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Resources, Conservation and Recycling 45 (2005) 195–209

Resources Conservation & Recycling

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Carbon dioxide emissions from non-energy use of fossil fuels: Summary of key issues and conclusions from the country analyses

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Available online 5 July 2005

Abstract

The non-energy use of fossil fuels is a source of carbon dioxide (CO_2) emissions that is not negligible and has been increasing substantially in the last three decades. Current emission estimates for this source category are subject to major uncertainties. One important reason is that non-energy use as published in energy statistics is not defined in a consistent manner, rendering calculation results based on these data incomparable across countries (concerns in particular the Intergovernmental Panel on Climate Change (IPCC) Reference Approach). Further reasons are the complexity and interlinkage of the energy and material flows in the chemical/petrochemical sector and the current use of storage fractions as default values in the IPCC Reference Approach, which are based on a different definition of storage and refer to other flows than those available from energy statistics. Several other shortcomings of the IPCC Reference Approach are identified in this paper, e.g. the fact that it neglects international trade of synthetic organic products.

In order to improve emissions accounting, the Non-Energy Use and CO_2 Emissions (NEU-CO_2) network developed a model called Non-Energy Use Emission Accounting Tables (NEAT), which is based on Material Flow Analysis (MFA). The NEAT model and other MFA approaches have been

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doi:10.1016/j.resconrec.2005.05.002

applied to several countries. In this paper, the results for Italy, Japan, Korea, the Netherlands and the USA are compared with the values published in National Communications to the United Framework Convention on Climate Change (UNFCCC). It is shown that the international harmonisation of the data sources (energy statistics) and the methods applied would lead to substantially different emissions results for some countries, in the order of several percent. Moreover, the NEAT model and the other MFA have proved to be a valuable tool to identify errors in energy statistics.

These results confirm the need for enhanced efforts to improve and harmonise energy statistics and estimation methods for CO_2 emissions from non-energy use. The articles in this special issue contribute to reaching these goals.
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Keywords: Non-energy use; Carbon storage; Solvents; Process emissions; Greenhouse Gas Inventories; Material Flow Analysis; Carbon balance; Chemical sector; IPCC

1. Introduction

When analyzing carbon dioxide (CO_2) emissions, so far most attention has been paid to the release from the combustion of fossil fuels. Apart from this CO_2 source, a significant fraction of fossil fuels is used for non-energy applications. Non-energy use is defined in this special issue as the total of:

- the consumption of fossil fuels as feedstock in the chemical industry (examples are the use of naphtha for the production of olefins and the use of natural gas for the production of ammonia);
- a limited number of non-energy use refinery and coke oven products that are consumed in various economic sectors and the use of solid carbon for the production of metals and inorganic chemicals (examples are the use of bitumen in the building industry, lubricants for transportation and the use of cokes for the production of metals).[1]

As shown in Fig. 1, non-energy use in OECD countries represents a significant share of the total fossil fuel use and in particular, of oil products. The share of non-energy use in total primary energy use has increased from 5.4% in 1971 to 7.0% in 2000 (IEA, 2002). The petrochemical industry is spread unevenly around the world. Therefore, in some countries, the relevance of feedstocks and non-energy use is significantly higher than the OECD average.

Only a fraction of the carbon contained in fossil fuels for non-energy applications enters the atmosphere as CO_2 as will be discussed later on in this paper (Section 2). Nevertheless, this is an important source of CO_2 emissions: the global share of non-energy use emissions increased from 1% in 1970 to almost 3% of total fossil fuel emissions of CO_2 in 1995 (Olivier and Peters, this issue). Within non-energy use, CO_2 from chemical feedstock use

[1] In energy statistics published by the International Energy Agency (IEA), only this second element is reported as non-energy use in: (i) industry/transformation/energy, (ii) transport and (iii) other sectors. In the IEA statistics, the use of chemical feedstocks is not presented as non-energy use because some of the feedstock is combusted. It is reported separately as so-called memo-item under the chemical industry.

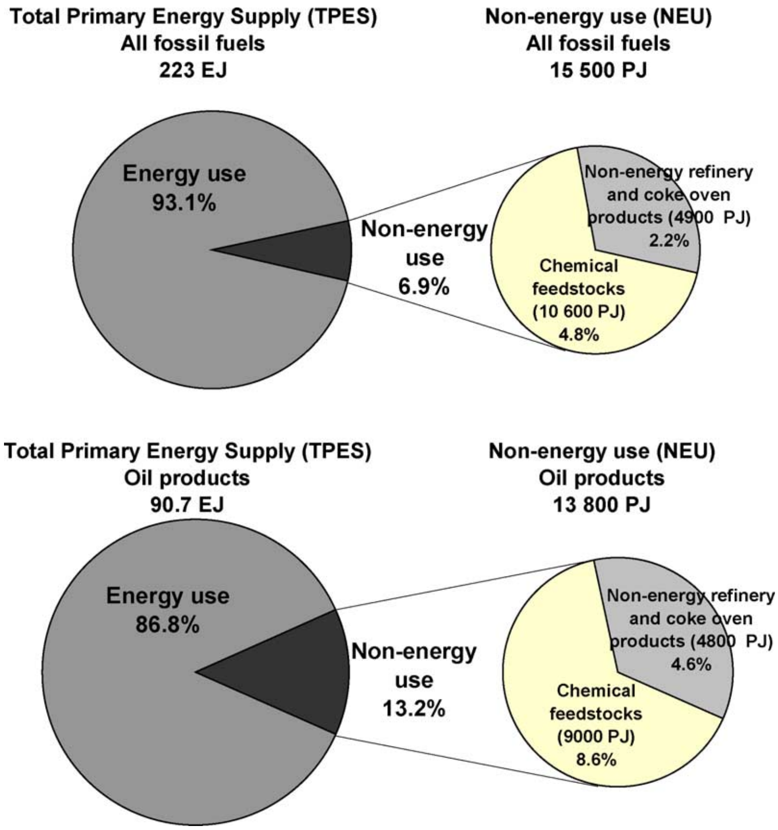

Fig. 1. Non-energy use in OECD countries in the year 2000 (IEA, 2002).

accounts for 70–100% of total CO_2 from non-energy use. The growth in CO_2 emissions from non-energy use is due primarily to the increased use as chemical feedstock. In 10 countries, CO_2 from non-energy use represented 20–50% of total industry emissions of CO_2. In another 15 countries, this source accounted for 10–20% of industry CO_2 emissions in 1990. Of all Annex I countries to the Kyoto Protocol, the Netherlands rank highest with a share of almost 30% in 1990 (all values from Olivier and Peters, this issue). The current importance and the growing share of CO_2 emissions from non-energy use are likely to cause non-energy use in many countries to be a Key Source according to the Good Practice Guidance of the Intergovernmental Panel on Climate Change (IPCC). An IPCC Key Source is defined as a source which is amongst the 95% largest sources of annual emissions (Level Key Source) or amongst the 95% largest contributors to the national total trend in emissions (Trend Key Source). For IPCC Key Sources, the IPCC Good Practice Guidance calls for the use of more detailed methods for calculating emissions, so-called Tier 2 methods (IPCC, 2000).

Due to the importance of non-energy use for greenhouse gas (GHG) emission accounting the Non-Energy Use and CO_2 Emissions network (NEU-CO_2) was formed a few years ago.

The work of the NEU-CO_2 network (funded by the European Commission; for further information see http://www.chem.uu.nl/nws/www/nenergy/) has resulted in this special issue. This paper discusses the key issues and draws conclusions from the country analyses. Section 2 provides an explanation of the pathways leading to CO_2 from non-energy use. Due to its importance for emission estimates, we discuss non-energy use definitions in Section 3. In Section 4, the difficulties related to standard IPCC methods for non-energy use emission accounting are discussed and recommendations are given. Material Flow Analysis (MFA) is introduced as an alternative approach in Section 5 and results are provided. The paper ends with conclusions and recommendations (Section 6).

2. Sources of CO_2 emissions from non-energy use and estimation methods

When fossil fuels are used for non-energy purposes, there are several ways how this can ultimately lead to CO_2 emissions. As shown in Fig. 2,[2] the following five pathways can be distinguished (see also Figs. 1–4 in Neelis et al., this issue-a):

(a) Chemical commodities such as solvents may lead to CO_2 emissions soon after use as a consequence of oxidation in the atmosphere (Fig. 2, see “Emissions 5” in diamond). This occurs, for example, after the application of a solvent-based paint with a brush in open space.
(b) In order to avoid VOC emissions such products may be incinerated (Fig. 2, see “Emissions 6” in diamond). For example, in large car sprays, the off-gases can be purified by oxidation of the organic compounds. Another example is the treatment of wastewater containing surfactants.
(c) Long lasting materials such as plastics do not degrade in the use phase (with the exception of the small market segment of degradable polymers) and they are hence converted to CO_2 only in the case of waste incineration (also “Emissions 6” in diamond). In contrast, land filling of these chemicals leads to carbon sequestration over long periods of time.
(d) Another pathway of CO_2 originating from non-energy use are certain industrial processes: if part of the feedstock is oxidised in the chemical conversion (e.g. in the case of hydrogen production), then this is typically considered as an inherent feature of the chemical process and not as fuel combustion (even though the process may be exothermal). In this case, the resulting carbon dioxide is referred to as industrial process emissions (Fig. 2, see “Emissions 2” and “Emissions 4” in diamonds).
(e) Finally, a chemical conversion may lead to fuel-grade by-products (e.g. the so-called “non-specs”) which are incinerated to raise heat. In this case, a part of the feedstock (non-energy use) is actually used for energy purposes (Fig. 2, see “Emissions 1” and “Emissions 3” in diamonds).

[2] For convenience, Fig. 2 presents only CO_2 emissions from non-energy use in the process chain of oil products. This is, however, no limitation for the conclusions because the same emission pathways apply for other feedstocks, i.e. natural gas and coal-derived feedstocks.

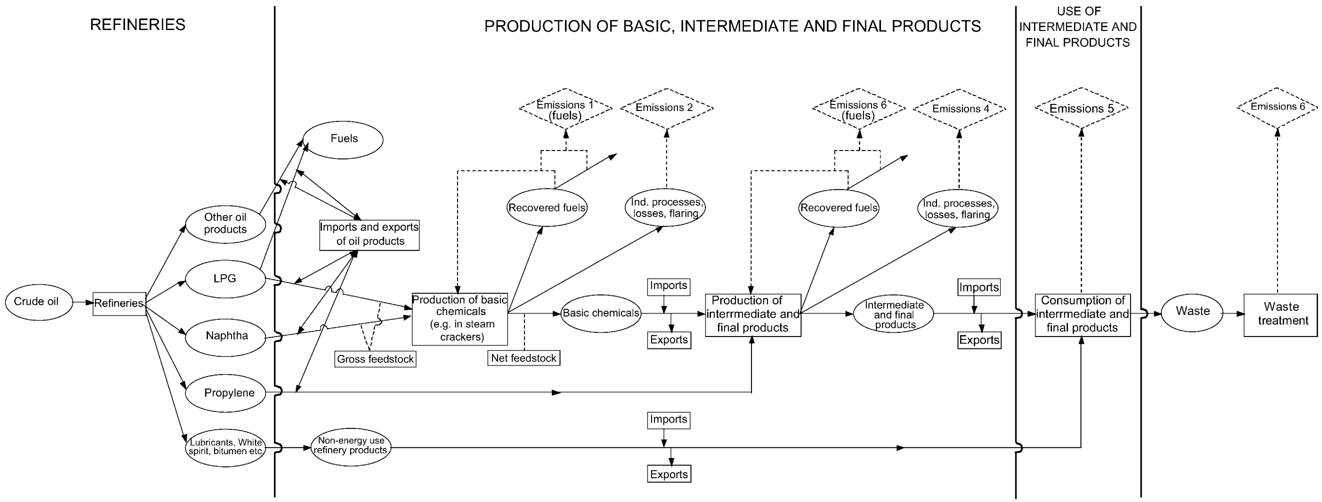

Fig. 2. Carbon storage and CO_2 emissions in the process chain of oil products (Theunis et al., 2002).

The IPCC has developed guidelines for the preparation of national inventories of GHG emissions (IPCC/IEA/OECD/UNEP, 1997). Two main methods are described in these guidelines, namely the IPCC Sectoral Approach (IPCC-SA) and the IPCC Reference Approach (IPCC-RA). The IPCC-SA is a detailed bottom-up estimation method for GHG emissions from all sources (not only non-energy use). In other words, the basic concept of the IPCC-SA is to add up carbon emissions for individual activities. The IPCC-SA distinguishes the source categories: “Solvent and other product use”, “Waste”, “Industrial process emissions” and “Energy” (essentially fuel combustion for heat raising). These four categories cover all the emission pathways distinguished above for non-energy use (see above (a–e)).

The IPCC-SA is the method according to which industrialized countries are expected to report their GHG emissions to the United Framework Convention on Climate Change (UNFCCC). In addition to the IPCC-SA, the IPCC Guidelines (IPCC/IEA/OECD/UNEP, 1997) describe the IPCC Reference Approach. The IPCC-RA is a rather simple top-down approach to estimate the total carbon emissions from fuel combustion in a country. The IPCC-RA uses the energy statistics to obtain the total supply of fossil fuel carbon and subtracts carbon stored in products. This carbon storage is estimated by multiplying deliveries of fuels for non-energy use by carbon storage fractions representing the fossil fuel carbon equivalents that are not converted to CO_2 during the production and use phase of the products (in this special issue, this method is explained in Neelis et al., this issue-a). The IPCC-RA is recommended as an overall check on carbon emissions from fuel combustion derived by the Sectoral Approach (SA).

Statistics of fuels used for non-energy purposes play an important role in the IPCC-RA. A harmonised definition for non-energy use (see above) is therefore indispensable to ensure that the results for CO_2 emissions according to the IPCC-RA are consistent and comparable across countries.

3. Definitions of non-energy use in energy statistics

Energy statistics often contain figures for deliveries of oils and natural gas for feedstock use. However, the definitions of feedstock use in various national and international energy statistics differ. This is a problem because an accurate and widely applicable method for emission accounting from non-energy use requires a consistent definition of non-energy use, if energy statistics are used as a basis. The different definitions have grown historically. One explanation is the difference in data availability. Another explanation is that different aggregation methods are applied, reflecting different system boundaries. There are multiple options for choosing system boundaries because the material flows are complex and interlinked (e.g. for steam crackers and aromatics production plants) and because fuel grade by-products in production processes and backflows (e.g. unconverted feedstocks of steam crackers) are not always returned to the refineries (see, e.g. Fig. 2). The fact that certain processes (e.g. steam crackers) may be operated on refinery sites or in chemical companies is a further reason why it is often not clear what exactly is included in statistical data for non-energy use. The statistics offices preparing the energy balances can provide insight into the system boundaries of non-energy data in official statistics. This can be complemented by Material Flow Analysis which allows to reconstruct non-energy use data (or parts of it) in a bottom-up approach.

Feedstocks should be presented in energy statistics in an internationally harmonised way. In 2000, the NEU-CO_2 network proposed to introduce as general definition of feedstock use in energy statistics the net amount of feedstocks that is determined by deducting from the gross deliveries to the petrochemical sector:

- firstly, the backflows from steam crackers to refineries;
- secondly, the equivalents of feedstocks used as fuel in industrial processes such as steam cracking, ammonia, methanol and carbon black production where a part of the feedstock is used for raising heat (see Fig. 2, “Emissions 1” and “Emissions 3” in diamonds).

In the second case, two cases can be distinguished: either a part of the feedstock is converted to fuel by-products and is combusted to provide the same process with heat (this is the case for steam cracking) or a part of the feedstock is directly oxidised in the reactor thus allowing the process to occur (this is the case for hydrogen production which is then used for ammonia and methanol production). Accurate accounting would require monitoring of energy recovery (use of fuel-grade by-products, e.g. in steam crackers) and at the company level on a yearly basis. This would also make international harmonisation necessary because, for some processes, the allocation of the total feedstock input to energy use versus non-energy use is somewhat arbitrary.[3]

The definition of feedstock use given above has been introduced in the IEA/EUROSTAT/UNECE oil questionnaire (Reece, 2000). While this definition is, in principle, straightforward, its implementation is complicated by complex and inter-linked material flows. This explains why the national bodies have so far hardly adapted their data submissions (to IEA/EUROSTAT/UNECE) to the requirements of the new questionnaire.

4. Recommendations concerning the IPCC methods RA and SA

For the IPCC Reference Approach, the IPCC Guidelines distinguish between carbon products that lead to emissions in the short (to medium) term and carbon equivalents that are fixed in products for longer periods of time; a threshold of 20 years is mentioned for the two product categories (IPCC/IEA/OECD/UNEP, 1997). However, the threshold of 20 years is not practical for annual emission inventories because no detailed data are available on the life span data for products that contain synthetic organic materials. Moreover, the default carbon storage fractions (f) that are proposed in the IPCC Guidelines for the IPCC-RA are based on work done by Marland and Rotty at the beginning of the 1980s (Marland and Rotty, 1984, p. 241–9). Their approach was developed before the IPCC guidelines were written. Marland and Rotty’s carbon storage fractions were not developed for the calculation of CO_2 emissions under the various IPCC source categories. Their fractions f represent the

[3] For example, the allocation is rather straightforward in the case of conventional steam reforming of natural gas for synthesis gas production, while it is not so obvious for the autothermal reforming which is an alternative process.

share of the non-energy use of a fuel which remains unoxidised for long periods of time. One can conclude that $(1-f)$ represents the CO_2 emissions from the oxidation during waste treatment (e.g. incineration) and during the use of products. The use of Marland and Rotty's default storage fractions in the IPCC-RA therefore leads to CO_2 emission estimates comprising fuel combustion, waste incineration and (autonomous) product oxidation. In contrast, the purpose of the IPCC-RA is generally regarded as a validation tool for CO_2 emissions from *fuel combustion* only (recently emphasized in the new Common Reporting Format, CRF; SBSTA, 1999). Hence, there is a clear *inconsistency in the IPCC Guidelines*. Furthermore, Marland and Rotty's storage fractions and the current IPCC approach are not based on the same flows of fossil fuels. For example, the 80% storage fraction for LPG is based on the chemical and industrial use of LPG and ethane produced in gas processing plants, including the direct use of fuel. The naphtha storage fraction is based on the total naphtha use worldwide, which includes energy use (Marland and Rotty, 1984, p. 244). Finally, Marland and Rotty's storage fractions do not account for chemical products trade (for explanation: large net imports of products that oxidise quickly increase a country's CO_2 emissions and vice versa; the trade with chemicals can therefore have an effect on the emissions; see below).

The issues listed above raise doubts concerning the validity and the practicality of the current approach. This is summarized below and further recommendations are given:

- The storage fractions in the IPCC Guidelines are inadequate to estimate non-energy use CO_2 emissions. It seems necessary to replace these storage fractions. It remains to be seen whether global average values are sufficiently accurate for country reporting. Analyses for individual countries or for regions are needed in order to come to a conclusion about this point.
- To ensure proper allocation of product-related emissions to the IPCC source categories, it is proposed to distinguish between products that are oxidised during use and products that are not oxidised during use (instead of the distinction between short-lived and long-lived products as made in the IPCC Guidelines). For products that are oxidised during use, the abbreviation ODU is introduced; examples are short-life products such as some solvents and part of the lubricants. ODU products are assumed to lead to CO_2 emissions directly within the inventory year. They fall into the IPCC source category "Solvent and other product use". For products that are not oxidised during use, the abbreviation NODU is introduced; examples are products such as plastics. NODU products are only converted into CO_2 in case of waste incineration; otherwise, they are assumed to remain unoxidised practically forever (e.g. bitumen and land-filled plastics). Depending on whether waste incineration occurs without or with energy recovery, NODU products are allocated to the source category "Waste" or "Energy". The distinction between the categories ODU and NODU is particularly relevant for the IPCC-SA but it has implications also for the IPCC-RA (see next point).
- The scope of the IPCC-RA should be redefined. While it was originally intended as a simple, top-down approach for the total national fossil-based CO_2 emissions, its scope in practical use was soon limited to CO_2 emissions from fuel combustion. This was also emphasized in recent versions of the UNFCCC's Common Reporting Format (SBSTA,

1999). On the other hand, according to certain sections in the IPCC Guidelines, part of the non-energy use is released as industrial process emission or as a result of product decomposition (Solvent and other product use; vol. 3, p. 1.25). These and further inconsistencies in the IPCC Guidelines should be removed in future revisions.[4] The NEU-CO_2 network therefore proposed in 2003 (Patel et al., 2003) to re-introduce the IPCC-RA as a validation tool for the total national fossil CO_2 emissions (exception: emissions from waste treatment without energy recovery[5]), regardless whether they originate from fuel combustion or from any other source. An important example for the latter is ODU products (see preceding point) and industrial process emissions. In 2004 and early 2005, the IPCC Guidelines were being revised (with contributions of the authors of this paper). At the time of writing this article, the majority of the experts involved seemed to advocate the use of the IPCC-RA as validation tool for CO_2 emissions from fuel combustion. Since, however, no final decision had been made at that stage, this paper takes the recommendation of the NEU-CO_2 network as a starting point (IPCC-RA as a validation tool for the total national fossil CO_2 emissions). This choice is important because the scope of the IPCC-RA has an effect on the storage fractions (the results that will be discussed in Section 5 refer to scope; however, due to lack of data, emissions from waste treatment have not been included at this stage).

- The IPCC-RA is exclusively based on energy statistics, thereby neglecting the *synthetic organic products trade*. This is not a problem for NODU products (whose emissions are accounted for in waste treatment and in energy recovery). However, it poses a problem for ODU products that lead to emissions during use. Imports (in net terms) of ODU products lead to higher CO_2 emissions within the national boundaries than balanced trade or net exports. Proper accounting requires a correction for trade in ODU products. The NEU-CO_2 team recommends to consider such a correction in national CO_2 accounts. However, this may create global underreporting of emissions if this correction is only applied by net exporting countries. This recommendation to introduce a trade correction applies

[4] In the new Common Reporting Format (SBSTA, 1999) (Table 1.A(b)), the CO_2 emissions calculated with the Reference Approach are named CO_2 emissions from fuel combustion activities. The results are compared with the CO_2 emissions from fuel combustion calculated in the IPCC-SA in Table 1.A(c). The IPCC Guidelines (IPCC/IEA/OECD/UNEP, 1997) also contain passages in which the Reference Approach is mentioned as an estimate for CO_2 emissions from fuel combustion (e.g. vol. 3, p. 1.1). However, in the calculation instruction for carbon storage, it is recognised that part of the non-energy use is emitted as CO_2 during ammonia production (industrial process emission) or as a result of product decomposition (solvent and other product use) as stated in vol. 3, p. 1.25. Thus, the emission estimate contains more than fuel combustion alone. This inconsistency in the IPCC Guidelines should be removed in future revisions. Furthermore, it is explicitly stated that waste emissions and emissions resulting from incomplete conversions are assumed to be included in the calculated storage. They are therefore excluded from the calculated emissions. The storage estimate can therefore be assumed to be an upper bound estimate (vol. 3, p. 1.26). As stated above, the storage fractions determined by Marland and Rotty (1984) exclude waste emissions from the calculated storage. The use of the Marland and Rotty fractions is therefore inconsistent with the current use in the IPCC-RA.

[5] If reported correctly in energy statistics, the combustible waste used for energy recovery in waste-to-energy facilities is reported as production of energy in the energy statistics and is therefore part of the TPES. The CO_2 emissions from energy recovery are hence considered as emissions belonging to the source category “Energy”. The accuracy of the calculated emissions depends not only on the quality of the data for combustible waste in energy statistics but also on the accuracy of the CO_2 emission factor applied (this is not trivial since combustible waste is composed of natural organic and synthetic organic compounds).

particularly to the IPCC-RA but it may also be relevant for the IPCC-SA (depending on the tier approach applied; see below).

- NODU products may lead to CO_2 emissions at the end of their useful life. As already mentioned, these emissions are either accounted for in the IPCC source category "Waste" (mainly for land filling and simple incineration) or in the source category "Energy" in the case of waste-to-energy facilities (energy recovery). In practice, it is likely that CO_2 emissions from waste incineration are overlooked due to the dispersed use, collection and waste management of synthetic organic products (e.g. lubricants, hazardous chemical waste and non-hazardous waste). Another important reason is that no internationally harmonised data are available for non-hazardous waste. Underreporting of waste management in general and waste incineration in particular, may lead to an underestimation of emissions. Emissions from the energy recovery and waste treatment of NODU products have not been studied by the NEU-CO_2 team. The basic assumption has so far been that these emissions are reported correctly in the National Communications. However, due to the risk of underreporting, it is recommended to study energy recovery and waste treatment of NODU products in more detail.
- Within the IPCC emission inventory framework, the IPCC-RA is usually applied for validation of the IPCC-SA results (except for non-Annex 1 countries which exclusively use the IPCC-RA). Some of the so-called tiered approaches represent hybrids of the IPCC-RA and the IPCC-SA. This can result in considerable methodological overlap with IPCC-RA and hence lack of independence of the two approaches. For these reasons, an independent method is required for validation. The existence of an independent validation method has become more important following the European Commission's decision to introduce CO_2 emission trading. While it is likely that any carbon trading measures will be monitored through data received directly from the enterprises involved, both the expectations and the outturns will be judged against the estimates of source category emissions used for national GHG inventories.

5. Material Flow Analysis as independent method for emission accounting

5.1. Methods

In the framework of the NEU-CO_2 project, Material Flow Analysis approaches have been developed for estimating CO_2 emissions from non-energy use. These approaches are independent from the standard IPCC approaches (RA, SA). MFA is based on materials balances. A set of mass balances describes the carbon input and output flows of individual processes. For each product, production, trade and consumption are modelled. The required production and trade data are extracted from the national statistics. Worldwide, the (petro-)chemical and the refinery sector show significant similarity with regard to the types of processes applied and their interlinkage. It is therefore possible to apply the same analytic framework to different countries, making only limited adaptations to the country studied. The NEU-CO_2 team has followed two principle lines to operationalise MFA for estimating CO_2 emissions from non-energy use. These are:

- firstly, a formalised, uniform model with a spreadsheet model called Non-Energy Use Emission Accounting Tables (NEAT; the current version is NEAT 2.0 (see Neelis et al., this issue-a));
- secondly, a variety of approaches that make larger use of country-specific studies on carbon-containing materials and emissions but that may also contain some of the elements incorporated in NEAT; this is the adequate choice when the data availability and/or the data quality does not allow to develop a formalised model such as NEAT.

The analyses for the Netherlands (Neelis et al., this issue-b), Italy (La Motta et al., this issue), Korea (Park, this issue) presented in this special issue and the analysis for Japan (Gielen and Yagita, 2002) are based on the application of the NEAT model. The study for the USA, which is also included in this special issue (Freed et al., this issue), is, on the other hand, an example of an approach making use of country-specific studies on carbon-containing materials and emissions.

The NEAT model provides results that comply with the source categories for GHG emissions as defined under the IPCC-SA:

- Within the emission category "Solvent and other product use", NEAT provides results for ODU products, i.e. for solvents.
- Within the emission category "Industrial processes", the production of ammonia, methanol, carbon black and non-ferrous metals and inorganic chemicals is taken into account.
- Within the emission category "Energy", the use of low-value by-products for raising heat in steam crackers and the use of process input to fuel ammonia, methanol and carbon black production are modelled.

CO_2 emissions from waste treatment are outside the scope of the NEAT model (Version 2.0) but should be included in future model versions. Apart from its use in the context of the IPCC-SA, the NEAT model can be used for the estimation of carbon storage as used in the IPCC-RA.

5.2. Conclusions from the country studies

In this section, we summarize the main conclusions that can be drawn from the country analyses presented in this special issue. In Table 1, we show a comparison between the NEAT results for total non-energy use, carbon storage and non-energy use emissions and the estimate according to the IPCC-RA calculation. For the NEAT results (rows 5–7), we use a net definition of non-energy use, which excludes the process input, which is directly or indirectly used as fuel (indirect use concerns the fuel-grade by-products, i.e. the "non-specs"). From the country MFAs, we can draw the following conclusions:

- The country analyses presented in this special issue show that the data required for detailed MFA are available. However, the data collection is not always easy and can require several person-weeks. The statistical data may have to be supplemented with expert estimates or with information directly provided by producers (e.g. based on interviews or publicly available capacity data).

Table 1
Comparison of NEAT model results with IPCC-RA estimates

Row		Unit	Italy, 1997	Japan, 1996	Korea, 2002	The Netherlands, 1993	The Netherlands, 1999
IPCC-RA calculation							
1	CO_2 equivalents of total fossil fuel consumption	Mt CO_2 eq.	443.1	1264.0	517.6	181.9	183.9
2	Non-energy use in the IPCC-RA	Mt CO_2 eq.	32.0	120.1[a]	98.0/68.3[b]	23.8	26.2
3	Carbon storage in the IPCC-RA	Mt CO_2 eq.	32.0	120.1	74.2/52.1[c]	15.5	16.6
4	Overall storage fraction IPCC-RA	Mt CO_2 eq.	100%	100%	76%	65%	63%
	Source		Romano et al. (2004)	GIO (2004)	Park (this issue)	Klein Goldewijk et al. (2004)	Klein Goldewijk et al. (2004)
NEAT model results							
5	Non-energy use MFA, net definition	Mt CO_2 eq.	26.8	107.0[d]	–	26.8	29.6
6	Carbon storage in MFA	Mt CO_2 eq.	20.8	84.0	61.4	22.3	23.1
7	Industrial process emissions	Mt CO_2 eq.	1.0	23.0	–	3.2	3.8
8	ODU emissions	Mt CO_2 eq.	5.0		–	1.3	2.6
9	Overall storage fraction[e]	Mt CO_2 eq.	78%	79%	–	83%	78%
	Source		La Motta et al. (this issue)	Gielen and Yagita (2002)	Park (this issue)	Neelis et al. (this issue-b)	Neelis et al. (this issue-b)

[a] According to GIO (2004, p. 3.4), all fuels used for non-energy use purposes are deducted from the emission estimate.

[b] The higher value refers to the uncorrected energy balance in which backflows and internal fuel use in steam crackers is not deducted and in which not all fuels used as feedstock are taken into account. In the lower value, these flows are deducted and the missing feedstocks (see text) have been included.

[c] Applying IPCC-RA default storage fractions to the non-energy use estimate.

[d] Total flow to petrochemical sector is 155 Mt CO_2 with 48 Mt CO_2 converted to fuels. According to a net definition, the non-energy use is therefore 107 Mt CO_2.

[e] It should be noted that the NEAT storage fractions in this row all refer to a *net* definition of non-energy use. If, in contrast, a *gross* definition is applied (including backflows and/or fuel use in steam crackers and ammonia, methanol and carbon black production), clearly *lower* storage fractions are obtained.

- The estimates for total non-energy use according to the NEAT model (row 5 in Table 1) follow a net definition and are lower (16% lower for Italy and 11% lower for Japan) or higher (13% higher for the Netherlands) than the non-energy use estimates used in the IPCC-RA (row 2 in Table 1). This proves that different system boundaries are being used for non-energy use, even though a clear identification of the system boundaries used could not always be made. Nevertheless, a number of conclusions can be drawn from the country studies. Park (this issue) showed that non-energy use in Korean energy statistics did not include some of the fuels used as feedstock and that the naphtha figure includes backflows to refineries and the part used as fuel within the steam cracking process. As a consequence of these findings, the Korean energy balance has been revised. The energy balance of the USA follows a gross definition of non-energy use, including inputs, which are recovered as fuel (Freed et al., this issue; data are not shown in Table 1). For the Netherlands, Neelis et al. (this issue-b) show that non-energy use estimates according to the Dutch energy statistics cannot directly be used for CO_2 emission accounting, partly because of the different carbon content of process inputs and outputs in the steam cracking processes, causing the non-energy use according to the energy statistics to be lower compared to the net definition applied in NEAT. Gielen and Yagita (2002) draw a similar conclusion for Japan. All these examples show the incomparability of the country data in terms of system boundaries, thus confirming the urgent need for international harmonisation of non-energy use data.
- Different interpretations of the concept of carbon storage are used in the IPCC-RA calculation of the countries studied (see row 4). Italy and Japan regard the total non-energy use as being stored, thereby excluding industrial process emissions and emissions from the use of products from the emission estimate according to the IPCC-RA. In the Netherlands, these emissions are included in the estimate, showing the unclear situation with respect to the interpretation of the IPCC-RA (Section 4).
- When a net definition of non-energy use is applied, the overall storage fraction is between 75% and 85% for all countries studied (row 8). This rather narrow range is the consequence of the similar structure (in terms of products and processes) of the chemical sector, which is very likely to hold for most other countries (countries *without* a petrochemical sector obviously represent an exception). This finding justifies, in principle, the use of default carbon storage fractions, which are influenced more or less by the country-specific conditions (e.g. the trade of petrochemical products and the relative contribution of ammonia production; see Park, this issue; Neelis et al., this issue-b).

6. Conclusions

Based on the empirical results presented (Section 5), it can be concluded that Material Flow Analysis is a suitable method for estimating, in a bottom-up approach, the CO_2 emissions from non-energy use. Various MFA approaches exist, the NEAT model is one option. Using MFA, estimates for CO_2 emissions from non-energy use can be generated that are *independent* from those derived from energy statistics data. Therefore, MFA is a suitable method to countercheck the results from the IPCC-RA and/or IPCC-SA and for the improvement of the calculation methods applied there. For example, MFA can be used to determine carbon storage fractions that are more accurate (country-specific) than the IPPC default values. The use of MFA has helped to identify inconsistencies in national emission inventories and in the IPCC guidelines with regard to calculation procedures and terminology (Section 4).

Apart from its usefulness for improving emission accounting, MFA has also proven to be a valuable tool for detecting errors in energy statistics. However, the application of MFA for this purpose must be complemented by in-depth investigations into the construction of energy statistics (in co-operation with the statistics offices and agencies involved). In combination (possibly in an iterative way), these two approaches allow to gain full insight into the differences across countries with regard to system boundaries and data processing. Confidential data often represent a bottleneck; depending on the policy of the national statistics office, this hurdle can be overcome by confidentiality agreements.

Based on the NEAT results discussed in Section 5, it can be concluded that the use of storage fractions to determine non-energy use storage makes only sense if these fractions have been determined based on a set of definitions that is consistent with the non-energy use values. It is therefore indispensable to improve the understanding of non-energy use data published in energy statistics and to continue the efforts to harmonise the definitions worldwide (see also Section 3).

According to the experience of the NEU-CO_2 team, changes in international energy statistics questionnaires (here, IEA/EUROSTAT/UNECE) do not result in prompt adaptation (harmonisation) of data in international statistics. A delay of several years is not exceptional. The harmonisation effort is important and should be pursued. In view of the time span involved, there is need for accompanying in-depth investigations in order to provide adequate information to the country statisticians. This would allow to identify the "hot spots" and those countries for which corrections are particularly urgent. To this end, it is necessary to continue improving the MFA methods (including NEAT) and to conduct studies for further countries. While the insight gained to date is bearing fruits in the ongoing revision of the IPCC Guidelines, the international harmonisation of input data (especially for non-energy use) and the consistent implementation of the new guidelines leading to fully comparable results across countries remains a challenge for the years to come.

Acknowledgements

This research was 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-CO_2). The network's homepage can be found on http://www.chem.uu.nl/nws/www/nenergy.

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