0,0000	0,0000	0,0000	0,0000
Xylenes (o-,m-,p-,mixed xylene)	0,0000	1.4406	0,0000	2.0835
Acetic acid	0,1018	0,1891	0,1012	0,1879
Acetone	0,0741	0,0494	0,0703	0,0468
Acrylic acid	0,1023	0,0000	0,1580	0,0000
Acrylonitrile	-0,5897	0,0000	-0,0642	0,0000
Aniline	0,0091	0,0023	0,0250	0,0062
Bisphenol A	0,0000	-0,0365	0,0000	0,0433
Cumene	0.0325	0,0000	0.2562	0,0000
Cyclohexane	0,0000	0.2238	0,0000	0,0736
Cyclohexanone	0,0000	0,2963	0,0000	0,3017
Dimethylterephthalate	0.2808	0,0000	0.3039	0,0000
Ethanol	0,0000	0,0635	0,0000	0,0635
Ethylbenzene	0,0000	0,0000	0,0000	0,0000
Ethylene glycol	0,0000	-1.0897	0,0000	-0,2561
Ethylene oxide	0,0000	-0.4229	0,0000	-0.3729
Formaldehyde	0,0000	-0.0874	0,0000	0,2793
I-Propanol	0,0000	0,0770	0,0000	0,0550
MTBE	0,0000	0,0000	0,0000	0,0000
Phenol	0,0000	0,0296	0,0000	-0,0569
Phthalic anhydride PSA	0,0000	0,5244	0,0000	0,3701
Propylene oxide	0,0000	0,3056	0,0000	0,3193
Styrene	1.2922	0,0000	0,1973	0,0000
Terephthalic acid TPA	5.1021	0,0000	4.3776	0,0000
Vinylchloride monomer VCM	-0.4132	0,0000	0,0101	0,0000

ABS	1.7463	0,0000	0,8471	0,0000
Epoxy resin	0,1673	0,0000	0,1339	0,0000
Melamineformaldehyde resin	0,0000	-0.0150	0,0000	0,0000
Phenolic resin	0,0000	0.2920	0,0000	0,3458
Polyacrylates	0.0000	0,0000	0,0000	0,0000
Polyacrylonitrile	0,0000	0,0000	0,0000	0,0000
Polyamide 6,66	0.0000	0,0000	0.0000	0,0000
Polycarbonate	0,0000	0,0000	0.0000	0,0000
Polyethylene PE	8.1589	0,0000	4.6310	0,0000
Polyethyleneterephthalate PET	4.8542	0,0000	4.5932	0,0000
Polypropylene PP	5.4585	0,0000	2,5762	0,0000
Polystyrene PS	3,1226	0,0000	1.8571	0,0000
Polyurethane PUR	0.0000	0,0000	0.0000	0,0000
Polyvinylacetate	0,0000	0,0000	0,0000	0,0000
Polyvinylchloride PVC	1,4025	0,0000	1,1815	0,0000
SAN	0,0000	0,0000	0,0000	0,0000
Saturated polyester	0,0000	0,0000	0,0000	0,0000
SBR	0,7049	0,0000	0,4877	0,0000
Unsaturated polyester/alkyd resin	0,0000	0,0000	0,0000	0,0000
Urea formaldehyde resin UF	0,0000	0,0000	0,0000	0,0000
Solvents	0,0000	0,0000	0,0000	0,0000
Total	40.8824	9,1801	29,0051	9,1699
	82%	21%	76%	24%

Note: In terms of carbon content, net imports of intermediates in the amount of 0.197 Mt CO_2 and net exports of products in the amount of 9.239 Mt CO_2 were estimated.

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 5. 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.[18] 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.

The refined NEAT model results for Korea are shown in Table 6. The estimates using both approaches, Production based approach and Consumption based approach, show an almost same carbon release (actual CO_2 emissions) of 9.2 Mt for the year 1996. The carbon storages (potential CO_2 emissions) of 29-40.9 Mt represent about 7-10 percent of the total Korean CO_2 emissions which were higher than in Germany with 4-5 percent and in the United Kingdom with 4 percent.[19]

Firstly, it is quite striking that the IPCC Approach results in much higher actual and potential CO_2 emissions than the NEAT model. This is because only bulk products and bulk intermediates are taken into account in the NEAT model, on the one side, and because the IPCC Approach does not consider actual emissions caused by traded short life materials and by intermediate imports and exports that are used for the production of short life materials, on the other side.

[18] Gielen et al. 1999, p. 7.

[19] Gielen et al., 1999, pp. 8-9.

Table 7: Comparison of estimates of carbon storage and release for Korea, Germany and the UK

	IPCC Approach		NEAT model Production based		NEAT model Consumption based	
	Storage	Release	Storage	Release	Storage	Release
Korea (1996)	45.2[1)] (75%)[2)]	15.5 (25%)[2)]	40.9 (82%)	9.2 (18%)	29.0 (76%)	9.2 (24%)
Germany (1995)[3)]	56.2 (78%)	15.8 (22%)	43.6 (72%)	16.7 (28%)	39.4 (66%)	20.0 (34%)
U K (1996)[3)]	30.8 (77%)	9.4 (23%)	20.7 (64%)	11.7 (36%)	24.1 (72%)	9.4 (28%)

1) in Mt CO_2 equivalents.
2) Carbon storage and carbon release ratios.
3) Patel, latest calculations, November 1999 (german95_6.xls).

Secondly, it is interesting to note that the difference between carbon storages estimated using both approaches, Production based approach and Consumption based approach, is very large. It amounted to 11.9 Mt CO_2 equivalents for the year 1996. This large difference is certainly due to large exports of petrochemicals in Korea. In CO_2 equivalents, net exports of products amounted to 9.2 Mt and net imports of intermediates were 0.2 Mt. As a result, the net exports of petrochemicals were about 9 Mt. The German case confirms this view. In CO_2 equivalents, Germany exported net petrochemicals in the amount of 4.3 Mt (1.9 Mt for intermediates and 2.4 Mt for products).[20] Accordingly, the German difference between carbon storages in question was with 4.2 Mt (43.6 Mt - 39.4 Mt) much smaller than the Korean one. In the case of carbon release, the estimates for both approaches are same for Korea.

Furthermore, the refined NEAT model results for Korea show negative figures in nine products like benzene, methanol, acrylonitrile and vinylchloride monomor VCM. There are three main reasons for negative figures:[21]

- The model may not be accurate enough.
- The statistical data on production, imports and exports may not be accurate enough.
- Negative values occur if statistical data for a certain product are not available and therefore, have not been entered in the NEAT model.

Thus, the NEAT model results have to be improved by checking whether the negative value originates from the non-availability of statistical data, by providing the model with more accurate statistical data and by improving the model. In fact, a change in the production process of the NEAT model may eliminate negative figures. For instance, the refined NEAT model for Korea eliminates a large negative value of -3.6026 (carbon storage in the Production based approach) and of -3.5794 (carbon storage in the Consumption based approach) for dimethyl terephthalate (DTM) by accounting for the fact that polyethylene terephthlate (PET) is produced

20 Information provided by Martin Patel of the Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany.

21 Patel, 2000, Discussion: Negative figures in the NEAT model.

in Korea not from DTM but, based on a more modern process, from terephthalic acid (TPA) (see box).

Box: Model adaptation for PET production

Country: Korea

1 kt PET requires 0.8646 kt terephthalic acid (TPA)
or 1.0104 kt dimethyl terephthalate (DMT)

Therefore,
2.118 Mt PET requires 1.831 Mt TPA
or 2.140 Mt DMT

For comparison: Total consumption according to statistics
2.089 Mt TPA
0.134 Mt DMT

Conclusion:
In Korea, the production of PET is practically exclusively based on TPA; in contrast, DMT plays a negligible role.
-> delete production option PET from DMT in the NEAT model, i.e. delete cells BE11-BG11 in sheet "Mass balances".

As a result, the sums of negative values for carbon storage decrease substantially as can be seen in Table 8.

Table 8: Comparison of negative values between original and refined NEAT models

		Production based		Consumption based	
		Storage	Release	Storage	Release
Original NEAT model	Sum of negative values	-6.1192	-2.3052	-4.5734	-0.7557
	Total	36.1390	9.4047	24.2617	9.3945
Refined NEAT model	Sum of negative values	-1.6565	-2.3051	-0.1340	-0.7557
	Total	40.8824	9.1801	29.0051	9.1699

6. Conclusions

This paper has estimated for Korea carbon release (actual CO_2 emissions) and carbon storage (potential CO_2 emissions) originating from non-energy use by applying both the IPCC Approach and a refined NEAT model. The estimation has shown that carbon release and carbon storage calculated according to the IPCC Approach are much higher than the ones calculated using the NEAT model, a bottom-up approach. This was because only bulk products and bulk intermediates are taken into account in the NEAT model, on the one side, and because the IPCC Approach does not consider actual emissions caused by traded short life materials and by intermediate imports and exports that are used for the production of short life materials, on the other side.

Moreover, the results have shown that there is a large difference between the estimates calculated using the NEAT model for carbon storage. The carbon storage calculated according to the production based approach was much higher than the one calculated according to the consumption based approach, because Korea was a large net exporter of petrochemicals. This highlights the importance of international trade with intermediates and short life materials in the carbon accounting. However, the estimates for carbon release are almost same in both approaches.

The estimation has shown once more the importance of energy statistics, in this case, non-energy statistics and statistics on production and international trade of petrochemicals. There is a need to harmonise or standardise the non-energy statistics as to have a common basis for carbon accounting. In principle, fossil fuels used for feedstocks should be all included and the coproduction of fuels in basic chemical production should be excluded from non-energy statistics. As for the NEAT model, more products and intermediates should be considered, this despite the problem with data confidentiality. Negative figures in some products show that a further refinement is required for the refined NEAT model for Korea. Nevertheless, a bottom-up approach like the NEAT model can contribute to overcome some of limitations of the IPCC guidelines, especially the treatment of international trade with intermediates and short life materials.

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