Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Resources, Conservation and Recycling 45 (2005) 251–274
Resources Conservation & Recycling
www.elsevier.com/locate/resconrec

CO_2 emissions and carbon storage resulting from the non-energy use of fossil fuels in the Netherlands, NEAT results for 1993–1999

M.L. Neelis *, M. Patel, K. Blok

Utrecht University, Copernicus Institute, Department of Science, Technology and Society, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

Abstract

Estimating CO_2 emissions resulting from the non-energy use of fossil fuels is not straightforward, because part of the carbon is released quickly as CO_2 whereas another part is first embodied in organic chemicals. To contribute to a more accurate non-energy use CO_2 emission accounting, the Non-energy use Emission Accounting Tables (NEAT) model has been developed, which is in this paper applied to the Netherlands for the time period 1993–1999. For this period, we estimate the total non-energy use in CO_2 equivalents in the Netherlands to vary between 26.1 and 30.2 Mt CO_2. Of this total, 4.6–6.6 Mt CO_2 is emitted in industrial processes and during product use. The remainder is stored, resulting in an overall storage fraction of approximately 80%. Given the uncertainties involved, we cannot distinguish clear trends for the years of study. We show that the definition of non-energy use has a significant effect on the calculated storage fractions. The carbon storage according to the Dutch national greenhouse gas (GHG) emission inventory is 5–9 Mt CO_2 lower compared to the NEAT result. As a result, total fossil CO_2 emissions (including those from fossil fuel combustion) according to the national inventory are higher by the same amount, which is 3–5% of the total Dutch emissions. The difference is among other things caused by difficulties associated with the direct use of non-energy use figures from the Dutch energy statistics for CO_2 emission accounting. We recommend improving the Dutch GHG emission inventory making use of the results of this study.

Keywords: Non-energy use; Carbon storage; Solvents; Process emissions; Greenhouse gas inventories; Material flow analysis; Carbon balance; Dutch chemical sector; IPCC

* Corresponding author. Tel.: +31 30 2537600; fax: +31 30 2537601.
E-mail address: m.l.neelis@chem.uu.nl (M.L. Neelis).

0921-3449/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.resconrec.2005.05.004

1. Introduction

A considerable fraction of fossil fuels is used for non-energy use purposes, either as feedstock in the petrochemical industry or for direct use such as bitumen used for road construction. Estimating CO_2 emissions resulting from the carbon embodied in the non-energy use of fossil fuels is by no means straightforward. Part of the carbon is oxidised to CO_2 during the production of certain chemicals (e.g. ammonia), whereas another part is first stored in chemical products with lifetimes ranging from days to decades or longer. These chemicals lead to emissions either during the use phase (e.g. solvents) or only in the waste treatment phase (e.g. incinerated plastics). In other cases, these chemicals do not lead to emissions at all within a time span relevant for emission accounting (e.g. asphalt or land filled plastics).

In their emission inventory guidelines (IPCC/IEA/OECD/UNEP, 1997), the IPCC recommends two principle methods for calculating national greenhouse gas (GHG) emissions, the Reference Approach (IPCC-RA) and the Sectoral Approach (IPCC-SA). The IPCC-RA only calculates CO_2 emissions resulting from the use of fossil fuels and is supposed to be applied as a crosscheck for the IPCC-SA and as the exclusive emission inventory method for countries with limited data availability. The principal idea of the IPCC-RA is to subtract the amount of fossil carbon stored in products from the national total apparent carbon consumption to obtain a value for national CO_2 emissions. The carbon storage is calculated by multiplying the non-energy use of a certain fuel with a storage fraction for this fuel:

$$\text{carbon storage (t carbon)} = \text{non-energy use (J)} \times \text{emission factor (t carbon/J)} \times \text{storage fraction (\%)} \quad (1)$$

In the more detailed IPCC-SA, CO_2 emissions from the use of fossil fuels are reported in various source categories. These include 'Fuel combustion' 'Industrial process emissions', 'Solvent and other product use'[1] and 'Waste'. The calculation of CO_2 emissions according to these source categories should be based on a combination of energy statistics and detailed bottom–up analyses, but – depending on the "Tier" applied – may include again the use of formula (1) to calculate the amount of carbon stored. The IPCC-RA and IPCC-SA and the difficulties associated with these methods with respect to non-energy use CO_2 emission accounting are discussed in more detail elsewhere in this special issue (Neelis et al., 2005; Patel et al., 2005).

To contribute to a more accurate accounting of CO_2 emissions and carbon storage resulting from the non-energy use of fossil fuels, the Non-energy use Emission Accounting Tables (NEAT) model has been developed. The model is based on a carbon flow analysis and is largely independent from energy statistics. The model is described in a separate paper in this volume (Neelis et al., 2005).

In the Netherlands, non-energy use accounted for 13.5% of the total primary energy supply in the year 2000. This is high compared to other countries (the European average

[1] Emissions from solvent and other product use are sometimes also reported as non-methane volatile organic compounds (NMVOC) emissions. In the context of this paper, we convert all flows to CO_2 equivalents and therefore refer to CO_2 emissions from solvent and other product use.

is 6.5%) and is a consequence of a large chemical industry (values for 2000; IEA, 2002). The advantages that methods working independently from the energy statistics could have in determining emissions resulting from the non-energy use of fossil fuels have already been recognised at an early stage in the Netherlands. In fact, the NEAT model in its current form (as described by Neelis et al., 2005) has been developed out of a bottom–up carbon flow analysis for the Netherlands for 1992 described by Gielen (1997). The study by Gielen for 1992 has been used to determine country specific storage fractions for the Netherlands. These time-independent storage fractions are used in the Dutch IPCC-RA and IPCC-SA methodology for calculating greenhouse gas emissions in the Netherlands described in a methodology report by Spakman et al. (2003).[2] It is, however, unclear whether it is justified to use storage fractions determined for a single year for the calculation of CO_2 emissions and carbon storage in subsequent years, because it is not clear how large the yearly variations in non-energy use emissions, carbon storage and resulting storage fractions are. With the NEAT model, we can in detail explore these yearly variations. The aim of this paper is therefore:

- to investigate yearly variations in non-energy use emissions, carbon storage and resulting storage fractions in the Netherlands by conducting a time-series analysis for the period 1993–1999 with the NEAT model;
- to investigate the quantitative effects of methodological differences between the NEAT approach and the non-energy use emission accounting methodology applied in the Dutch GHG emission inventory.

In Section 2, the data sources used in this study are discussed. In Sections 3 and 4, we present the NEAT model results. The comparison with the official GHG inventory for the Netherlands is made in Section 5. The methodology applied in the NEAT model will only briefly be repeated here, for more detailed information the reader is referred to Neelis et al. (2005) elsewhere in this volume. The application of the NEAT model to the Netherlands is discussed in more extensively in Neelis et al. (2003).

2. Data sources for the NEAT Netherlands model

Three data sources were used for this study:

1. International trade statistics according to the Combined Nomenclature 8-digit product classification used throughout the European Union (Eurostat, 2004).
2. Production statistics according to the PRODCOM 8-digit product classification used throughout the European Union (Eurostat, 2004). In the PRODCOM classification, the corresponding classification in the Combined Nomenclature classification is given for each product.
3. Energy balances of individual firms used for the preparation of the Dutch energy statistics.

Most chemicals in the Netherlands are produced by only a few (less than five) producers. For this reason, the production statistics for about 90% and the trade statistics for about 10%

[2] In this report, also the calculation of storage fractions using the study by Gielen for 1992 is described.

of the products included in the NEAT model are confidential. These confidential data can be accessed at Statistics Netherlands, but the results can only be presented in aggregated form. An important reason for applying the NEAT model is to generate estimates that are independent from the energy statistics. For six NEAT core products (bitumen, lubricants, waxes and paraffins, MTBE (methyl tertiary butyl ether), petroleum coke and other tar products), this was not possible since no production and trade statistics independent from the energy statistics are collected for those products. Moreover, some of these products can be used both for energy and non-energy purposes (most notably petroleum coke) and only the detailed energy balances for the individual firms (data source 3) could be used to distinguish between the two.

3. CO_2 emissions from non-energy use

In this section, CO_2 emissions resulting from the non-energy use of fossil fuels are presented. Part of the carbon embodied in fuels used for non-energy use is embodied in chemicals. Some of these chemicals (e.g. solvents) lead to GHG emissions already during the use phase (fully or at least partially). In NEAT, these products are referred to as products that are 'oxidised during use (ODU)'. Other chemicals only lead to emissions during incineration of post-consumer waste; these chemicals are referred to as products that are 'not oxidised during use (NODU)'. The emissions from ODU products are assigned to the IPCC source category 'solvents and other product use' and are discussed in Section 3.1. Based on the total carbon embodied in chemicals and the domestic consumption of ODU and NODU products, the NEAT model also estimates the net trade flows of carbon containing chemicals. This estimate is presented in Section 3.2. Another part of the carbon embodied in the fuels used for non-energy use is already oxidised during the production phase of certain chemicals such as ammonia, resulting in CO_2 emissions from 'industrial processes', discussed in Section 3.3.

3.1. Emissions from solvent and other product use

The NEAT model estimates, in CO_2 equivalents, the consumption of ODU and NODU products based on a carbon balance modelling the conversion from 22 basic chemicals to 55 intermediates and final products. The products included and the method to split the consumption into ODU and NODU fractions is described in Neelis et al. (2005). The downstream consumption of ODU and NODU products together in the Netherlands is given in Table 1 and varies between 7.8 and 12.4 Mt CO_2. Although 1995 was a good year for the chemical industry,[3] this cannot fully explain the very high number for 1995. The wide variation from year to year results from the poor quality of the technical production and international trade data used in the model. This is especially the case for the intermediate products in the model. Companies tend not to report (fully) the production volumes of chemicals that are converted on-site to other chemicals. In case of apparent mistakes, we

[3] Production index of 0.94 in 1994 and 0.96 in 1996 compared to 1.00 in 1995 according to VNCI (2004).

Table 1
NEAT model results for final consumption of carbon in ODU and NODU products, the Netherlands, 1993–1999

	1993	1994	1995	1996	1997	1998	1999
Total consumption of carbon in chemicals (Mt CO_2)	7.8	8.0	12.4	8.4	8.8	11.2	10.0
Estimated error (for each year) (Mt CO_2)				±1.8			
Of which oxidised during use (ODU) (Mt CO_2)	1.3	1.7	3.0	1.8	2.1	2.3	2.6
Estimated error (for each year) (Mt CO_2)				±0.8			
Of which not oxidised during use (NODU) (Mt CO_2)	6.5	6.3	9.4	6.6	6.7	8.9	7.4
Estimated error (for each year) (Mt CO_2)				±1.5			
Percentage NODU in total consumption (%)	83	78	76	79	76	79	74

made corrections to the raw data. Such apparent mistakes included missing production data in some of the years for some of the products and cases where the net export (export–import) of a product exceeded the production of that product. Corrections were made by contacting the companies producing the products under investigation and by using mass balance principles. Manually corrected data instead of statistical data were used for production values of about one quarter of the 77 products and for trade values of a few of the 77 products. No corrections were made in cases of less apparent mistakes such as unexplainable but not impossible variations for some products from year to year.

As explained by Neelis et al. (2005), a sensitivity analysis for the division between ODU and NODU derivatives of each chemical is implemented in the model. We assume the resulting ranges for the percentage of ODU and NODU products to reflect the 95% confidence interval for these percentages. We further assume the 95% confidence interval in the consumption values for each of the chemicals to be 50% of the difference between minimal and maximal consumption between 1993 and 1999 of that chemical, thereby attributing the full variation in consumption values in the years of study to the weak data situation. Using standard error propagation rules we then come to the 95% confidence intervals for the consumption of ODU and NODU products given in Table 1. Given these substantial error ranges, we cannot distinguish a clear trend in the emissions from solvent and other product use as calculated with the NEAT model.

3.2. Net trade of organic chemicals

The carbon balance in the NEAT model can also be used to estimate, in CO_2 equivalents, the amount of the total carbon associated with non-energy use that is embodied in chemical products. This is done by summation of two elements:

- the CO_2 equivalents of the non-energy use refinery and coke oven products consumed for non-energy use applications;
- the amount of the carbon in hydrocarbon feedstocks, which is embodied in chemical products, estimated by taking the CO_2 equivalents of all basic chemicals produced from these feedstocks.[4]

The difference between the total non-energy use carbon embodied in chemical products upstream (at the level of feedstocks) and the consumption of ODU and NODU products downstream (Table 1) equals the net export of the chemical products included in the NEAT model. We present an overview in Table 2. The Table clearly shows the export-oriented nature of the Dutch petrochemical industry in which large amounts of basic chemicals and

[4] In the Dutch oil statistics survey (Statistics Netherlands, 2001) and consequently in the Dutch energy statistics, the pure aromatics benzene, toluene, the xylenes, ethylbenzene, styrene, naphthalene and cumene are included as energy commodities. As a result, the trade in these chemicals is already accounted for in the Dutch energy statistics and only the domestic consumption of these chemicals is reported as non-energy use. We adapted the NEAT calculations to reflect this accounting practice in the Netherlands and refer to Neelis et al. (2003) for a detailed description of the calculations. The Netherlands is a significant net exporter of these basic aromatics (approximately 5 Mt CO_2 equivalents). If these aromatics were not regarded energy commodities in the Dutch energy statistics, the production of these aromatics would be reported as non-energy use. The total primary energy supply and the total non-energy use in the Netherlands would in that case be about 5 Mt CO_2 equivalents higher.

Table 2
NEAT model results for non-energy use carbon embodied in chemicals, net export and final consumption of chemicals, the Netherlands, 1993–1999

	1993	1994	1995	1996	1997	1998	1999
Fraction of non-energy use carbon embodied in chemicals (Mt CO_2)	23.6	22.5	26.7	23.3	23.5	25.2	25.8
Total net export of chemicals included in NEAT (Mt CO_2)	15.8	14.5	14.3	14.8	14.7	14.0	15.8
Of which							
Basic chemicals/intermediates (Mt CO_2)	9.4	7.7	7.7	7.6	6.3	5.2	6.1
Polymers (Mt CO_2)	6.4	6.8	6.6	7.2	8.4	8.8	9.7
Total domestic consumption of chemicals (Mt CO_2) (Table 1)	7.8	8.0	12.4	8.4	8.8	11.2	10.0

intermediates (6–9 Mt CO_2) and polymers (6–10 Mt CO_2) are exported. The increase in ethylene production capacity by 600 kt/year at the Dow chemical complex in Terneuzen in 2002 (C&EN, 2002) further enhanced the position of the Netherlands as a major exporter of hydrocarbons in the years following the years of this study.

3.3. Industrial process emissions

For the calculation of CO_2 emissions from the production of ammonia, methanol and carbon black, we used the default CO_2 emission factors given by Neelis et al. (2005) multiplied with the production volumes for those chemicals in the years of study. In the Dutch energy statistics, energy conversions within industrial sectors (e.g. the conversion of feedstocks to hydrogen, methane and other fuels in steam crackers) are in detail monitored and parts of process inputs (in e.g. ammonia, methanol and carbon black), which are used as fuel are excluded from the non-energy use statistics and reported under final energy use (see also Box 1 and Section 5). In our calculations, we corrected for this accounting practice: for methanol and carbon black, we allocated a part of the process input (in CO_2 equivalents) equal to the carbon embodied in the methanol and carbon black product to non-energy use and the remainder to final energy use.[5] As a result, the industrial process emissions from these processes are zero by definition and all emissions are allocated to fuel combustion. For ammonia production, we assumed that a 70% versus 30% split is made between final energy use and final non-energy use of the process input. In Section 6, we discuss whether the assumptions made with respect to non-energy use allocation are justified given the actual Dutch situation. For ammonia, we corrected the *gross* industrial process emissions (resulting from the non-energy use) for CO_2 embodied in urea to yield *net* industrial process emissions. The results are given in Table 3. The ammonia production is fairly constant over the years and as a consequence both the emissions from fuel combustion and the *gross* industrial process emissions from ammonia are quite stable. The *net* industrial process emissions from ammonia production increase from 2.4 to 2.9 Mt CO_2 between 1993 and 1999, because of a decreasing production of urea, leading to less CO_2 storage in urea. The emissions from ammonia production are about a factor 10 higher than the emissions from methanol and carbon black production, which are relatively stable over the years.

In the NEAT model, emissions from steam cracking are calculated based on ethylene production figures and the feedstock composition applied in the crackers. We based this feedstock composition for steam cracking in the Netherlands on the energy balances of the companies operating steam crackers in the Netherlands. The share of naphtha in the input was estimated at 81–86% with gas oil and LPG making up the rest. The resulting emissions and backflows from the steam cracker process as estimated with the NEAT model are given in Table 3. Analogous to the production of ammonia, methanol and carbon black, we assume that the fuel use and backflows from steam crackers are not included in the non-energy use according to the Dutch energy statistics, but are reported as final energy use. As a result,

[5] For methanol, we further assume that the part used for the production of MTBE (approximately 0.4 Mt CO_2 equivalents in the years of study) is included as an energy conversion process and is therefore excluded from the non-energy use in the energy statistics.

Table 3
NEAT model results for CO_2 emissions in steam cracking and ammonia, methanol, carbon black, metals and inorganics production in the Netherlands, 1993–1999 (all values in Mt CO_2-equivalents)

	1993	1994	1995	1996	1997	1998	1999
Total natural gas input to ammonia production	4.9	4.9	4.9	4.6	4.9	5.0	5.0
Of which emissions from fuel combustion	1.5	1.5	1.5	1.4	1.5	1.5	1.5
Of which gross industrial process emissions	3.4	3.4	3.4	3.2	3.4	3.5	3.5
CO_2 embodied in urea	1.0	0.7	0.7	0.7	0.6	0.7	0.6
Net industrial process emissions ammonia production[a]	2.4	2.7	2.7	2.5	2.8	2.8	2.9
Total natural gas input to methanol production	1.5	1.4	1.9	1.5	1.6	1.3	1.4
Of which emissions from fuel combustion	0.3	0.3	0.4	0.3	0.3	0.3	0.3
Of which CO_2 embodied in methanol	1.2	1.1	1.5	1.2	1.2	1.0	1.1
Of which industrial process emissions methanol production	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total hydrocarbon input to carbon black production	0.7	0.6	0.7	0.7	0.8	0.6	0.6
Of which emissions from fuel combustion	0.2	0.2	0.3	0.2	0.3	0.2	0.2
Of which CO_2 embodied in carbon black	0.4	0.4	0.5	0.4	0.5	0.4	0.4
Of which industrial process emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total hydrocarbon input into steam cracking	24.1	24.0	27.2	24.9	24.2	24.3	26.8
Of which emissions from fuel combustion	4.2	4.1	4.7	4.3	4.2	4.2	4.6
Of which backflows from steam cracking	2.3	2.3	2.6	2.4	2.4	2.4	2.6
Of which industrial process emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial process emissions from metals and inorganics production	0.8	0.9	0.8	0.9	0.9	1.0	0.9

[a] Determined by deducting 'CO_2 embodied urea' from the gross industrial process emissions.

the industrial process emissions are zero by definition and the emissions are allocated to emissions from fuel combustion (in Box 1, the difficulties associated with CO_2 emission accounting based on the Dutch energy statistics for the steam cracking process are further discussed).

The industrial process emissions from the production of metals and inorganics are also given in Table 3. They were calculated combining production volumes for the various chemicals with the standard emission factors given in Neelis et al. (2005). The emissions range from 0.8–1.0 Mt CO_2 in the years of study and mainly result from the production of aluminium, phosphorus and silicon carbide.

4. Total non-energy use in CO_2 equivalents, carbon storage and storage fractions

In Table 4, we present an overview of the total non-energy use in CO_2 equivalents, the carbon storage and the resulting storage fractions. In Section 4.1, we will discuss the NEAT results. In Sections 4.2 and 4.3, we will show the influence of non-energy use definition and system boundary choices on these results. The differences with the Dutch National Inventory Report on greenhouse gas emissions (NIR; Klein Goldewijk et al., 2004) will be discussed in Section 5.

4.1. NEAT model results

The non-energy use in CO_2 equivalents is calculated by adding the industrial process CO_2 emissions calculated in Section 3 of this paper (totals from Table 3) to the fraction of non-energy use carbon embodied in chemical products (Table 1). The total non-energy use in CO_2 equivalents is broken down into the various fuel types used for non-energy use purposes by allocating the industrial process CO_2 emissions to the respective fuels used and by allocating the basic chemicals to the feedstock they are produced from (natural gas or the total of 'other oil products'). The total non-energy use in the Netherlands according to the NEAT model varies between 26 and 30 Mt CO_2 in the years of study. The total of 'other oil products' (the sum of all feedstocks in the petrochemical industry) and natural gas contribute approximately 90% to the total non-energy use, whereas the other fuels used for non-energy use purposes contribute approximately 10% to the total. The non-energy use of natural gas is stable in the years of study (varying between 4.2 and 4.5 Mt CO_2) as a result of the stable production volume of ammonia and methanol (together contributing more than 90% to the non-energy use of natural gas). For the total of 'other oil products', the total non-energy use varies between 19 and 23 Mt CO_2 in the years of study. We expect this value to have an uncertainty of ± 2 Mt CO_2 as a result of the limited reliability of the production and trade statistics (comparable to the uncertainty in the consumption figures of chemicals given in Table 1). We are therefore reluctant to draw any conclusion based on the observed variation from year to year.

The carbon storage[6] given in Table 4 consists of two parts:

[6] The use of the term 'carbon storage' might be confusing, because it includes carbon embodied in NODU products that are incinerated within the inventory year (assumed to be accounted for properly under emissions

Table 4
Total non-energy use in CO_2 equivalents in the Netherlands, 1993–1999: comparison between NEAT and the NIR (all values in Mt CO_2)

	1992	1993		1994		1995		1996		1997		1998		1999	
	NIR	NEAT	NIR	NEAT	NIR	NEAT	NIR	NEAT	NIR	NEAT	NIR	NEAT	NIR	NEAT	NIR
Coal/lignite/coke															
Non-energy use	0.42	0.30	0.37	0.34	0.38	0.32	0.39	0.32	0.43	0.34	0.42	0.32	0.41	0.32	0.45
Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Storage fraction (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal oil and tars															
Non-energy use	0.55	0.70	0.70	0.56	0.56	0.60	0.60	0.63	0.63	0.58	0.58	0.59	0.59	0.59	0.16
Storage	0.55	0.65	0.70	0.50	0.56	0.55	0.60	0.58	0.63	0.52	0.58	0.52	0.59	0.52	0.16
Storage fraction (%)	100	92	100	90	100	91	100	91	100	90	100	88	100	88	100
Lubricants															
Non-energy use	0.44	0.23	0.23	0.29	0.29	0.57	0.57	0.57	0.57	0.54	0.54	0.58	0.58	0.58	0.58
Storage	0.00	0.15	0.00	0.19	0.00	0.38	0.00	0.38	0.00	0.36	0.00	0.39	0.00	0.39	0.00
Storage fraction (%)	0	67	0	67	0	67	0	67	0	67	0	67	0	67	0
Bitumen															
Non-energy use	1.34	1.33	1.33	1.35	1.35	1.28	1.28	1.16	1.16	1.09	1.09	0.96	0.96	1.15	1.15
Storage	1.34	1.33	1.33	1.35	1.35	1.28	1.28	1.16	1.16	1.09	1.09	0.96	0.96	1.15	1.15
Storage fraction (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Other oil products															
Non-energy use	18.85	19.89	15.78	19.26	16.08	22.73	15.40	19.73	13.91	20.14	16.03	22.18	15.71	22.44	17.86
Storage	15.45	18.42	12.94	17.20	13.18	19.72	12.63	17.93	11.41	18.03	13.14	19.89	12.88	19.71	14.65
Storage fraction (%)	82	93	82	89	82	87	82	91	82	90	82	90	82	88	82
Natural gas															
Non-energy use	5.67	4.39	5.41	4.30	5.75	4.72	6.12	4.24	5.87	4.46	6.30	4.39	5.99	4.51	5.94
Storage	0.57	1.72	0.54	1.54	0.57	1.76	0.61	1.42	0.59	1.40	0.63	1.17	0.60	1.35	0.59
Storage fraction (%)	10	39	10	36	10	37	10	34	10	31	10	27	10	30	10
Total															
Non-energy use	27.26	26.83	23.81	26.10	24.40	30.23	24.37	26.65	22.57	27.15	24.95	29.03	24.24	29.60	26.15
Storage	17.91	22.26	15.51	20.78	15.67	23.70	15.13	21.47	13.78	21.40	15.44	22.93	15.04	23.13	16.56
Emissions[a]	9.35	4.57	8.30	5.32	8.73	6.53	9.24	5.18	8.79	5.75	9.51	6.10	9.20	6.47	9.59
Storage fraction (%)	66	83	65	80	64	78	62	81	61	79	62	79	62	78	63

[a] The sum of emissions from solvent and other product use (Table 1) and industrial process emissions (Table 3).

- the consumption of NODU products in the country of study (Table 1);
- the net export of all basic chemicals, intermediates and final products included in the NEAT model (Table 2).[7]

The carbon storage is stable in the years of study and varies between 21 and 24 Mt CO_2 in the years of study. The storage resulting from natural gas derived chemicals shows a clear trend, resulting from the decreasing production of urea (Table 3).

We also calculate storage fraction by dividing the carbon stored by the total non-energy use in CO_2 equivalents. The storage fraction for coal/lignite/coke is 0% since these products only lead to industrial process emissions. For bitumen and lubricants, the storage fraction equals the fraction that is not oxidised during use, 100% (bitumen) and 67% (lubricants), respectively (Neelis et al., 2005). For coal oils and tars (residues from coke production), the fraction emitted in the Netherlands is approximately 10% (as part of the industrial emissions in Table 2) with the remaining 90% being stored in NODU products. The storage fraction for natural gas is between 27 and 39% and is the only one showing a clear trend as a result of the declining production of urea in the years studied. For oil products, a storage fraction of between 87 and 93% is calculated. The variation can be fully explained by the uncertainties in the fraction of ODU vs. NODU products (Table 1) and we can therefore not distinguish a trend. It is important to note that the carbon storage fractions presented in Table 4 must not be directly used for CO_2 emission calculations according to the IPCC-RA as long as there are differences in total non-energy use in CO_2 equivalents between the NEAT model and the NIR as is indeed the case in the Netherlands (see Section 5).

4.2. Influence of non-energy use definitions

In the results shown in Section 4.1, we used a net definition of non-energy use for the production processes for ammonia, methanol and carbon black and in the steam cracking process, excluding from the non-energy use the part of the hydrocarbon input which is directly or indirectly (via the production of waste gas) used as fuel. This was done to reflect the practice in Dutch energy statistics (see Section 3.2). In other countries, gross definitions of non-energy use are applied, allocating the total input into the processes mentioned above to non-energy use, thereby including the parts used directly or indirectly as fuel. In Table 5, we show the effect of this different definition of non-energy use on the non-energy use in CO_2 equivalents and on the storage fractions for both natural gas and the 'other oil products'. The difference between the total non-energy use according to the gross and the net definition (for the total of natural gas and 'other oil products') equals the sum of the fuel combustion emissions and backflows given in Table 3. The results show that it is very important to understand which definition is used in the non-energy use statistics applied in the inventory and to adapt the storage fractions accordingly in order to come up with correct estimates for carbon storage. Furthermore, it is important to realise that the CO_2 emissions

from fuel combustion or waste) and also includes carbon embodied in ODU products that lead to emissions abroad. We still decided to use the term to be consistent with the terminology used in the IPCC guidelines.

[7] Except for the non-energy use refinery and coke oven products and the basic aromatics for which the trade is already accounted for in the energy statistics.

Table 5
Effect of non-energy use definition on total non-energy use and storage fractions in the Netherlands, 1993–1999

	1993	1994	1995	1996	1997	1998	1999
Non-energy use natural gas, net definition (Mt CO_2)	4.4	4.3	4.7	4.2	4.5	4.4	4.5
Non-energy use natural gas, gross definition (Mt CO_2)	6.2	6.1	6.6	6.0	6.3	6.2	6.3
Carbon storage, natural gas, both definitions (Mt CO_2)	1.7	1.5	1.8	1.4	1.4	1.2	1.4
Storage fraction, natural gas, net definition (%)	39	36	37	34	31	27	30
Storage fraction, natural gas, gross definition (%)	28	25	27	24	22	19	21
Non-energy use other oil products, net definition (Mt CO_2)	19.9	19.3	22.7	19.7	20.1	22.2	22.4
Non-energy use other oil products, gross definition (Mt CO_2)	26.7	26.1	30.4	26.7	27.0	29.0	29.9
Carbon storage, other oil products, both definitions (Mt CO_2)	18.4	17.2	19.7	17.9	18.0	19.9	19.7
Storage fraction, other oil products, net definition (%)	93	89	87	91	90	90	88
Storage fraction, other oil products, gross definition (%)	69	67	65	67	67	69	66

from non-energy use calculated assuming either a gross or a net definition for non-energy use are incomparable to each other. In the case of a gross definition, some CO_2 emissions from fuel combustion are included in the emissions from non-energy use, whereas these are excluded in case of a net definition. For a further discussion on the influence of these differences on the correct methodology to be applied in national GHG inventories, we refer to Sections 4 and 6 of the paper by Neelis et al. (2005).

4.3. Including all products in the calculated storage

In the results presented in Table 4, we excluded the consumption of ODU products, but included the consumption of NODU products in the calculated storage. This was done, because our hypothesis is that the emissions from the waste treatment of these NODU products are correctly accounted for in the GHG inventory, either as emissions from fuel combustion or from waste. One can also calculate a carbon storage in which the consumption of ODU products is also included. This choice could be made when reliable emission inventories for solvent and other product use are available (e.g. bottom–up surveys). In that case, the calculation using the storage fractions only results in an estimate for CO_2 emissions, excluding ODU products. Depending on the definition of non-energy use applied, the calculation with the storage fractions in that case yields either an estimate for industrial process emissions (net definitions) or for industrial and some fuel combustion emissions (gross definition). In Table 6, we show the results using these system boundaries. The storage fraction for 'other oil products' is in this case close to 100%, because only a very small part results in direct CO_2 emissions (petroleum coke used in the metal industry).

5. Comparison with the National Inventory Report

Deducting the carbon storage according to NEAT (values according to Table 4) from the total primary energy supply of the Netherlands in CO_2 equivalents yields an estimate for total fossil CO_2 emissions, which can be compared with estimates according to the IPCC-RA and IPCC-SA. We show this comparison in Fig. 1. We will compare the NEAT results with the IPCC-RA in Section 5.1 and with the IPCC-SA in Section 5.2.

5.1. Comparison with the IPCC-RA

The NEAT model estimate is 5.1 (1994)—8.6 (1996) Mt CO_2 lower compared to the value according to the IPCC-RA. The difference is by definition equal to the difference in total carbon storage between NEAT and the NIR presented in Table 4, since both estimates are obtained by deducting the carbon storage from the total primary energy supply in the Netherlands. The difference in carbon storage can either be caused by differences in (compare equation (1)):

- the storage fractions used in the NIR (based on the study by Gielen for 1992, see below) and calculated in the NEAT model and/or

Table 6
Effect of system boundary choices on total non-energy use and storage fractions in the Netherlands, 1993–1999

	1993	1994	1995	1996	1997	1998	1999
Non-energy use natural gas, both system boundaries (Mt CO_2)	4.4	4.3	4.7	4.2	4.5	4.4	4.5
Carbon storage, natural gas, excluding ODU products (Mt CO_2)	1.7	1.5	1.8	1.4	1.4	1.2	1.4
Carbon storage, natural gas, including ODU products (Mt CO_2)	2.0	1.6	2.0	1.7	1.7	1.6	1.6
Storage fraction, natural gas, excluding ODU products (%)	39	36	37	34	31	27	30
Storage fraction, natural gas, including ODU products (%)	45	37	42	40	38	36	36
Non-energy use other oil products, both system boundaries (Mt CO_2)	19.9	19.3	22.7	19.7	20.1	22.2	22.4
Carbon storage, other oil products, excluding ODU products (Mt CO_2)	18.4	17.2	19.7	17.9	18.0	19.9	19.7
Carbon storage, other oil products, including ODU products (Mt CO_2)	19.4	18.8	22.3	19.2	19.7	21.6	21.9
Storage fraction, other oil products, excluding ODU products (%)	93	89	87	91	90	90	88
Storage fraction, other oil products, including ODU products (%)	98	98	98	98	98	97	98

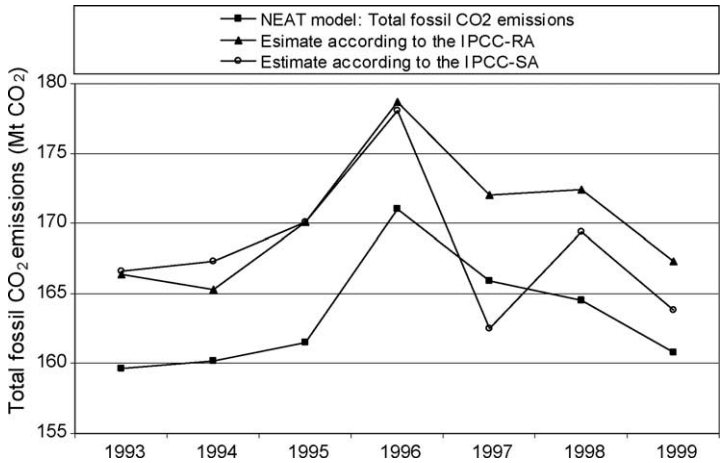


Fig. 1. Total fossil CO_2 emission the Netherlands, 1993–1999: NEAT results compared to the NIR.

- the total non-energy use in CO_2 equivalents used in the NIR and the total non-energy use in CO_2 equivalents according to the NEAT model.

Table 4 reveals major differences both in carbon storage and total non-energy use between the NEAT model and the NIR for especially the 'other oil products' and to a lesser extent also for natural gas. We will explore these differences on a fuel-by-fuel basis.

5.1.1. Coal/lignite/coke

For coal/lignite and coke, the storage fractions according to the NIR and NEAT are both 0%, because the use of these products for non-energy use purposes only lead to CO_2 emissions from industrial processes and not to carbon storage. The small differences in non-energy use between NIR and NEAT is caused by small differences in specific emission factors between the actual Dutch situation and the default values used in the NEAT model.

5.1.2. Coal oils and tars

The use of coal tars and oils (residues of coke ovens) is in our NEAT calculations directly taken from the energy statistics. As a result, the total non-energy use according to the NIR and NEAT is equal, with the exception of 1999. In 1999, a fraction of the use of coal tars and oils is reported as final energy use in the energy statistics, whereas in all other years, the same use was reported as non-energy use. In NEAT, we corrected for this inconsistency. In the NIR, the total non-energy use of coal tars and oils is assumed to be stored, whereas in the NEAT model, small CO_2 emissions are calculated from coal tar. These are partly used for the production of anodes that are converted to CO_2 in the production of aluminium.

5.1.3. Lubricants and bitumen

For lubricants and bitumen, the consumption figures in the NEAT model were also taken directly from the energy statistics (see Section 2) and as a consequence, the non-energy use according to NEAT and NIR are identical. For bitumen, storage fractions of 100% are used

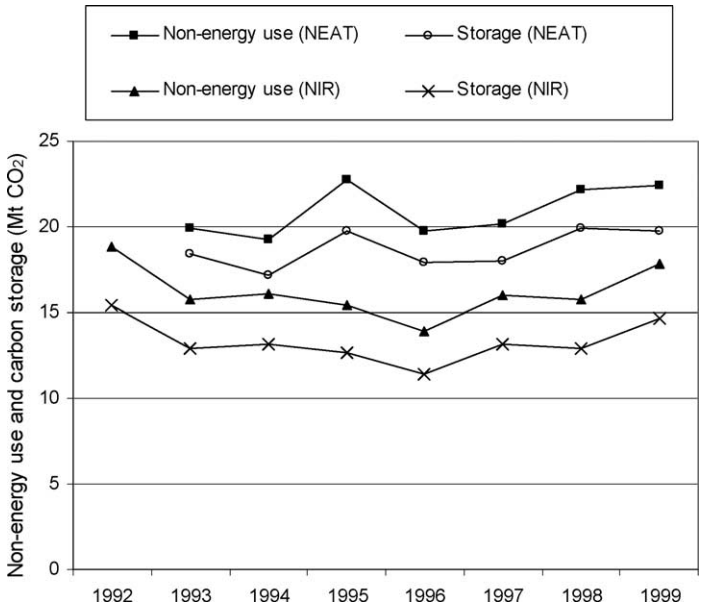


Fig. 2. Non-energy use and carbon storage for 'other oil products' in the Netherlands, 1993–1999: NEAT results compared to the NIR.

both in the NEAT model and in the NIR. For lubricants, the NIR assumes no storage of lubricants, whereas a fraction of 67% is used in NEAT to correct for lubricants, which are incinerated with energy recovery (emissions are already accounted for as emissions from fuel combustion). There is, however, a strong need to further study the final fate of lubricants and their position in both energy statistics and GHG emission inventories (see also, Neelis et al., 2005).

5.1.4. Total 'other oil products'

The carbon storage of the 'other oil products' according to the NEAT model is much higher than the values according to the NIR (Fig. 2). The difference can be explained as follows.

5.1.4.1. Differences in storage fractions. The storage fraction of 82% used in the NIR was derived based on an estimate of carbon storage of 15.4 Mt CO_2 for 1992 (Table 4). This value was derived from the study by Gielen (1997) for 1992 and differs in two ways from the NEAT carbon storage estimates presented in Table 4 and Fig. 2.

In the first place, Gielen gave two methodologically different storage estimates in his study for 1992. The first estimate (16.0 Mt CO_2 excluding bitumen) allocated emissions from exported ODU products to the Netherlands (producer approach), whereas the second estimate (18.1 Mt CO_2 excluding bitumen) allocated these emissions to the importing country (consumer approach). The consumer approach is in line with the approach of the NEAT model and with the generally accepted principle of allocating emissions to the country where

they take place. However, in the storage fraction calculation, the first storage estimate of 16.0 Mt CO_2 was used. For unclear reasons, 15.4 Mt CO_2 of this total has been allocated to the total of 'other oil products' and 0.6 to natural gas. This resulted in the storage fraction for oil products of 82% for 1992 (Spakman et al., 2003), which has been used ever since then (Table 4).

In the second place, the considerable export of anodes for aluminium production produced from petroleum coke (part of the 'other oil products') has not been included in the carbon storage estimate for 1992. This export was 0.8 Mt CO_2 in 1993. Using the carbon storage estimates for the consumer rather than those for the producer approach and adding the storage in exported anodes to the carbon storage results in an estimated carbon storage for oil products for 1992 equal to 17.1 Mt CO_2 rather than the 15.4 Mt CO_2 used in the calculation of the storage fraction. This estimate (17.1 Mt CO_2) is quite in line with estimates for carbon storage obtained with the NEAT model (Table 4) and would have resulted in a storage fraction of 91% for 1992, which is also in line with the NEAT model estimates (Table 4).

5.1.4.2. Differences in total non-energy use in CO_2 equivalents. The total non-energy use in CO_2 equivalents in 1992 in the NIR (18.9 Mt CO_2) is 1 Mt CO_2 lower compared to the NEAT estimate for 1993 (19.9 Mt CO_2). However, from 1992 to 1993, the non-energy use in the NIR dropped to 15.8 Mt CO_2, which is 4.1 Mt CO_2 lower compared to the NEAT estimate for 1993. It is unclear why the non-energy use in the energy statistics (used directly in the NIR) dropped so significantly from 1992 to 1993, since the drop cannot be explained by developments in the relevant sectors. As a result of this drop, a carbon storage of 12.9 Mt CO_2 was calculated for 1993 in the NIR, which is 2.5 Mt CO_2 lower than the storage of 15.4 on which the calculation of the storage fraction was based and 4.2 Mt CO_2 lower compared to the storage of 17.1 Mt CO_2 according to the consumer approach and taking into account the export of anodes.

So far, the following reasons for the observed gap have been found:

- The non-energy use of fuels reported by the three firms operating steam crackers in the Netherlands to the energy statistics varies significantly from year to year. The total is between 0.4 and 1.4 Mt (normal metric tonnes) lower than the production of ethylene, propylene, butadiene and other C_4 products from steam crackers. Multiplied with the carbon emission factor for naphtha (3.21 Mt CO_2/Mt), this explains 1.3–4.5 Mt CO_2 of the difference in total non-energy use in CO_2 equivalents. This underreporting is most probably a direct result of the difficulties associated with the position of the complex energy conversions in the steam cracker process in the Dutch energy statistics and the direct use of these statistics for CO_2 emission accounting. We further elaborate on these difficulties in Box 1.
- A considerable part of the non-energy use of 'other oil products' in the energy statistics results from the use of aromatics (50 PJ) and petroleum cokes (20 PJ). In the NIR, an emission factor of is 73 kt CO_2/PJ is used for these products, whereas both aromatics and petroleum cokes have emission factors quite different than 73 kt CO_2/PJ. The correct emission factor for aromatics is about 80 kt CO_2/PJ and for petroleum cokes the correct emission factor is even higher (approximately 100 kt CO_2/PJ). Multiplication of the non-

Box 1: Difficulties associated with using Dutch energy statistics for CO_2 accounting

In the Dutch energy statistics, the conversion of one fuel (column: 'used for energy conversions') to another fuel (column: 'produced from energy conversions') is monitored as well as the final energy and non-energy use of fuels. This can cause problems when the energy statistics are applied to estimate CO_2 emissions. This can best be explained with the energy and CO_2 balance of the Dutch steam crackers in 1999 presented in Fig. 4 (based on the NEAT steam cracker model). In steam crackers, the hydrocarbon feedstock is converted to non-energy use products, fuel gas used internally to fuel the endothermic process and remaining fuels, which are used elsewhere within or outside the chemical industry. It is very likely that the companies operating steam crackers report the production of the fuel gas used in the steam crackers (96 PJ) and of the remaining fuels (61 PJ) in the column: 'produced from energy conversions'. The use of these fuels will be put in the column: 'final energy use'. To close the energy balance, 157 PJ of the hydrocarbon input will be put in the column 'use for energy conversions'. The remainder of the input (211 PJ) will be allocated to the column 'non-energy use'. However, as a result of the endothermicity of the process, part of the energy of the fuel gas is in the cracker converted to chemical energy. As a result, the energy loss in the cracker is not 96 PJ, but only 71 PJ, with the remaining 25 PJ being embodied in the chemicals produced in the cracker (energy content of these chemicals 236 rather than 211 PJ). We checked these assumptions with the energy balances of firms operating steam crackers. This comparison showed that our basic reasoning is valid, but also that there are differences from year to year in the reporting practice of individual firms. The details of the comparison cannot be published for reasons of confidentiality. The resulting energy balance, already complex from an energy point of view, can easily create more problems when applied to CO_2 emission accounting. First, there is a gap between the two columns 'used for' and 'produced from' energy conversions, since the carbon content of the fuels produced (10.6 Mt CO_2) is not equal to the carbon content of the feedstock used ($157/368 \times 26.8$ Mt CO_2/PJ = 11.4 Mt CO_2). Secondly, the feedstock part, which is put in the column 'non-energy use', is equivalent to 15.4 Mt CO_2 ($211/368 \times 26.8$ Mt CO_2), whereas the non-energy products have a carbon content of 16.0 Mt CO_2. In general, it can for these reasons be doubted whether the non-energy use in the energy statistics can be used directly for CO_2 emission calculations, especially since the reporting practice varies from year to year and between firms. It would require detailed carbon, mass and energy balances for all firms operating steam crackers to assess these problems in more detail, since small inaccuracies in the assumptions can lead to substantial errors in the calculations due to the very large throughputs in the process. Because of the confidential nature of the information involved, such a comparison can only be done by Statistics Netherlands.

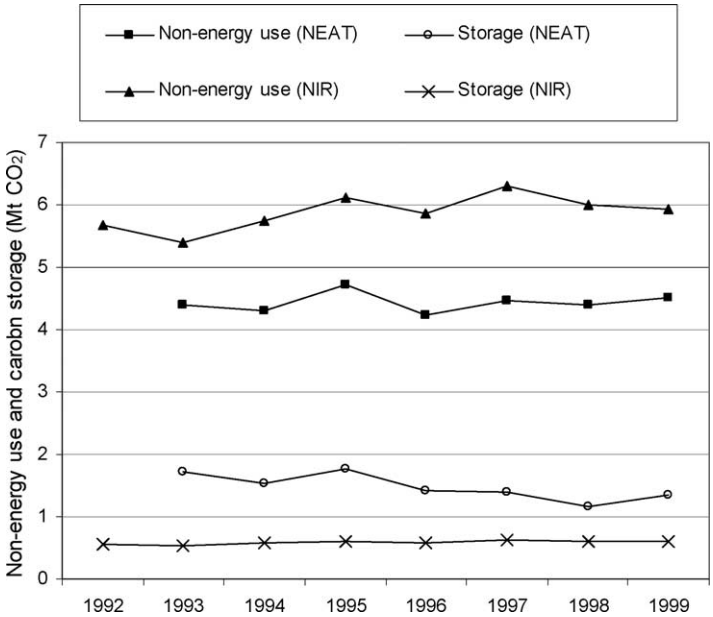


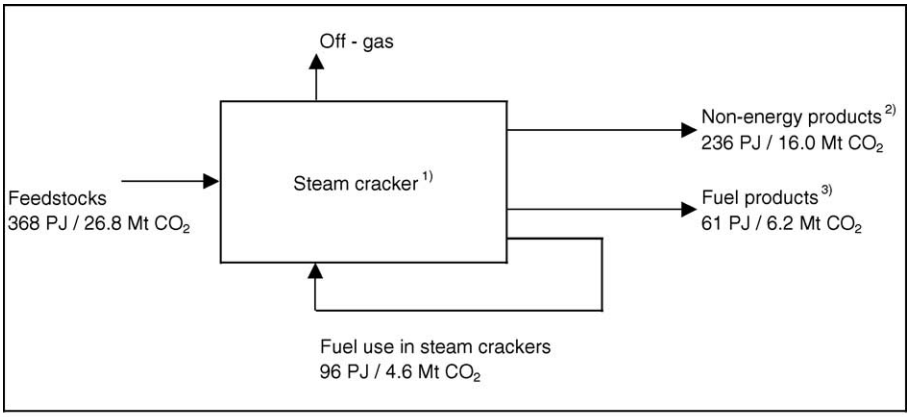
Fig. 3. Non-energy use and carbon storage for natural gas in the Netherlands, 1993–1999: NEAT results compared to the NIR.

energy use from the energy statistics (in energy units) with their correct emission factors would yield a non-energy use in CO_2 equivalents of the 'other oil products' in the NIR that is approximately 0.9 Mt CO_2 higher. This systematic error is also made in 1992 and is therefore no explanation for the drop in non-energy use between 1992 and 1993.

5.1.5. Natural gas

The methodological difference between consumer and producer approach also applies to natural gas derived chemicals such as urea. Applying the consumer approach to the data by Gielen for 1992 yields a storage estimate for natural gas equal to 1.8 Mt CO_2 rather than the 0.5 Mt CO_2 applied in the calculation of the storage fraction of 10% for 1992. This would for 1992 have resulted in a storage fraction of 32%. Fig. 3 also shows significant differences in total non-energy in CO_2 equivalents between the NEAT model and the NIR. The following reasons for the gap have been identified (Fig. 4):

- Within NEAT, the methanol used for the production of MTBE is subtracted from the non-energy use of natural gas because the MTBE is ultimately used as a component of transportation fuel. It has been found out that this correction has not been applied in the energy statistics. This correction is approximately 0.4 Mt CO_2 per year.
- In the Netherlands the raw material requirements for ammonia, methanol and carbon black production are higher than the estimates used in the NEAT model, which are based on very efficient plants. The reported non-energy use for ammonia production at the company level is about 0.8 Mt CO_2 higher compared to NEAT (or 0.3 t CO_2/t ammonia).



1) The picture simplified. Recycle flows of unconverted ethane and propane and steam production and export are not shown.
2) In line with the Dutch energy statistics, we regard aromatics as energy commodities and only regard ethylene, propylene, butadiene and other C4 products as non-energy products.
3) All remaining products (e.g. fuel oils, aromatics) minus the internal fuel use.

Fig. 4. Simplified Dutch steam cracker balance for 1999 (based on the NEAT steam cracker model for 1999).

For methanol and carbon black, the inputs are 0.1 and 0.05 Mt CO_2 higher, respectively.

The two reasons given above explain about 1.35 Mt CO_2 of the observed gap between the NIR and this study. The remainder of the gap (at most 0.4 Mt CO_2 in 1997) is less than 10% of the total non-energy use of natural gas for all years.

5.1.6. Summary

To summarise, we found tow clear reasons for the difference between the NEAT estimate for carbon storage and the IPCC-RA estimate in the NIR:

- The producer approach methodology applied in the NIR that partly allocates emissions that occur abroad to the Netherlands (∼2 Mt CO_2).
- Overlooking in the NIR methodology the carbon storage resulting from the export of anodes for aluminium production (∼1 Mt CO_2).

The remainder of the difference is caused by non-energy use estimates in the energy statistics (and consequently in the NIR) that are much lower compared to the estimates according to the NEAT model.

5.2. Comparison with the IPCC-SA

The difference between the NEAT results and the IPCC-SA is comparable to the difference between NEAT and the IPCC-RA (Fig. 1) with the exception for 1997 for which an unexplainable difference between the IPCC-RA and IPCC-SA is observed. In principle, the emissions according to NEAT, the IPCC-RA and the IPCC-SA should be more or less comparable, because all three estimates given in Fig. 1 include the fossil CO_2 emis-

sions from 'industrial processes' and the emissions from 'solvent and other product use' as well as fuel combustion emissions making the system boundaries between the three estimates comparable.[8] For the chemical industry, the IPCC-SA CO_2 emissions are as much as possible based on the CO_2 emission registration (ER) for individual firms and on the corresponding fuel use reported there. If, however, a company reports CO_2 emissions without reporting fuel use, the emissions are regarded CO_2 emissions resulting from non-energy use. The resulting CO_2 emissions from non-energy use are compared per sector with the non-energy use emission estimate using equation (1) (the total emissions according to the NIR given in Table 4). The highest estimate of the two is used in the official CO_2 emission inventory. This method has several drawbacks:

- As explained above, the storage fractions currently used in the NIR were determined based on work by Gielen for 1992, based on the producer approach and ignoring the storage in exported anodes for aluminium production. Furthermore, the storage was calculated for the country as a whole and cannot without adaptation be used at the level of individual sector.
- For the oil products, the emissions that are in the emission registration (ER) allocated to non-energy use (in cases where no fuel use reported in the emission registration) are high compared to expected values based on NEAT. It is very likely that at least part of these emissions actually correspond with emissions from fuel combustion. The residual CO_2 emissions for firms not individually reporting in the emission registration (ER) are estimated by deducting the reported fuel use in the emission registration from the total fuel use in the energy balance and multiplying the resulting 'residual fuel use' with default emission factors. The emissions falsely allocated to non-energy use can therefore easily be double-counted. This risk is acknowledged in the NIR (Klein Goldewijk et al., 2004, p. A-30) and can be in the order of several Mt CO_2.

Without going into detail of the complex calculation methods for the IPCC-SA in the Netherlands (for details we refer to Spakman et al., 2003), one can say that the methodology applied contains enough elements that can explain the apparent overestimation of CO_2 emissions compared to NEAT results presented in this paper.

6. Conclusions

The yearly variations in carbon storage and non-energy use CO_2 emissions in the years of this study are shown to be limited. Using a net definition of non-energy use, excluding the fuel use in steam crackers and in ammonia, methanol and carbon black production from the non-energy use, we estimate the total non-energy use in CO_2 equivalent to vary between 26 and 30 Mt CO_2. Given the uncertainties involved (estimated to be ± 2 Mt CO_2, mainly

[8] The IPCC-RA is nowadays generally regarded as a tool to estimate CO_2 from fuel combustion only (see Neelis et al., 2005 for further details regarding the interpretation of the IPCC-RA). In the Netherlands, however, the approach intends to include also all fossil industrial process CO_2 emissions and emissions from 'solvent and other product use'. Since the IPCC-SA in the Netherlands also uses the storage calculation from the IPCC-RA, these emissions are in the IPCC-SA also included under emissions from fuel combustion.

resulting from limited reliability of production and trade statistics), we cannot distinguish a clear trend in this total. Industrial process CO_2 emissions resulting from non-energy use vary between 3.2 and 3.8 Mt CO_2, emissions from the use of ODU products between 1.3 and 3.0 Mt CO_2. The latter have an estimated error of approximately 0.8 Mt CO_2 (again resulting from the limited reliability of production and trade statistics), which makes it difficult to distinguish a clear trend or to draw solid conclusions about the magnitude of these emissions. The remainder of the carbon embodied in the non-energy use (21–24 Mt CO_2) is stored in chemicals that are exported from the country or in products that remain un-oxidised during their use. Approximately 90% of the non-energy use n the Netherlands results from natural gas and the total of 'other oil products' (excluding bitumen and lubricants). The storage fraction for the total of 'other oil products' varies between 87 and 93%, with the variation being the result of the variation in emissions from the use of ODU products. For natural gas, a storage fraction between 27 and 39% is calculated. The storage fraction for natural gas shows a declining trend as a result of the decreasing production of urea in the years of study.

We also calculated carbon storage fractions including all products produced from non-energy use in the carbon storage and using different definitions of non-energy use (including the total input into steam crackers and ammonia, methanol and carbon black production in the non-energy use). The effect on the resulting storage fractions is substantial, showing the importance of choosing storage fractions consistent with the desired system boundaries and consistent with the applied definitions of non-energy use.

The carbon storage according to the NEAT model is 5.1–8.6 Mt CO_2 higher compared to the carbon storage estimate in the NIR. As a result, total fossil CO_2 emissions according to the IPCC-RA are higher by the same amount, which is 3–5% of the total fossil CO_2 emissions in the Netherlands. We have shown that this difference can partly be explained by a methodology that allocates emissions from product use abroad to the Netherlands ($\sim$2 Mt CO_2), partly by the omission of storage in exported anodes ($\sim$1 Mt CO_2) and partly by low estimates for total non-energy use in CO_2 equivalents in the Netherlands compared to the estimates according to the NEAT model (remainder of the difference). The latter is mainly caused by difficulties associated with the direct use of non-energy use figures from the Dutch energy statistics for CO_2 emission accounting. It is strongly recommended to critically assess the current emission inventory methodology in the Netherlands using the results of this study. Detailed analyses of the energy and carbon balances of the main companies for which non-energy use is relevant could help to identify possible improvements.[9]

The NEAT model is a valuable tool to generate estimates for total non-energy use in CO_2 equivalents, non-energy use CO_2 emissions, carbon storage and storage fractions, which are largely independent from the energy statistics. At the same time, the main drawback of conducting a material flow analysis like the NEAT model is the considerable data requirement. The most data intensive part of the analysis is the preparation of a carbon balance that is used to model the downstream structure of the chemical industry. Aim of that balance is to estimate the emissions from 'solvent and other product use' (ODU products). As a

[9] Currently, the methodology for calculating emissions and carbon storage from non-energy use in the Dutch inventory is indeed being changed using the outcome of this study. The changes involve a different interpretation of the energy statistics (along the lines of Box 1) and a less prominent role of the Emission Registration data in the IPCC-SA.

result of the limited quality of the production and trade data, the largest uncertainty is also in this carbon balance. It is therefore recommended to conduct surveys for the emissions from solvent and other product use to further improve inventories of CO_2 emissions from non-energy use.

Acknowledgements

This research was partly supported by the European Commission (Research Directorate General), 5th Framework European Network for Research in Global Change (ENRICH) programme, through Research Contracts ENV-CT98-0776 and EVK2-CT-2000-80003 (International network Non-energy Use and CO_2 emissions, NEU-CO2). Partly, the research was sponsored by the Dutch Ministry of Housing, Spatial Planning and the Environment. The empirical part of this research was executed at the Centre for Research of Economic Micro Data (CEREM) at Statistics Netherlands. The views expressed in this article, however, are those of the authors. Dolf Gielen (International Energy Agency) is acknowledged for commenting on earlier drafts of this paper.

References

C&EN. Cover Story: Petrochem. Chem Eng News 2002;80(11):21–6.

Eurostat, 2004. The PRODCOM and Combined Nomenclature classification can be downloaded from the Eurostat webiste: http://www.europa.eu.int/comm/eurostat/ramon/.

Gielen DJ. Potential CO_2 emissions in the Netherlands due to carbon storage in materials and products. Ambio 1997;26:101–6.

International Energy Agency (IEA). Energy Balances of OECD Countries, 2002 ed. Paris, France; 2002.

IPCC/IEA/OECD/UNEP. Greenhouse Gas Inventory Reporting Instruction, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, vols. 1–3. United Kingdom: IPCC WGI Technical Support Unit, Bracknell; 1997.

Neelis M, Patel M, de Feber M. Improvement of CO_2 emission estimates from the non-energy use of fossil fuels in the Netherlands, Report NW&S-E-2003-10. Utrecht, The Netherlands: Utrecht University, Copernicus Institute, Department of Science, Technology and Society; 2003.

Neelis ML, Patel M, Gielen DJ, Blok K. Modelling CO_2 emissions from non-energy use with the non-energy use emission accounting tables (NEAT) model. Resour Conserv Recycl 2005;45:226–50.

Klein Goldewijk K, Olivier JGJ, Peters JAHW, Coenen PWHG, Vreuls HHJ. Greenhouse Gas Emissions in the Netherlands, 1990–2002, National Inventory Report 2004. RIVM Report 773201008/2004, Bilthoven, the Netherlands. The corresponding Common Reporting Format (CRF) Tables used in this report are the submissions 2004, Version 1.0; 2004.

Patel M, Neelis M, Gielen D, Olivier J, Simmons T, Theunis J. Carbon dioxide emissions from non-energy use of fossil fuel: Summary of key issues and conclusions from the country analyses. Resour Conserv Recycl 2005;45:195–209.

Spakman J, van Loon MMJ, van der Auweraert RJK, Gielen DJ, Olivier JGJ, Zonneveld EA. Method for calculating greenhouse gas emissions, Emission Registration Series/Environmental Monitor, Nr. 37b, March 2003. Electronic update of No. 37, July 1997. The Hague, The Netherlands: Dutch Ministry of Housing, Spatial Planning and the Environment (VROM); 2003.

Statistics Netherlands. Aardoliegrondstoffen en aardolieproducten, Z-029, Statistics Netherlands, Taakgroep Energie, Voorburg, The Netherlands (in Dutch); 2001.

Vereniging van de Nederlandse Chemische Industrie (VNCI). Jaarverslag 2003. Vereniging van de Nederlandse Chemische Industrie, Leidschendam, the Netherlands (in Dutch); 2004.