CREEA - Compiling and Refining Environmental and Economic Accounts

Report on Update EXIOPOL Emissions Database

Authors:
Jeroen Kuenen (TNO), José Acosta Fernández (WI), Arkaitz Usubiaga (WI), Dominic Wittmer (WI)

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About CREEA

The main goal of CREEA is to refine and elaborate economic and environmental accounting principles as discussed in the London Group and consolidated in the future SEEA 2012, to test them in practical data gathering, to troubleshoot and refine approaches, and show added value of having such harmonized data available via case studies. This will be done in priority areas mentioned in the call, i.e. waste and resources, water, forest and climate change / Kyoto accounting. In this, the project will include work and experiences from major previous projects focused on developing harmonized data sets for integrated economic and environmental accounting (most notably EXIOPOL, FORWAST and a series of EUROSTAT projects in Environmental Accounting). Most data gathered in CREEA will be consolidated in the form of Environmentally Extended Supply and Use tables (EE SUT) and update and expand the EXIOPOL database. In this way, CREEA will produce a global Multi-Regional EE SUT with a unique detail of 130 sectors and products, 30 emissions, 80 resources, and 43 countries plus a rest of world. A unique contribution of CREEA is that also SUT in physical terms will be created. Partners are:

1. Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek (TNO), Netherlands (co-ordinator)
2. JRC -Joint Research Centre- European Commission (DG JRC IPTS), Belgium /Spain
3. Universiteit Leiden (Unileiden), Netherlands
4. Centraal Bureau voor de Statistiek (CBS), Netherlands
5. Norges Teknisk-Naturvitenskapelige Universitet (NTNU), Norway
6. Statistiska Centralbyran (SCB), Sweden
7. Universiteit Twente (TU Twente), Netherlands
8. Eidgenössische Technische Hochschule Zürich (ETH) Switzerland
9. 2.-0 LCA Consultants Aps (2.-0 LCA), Denmark
10. Wuppertal Institut Fur Klima, Umwelt, Energie Gmbh. (WI), Germany
11. SERI - Nachhaltigkeitsforschungs Und –Kommunikations Gmbh (SERI) Austria
12. European Forest Institute (EFI), Finland / Spain

For more information contact the co-ordinator at: arnold.tukker@tno.nl

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Executive Summary

One of the important inputs to the EXIOBASE system is information on the environmental pressures related to climate change and air pollution issues, i.e. energy supply/use, land use/land use change and emissions to air. This report describes the applied approaches and calculation procedures for compiling energy accounts, and air emissions accounts. Both resulting datasets are to be used in the EXIOBASE 2.0 system.

Energy and combustion related air emission accounts are generated following the accounting rules described in the SEEA. The calculations are based on the energy IEA dataset. Due to the basic energy data follow the territory principle and the physical energy accounts – as in general National and Environmental Accounts – follow the resident principle, the first step is the adjustment of the IEA energy balances using auxiliary datasets to account the energy use differences between the territory and resident principles. That allows recording all energy flows associated with activities of resident economic units regardless where these activities actually take place geographically. The most important of these adjustments refers to the energy used by the economic units for their transport activities.

Meantime, emission factors for greenhouse gases and air pollutants are calculated based on the best available guidance for estimating emissions of both air pollutants and greenhouse gases at country level. These methodologies also form the basis for the UNFCCC and CLRTAP official emissions. The methods are applied for each sector and each country on the global level, resulting in a global emission dataset. This dataset is compared to the emissions reported officially according to the UNFCCC and CLRTAP guidelines to ensure good data quality and verify the total emissions. These emission factors, which are calculated by dividing emissions and corresponding fuel use, are used for the calculation of the total emissions.

A complicated but crucial final step concerns the breakdown of the previously generated, but still highly aggregated, energy accounts and combustion related emissions. These, are first calculated in the format of the IEA energy balances (but already according to the residence principle), have to be disaggregated to match the EXIOBASE 2.0 industry and product classifications. For that a general allocation/breakdown approach was developed and used for each country. The application of this allocation procedure allows the generation of the energy accounts (i.e. Physical Energy Flow Accounts), and of the combustion air emissions accounts, both core environmental extensions in the EXIOBASE 2.0 system.

For the non combustion air emission accounts, emissions are calculated similarly to the emissions from combustion by using standard and accepted methodologies used by countries to make their emission inventories. Similarly, emission factors are taken from the corresponding guidance documents and applied to selected activity data for each sector. The resulting emissions are used for comparisons with the official UNFCCC and CLRTAP emissions, as well as to other estimates. Finally, emission factors for each source are related to a distinct product in the EXIOBASE 2.0 classification, to use the emission factors in the EXIOBASE 2.0 system.

This all in all results in a state-of-the-art dataset on Energy Accounts and Air Emission Accounts to be fed into the EXIOBASE 2.0 system, with several improvements implemented compared to the energy and air emission accounts that were created for the EXIOBASE 1.0 system.

1 Introduction

The project CREEA aims on refining and elaborating economic and environmental accounting principles as discussed in the London Group and consolidated in the future SEEA 2012. These refined accounting principles are tested by practical data collection in order ensure their applicability (work packages 3-7). Further, added value of having such harmonised data available will be shown via case studies in the three areas *water*, *resources and waste*, and *climate change, land use and forestry* (work package 8). For this purpose, CREEA builds on work and experiences from major previous projects, which developed harmonised data sets for integrated economic and environmental accounting, notably the CEC FP6 projects EXIOPOL and FORWAST, but also a series of EUROSTAT projects on Environmental Accounting.

Most of the data gathered in CREEA is consolidated in the form of Environmentally Extended Supply and Use tables (EE SUT). This data is used to update and to expand the current EXIOPOL database. In this way, CREEA will produce a global Multi-Regional EE SUT with a unique detail of:

- 163 sectors,
- 200 products,
- 30 emissions,
- 80 resources, and
- 43 countries plus 5 rest of world groups.

Within CREEA, the work package "Climate Change Issues" (WP6) is responsible for updating and expanding the environmental pressures data related to climate change issues, i.e. data on emissions to air, on energy, land use change) to the other work packages (more specifically, WP7) for integration into the EXIOBASE system; EXIOBASE is the database that contains the results from the project EXIOPOL and that is planned to be continuously advanced over time. A unique contribution of CREEA is that also SUT in physical terms will be created, i.e. so-called physical supply and use tables (PSUT).

The work package "Climate Change Issues" consists of four specific tasks:

- T6.1 Energy and related Air emission accounts: Update of EXIOBASE;
- T6.2 Land use cover change accounts;
- T6.3 Emission allowances and emission trading accounts;
- T6.4 Inclusion of other economic response methods in SEEA

While task 6.1 and task 6.2 deliver energy and air emission accounts and land use cover change accounts, respectively, that feed into the EXIOBASE 2.0 system (WP7), task 6.3 and task 6.4 are striving for an overview of what data would be available and to what extent it is possible to apply such data reasonably.

The main aim of task 6.1 is to update and to upgrade energy and emission accounts that have been developed within the project EXIOPOL; the updated and upgraded data sets are used for integration into EXIOBASE 2.0 (input for WP7). The upgrade includes a refining of the bridging procedure between United Nations Framework Convention on Climate Change (UNFCCC) inventories and EE accounting systems, particularly for transport. The other tasks support specific methodological improvements whose implementation into EXIOBASE cannot be achieved within the scope of this work package and/or is not planned, or that address selected issues conceptually.

Task 6.2 addresses the land-related potential of carbon storage and release by accounting agricultural and forestry areas, and how such data could fit into integrated environmental and economic accounting systems like the EXIOBASE. The estimation of carbon stocks, emissions and removals that are associated with so-called *Land Use, Land-Use Change and Forestry activities* (LULUCF) require adequate areal data. For this purpose, Land Use, Land-Use Change (LULUC) Kyoto (national inventory) reports are processed so that they can be included into environmental accounts. The reporting by the UNFCCC covers data on the diverse land use categories and on the related emissions and releases of greenhouse gases, but also those caused by biomass burning and wild fires. In order to cover all EXIOBASE countries, alternative processes are used for countries without LULUC data reporting[1], e.g. the revision of alternative land use data bases such as the European CORINE land cover databases of EEA, or qualified estimates. Finally, the land use data are allocated to the CREEA industries. Land use data was derived separately for cropland by crop type, for permanent meadows and pastures, and for forest area, from detailed data from the *Statistics Division of the Food and Agriculture Organization of the United Nations* (FAOSTAT) and a multitude of further data sources. Regarding the built up and related land, data from the Greenhouse Gases (GHG) Inventory Submissions under the UNFCCC were taken as basis and amended by other data sets such as the CORINE land cover data, in order to be able to cover all CREEA countries comprehensively. Like the data sets of task 6.1, the data sets developed by task 6.2 are used for integration into EXIOBASE (input for WP7) along with special reports on land use data and land use change data, respectively.

Task 6.3 develops and applies methods to include the so-called flexible mechanisms (according to the Kyoto Protocol) into the SEEA accounting system, i.e. data on costs and investments due to *emission trading, joint implementation* and the *clean development mechanism*. This activity builds on related achievements of the UNSD SEEA development process, namely on standard tables that have been agreed on for the reporting of the physical and monetary flows involved in these mechanisms. A promising contribution with regard to data gathering and reporting seems to be the generalisation of pilot studies of Denmark. The methodology to be developed for the Kyoto issues and mechanisms will allow for quantitatively express economic intensities related to the flexible mechanisms, including the integration of information on *clean development* mechanism projects as inventoried by UNFCCC databases into the accounting system.

Task 6.4 aims to assess the possibilities to elaborate other Kyoto related economic issues and how to integrate them into the framework of economic and environmental accounting. Firstly, Kyoto related economic responses shall be incorporated as environmental accounts into SEEA. Obviously, environmentally related taxes and subsidies influence directly the price levels of energy and energy carriers, respectively. In this way, they generally also influence the level of energy use, and the preferences regarding the type of energy (type of fuel). Consequently, the indirect influence on greenhouse gas emissions is significant. For this purpose, environmentally related taxes and subsidies on energy (also called transfers in the accounting world) shall be recorded

[1] The countries for which UNFCCC reports data are called Annex I countries.

and an international data base be built up that illustrates the differences in tax and subsidy schemes over the world. The aim is a set of internationally harmonised data, in particular for the EU, that shows a suited resolution of taxes and subsidies, respectively, e.g. into split up into VAT, fuel taxes, other taxes. The most suitable accounting method will be elaborated, considering also practical data availability, and the method will be tested for a few European countries. Secondly, the new SEEA manual for the areas of Environmental Goods and Services will be tested by data collection based on first experiences in Sweden and The Netherlands, and conclusions will be used to elaborate further this manual. Thirdly, data gathering on adaption and mitigation costs is a new area in environmental accounting, without formal definitions or experience in data gathering. Data on environmental protection expenditure will be gathered to support the formation of definitions and classifications needed in this area.

This report describes the procedures of task 6.1 and provides an overview on its achievements. The results of the tasks 6.2, 6.3 and 6.4 are each described in individual reports (D6.2, D6.3, D6.4).

Interlinkage with other work packages within CREEA

The final results of this work package are physical supply and use tables for Energy (P-SUT), and for air emissions. Further, emission factors (kg emission per TJ energy product) are provided per sector, country, and emission type (emission coefficient tables) as input for automated disaggregation routines within WP7.

Land use data are used directly by WP7 feeding in as environmental extensions data set.

Overview

This report describes how the upgrade and update of energy and air emission accounts was performed within task 6.1. It provides general and specific methodological background, illustrates the development procedures of these accounts and discusses the results achieved:

- chapter 2 presents the statistical framework for accounting of energy and air emissions, and the methodology applied to calculate the energy and emissions within this framework;
- chapter 3 describes in detail the process to generate energy accounts
- chapter 4 describes in detail how the diverse emission accounts are calculate. These include the air emissions that result from the combustion of energy, and from other sources than the combustion of energy, such as industrial processes, agriculture and waste treatment. Methodologically, there is a strong link of the emission factors from both agriculture and waste treatment to WP4;
- chapter 5 discusses the differences between the emissions as they are used in the national accounting systems, and how they are calculated under other international reporting instruments, such as the Kyoto Protocol;
- chapter 6 discusses the results and places them into the appropriate context.

2 "From Statistics towards Accounts"

2.1 Statistical Framework

Statistics is often considered as a mathematical body of science that comprises the collection, analysis, interpretation or explanation, and presentation of data. "Official statistics" are gathered by or on behalf of statistical offices or other official departments or agencies. They perceive generally an elevated degree of trust due to the application of statistical standards.

In environmental science and policy, statistics are often used to describe or summarise environmental measures like environmental pressures, the state of the environment, environmental impacts, environmental responses, or environmental drivers. Beside environmental statistics, also environmental accounts provide such information. The main difference between traditional environmental statistics and the more recently developed environmental accounts are related to the system boundaries. For example, the inventories produced for the reporting of air emissions to the UNFCCC are based on the geographic boarders of a country while air emission accounts by definition use the boundary of a specific economy. Accordingly, environmental statistics and environmental accounts are connected with each other, however in a non-trivial way. While environmental statistics exist with regard to almost any environmental issue, environmental accounts are more labourious and thus exist only for selected areas, for example air emission accounts, energy accounts, land use accounts, material flow accounts, water accounts, and environmental expenditure accounts.

The following chapters picture how the environmental accounts are related to environmental statistics, and how they can principally be derived from them. An introduction into the System of National Accounts (SNA) as the authoritative global monetary accounting framework is provided (chapter 2.1.1), including an outline of the SNA history and explanations on the purpose of the SNA and of industrial classifications. Then, the System of Environmental-Economic Accounting (SEEA), the family of SEEA accounts, and their linkage to the SNA are explained (chapter 2.1.2). Finally, the method of Environmentally Extended Input-Output Analysis (EE-IOA) is introduced, whereat the purpose and applicability of environmental accounts and physical supply and use tables, respectively, are introduced.

2.1.1 Introduction into the System of National Accounts Framework

General Overview

The System of National Accounts[2] is an international standard system of national accounts. The first international standard was published in 1953 and since then it was

[2] The full name is United Nations System of National Accounts, sometimes abbreviated (UNSNA)

successively enhanced (revisions in 1968, 1993, 2008[3]); the SNA is permanently advanced according to upcoming requirements and improvements in (statistical) performance, namely on conceptual and measurement issues. The driving institution that supports and reports the SNA developments (including SNA revisions), but also publishes the results, is the United Nations Statistics Division (UNSD).

The SNA provides integrated system accounts, as complete as possible, that allows comparisons between countries of all significant economic activities. The suggestion is that individual countries use the SNA as a guide in constructing their own national accounting systems, thus promoting a maximum of international comparability. It should be noted that several countries do not follow strictly the SNA within their national accounting systems due to national requirements and conditions, e.g. USA and PR China.

The data published in the United Nations Yearbook "National Accounts Statistics: Main Aggregates and Detailed Tables" comprise annual and quarterly economic and financial data on gross product, investment, capital transactions, government expenditure and foreign trade. The data are provided by the UN member countries and given in the corresponding national currencies.

The SNA includes a set of nine standard accounts that are commonly delivered by the member states, including production accounts, primary distribution of income accounts, transfers accounts, household expenditure accounts, capital accounts[4]; these standard accounts commonly comprise diverse annexes and sub-accounts.

The SNA is a most widely accepted framework, nevertheless, the comprehensiveness and certainly the quality of the data differ between countries significantly. Main reasons for these differences comprise the efforts that are made by the national statistical offices (related to the societal esteem for applying statistics in general), the national societal conditions for measuring the economic activities, the degree of autonomy of the statistical offices performing the data surveys and analyses, and external incentives like membership in supranational organisations that require and facilitate related statistics.

Scope of SNA

The SNA comprises an internationally agreed standard set of recommendations on how to compile measures of economic activity in accordance with strict accounting conventions based on economic principles (SNA 2008). The recommendations are expressed in terms of a set of concepts, definitions, classifications and accounting rules that comprise the internationally agreed standard for measuring indicators of economic performance. The accounting framework of the SNA allows economic data to be compiled and presented in a format that is designed for purposes of economic analysis, decision-making and

[3] Full text of the 2008 SNA revision is available at the Intersecretariat Working Group on National Accounts website, see: http://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf

[4] The accounts considered as core accounts are: the production account (components of the gross output), the primary distribution of income account (those generated by production), the transfers redistribution account (including social spending), the household expenditure account, the capital account, the domestic financial transactions account (i.e. flow of funds), the changes in asset values account, the assets and liabilities account (balance sheet), and the external transactions account (balance of payments). While production accounts and primary distribution of income accounts are provided by most of the member countries, others are hardly reported and/or are still under development.

policymaking. The accounts are organised according to economic principles and the perceptions about the working of economies, thus, they provide a comprehensive and detailed record of the complex economic activities taking generally place within an economy. Accordingly, the framework of the SNA provides accounts that are comprehensive in covering the diverse activities within an economy, consistent due to the use of the same accounting rules throughout the economy, and integrated (SNA 2008). Further, an external account shows the links of the (national) economies with the corresponding rest of the world.

In order to be able to analyse the economic interaction between the different sectors of the economy, these sectors need to be accounted for individually. The classification applied is the International Standard Industrial Classification of All Economic Activities Revision 4 (ISIC, Rev.4). Production[5] units are grouped according to their principal activity into 88 industries that correlate to the following list of 21 top level industry codes (A-U). Each top level industry (section) is constituted by one to many of the 88 ISIC industries (division), which are themselves constituted by more homogeneous groups; for a full list of the ISIC, Rev. 4, on the level of industries (division). The detailed description of the structure is provided by the UNSD statistical paper of the same name (UNSD 2008).

Table 1: International Standard Industrial Classification of All Economic Activities, Revision 4: Sections A-U

A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households as employers; undifferentiated goods
U	Activities of extraterritorial organizations and bodies

[5] Goods and Services are the result of production, accordingly, the term products covers both goods and services.

The ISIC is the international classification that has been developed by the United Nations and successively was implemented by diverse national and supranational classification systems. The EU like other countries have taken over the ISIC classification by the Statistical Classification of Economic Activities in the European Community (NACE). NACE is applied not only by the EU member states, but also by the candidate countries and several other non-EU countries.

As ISIC is not designed to measure product data at detailed level, a separate classification exists that focuses on products, namely, the Central Product Classification (CPC). The most recent version of the CPC that is used also by the SNA to study transactions in goods and services is the CPC Version 2 (UNSD 2008). Correspondence tables exist between activities and products, i.e. between ISIC and CPC[6].

2.1.2 Environmental-Economic Accounting

Environmental-Economic Accounting on National and European Level

Environmental-economic accounting aims to link environmental statistics to economic statistics and thus to broaden and deepen the potential for integrated analysis. Depending on the level of the economy in focus, environmental accounts (EA) can be developed at the EU, national, regional, but also on sector and industry level. In basic terms, environmental-economic accounting allows to measure what impacts the economy has on the environment (e.g. pollution) and how the environment contributes to the economy (e.g. use of raw materials) by using the accounting framework and concepts of the national accounts (as defined by the SNA). It thus helps policymakers to set priorities for action by indicating e.g. where it is most cost-efficient to act with targeted measures, or what policy measures could contribute to improve environmental conditions.

Although based on the same basic accounting framework of national accounts, EA on different topics are structured by several modules, each focusing on a specific area of environmental concern or issue, respectively. National accounting schemes develop and run environmental accounts according to national priorities. Eurostat, the statistical office of the European Union that reflects and guides efforts of national statistical offices in the accounting area, is currently working on three broad sets of modules (Eurostat 2013):

- Environmental accounts expressed in physical terms (see below),
- Environmental accounts expressed in monetary terms (environmental taxes, environmental subsidies, environmental protection expenditure, resource use and management expenditure, environmental goods and services sector),
- Asset accounts (forestry, natural resource accounts oil/gas)

The physical environmental accounts focus on air emissions accounts incl. greenhouse gases, economy-wide material flow accounts, energy accounts, and water accounts.

In most cases, primary data from environmental statistics apply classifications and accounting rules that are not compatible with the SNA, so environmental statistics generally cannot provide data that can be used for environmental-economic accounting. Thus, primary environmental data, such as emission inventories or energy statistics,

[6] See http://unstats.un.org/unsd/cr/registry/regdnld.asp?Lg=1

need adjustment to the classifications and accounting principles of national accounts beforehand. This work step to generate environmental accounts from environmental statistics is complex, but inevitable because environmental accounts do not show independent acquisition of primary data, but basically builds on existing data such as environmental or energy statistics. At the European level Eurostat supports the National Statistical Offices (NSOs) in this work (EEA 2013).

System of Environmental-Economic Accounting

Beside the development of environmental accounts on national and European level, the United Nations drives the development and implementation of harmonised environmental accounting globally by a comprehensive conceptual framework. The System of Environmental-Economic Accounting (SEEA) is a multipurpose, conceptual framework that enables to describe the interactions between the economy and the environment, and the stocks and changes in stocks of environmental assets. It thus builds the basis to compile statistics linking environmental statistics to economic statistics, furthermore, the development of aggregates and indicators across a broad spectrum of environmental and economic issues (EC *et al.* 2012).

The SEEA is conceptualised as a satellite system to the SNA; accordingly, the definitions, guidelines, accounting concepts, structures, rules and practical approaches of the SNA are systematically applied to the SEEA. Consequently, the SEEA is like the SNA designed to be applicable across all countries independent from their level of economic and statistical structure and development, and the composition of their environment. This approach enables environmental statistics to be compared to economic statistics as the system boundaries are basically identical (after some processing of the input statistics). The strength of SEEA is the potential to analyse statistics on the economy and the environment at the same time, and further on to show different patterns of sustainability for production and consumption. Particular examples for applications are the assessment of trends in the use and availability of natural resources, the extent of emissions and discharges to the environment resulting from economic activities, and the degree of economic activity undertaken for environmental purposes (EC *et al.* 2012).

The SEEA consists of the *SEEA Central Framework*, the section of *Experimental Ecosystem Accounting* and of *Applications and Extensions*. After a global consultation, the Central Framework was adopted in 2012 by the UN Statistical Commission as the first international standard for environmental-economic accounting[7], and as such it provides the interdisciplinary foundation for SEEA topic specific approaches. The Central Framework organises systematically a diversity of environmental and economic information addressing stocks and flows, which are relevant to the analysis of environmental and economic issues. By doing so, the SEEA Central Framework affiliates information on water, minerals, energy, timber, fish, soil, land and ecosystems, pollution and waste, production, consumption and accumulation. Each of these areas has specific detailed measurement approaches that are integrated in the SEEA Central Framework within a single measurement system to allow a more holistic view (EC *et al.* 2012).

[7] The White Cover version of the *SEEA Central Framework* was published in May 2012, while the revisions of the *Experimental Ecosystem Accounting* and of *Applications and Extensions* sections are still ongoing.

The above-mentioned topic specific approaches are itself multi-disciplinary, multi-purpose, conceptual frameworks for organising topic-related statistical information. They are fully consistent with the overarching SEEA, but in addition provide topical details and prepare bridging terminological and conceptual gaps between the accounting community and the community of (statistical) topical experts. Topics that have already been addressed substantially are energy, water, fisheries, agriculture, and land and ecosystems. Energy and water, respectively, have been identified by the UNSD as priority areas for the implementation of the SEEA. Accordingly, sub-systems of the SEEA are currently developed in these topical areas in order to provide compilers and analysts with agreed concepts, definitions, classifications, tables, and accounts for energy and energy-related air emission accounts, namely SEEA-Energy and SEEA-Water[8], while also focus is put on advancements in the area of land and ecosystems that are going to be incorporated in the Experimental Ecosystem Accounting section of the SEEA 2008.

Within the context of the CREEA task "Energy and related Air emission accounts" (task 6.1), energy and emission accounts were developed that follow the SEEA-Energy. The SEEA-Energy has been drafted by the UN Statistics Division and is currently still under global consultation. SEEA-Energy (SEEA-E) elaborates guidance on accounting and by doing so builds on the International Recommendations for Energy Statistics (IRES)[9]..

Outcomes from Environmental-Economic Accounting

Environmental-economic accounting includes the compilation of physical supply and use tables, functional accounts, and asset accounts for natural resources. These list for example, the amounts of pollution produced by different industries, which may in turn be compared with economic accounts, e.g. on employment or the value of output produced by these industries.

Environmental accounts can in particular be used to analyse the impact of current production and consumption patterns on natural resources and the environment, e.g. by reduction of the resource use, or by indicators such as energy and carbon intensity of industries or products; it can further be used to analyse the actual and foreseeable effects on the environment induced by economic measures, such as environmental taxes, subsidies, environmental expenditures, or even environmental investment by industries (Eurostat 2013). It should be stressed that the development of applications is currently under development, and the projects EXIOPOL[10] and CREEA with its case studies (work package 8) is expected to contributes here.

[8] Part I of SEEA-Water addresses internationally agreed concepts, definitions, classifications, standard tables and accounts covering the framework, physical and hybrid supply and use tables and asset accounts; it was adopted as an interim international statistical standard by the UN Statistical Commission in 2007. Part II that has not been adopted so far due to missing international acceptance compiles those accounts that are considered to be of high policy relevance.

[9] IRES provides a set of international recommendations for the collection, compilation and dissemination of energy statistics and thus contributes to harmonise globally energy statistics. It was developed by the UN Statistics Division in cooperation with the Oslo Group on Energy Statistics and the Intersecretariat Working Group on Energy Statistics. IRES was adopted by the UN Statistical Commission in 2011.

[10] With regard to the development of the environmentally extended input-output that is further developed in CREEA, the FP6 project EXIOPOL with its database EXIOBASE 1.0 has served as predecessor of the database EXIOBASE 2.0 that is developed by CREEA (cf. http://www.feem-project.net/exiopol).

2.1.3 Environmentally Extended Input-Output Analysis

Environmental accounts can be combined with input-output tables to extend the potential types of data analyses. Such sets of data, (monetary) input-output tables extended by environmental accounts, are termed *Environmentally-Extended Input-Output Table (EE-IOT)*[11]*.* EE-IOT can be used for different kinds of analyses: Firstly, in their basic format they show directly what industries generate environmental pressures, e.g. emissions, waste, direct resource use, and also economic figures per industry, e.g. economic output for domestic final consumption and export; there are several possibilities how these data can be used for analyses directly or after additional data processing, for example the quotient of environmental pressure per monetary unit of output is frequently discussed as the (sectoral) environmental intensity (EEA 2013). Secondly, EE-IOT can be used – once they are transferred to symmetric IOT – for environmentally extended input-output analyses (EE-IOA), a powerful economic method with a variety of applications, for example the question what products, which are consumed, cause what emissions – along the supply chain. Thirdly, EE-IOTs usually form the core of environmental-economic models and thus are an essential part to allow forecasting environmental effects related to economic changes.

While the first type of analyses deal with the industries that *produce* the goods and services, the second type of analyses allow assessing the environmental pressures in relation to the final use categories that finally *consume* the goods and services. In this respect, these approaches related to these two types of analyses are commonly termed "production perspective" and "consumption perspective", respectively (EEA 2013). Details on the development and use of EE-IOA are provided by the recent study in integrated environmental and economic analysis, EEA Technical report 2/2013 (EEA 2013).

EE-IOA can be used for a multitude of analyses, including the estimation of environmental pressures and external costs of different economic sector activities, final consumption activities and resource consumption. It has been shown that EE-IOA can support the process of identifying focus points for product policies like sustainable consumption and production (SCP) policy, and further to develop policy programs like the Roadmap to a Resource Efficient Europe (EEA 2013). Applied on national EE-IOTs, EE-IOA provides an overview of which industries are key contributors to (national) environmental pressures, and an in-depth understanding of what the consumption of which products indirectly causes significant environmental pressures. Thus, policy actions can be streamlined and focused on those areas where they show the most efficient application (EEA 2013).

An enhancement of the EE-SUTs or EE-IOTs is the generation of physical supply and use tables (PSUT), or in the case of energy: energy supply and use tables (ESUT). In contrast to environmental extensions, the information on physical flows is there not provided by simple add-on accounts (environmental accounts), i.e. as row vectors in the EE-IOT, but as full physical layers in analogy to the monetary layer (MSUT).

[11] At the national level, EE-IOTs are often termed NAMEA. The term NAMEA is derived as composition of the acronyms of the two constituting blocks of data, i.e. National Accounting Matrices (NAM) and the Environmental Accounts (EA) expressed in physical accounts.

2.2 Energy and Air Emissions within SEEA

The (final) aim of CREEA task 6.1 "Energy and related air emission accounts" is the estimation of the energy supply and use, and air emissions according to the accounting rules of SEEA. As the key share of many air emissions is directly caused by the use (combustion) of energy carriers, the calculation of combustion related air emission accounts is based on the energy accounts. So far, there is no SEEA chapter dealing explicitly with (air) emissions, but the SEEA-Energy has received much attention and is well-developed (cf. chapter 2.1.2). This means that the transition from environmental statistics as reported by statistical offices to environmental accounts is most effectively taken for the energy, rather than for the air emissions, because there the methodological basis for this transition has been developed further, leaving fewer issues ambiguous.

Beside combustion related air emissions, the non-combustion related air emissions and the air emissions from non-energy uses are also calculated in Task 6.1, thereby covering all the major air emissions forms.

2.2.1 Territory versus Residence Principle

As described in section 2.1.2, environmental statistics and environmental accounts differ with regard to their purposes, and thus as well their accounting rules. With regard to air emissions (AE) of a specific country, the inventories generated for the reporting of air emissions to the UNFCCC refer to the geographical external border of the country: As the system border is here defined by the "territory" of the country, this conceptual approach is called "territory principle". In contrast, air emission accounts that apply the SEEA definition refer to the functional border of the country's economy: As the system border is here defined by the "residence" of the polluter of the air, this conceptual approach is called "residence principle". The air emissions of these two principles differ considerably in certain cases.

A significant systematic difference between the territory principle and the residence principle are those air emissions that are caused by residents (i.e. companies, citizens, governments) with an emission location outside the country of residence. Accordingly, such terms can lead to net increases or decreases of the air emissions in the AE accounts compared to the AE statistics. These differences can be significant not only on the country or regional level, but also at global level, since country totals in emission inventories do not include the emissions related to international marine and aviation bunkers, although they are reported as a separate item (UNFCCC 2013).

In practical terms, the main difference in emission figures between the two conceptual approaches demonstrated to be reasoned principally by the emissions of the transport activities of industries and households, as (almost) all emissions from other industries are for the very most part covered as well by the environmental statistics. This different may lead to very different results, especially in countries with important international transport activity. Transport of ships and planes tends to be used for medium to long distances, so for many international transports they are the preferred choice of transport (almost all intercontinental transports are addressed by these two kinds of transports).

Therefore, in order to calculate the emission accounts and energy accounts, respectively, from environmental statistics, correction terms on marine transport and international air transport with sufficient detail are crucial.

Further, road transport is also a relevant category to take into account when bridging from the territory to the residence principle. While the emission inventories account for the road transport activity occurring within the geographical borders of a country, the emission inventories have to subtract the emissions related to foreign households (tourists) and foreign freight truck operators. The same way, they have to add the emissions related to resident tourists abroad and resident road freight transport operators.

In other words, this means that emissions from international transport by ships, airplanes, and trucks are allocated to their country of origin, even if the emissions occur outside the external borders of the country of residence. Moreover, the air emissions reported according to the UNFCCC inventories show all emissions caused by transport by a dedicated sector "transport", thus extra estimates are required to allocate transport emissions according to the share of households and the different industries. Consequently, as the estimation of air emission accounts is based on energy accounts, the precision of this transition from energy statistics to energy accounts is of crucial importance, and certainly not trivial if done with sufficient detail.

2.2.2 Usefulness and Limitations of UNFCCC for Environmental Accounting

Under the UNFCCC, the Kyoto Protocol is a binding obligation for reducing emissions of greenhouse gases, which has been accepted by most industrialised countries. To check if the Parties to the Convention achieve their promised reductions, an annual reporting of the greenhouse gas emissions by country is obliged.

Reporting of emissions under the UNFCCC starts from the territory principle: All emissions that are emitted by certain activity within the geographical borders of country have to be reported.

The annual reporting of emissions by Parties to the Convention is the necessary piece of information needed to check whether the Party has achieved its targets, for instance the emission reduction targets as prescribed by the Kyoto Protocol. If a country fails to meets its targets, this could have serious consequences such as large fines.

To ensure a level playing field on the one hand, and taking into account all sources and science on the other hand, a set of Guidelines and guidance materials have been supplied by UNFCCC (IPCC, 1996; IPCC, 2006) and CLRTAP (TFEIP, 2009). The guidance prescribes how to set up your emission inventory, which methodologies to use, which sources to take into account and which not, etc. This ensures that the inventories between countries are as comparable and transparent as possible.

On an annual basis, reported emissions by countries are checked against the rules, to ensure that countries do not cheat.

The countries that ratified the Kyoto Protocol and have to report their emissions on an annual basis, are most EU countries and other industrialised countries. Upcoming economies like China, India and Brazil currently do not have the obligation to report.

Country reported data are published online in the reporting format used. These data form the backbone of many environmental analyses, for instance regarding new policy development, ex ante or ex post policy evaluation.

For air pollutants, also spatially disaggregated emissions in a prescribed grid (x,y) are required for reporting. Spatially distributed emissions form the key input for air quality modelling and environmental impact assessments.

For the purpose of environmental accounting however, a number of problems exist, which is why these data cannot be used directly.

1. The territory principle of the data (the emission belongs to the country where the activity occurs, independent of where the emitter is originating from).
2. The sectoral (industry) disaggregation and product disaggregation are insufficient to feed an environmental accounting system.
3. Only major industrialised countries officially report their emissions to the international Conventions. For developing countries, including major upcoming economies such as China and India, such dataset is not available.

Because of these limitations to the official reported data, within this project (and also the earlier EXIOPOL project) we apply an emission model to calculate the air emissions, in a consistent and transparent way for all industries, products and regions around the world. This emission model is described in chapter 4.

2.2.3 Calculation of Energy and Air Emission Accounts

2.2.3.1 Structure and coverage of Energy Accounts

The energy accounts cover the specifications given in the SEEA. The accounts are organised in supply and use tables that represent the energy from natural inputs, the energy products and the energy residuals. The energy products are further disaggregated according to their purpose (transformation, end use, own end use and end use for non-energy purposes.

The supply is given as gross supply, while the use is given as gross use and emission relevant energy use[12]. A simplified representation of the overall structure is shown in Table 7 and Table 8 in Chapter 3.1.2.

[12] In order to avoid introducing new terminology, the report uses the term “emission relevant energy use” to refer to the energy use related to combustion. The combustion related energy use is needed to calculate the air emissions resulting from the combustion of energy products.

2.2.3.2 Structure and coverage of Air Emission Accounts

The air emission accounts include in principle all relevant air emissions from both greenhouse gases (impact on global warming) and air pollutants (impacts on health and ecosystems). The list of substances included is given in Table 2.

Table 2: Overview of substances for which air emissions have been calculated

Group	Substances
Greenhouse gases	CO_2, CH_4, N_2O, SF_6, PFCs, HFCs
Main air pollutants	NO_x, SO_x, NMVOC, CO, NH_3
Particulate matter	TSP, PM_{10}, $PM_{2.5}$
Heavy metals	As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
Polycyclic Aromatic Hydrocarbons (PAH)	Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total PAHs
Other persistent organic pollutants	HCB, PCB, Dioxins and Furans

For each substance included, and for each country considered in CREEA, an air emission account is created similar to the template in Table 3. This means total a set of A x B air emission accounts like the one in Table 3.

Table 3: Structure of the air emission accounts

Air Emissions (kg) Country A Substance B	Industry 1	Industry 2	...	Industry j	...	Industry n	Private Households
Product 1							
Product 2							
Product 3							
....							
Product i							
....							
Product m							

A value for the emission to air is given for each country A and each substance B, for industry *j* and product *i*. The size of the matrix is equal to the total number of CREEA products *m* (rows) considered and the total number of CREEA industries *n* plus the households (columns). A matrix like this is developed for each country *A* and for each substance *B*, for the year 2007 as defined the base year for the CREEA project.

3 Energy Accounts

3.1 Energy Supply and Use Tables

In task 6.1, energy supply and use tables are generated as core of the energy accounts. In order to do so, the IEA extended energy balances (that are based on the territory principle) have to be bridged into the residence principle, which is in line with the SNA and SEEA accounting rules.

Broadly speaking, the bridging process requires building several transport models (marine bunkers, aviation bunkers, road transport and fishing[13]), which will be used to transform the energy balances into energy accounts. Further, the energy supply and use flows given in the IEA energy balances and adjusted according to the resident principle have to be assigned to the CREEA industries and final use categories by means of complex allocation and breakdown procedures, while maintaining the system balanced by energy product.

Last, the obtained energy supply and use matrices balanced by energy product have to be aligned with the SEEA framework by adequately recording the energy natural inputs (e.g. solar energy), energy products (e.g. coal) and energy residuals (e.g. distribution losses). This implies some additional calculations and recording of the energy flows in a way each single cell value into the already generated supply and use matrices is represented in the "appropriate" place in the Physical Supply Table and/ or Physical Use Table[14]. A more detailed explanation is given in chapter 3.1.2.

3.1.1 Linking Air Emission Accounts and Energy Supply and Use Tables

Air emissions, as calculated in CREEA, can be split into (i) air emissions related to the combustion of energy products, (ii) the non-combustion of energy products and (iii) to the non–energy products. The former type of emissions (i) is calculated by multiplying the emission relevant energy use of an energy products and its corresponding emission factor. This approach is valid for all the air emissions resulting from the combustion of energy products. Chapter 3.1.2 describes in detail how the emission relevant energy uses are calculated according to the SEEA accounting rules.

In contrast, the second and the third type of air emissions (ii, iii) do not depend on the energetic use of the product as such, and are therefore calculated in a different manner as explained in chapter 4.

[13] The IEA item "Fishing" includes fuels used for inland, coastal and deep-sea fishing. Fishing covers fuels delivered to ships of all flags that have refuelled in the country (including international fishing) as well as energy used in the fishing industry [ISIC Rev. 4 Division 03] (IEA 2011). Thus, this item also has to be bridged to the residence principle to account for the energy products used by the domestic fishing vessels.

[14] Eurostat recommends doing this step by step for each row of the energy balance beginning with the energy product flows and continuing with the natural energy inputs and energy residual flows (Eurostat 2011).

The process of obtaining the specific combustion-related emission factors for each pollutant and country is explained in Chapter 4.1.

3.1.2 Estimating Energy Supply and Use Tables

This section describes the process of generating E-SUTs (according to the SEEA) that cover the supply and use of natural energy inputs, energy products, and energy residuals for the 43 countries in CREEA and 5 Rest of World regions. The energy use tables are further processed to generate use tables of emission-relevant use of energy flows.

The conversion of the energy balances (IEA/OECD-Eurostat) into energy accounts (SNA/ESA-SEEA) (see above) requires appropriate specific procedures to build the link between the two statistical concepts. This section provides an overview of the transformation procedure of the IEA extended energy balances that are based on the IEA energy statistics, into energy accounts as required by the analytical requirements of CREEA. The energy accounts are further elaborated by aligning them with the SEEA framework. In a broad sense, this is done by splitting the accounts into three main matrices: flows of natural energy inputs, flows of energy products and flows of energy residuals. The simplified representation of the applied approach is shown in Figure 1.

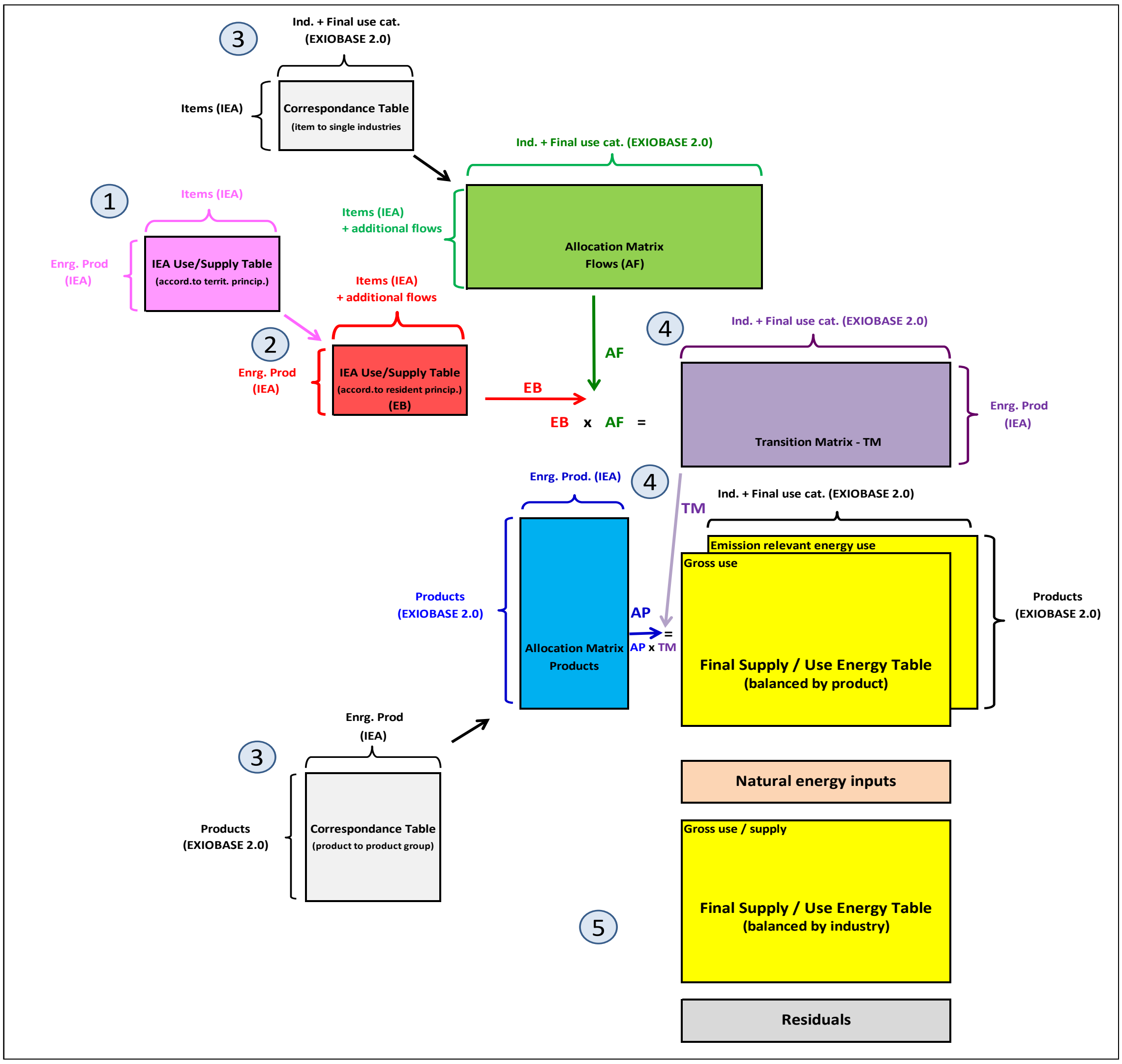


Figure 1: Simplified approach for the generation of E-SUTs[15]

The operation steps are arranged in five consequential tasks. An overview of these is given in the following paragraphs.

Task 1 **"From IEA - Energy Balances to Raw Gross Energy Tables"** describes the splitting of the IEA energy balances into the supply and the use of energy flows. While in the original energy balances the supply and the use are presented in a single table, the Raw Gross Energy Tables show use and supply separately in two different tables.

Task 2 **"Bridging from the `Territory Principle´ to the `Residence Principle"** refers to the table adjustments necessary due to the differing analytical boundaries between the `territory principle´ - as applied in the energy balances - and the `residence principle´ - as applied in the energy accounts. The country boundaries are conceptually different for these two principles, especially regarding the energy consumption by residents in foreign territory and the one of non-residents in the domestic territory.

[15] The format of the tables might differ depending on whether the use tables or the supply tables are being generated. Nonetheless, the logic of the process is the same in both cases.

Task 3 **"Generation of Correspondence Tables"** describes, on the one hand, the correspondence between the several items (i.e. groups of industries and final use categories as represented in the IEA balances) of the Raw Gross Energy Tables (both supply and use, respectively) and the "single industries and final use categories" as classified within EXIOBASE 2.0. The description specifies which relations are trivial one-to-one relations and which ones are of different nature. In this way, it frames the detailing descriptions of task 4.

On the other hand, this task also describes the assignment of the energy products listed in the IEA extended balances to each product group of the product classification as used within EXIOBASE 2.0.

Task 4 **"Allocation of Items in the Raw Gross Energy Tables to CREEA Industries and Final Use Categories"** explains how the items of the Raw Gross Energy Tables (both supply and use) are allocated to the corresponding single industries and final use components of the EXIOBASE 2.0 SUTs. Mathematically, this allocation is usually a breakdown of aggregated industry groups.

Task 5 **"Generation of the final Use and Supply Energy Tables"** comprises the preparation of the E-SUT according to the SEEA framework and the data arrangements based on the analytical requirements of CREEA. This procedure ensures the linkage between the generated E-SUT and the energy accounts derived from them with the monetary SUTs of EXIOBASE 2.0. At the same time, the set of final tables is generated including the representation of emission relevant energy use, gross use, as well as the total supply table.

Sources and data quality

The main data sources for the generation of the E-SUT and the environmental extension “Energy” are country-specific sets of physical and monetary data. The data can be distinguished according to its usage into:

a) primary data (core data), i.e. physical data on the use and supply of energy, and

b) secondary data (auxiliary data), mainly diverse physical and monetary data.

In the following, these two types of data are discussed.

Physical data on the use and supply of energy

The primary data source on the supply and use of energy are the IEA extended energy balances (IEA 2010a, 2010b). They provide data on the use and supply of 63 energy products by 85 items for a country or world region (see Figure 2). All the countries covered in CREEA have their own energy balance. The balances for the RoW regions have been built by adding the balances of the countries included in each RoW region, and removing the intra-trade using data from the BACI database.

The 85 items for users and suppliers are divided into 4 sectors:

a) “Supply",

b) "Transformation",

c) "Energy" and

d) "Final consumption".

In addition, the sector "Final consumption" is divided into 4 sub-sectors: d.1) "Industry sector", d.2) "Transport sector", d.3) "Other sectors", and d.4) "Non-Energy Use". Each of these sectors and sub-sectors show a subtotal within the list of flows. Consequently, these are set to 0 at the beginning of the procedure.

The 63 products contain 4 "umbrella products" that are intended to gather remainders, where the energy could not be attributed to the respective products. These 4 umbrella products ("hard coal (if no details)", "brown coal (if no details)", "crude/LNG/feedstock (if no details)", "non-specified primary biomass and wastes") are empty columns.

An overview of the energy balances is given in Figure 2.

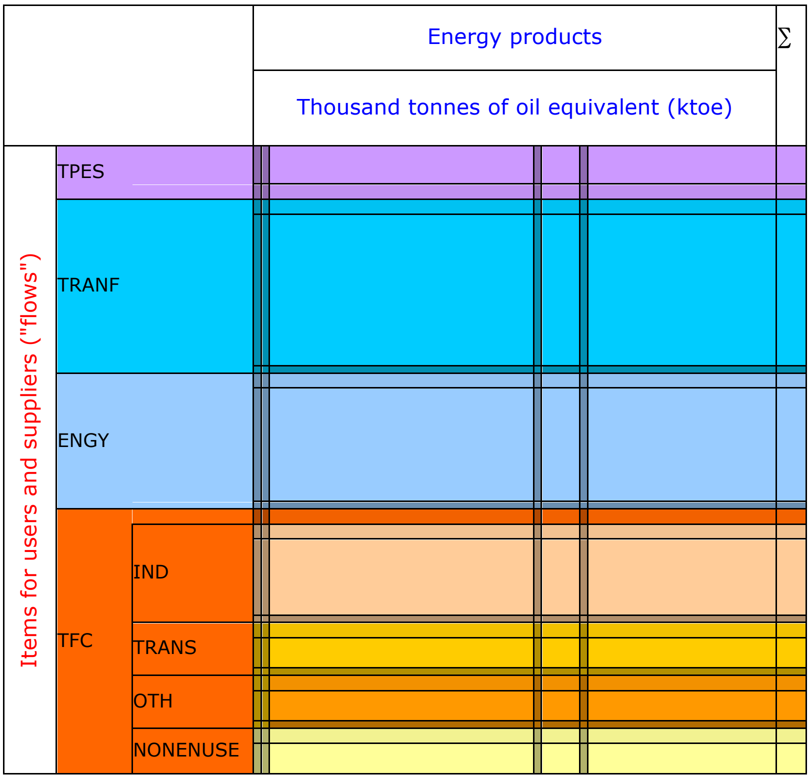


Figure 2: Schematic overview of IEA extended energy balances (own illustration)

The sector "Supply" of the IEA extended energy balances contains among others the following six flows:

- Two flows referring to the supplied quantities, i.e. "Production" and "Imports"
- Three flows referring to the foreign use of domestically produced energy products, i.e. "Exports", "International Marine Bunkers" and "International Aviation Bunkers"
- One flow referring to the "Stock Changes" (positive or negative).

The sub-total "Total primary energy supply" (TPES) is made up of the sum of these six flows.

The sector "Transformation" represents the conversion of primary and secondary energy products into secondary energy products (e.g. coking of coal, transforming crude oil to petroleum products, or heavy fuel oil to electricity). It is composed of 21 items. In this sector, use and supply of energy products are frequently attributed by different signs.

The sector "Energy" represents the amount of sources used by the energy producing industries (e.g. for heating, lighting and operation of all equipment used in the extraction process, for traction and for distribution). This use of the energy producing industries is represented by 18 items.

The sector "Final Consumption" represents the consumption of energy products in the industry categories and final use categories. It is presented by 29 items[16] in total that are distributed as follows among the sub-sectors:

- "Industry" (13 items),
- "Transport" (7 items),
- "Others" (5 items),
- "Non-energy use" (4 items).

The final consumption of private households (item residential) covers mostly what is delivered to the final consumers (see IEA 2011).

Auxiliary physical and monetary data

Beside the need of physical data on the use and supply of energy, there is an extensive need for auxiliary parameters. These auxiliary data are necessary to bridge the energy balances and the energy accounts and to split the aggregated items of the IEA energy balances[17]. The datasets can be grouped into physical data, monetary data and other auxiliary data[18]:

a) The first group of data contains physical data (in physical units as joule, tonnes, etc.) on auxiliary parameters. It essentially comprises additional data on energy, data on resource extraction, data on production volume and consumption quantities, and data on life cycle inventories of several products.

b) The second group of data contains monetary data (in euro or national currencies) on auxiliary parameters. This data basically refers on intermediate use as well as on total production and final consumption of several goods and services. They were mainly extracted from the monetary supply and use tables of EXIOBASE 2.0.

[16] In the IEA extended energy balances (2010), the sector "Final consumption" contains 30 flows, because the flow "international aviation" is included in the sub-sector "Transport".

[17] Several items contained in the IEA energy extended balance are aggregates that represent the energy supply or use, respectively, of several industries or services. This original breakdown of flows responds mainly to technical criteria, and to a lesser degree, to accounting rules in line with the SNA.

[18] Other auxiliary data refer to e.g. employment data is used to allocate the energy consumption of road transport to the EXIOBASE 2.0 industries.

c) The third group comprises additional auxiliary data that has been used for very specific disaggregations, e.g. sectoral employment data from ILO.

The following table provides an overview on the main data sets used as auxiliary data including the sources (Table 4).

Table 4: Overview of the auxiliary data, their purpose, type and source

Parameter	Type	Database	Source
Energy supply and use	Electricity and heat use and supply by producer and energy product	Extended Energy Balances of OECD and Non-OECD countries - Beyond 2020	International Energy Agency (IEA)
Physical output of Agriculture	Produced crops and livestock	FAO – FAOSTAT – Agriculture	Food and Agriculture Organization of the United Nations (FAO), 2012
Food production and consumption	Food Balance sheets by country	FAO – FAOSTAT	Food and Agriculture Organization of the United Nations (FAO), 2012
Physical output of forestry	Output of forestry, wood and wood-related products	FAO – FAOSTAT - Forestry	Food and Agriculture Organization of the United Nations (FAO), 2012
Physical output of fishing	Output f fishing	FishStat	Food and Agriculture Organization of the United Nations (FAO), 2012
Physical output of agriculture and fishing	Produced crops and livestock. Fishing output.	Council of Agriculture - Taiwan	Council of Agriculture - Taiwan
Physical and monetary outputs of various sectors	Physical and monetary outputs of various sectors	Data gathered by several CREEA partners	Various – See D.4.2
Life cycle inventories	Life cycle inventory database Library for life cycle data	Ecoinvent v.2.2 “PROBAS” (Prozessorientierte Basisdaten für Umweltmanagement-Instrumente)	Swiss Centre for Life Cycle Inventories Federal Environment Agency (UBA) and Öko-Institut
Traded quantities and prices of energy products	Trade database	BACI	CEPII
Sectoral employment	Employment database	LABORSTA	International Labour Organization (ILO)
Marine fleet per nationality of the owner	Annual fleet statistics	World Fleet Statistics 2007	Lloyd's Register Fairplay
Average fuel consumption per ship type	GHG Study	Second IMO GHG Study 2009	International Maritime Organisation (IMO)
Aircraft fleet,	Annual air transport	World Air Transport Statistics	International Air Transport

Parameter	Type	Database	Source
air traffic, etc.	statistics Online air fleet database	2008 Edition http://www.airfleets.net	Association (IATA)
Fuel consumption per aircraft types	GHG reporting guidelines	Emission Inventory Guidebook 2009	EMEP/EEA
Vehicles fleet, road traffic, etc.	Traffic – Stock of vehicles and vehicle-kilometres (VKM)	Eurostat's transport database UNECE's transport database World Road Statistics 2007 OECD's transport database Other transport statistics	Eurostat UNECE IRF OECD National Statistical Institutes
Fuel consumption of road vehicles	GHG reporting guidelines	Emission Inventory Guidebook 2009	EMEP/EEA
Tourism by transport mode, outbound stays, etc.	Tourism statistics	Eurostat's tourism database Compendium of Tourism Statistics	Eurostat WTO

Task 1: From Original Energy Balances to Raw Gross Energy Tables

The IEA energy balances show the supply and the use of products by items (groups of industries and final use categories). All products supplied or used are provided in thousand tonnes of oil equivalent [ktoe].

The figures, which represent a product use are signed by the algebraic sign "-" (minus), and those, which represent a "product" supply, with "+" (plus). The sum of all used and supplied quantities for a certain "product" (sum per column), is the "net supply" for the respective energy product.

Since this structure is not suited for the purposes in CREEA, a direct linkage between the data on energy use and supply, and the monetary SUTs is not possible. The SUT approach applied in CREEA requires a split of the data in use and in supply, i.e. two separate tables for the 'use' and the 'supply'. For this purpose, the following procedure was performed (Figure 3).

Separation of supplied and used "products"

Firstly, the "item by product" basic table was transposed to a "product by item" table. Then, the used and supplied "products" were split into a supply table and a use table as follows.

The sectors 'Supply' and 'Transformation' show both positive and negative figures, while the sector 'Energy' shows only negative figures. The positive figures were accounted in the supply table, whereas the negative ones were accounted in the use table with a changed algebraic sign. The sector ´Final Consumption´ shows positive figures only that were accounted in the use table.

The results of these algebraic manipulations are two separate product-by-item tables. Henceforth, these tables are named ´Raw Gross Energy Supply Table´ (RGEST) and 'Raw Gross Energy Use Table' (RGEUT), respectively.

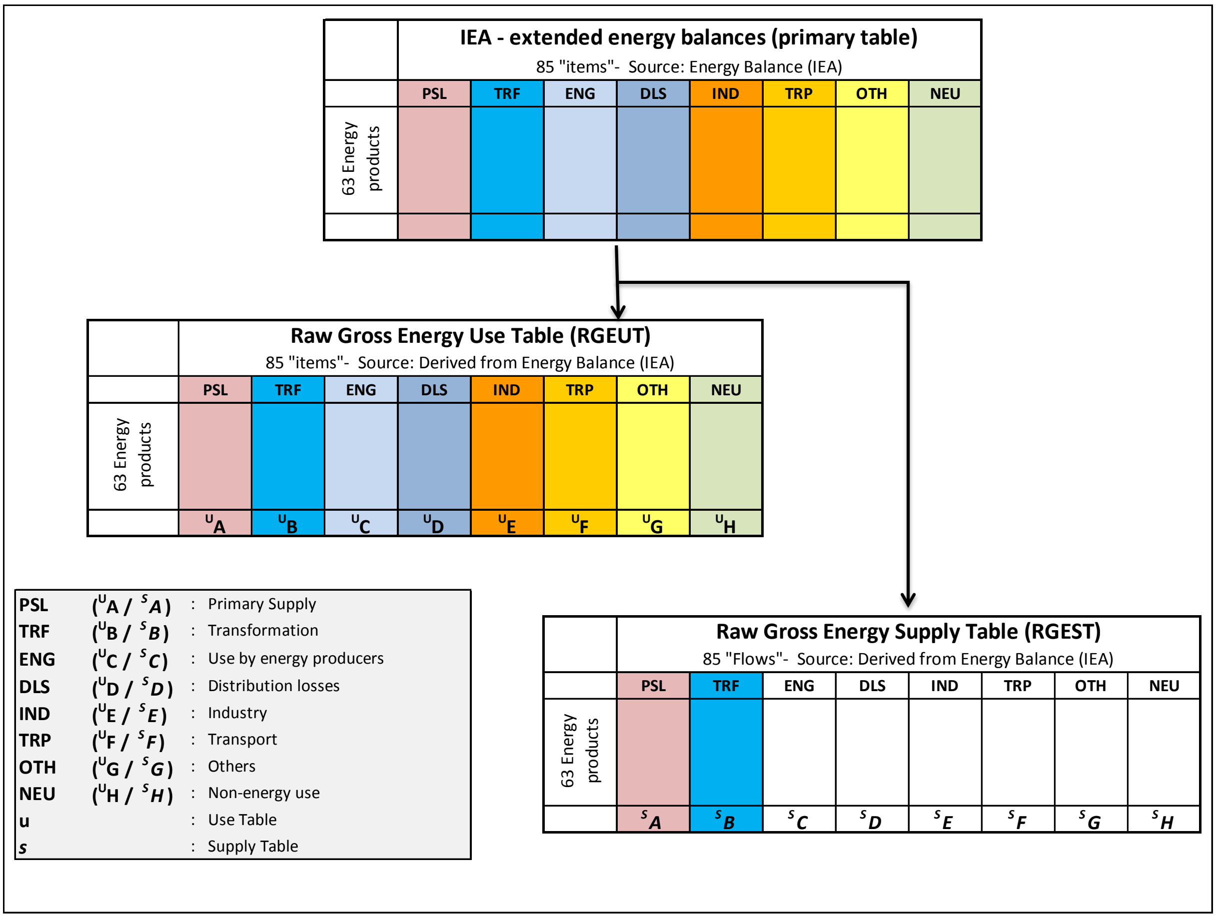


Figure 3: Data flow of Task 1

Both RGEST and RGEUT show the "products" in rows and the "items" in columns. Within the RGEST and RGEUT the items are grouped in accounting areas: "Supply", "Transformation", "Use by energy producers", "Industry", "Transport", "Others", and "Non-energy use". These accounting areas correspond directly with the sectors and sub-sectors, respectively, of the IEA balances[19]. The used and supplied quantities of energy products in the RGEST and RGEUT are given in terajoule [TJ] on a gross calorific value basis (IEA 2011). For the conversion of units, the conversion factor 1 ktoe = 41.868 TJ was used.

[19] In the following chapters, the terms "sector", "sub-sector", and "item" are used only when referring to IEA energy balances, however, the terms "accounting area", "energy product" and "items" are used when referring to RGEST/RGEUT.

Consistency Check of the 'Supply' and 'Use' per Energy Product

Finally, the values for the supply and use must be identical for the totals and for each single energy product. Discrepancies were interpreted as incompleteness. Therefore, correction terms have been added where necessary.

Task 2: Bridging from the 'territory principle' to the 'residence principle'

Energy statistics (as those provided by the IEA) apply the territory approach, while energy accounts apply the residence approach (cf. chapter 2.2.1). As the energy statistics are the starting point for the generation of the energy accounts, bridging is necessary to compensate the differences between the two approaches. The main calculations necessary for this bridging are located in the accounting area "Transport" due to the internationality of this activity. In many cases, this causes that the "means of transport" (road vehicles, ships, aircrafts, etc.) fill up fuel in countries different to those where they are registered (by the corresponding residents). Further, adjustments have also been made to the item "Fishing" in order to better represent the use of fuels related thereto by residents.

As a consequence, special attention is required to consider the system boundaries related to the two differing principles in order to derive accurately the energy SUTs from the extended IEA energy balances. This task covers the procedure applied where a direct adoption of 'raw' data contained in the IEA energy balances is not sufficient, and thus correction terms (so-called bridging procedures) were applied[20].

The following transport types are affected:

- International road transport[21];
- International maritime transport, which is directly associated with the deliveries to the international marine bunkers;
- International air transport, which is directly associated with the deliveries to the international aviation bunkers; and
- Fishing.

The energy products that are mainly involved within these transport activities are several secondary energy products produced from crude oil as well as liquefied petroleum gas and natural gas. The bridging adjustments for the use of these energy products were done based on data extracted from several auxiliary datasets (Table 4). For simplification, quantities of other energy products have been assigned using the same shares for which either the product quantities were negligible, or availability of auxiliary data was insufficient.

For bridging from the 'territory principle' to the 'residence principle', a 4-step process has been applied".

[20] As these corrections do not concern allocations in the strict sense, but rather *additional* calculations, they are shown here instead of in task 4.

[21] The term "international road transport" applies to fuelling in a country other than the vehicle's country of registration.

Step 1: Bottom-up Estimation of the Distribution of the Energy Use by Transport activities based on the 'Residence Principle'

The country estimation procedure has been split up into "fishing" and the three transport types "road transport", "international maritime transport", and "international air transport". The aim of the models is not to calculate precisely the energy use of each of these items for each country, but to provide distribution shares that are multiplied by the total energy uses given by the IEA energy balances. In Annex I, the models used to estimate their respective energy use are described individually.

To this end, fictional estimates have been calculated, which are named Total Fuel Use ($TFU_{R,}$ $TFU_{M,\ or}$ TFU_A, respectively, per transport type and TFU_F for fishing) in the following section. Each country's values have been divided by the total energy use calculated to estimate the corresponding shares.

Concretely, the distribution shares applied to the IEA items correspond to the following:

- Road transport: Total fuel use of road vehicles
- International maritime transport: Total fuel use of vessels bigger than 1.000 GT
- International air transport: Total fuels use of aircrafts engaged in international transport
- Fishing: Total fuel use of shipping vessels bigger than 1.000 GT

Step 2: Adjustment of the Estimated Energy Uses of the Transport Fleets by Use of IEA Balances

Within step 1, the distribution of total energy use (TEU) based on the residence principle was estimated for the three transport fleets (road, maritime and air) and fishing. These distribution shares have been multiplied by the total energy use given by the IEA for each of the items concerned. The results of this adjustment are called "adjusted TEU" ($_{R,}$ $_{M,}$ or $_A$, respectively, per transport type, and $_F$ for fishing).

Step 3: Recalculation of the "Imports" and "Exports" of Fuel Related to the different Means of Transport

The induced "imports" and "exports" of fuel – due to "tank tourism" and the mismatch generated by outbound and inbound tourism and freight transport in the case of road transport, and operation of international bunkers in the cases of maritime and air transport – are determined separately for each of the three transport modes. These induced imports and exports, respectively, were assigned to the regular imports and exports. This procedure has also been used in the case of fishing.

- Road Transport

In general, the adjusted country TEU_R differed from the country energy use by "road transport" within the RGEUT. These differences are interpreted as the net foreign trade.

Thus, the net imports or net exports, respectively, of fuels are calculated for each country separately. This means, that surplus of TEU_R is interpreted as imports, while surplus of country deliveries to "road transport" is interpreted as exports.

- International Maritime Transport

The deliveries from countries to international marine bunkers leave the national territories and thus were interpreted as fuel exports. Likewise, the consumption of fuel by the country ship fleet as estimated in step 2 ("adjusted TEU_M") was interpreted as fuel imported from the international marine bunkers. This procedure was performed for each energy product separately.

- International Air Transport

For the international air transport, the imports and exports were calculated analogue to the international maritime transport.

- Fishing

For fishing, the induced imports and exports were calculated analogue to "road transport".

Step 4: Assignment of the Estimated Use, the Imports, and the Exports to Corresponding Items

In order to generate the RGEST and the RGEUT according to the ´residence principle´, the estimates of steps 2 and 3 were assigned as follows to the corresponding items.

The estimated and adjusted (step 2) country fuel consumption per vehicle fleet was assigned to the items "road transport", "international maritime transport", "international air transport" and "fishing", respectively. The exported quantities were added to the category "exports" as part of the Final Use of the RGEUT. Accordingly, the imported quantities were added to the category "imports" as part of the RGEST.

The results of this procedure are RGEUT and RGEST, respectively, according to the 'residence principle'. The RGEUT in compliance with the residence principle is a 63 x 89 matrix, that contains the original 63 products and the original 85 flows, plus 4 newly added flows (imports and exports induced by road transport and fishing).

Task 3: Generation of correspondence tables

The result of task 2 is – for each CREEA country – a set of RGEST and RGEUT according to the residence principle, already checked for consistency. In order to break down the aggregated items of the RGEST/RGEUT according to the requirements of CREEA, it is necessary to determine the correspondences between the *items* and *the industries and final use categories*, henceforth named "IFU categories", of the SUTs within EXIOBASE 2.0.

Some of these correspondences can be performed by a one-to-one allocation from one specific item to one specific IFU category. Other correspondences entail a deviation thereof for the allocation. Here, two cases are distinguished:

- Breakdown of one RGEST/RGEUT item into several IFU categories;

- Assignment of several RGEST/RGEUT items to one IFU category.

These correspondences are summarised in Correspondence Tables, one for the supply and one for the use, showing which correspondence type is applied for which item. For illustration purposes, an excerpt of the Correspondence Table for the use is shown in Table 5.

Table 5: Correspondence table specifying the correspondences between items (IEA classification) and IFU categories (EXIOBASE 2.0 classification). Excerpt from the applied Correspondence Table.

IEA Classification			EXIOBASE 2.0 Classification	
Area	**IEA Flow code**	**Flow label (Item label)**	**Code**	**Label**
I	**PAPERPRO**	Paper, Pulp and Print	i21.1 i21.w.1 i21.2 i22	Pulp Re-processing of secondary paper into new pulp Paper Publishing, printing and reproduction of recorded media (22)
I	**WOODPRO**	Wood and Wood Products	i20 i20.w	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20) Re-processing of secondary wood material into new wood material
I	**CONSTRUC**	Construction	i45 i45.w	Construction (45) Re-processing of secondary construction material into aggregates
I	**TEXTILES**	Textile and Leather	i17 i18 i19	Manufacture of textiles (17) Manufacture of wearing apparel; dressing and dyeing of fur (18) Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)

The results of task 3 are the Correspondence Tables that indicate how the items and IFU categories correspond. The specific instructions for the allocations are provided in task 4.

Task 4: Allocation of RGEUT/RGEST Items and Products to CREEA IFU and Product Categories

In this chapter, the procedure of the breakdown and allocation of the 89 items of the modified RGEUT and RGEST, respectively, into the corresponding CREEA IFU categories is described. Since the IEA extended energy balances, and also the derived RGEUT/RGEST show an identical structure for all countries, this procedure was used for the data sets of all countries.

As shown in the simplified scheme represented in Figure 4, two allocation matrices have been used to obtain the final energy SUTs. Nonetheless, the reality is much more complex, since this is not done in one single step neither for the supply, nor for the use.

Allocation matrices for supply and use flows

The general allocation approach is based on the following formula:

$$S \times AMS = TMS$$

$$U \times AMU = TMU$$

where:

S: Extended supply table with dimension 63 x 5607 as represented in Figure 4. This matrix is obtained by diagonalizing the 63x1 vector corresponding to each item.

U: Extended use table with dimension 63 x 5607 as represented in Figure 4. This matrix is obtained by diagonalizing the 63 x 1 vector corresponding to each item.

AMS: Allocation matrix for supply flows with dimensions 5607 x 175 as represented in Figure 4. This matrix is obtained based on the correspondence tables generated in Task 3 and auxiliary data.

AMU: Allocation matrix for use flows with dimensions 5607 x 175 as represented Figure 4. This matrix is obtained based on the correspondence tables generated in Task 3 and auxiliary data.

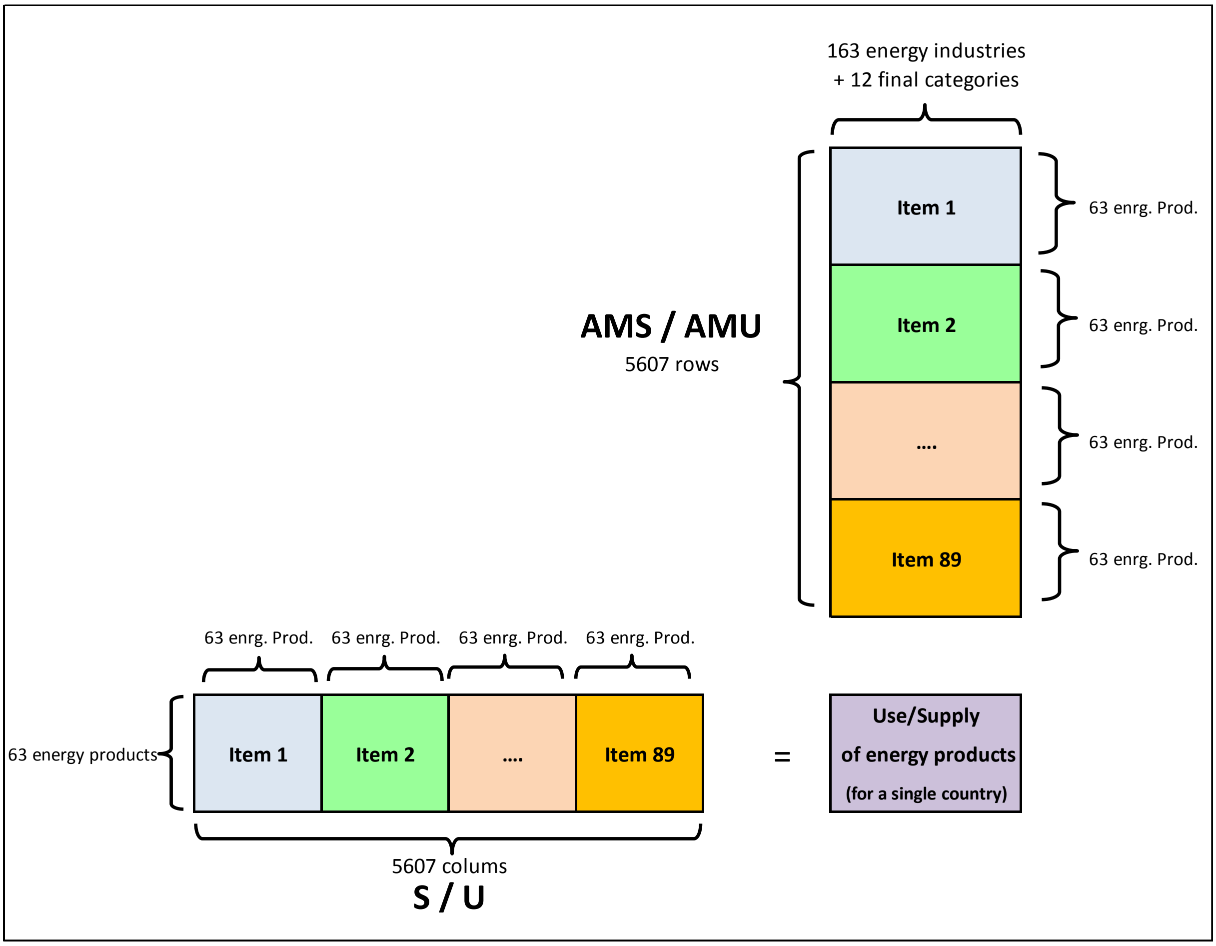


Figure 4: Representation of the allocation of IEA items and products to CREEA IFU and product categories

The result is a single 63 x 175 matrix that represents either the use or the supply of energy products.

Each of the submatrices represented in the element AMS and AMU are single allocation matrices that have been generated based on the correspondence tables generated in Task 3. However, their application is subject to the adequately use of the general allocation approach and the data sets to be used for the calculation of the weighting factors (allocation coefficients).

The exact allocation sequence and the approach that is used for the calculation of the allocation weighting factors are relevant for an accurate breakdown of the aggregated items.

The application of a certain approach to generate an allocation submatrix depends directly on the availability of data on auxiliary parameters that are required for the breakdown of the aggregated items. The approaches used for the allocation of the energy uses and supplies can be grouped in six main classes:

Allocation approaches

a) one-to-one allocation;

b) based on LCI data;

c) based on monetary data;

d) based on allocation matrices for road transport related items;

e) related to the use / supply by electricity and CHP plants;

f) based on data on specified supply of energy products

The following subchapters describe the particular characteristics for the five identified approaches for deriving the allocation submatrix required to break down the energy use and energy supply by a certain aggregated item (e_{item}) of the modified RGEUT/RGEST[22] into the energy use and energy supply by the corresponding IFU categories (E_{IFU}). The type of allocation used for each item is shown in Table 6.

Table 6: Items of the RGEUT/RGEST (IEA-Flows), on which a determined allocation approach was applied in order to derive the energy use and energy supply of the CREEA industries and Final use consumption categories

Nr.	Accounting area by RGEUT and RGEST	RGEUT and RGEST classification		Applied allocation approach	
		IEA Flow code	Item label	Short label	Long label
1	Transformation	MAINELEC	Main Activity Producer Electricity Plants	Approach "e"	Allocation related to the use and supply by electricity and CHP plants
2	Transformation	AUTOELEC	Autoproducer Electricity Plants	Approach "e"	Allocation related to the use and supply by electricity and CHP plants
3	Transformation	MAINCHP	Main Activity Producer CHP Plants	Approach "e"	Allocation related to the use and supply by electricity and CHP plants
4	Transformation	AUTOCHP	Autoproducer CHP Plants	Approach "e"	Allocation related to the use and supply by electricity and CHP plants
5	Transformation	TNONSPEC	Non-specified (Transformation)	Approach "c"	Allocation based on monetary data

[22] The modified RGEUT is the result of Task 2.

6	Use of energy producers[23]	EOILGASEX	Oil and Gas Extraction	Approach "b"	Allocation based on LCI data
7	Use of energy producers	EPOWERPLT	Own use in electricity, CHP and heat plants	Approach "c"	Allocation based on monetary data
8	Use of energy producers	ENONSPEC	Non-specified (Energy)	Approach "c"	Allocation based on monetary data
9	Use of energy producers	DISTLOSS	Distribution Losses	Approach "f"	Allocation based on data on specified supply of energy products
10	Industry	IRONSTL	Iron and Steel	Approach "c"	Allocation based on monetary data
11	Industry	CHEMICAL	Chemical and Petrochemical	Approach "b"	Allocation based on LCI data
12	Industry	NONFERR	Non-Ferrous Metals	Approach "b"	Allocation based on LCI data
13	Industry	NONMET	Non-Metallic Minerals	Approach "b"	Allocation based on LCI data
14	Industry	TRANSEQ	Transport Equipment	Approach "c"	Allocation based on monetary data
15	Industry	MACHINE	Machinery	Approach "b"	Allocation based on LCI data
16	Industry	MINING	Mining and Quarrying	Approach "b"	Allocation based on LCI data
17	Industry	FOODPRO	Food and Tobacco	Approach "b"	Allocation based on LCI data
18	Industry	PAPERPRO	Paper, Pulp and Print	Approach "b"	Allocation based on LCI data
19	Industry	WOODPRO	Wood and Wood Products	Approach "b"	Allocation based on LCI data
20	Industry	CONSTRUC	Construction	Approach "c"	Allocation based on monetary data
21	Industry	TEXTILES	Textile and Leather	Approach "b"	Allocation based on LCI data
22	Industry	INONSPEC	Non-specified (Industry)	Approach "c"	Allocation based on monetary data
23	Transport	ROAD	Road	Approach "d"	Allocation based on allocation matrices for items related to road transport
24	Transport	TRNONSPE	Non-specified (Transport)	Approach "c"	Allocation based on monetary data
25	Others	COMMPUB	Commercial and Public Services	Approach "c"	Allocation based on monetary data
26	Others	AGRICULT	Agriculture/Forestry	Approach "b"	Allocation based on LCI data
27	Others	ONONSPEC	Non-specified (Other)	Approach "c"	Allocation based on monetary data
28	Non-Energy Use	NEINTREN	Non-Energy Use Industry/Transformation/Energy	Approach "c"	Allocation based on monetary data
29	Non-Energy Use	NETRANS	Non-Energy Use in Transport	Approach "d"	Allocation based on allocation matrices for items related to road transport
30	Non-Energy Use	NEOTHER	Non-Energy Use in Other Sectors	Approach "c"	Allocation based on monetary data

a) One-to-one allocation[24]

In this case, the item to be allocated has a one-to-one correspondence with one IFU category.

b) Allocation based on LCI coefficients and on data on physical output volumes

In order to derive the allocation submatrix by means of this approach two types of auxiliary data are required:

- data on the energy use (by energy product) per unit of physical output of a certain product ($c_{IFU.i.q.z}$);

[23] Accounting area "Own use of energy producers" corresponds with the sector "Energy" of the IEA extended energy balances.

[24] The direct use of solar thermal and geothermal energy by households to generate heat is allocated to the item AUTOHEAT and then, one to one to i40.3 following the recommendations of the SEEA Energy (UN 2013, p. 29). To be consistent with this approach, the same is done in the case of the remaining non-energy producing industries.

- data on physical output, i.e. quantities of the production or of the extraction of resources (${}_{p}x_{IFU.i.q.z}$), respectively, that are supplied by the corresponding CREEA industries.

Auxiliary data on the energy use (by energy product) per physical output ($c_{IFU.i.q.z}$) was taken from appropriate life cycle inventory databases. In some cases, such information covers the use of heat, electricity and various fuels. When these measures showed differing physical units, they were converted into TJ (as common unit), and subsequently normalised on one unit of physical output of the corresponding product type. If such specific LCI coefficients were not available for a certain product type, the LCI coefficient of the most similar product type was assumed.

Two different allocation types have been used in this approach, one at CPA 6-digit level and other at CREEA industry level.

In the case of the items "Agriculture / forestry", "Food and tobacco" and "Wood and wood products", data on the physical output (${}_{p}x_{IFU.i.q.z}$) has mainly been obtained from the FAO database, which is at a high disaggregation level compared to the corresponding CREEA products. Thus, a FAO to CPA 6-digit correspondence table has been built to link the products with the LCI coefficients.

In the second case, LCI coefficients at CREEA industry level have been used to allocate the energy uses of other items related to manufacturing.

However, as the allocation refers to CREEA industries and this level is defined by product groups, LCI coefficients ($c_{IFU.i.q.z}$) referring to a specific product or product type are not adequate. Therefore, an additional abstraction step was generally required, whereat the energy used for the production of these product groups is estimated. This means that the total energy use of a CREEA industry ($e_{IFU.j}$) is estimated based on the single components of the energy use ($e_{IFU.i.q}$) for the production of the specific products of which it is composed.

The procedure is based on the application of the following equations:

$$
\begin{aligned}
e_{i.q.z} &= c_{IFU.i.q.z} \cdot {}_{p}x_{IFU.i.q.z} \\
e_{i.q} &= e_{i.q.1} + \ldots + e_{i.q.z} + \ldots + e_{i.q.l} \\
e_{IFU.j} &= e_{i.1} + \ldots + e_{i.q} + \ldots + e_{i.m} \\
e_{IFU} &= e_{IFU.1} + \ldots + e_{IFU.j} + \ldots + e_{IFU.n} \\
w_{IFU.j} &= e_{IFU.j} / e_{IFU} \\
1 &= w_{IFU.1} + \ldots + w_{IFU.j} + \ldots + w_{IFU.n}
\end{aligned}
$$

The estimated total apparent energy use by a certain aggregated item (e_{IFU}) is given by the sum of the physical measures corresponding to the CREEA industries, into which the aggregated item is split. Hence, the weighting factors ($w_{IFU.j}$) are the shares of the estimated energy use by the corresponding CREEA industries ($e_{IFU.j}$) in the total estimated energy use (e_{IFU}). Accordingly, the sum of the weighting factors ($w_{IFU.j}$) makes up the total and equals 1.

While this is true for the cases in which the energy products to be distributed in each item match with those given in the LCI coefficients, it is not uncommon to have cases in which a quantity of a certain energy product has to be distributed for which the LCI coefficients do not contain a value, e.g. it might happen that the item "Agriculture / forestry" (according to the IEA energy balance) has a use of 5 TJ of anthracite, but the available LCI coefficients do not include any use of this energy products. In these cases, a second allocation is carried out based on monetary allocation matrices (see c).

c) Allocation based on monetary data

This allocation is solely based on the monetary use tables in basic prices[25]. Thus, the allocation coefficients used in this approach are in line with the monetary structure of the country. Mathematically this could be expressed as follows:

$$ {}_m x_{IFU} = {}_m x_{IFU.1} + \ldots + {}_m x_{IFU.j} + \ldots + {}_m x_{IFU.n} $$

$$ w_{IFU.j} = {}_m x_{IFU.j} / {}_m x_{IFU} $$

$$ 1 = w_{IFU.1} + \ldots + w_{IFU.j} + \ldots + w_{IFU.n} $$

d) Allocation based on allocation matrices for items related to road transport

This approach was applied to derive the allocation submatrix needed to break down the energy used by vehicle fleets (e_{IFU}) into the share of households (e_H) and the share of CREEA industries (e_I).

For this purpose, this approach makes use of the following types of auxiliary data:

- estimates of the fuel consumption per vehicle type (in TJ);
- data on the energy use for transportation purposes by industries; as for most countries such data is not available, the energy use for transportation purposes by industries was generally deduced by data on the energy use from "proxy countries";
- employment data by industry. Estimates for the CREEA industries are calculated based on auxiliary physical and monetary output data.
- supply of products and services by CREEA industries (output).

[25] The MSUTs might need to be further process to deal with the inconsistencies between original MSUTs and the IEA balances. For instance, there are times in which the MSUTs do not contain any values for a given energy product, while the IEA balances have. In these cases, the distribution of a similar product within the country has been taken.

The procedure is based on the application of the following equations:

$$e_{IFU} = e_H + e_I$$

$$e_I = e_1 + ... + e_j + ... + e_{163}$$

$$e_j = ({}^{pr}e_j \,/\, {}_m{}^{pr}x_j) \cdot {}_m x_j$$

$$w_j = e_j \,/\, e_I$$

$$w_H = e_H \,/\, e_{IFU}$$

$$1 = w_H + w_1 + ... + w_j + ... + w_{163}$$

The apparent direct fuel consumption for transportation purposes by households (e_H) is estimated by use of data on vehicles of the categories "passenger cars" and "motorcycles", while the fuel consumption for transportation purposes of industries (e_I) is estimated by use of data on light trucks and heavy-duty vehicles, such as tractors, buses and lorries (cf. task 2). Thus, the weighting factor for households (w_H) is given by the share of fuel consumption by "passenger cars" and "motorcycles" in the fuel consumption by the whole vehicle fleet.

Only data for one country (DE) has been found that refers to the fuel consumption of road transport by industries. This has been used as a proxy to estimate the data for the remaining countries.

Since the energy use of road transport by industry for the proxy country does not exactly match the CREEA classification, a few items have been disaggregated based on monetary and physical output data. Intensities are needed (e.g. in the form of MJ/kg output or MJ/€ output) to make extrapolations to the remaining countries. Nonetheless, the physical output of the service industries is negligible, while the monetary output is a misleading parameter when it comes to link the output with the energy use related to transport. Thus, employment has been used as a common indicator for all the sectors. This allows calculating energy use intensities in the form of TJ/.000 employees.

For countries with lack of country-specific adequate data, the fuel consumption for transportation purposes by a certain CREEA industry (e_j) is estimated by assuming the same energy use per thousand employees as the so-called "proxy country" $({}^{pr}e_j \,/\, {}_m{}^{pr}x_j)$.

e) Allocation related to the use and supply by electricity and CHP plants

This approach was applied to derive the allocation submatrix needed to break down and assign, respectively:

- the energy supplied by electricity plants (${}^{S}e_{item}$), i.e. electricity, into the corresponding electricity producing CREEA industries (${}^{S}E_{IFU}$);

- the energy used by electricity plants (${}^{U}e_{item}$), i.e. several energy products, into the corresponding electricity producing CREEA industries (${}^{U}E_{IFU}$);

- the energy supplied by CHP plants (${}^{S}e_{CHP}$), i.e. electricity and heat, into the corresponding electricity and heat producing CREEA industries (${}^{S}E_{IFU}$);

- the energy used by CHP plants ($^{U}e_{CHP}$), i.e. several energy products, into the corresponding electricity producing CREEA industries ($^{U}E_{IFU}$).

The auxiliary data ($^{S}E_{j.z}$) used for deriving the allocation vector according to this approach are:

a) *additional data* on the supply of electricity and heat by type of energy product. This data is provided by the IEA by an additional matrix next to the extended energy balance for each country;

b) data on average conversion efficiency in water turbine plants for generating steam.

The 63 energy products, from which electricity and heat are produced, were grouped in 12 product groups. Each product group could be directly assigned to one electricity producing CREEA industry.

<u>Supply by electricity plants</u>
The allocation submatrix is derived basically by means of a "manual" allocation of the produced electricity according to the energy product used for their production. The electricity produced by each group matches one-to-one with an electricity producing CREEA industry.

<u>Supply by CHP plants</u>
The allocation of the output of the CHP plants (electricity and heat) to the corresponding CREEA industries consists basically in the allocation of the produced electricity and heat according to the energy products used for their production. The total produced heat was allocated to the heat producing CREEA industry, while the total produced electricity resulting for each group into which the 63 energy products were previously divided was assumed as the quantity of electricity supplied by the corresponding electricity producing CREEA industry. This is in accordance with the recommendations from Eurostat (Eurostat 2011, p. 52).

<u>Use by electricity plants</u>
The allocation submatrix for the use was determined the same way as the assignment of the supply by electricity plants.

Each energy product used by a certain producer of electricity (main-producers or auto-producers) is assigned to one of the 12 groups, into which the 63 energy products were previously divided. Since each group of energy products corresponds directly with an electricity producing CREEA industry (i40.1a to i40.1l), the used quantities of energy products within a given group are assumed as quantity used by the corresponding CREEA electricity producing industry.

<u>Use by CHP plants</u>
First, the use of energy products for the production of electricity and heat by CHP plants was broken down into the use for electricity and use for heat by energy product. The estimation of the energy use for the production of heat (in form of steam) by a CHP plant is based on the assumption that the calorific value of the heat output of the CHP plants

corresponds with the calorific value of the energy product used for its generation. The efficiency factor, i.e. the ratio between the calorific value of the input and the calorific value of the output (i.e. heat in form of steam), is assumed to be 1.1 (90% efficiency).

The energy use for the production of electricity in CHP plants was estimated as the difference between the total quantity used in CHP plants and the quantity used for heat production. This exercise was carried out for each energy product separately.

Second, the estimated use of each energy product for the production of electricity was assigned to one of the 12 groups, into which the 63 energy products were previously divided (see above). Then, the used quantities of energy products within a given group are assumed as quantity used by the corresponding CREEA electricity producing industries (i40.1a to i40.1l).

Third, the assignment of the estimated use of energy products for the production of heat is interpreted similarly to the allocation of the energy products used for the production of electricity. This procedure was applied in order to ensure the highest level of compatibility with the monetary SUTs referring to this allocation.

However, there is not a total compatibility between both, since they use a different principle to allocate the products used under the items AUTOELEC and AUTOCHP. The MIOTs allocate the products used for the generation of electricity by a facility in which electricity production is not the main activity to the industrial category to which the facility belongs. Nonetheless, this monetary value will be mixed with the one belonging to its main activity, so there is no chance of estimating the share of both activities. In the energy SUTs built from the IEA extended energy balances the items AUTOELEC and AUTOCHP have been allocated to the electricity generation industries, since no auxiliary data has been found that would allow a proper assignation to the industry category to which the facility belongs.

f) Allocation based on data on specified supply of energy products

This allocation type has been used for the losses occurring during the distribution, and transmission of energy products. Thus, these losses have been allocated to the supplier industries.

Resulting tables

Two main matrices result from Task 4, the gross energy supply table (matrix 63 x 175) and the gross energy use table (matrix 63 x 175). The 63 energy products as given by the IEA have to be adapted to the EXIOBASE 2.0 classification (200 products) with the aid of the correspondence tables in two steps.

First, the energy products “Industrial waste”, “Municipal waste (renewable)”, “Municipal waste (non-renewable)” and “Primary solid biomass” represented in the two main matrices resulting from Task 4 have to be disaggregated into their corresponding CREEA products, which results in two 82 x 175 matrices. For this, monetary coefficients are used. Since the rest of the IEA products are mapped one to one to CREEA products, a mere correspondence table is enough to obtain the 200 x 175 supply and use tables.

The 200 products covered in the rows of these tables contain the 63 IEA energy products. The columns contain the CREEA industries that use and/or supply the various energy products, the final use components of the SUTs of CREEA, and several additional elements[26]:

- "Transfers";
- "Statistical differences";
- "International air bunkers";
- "International marine bunkers";
- "Induced imports/exports by means of road transport[27]"
- "Induced imports/exports by means of fishing.

The item "transfers" is allocated to the petroleum refineries on the use side and to the petrochemical industry on the supply side.

The item "statistical differences" are arranged in the final tables as parts of the final use component "changes in inventories", thus next to the item "stock changes".

The items "international air bunkers", "international marine bunkers", "induced imports/exports by means of road transport", and "induced imports/exports by means of fishing" are considered as "other" exports or imports, respectively, since they are exported or imported by some kind of international transport. They are arranged in the final tables next to the final use categories "imports" or "exports", respectively.

Besides the gross supply and use tables, two additional elements have been generated: the emission relevant energy use tables and the net energy use vector. The former is the basis for calculating the combustion related air emissions. To compile this table, all the items of the IEA balances have been classified according to a dummy distribution that indicates whether the products of a specific item are combusted or not.

By applying the procedure described above (Tasks 1 to 4), the emission relevant energy use tables (200 x 175) have been calculated.

As for the net energy use vector (1 x 175), this can easily be calculated by subtracting the supply from the use by industry.

Task 5: Generation of the final Use and Supply Energy Tables

The objective of this task was the alignment of the calculated flows of energy products with the SEEA framework. In the SEEA Energy the physical flows are organised into three broad groups (energy from natural inputs, energy products and energy residuals) according to whether they represent a supply of energy or a use of energy. An example is given in Table 7 and Table 8.

[26] These categories were introduced in order to balance the supply and use by energy product.

[27] "Induced imports/exports by means of road transport" are the result of the tanking of non-residents in the domestic territory and of the residents in a foreign territory. The phenomenon called "petrol tourism" partially explains this trend. "Petrol tourism" refers to vehicle drivers who drive purposely to a far-off, but cheaper petrol station, whereat the reduced price is caused dominantly by different tax schemes of different countries. This phenomenon mainly occurs next to the country borders.

Table 7: Example of Supply table according to SEEA.

	Intermediate consumption				Accumulation	Flows from RoW	Flows from the environment	Total Supply
	I_1	…	I_n	HH		Imports		
Energy from natural inputs								
Natural resource inputs								
Mineral and energy resources								
NI_1								
…								
NI_n								
Timber resources								
Inputs of energy from renewable resources								
NI_{n+1}								
…								
NI_x								
Other natural inputs								
Energy inputs to cultivated biomass								
Total energy from natural inputs								
Energy products								
Prod. Energy products (exc. Own use)								
EP_1								
…								
EP_n								
Own use								
EP_1								
…								
EP_n								
Energy residuals								
ER_1								
…								
ER_n								
Other residual flows								
Residuals from end use for non-energy purposes								
Energy from solid waste								
Total Supply								

The dark areas refer to 0s.

Table 8: Example of Use table according to SEEA.

	Intermediate consumption			Final consumption	Accumulation	Flows to RoW	Flows to the environment	Total Use
	I_1	…	I_n	HH		Exports		
Energy from natural inputs								
Natural resource inputs								
Mineral and energy resources								
NI_1								
…								
NI_n								
Timber resources								
Inputs of energy from renewable resources								
NI_{n+1}								
…								
NI_x								
Other natural inputs								
Energy inputs to cultivated biomass								
Total energy from natural inputs								
Energy products								
Transformation								
EP_1								
…								
EP_n								
End use								
EP_1								
…								
EP_n								
Own end use								
EP_1								
…								
EP_n								
End use for non-energy purposes								
Energy residuals								
ER_1								
…								
ER_n								
Other residual flows								
Residuals from end use for non-energy purposes								
Energy from solid waste								
Total Use								

The dark areas refer to 0s.

This is done in a several-step process on the basis of the accounting rules described in chapter 3 of revised SEEA and the recommendation of the manual for energy accounts from Eurostat (UN 2013, Eurostat 2011). By means of these additional steps, each energy flow should be represented in the "appropriate" place in the Physical Supply Table and/ or Physical Use Table in a way that the resulting Energy Supply Tables and the Energy Use Tables match the analytical requirements of CREEA and SEEA.

For the derivation of the amounts of energy from natural inputs following procedure were applied:

A flow of energy from natural inputs occurs when energy is removed or captured from the environment by resident economic units. Such flows include energy from natural resource inputs (e.g. oil, natural gas, uranium, coal and peat, timber resources), inputs from renewable energy sources (e.g. solar, wind, hydro, geothermal), and other natural inputs (energy inputs to cultivated biomass).

The amounts of the energy associated to these flows were derived directly from the datasets previously calculated in Task 4 (RGEUT/RGEST) and represented as use of the economic unit (i.e. mostly industries) responsible for the extraction or capture of energy from the environment. In some cases additional estimations based on conventions or data on input-output efficiency were used (e.g. in energy statistics it is assumed by convention an input-output efficiency of approx. a third for nuclear power plants. This implies that 33% of the energy input – heat from nuclear fission – comes out in form of electricity. The amount of the energy from the natural resource input is estimated therefore with a factor of three of total produced nuclear power).

The non-fuel sources of energy provided by the environment: solar, hydro, wind, wave and tidal, geothermal energy etc. were accounted as natural inputs used in the production of electricity or heat/steam to ensure the balance of flows of energy between the environment and the economy.

Energy from cultivated biomass, including from cultivated timber resources[28], is treated as being produced within the economy and hence is first recorded as the flow of an energy product. However, to ensure a complete balance of energy flows in the PSUT, a balancing entry equal to the energy products from cultivated biomass is recorded as a component of energy from natural inputs in both the supply and the use tables. In the energy from natural inputs part of the use table the corresponding value for energy inputs to cultivated biomass is generally split among a number of industries depending on end use (UN 2013).

Solid waste incinerated for energy purposes is also treated as being produced with the economy. The energy embodied in solid waste is shown as entering the energy system as a residual flow (waste without monetary value) before becoming an energy product. By convention, the energy from solid waste is shown as supplied from within the economy in the accumulation column.

Residuals comprise two groups: energy residuals and other residuals, the energy flows to be accounted refer (as defined in the SEEA) to the physical energy flows that are

[28] Although natural timber resources represent an energy input from the environment, they were accounted as cultivated biomass due to the characteristics of the use data, which do not make this distinction.

discharged, or emitted by industries and households through process of production or consumption, or accumulation.

Amounts of energy residuals in terms of distribution losses were derived by means of the allocation of the available data on the original IEA balances. For the estimation of the "other energy residuals" (primarily heat generated when end users use energy products for energy purposes, i.e. dissipative losses) the calculation of the non energy uses by the industries and households was required.

After those derivation procedures, the submatrices represented in Table 7 and Table 8 were generated.

4 Air Emission Accounts

4.1 General Methodology for Calculating Air Emissions

The TNO Emission Assessment Model (hereafter referred to as "TEAM") is an emission estimation model that explicitly models the use of certain technologies (Pulles et al., 2007). This is mainly important when longer time series are studied, allowing for the introduction of new, cleaner technologies in later years. By doing so, the use of country specific emission factors (that only contain information on the "average" technology in this country) is avoided. Within this project, the model is applied to both combustion and non combustion emissions. This general methodology is similar to the methodology applied for calculating air emissions for EXIOBASE 1.0.

TEAM models the emission of a substance by applying the following equation for all countries and substances:

$$E_{substance} = \sum_{activities} \left(AR_{activity} \times \sum_{technologies} \left(EF_{technology,substance} \times P_{technology} \right) \right)$$

while at the same time ensuring that for all *activities* and all *t*:

$$\sum_{technologies} P_{activity,technology}(t) = 1,$$

where:

$E_{substance}(t)$	The emission of a certain *substance* at time *t*
$AR_{activity}(t)$	The activity rate for a certain *activity* at time *t*
$P_{activity,technology}(t)$	The penetration: fraction of the *activity* performed using the specific *technology*, at time *t*
$EF_{technology,substance}$	The emission factor, an attribute of the selected technology, which determines the linear relation between the activity rate and the resulting emission of a certain *substance*, using a specific *technology*

The various parameters in the equation have a different nature:

The changes in the structure and production of the economy are taken care of by the activity variable. The activity data contain information on production rates, but also separate sources of emissions like households and various types of transport.

Technologies determine the emission factors: each technology has a set of emission factors, one for each relevant substance, which describe the relation between the intensity of the activity and the resulting emission from the activity.

The penetration determines the selection of technologies for a certain activity. The penetration is defined as the fraction of a technology used for estimating the emissions from an activity.

The activity rate is a variable changing over time. In most inventories, the activity rate is dependent on location and time (in most inventories: country and year). The spatial and temporal resolution of the resulting emission dataset is in principal determined by the spatial and temporal resolution of the activity data.

Using this approach, the emission factors are explicitly independent of time and location. The spatial and temporal information is accounted for by the activity as well as implicitly in the penetration, which models the use of technologies varying with time and location. Emission factors are therefore only a property of the technology and not of the activity. The country specific implied emission factors as used in the classical emission inventorying are related to the emission factors in this model as being the weighted average of all technologies applied for a certain activity.

The database in which all data used in equation x is collected has been built in MS Access. Figure 5 gives an overview of the core structure of the database.

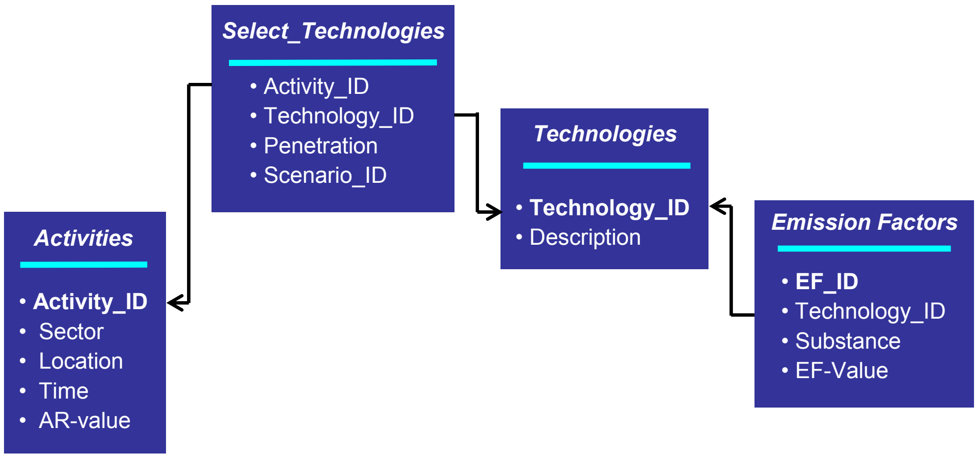


Figure 5 Overview of the core tables in the TEAM database structure

The emission inventory in TEAM is compiled in a 3-step procedure:

The "Activities" table is filled with activity rates dependent on the sector and with spatial and temporal component. This table represents the economic aspect, similar to the classical inventory approach. The activities table may be preceded by a "Sources" table, in which the sector is further specified (source description, fuel type (if applicable)).

The technological aspect is represented by the "Technologies" table, which is filled with relevant technologies that can be used to perform the activity, independent of the spatial and temporal variables. In the "Emission Factors" table, each technology has a set of emission factors, one for each relevant substance.

The "Select_Technologies" table represents the behavioural aspect and chooses one or more technologies for each activity, each weighted with its penetration rate. The model has also the opportunity to assess various scenarios, but this function is not used in the framework of CREEA.

As soon as one or more technologies have been chosen for each activity (i.e. the "Select_Technologies" table has been filled), the emissions may be calculated by applying the equation given in the beginning of this section. Depending on the level of detail required for the resulting emissions of each substance, a summation over technologies and/or activities is made.

The TEAM model uses the "sector classifications" as used in the official air emission reporting requirements (following the territory principle).

The (total) air emission accounts are calculated by adding up the following partial air emission accounts (all in tons):

- Air emission accounts from combustion uses of energy products, see Chapter 4.2;
- Air emission accounts from non-combustion uses, which can be further disaggregated into:
    - Air emission accounts from the non-combustion use of energy products (chapter 4.3);
    - Air emission accounts from the use of non-energy products (chapter 4.4).

Air emission accounts from agriculture and waste are calculated separately, this is described in deliverable D4.2.

4.2 Air Emissions from Combustion Uses

4.2.1 Emission Factors

As mentioned in Section 2.2.3, the calculation of air emissions is a combination of an activity rate, emission factor, and technology penetration grade. The delivery of WP6.1 is a dataset of emission factors, however within the task an emission model (TEAM) has also been developed, which applies these emission factors. The goal of this emission model is to check the validity of the results when the emission factors are applied, and to correct/adjust them where necessary. Also, the resulting emissions can directly be compared to other datasets, highlighting the similarities and differences (see Chapter 5). This section describes in detail the selected emission factors and their link to the energy supply and use tables discussed in the preceding chapter 3.1.2.

The activity rate in this case is the amount of energy used (in energy units). For CREEA, the IEA energy statistics are used. Emissions from combustion are calculated by selecting those sectors (here IEA items and products) which represent emission relevant energy use. For each of these activities, one or more technologies are selected with each their emission factors for the relevant substances.

Emission factors are selected for both greenhouse gases and air pollutants. For both, internationally established methodologies do exist on how to make an emission inventory at national level which is suitable for reporting under the international reporting obligations (UN Framework Convention on Climate Change, UNECE Convention on Long Range Transboundary Air Pollution).

4.2.1.1 IPCC Guidelines for National Greenhouse Gas Inventories

The 2006 version IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) has been written and published by the IPCC's National Greenhouse Gas Inventories Programme (IPCC NGGIP). The Guidelines contain emission estimation methods for greenhouse gases and all sources which are considered to be possibly important on a local scale.

The emission estimation methods are based on the IPCC source classification, which is in general similar to the NFR (Nomenclature For Reporting) format as used in this inventory. Where necessary, emissions have been aggregated to a higher level to create one general reporting format for the inventory.

For each source, the Guidelines describe one or more methods to estimate the emissions for the source, through the concepts of Tiers:

A Tier 1 method is the simplest available emission estimation method for each source category. A typical activity parameter (energy use, production volume) is multiplied by one generic emission factor for each substance to get the total emissions from this source category.

A Tier 2 method is more detailed than the Tier 1. A breakdown of the sector in various technologies is performed, which are defined as alternative ways to perform the activity (with each its relevant emission factors). For each technology, the proportion of the activity performed using this technology is multiplied by the relevant emission factor. A summation over technologies results in the total emissions from each substance.

A Tier 3 method is again a more detailed method than the Tier 2 method. There is no general description for the Tier 3 method, since it depends on the source category what the more detailed methods would look like. The basic definition of a Tier 3 method is "anything beyond Tier 2".

In the national reporting requirements, Tier 2 or Tier 3 must be used if a source is important in the national inventory. A Tier 1 method is only allowed to be used if the contribution of emissions from a certain source category is unimportant with respect to the total emissions (for a selected substance).

For the inventory described in this report, only the emission factors for the 3 most important greenhouse gases have been used: CO_2, CH_4 and N_2O. As for the other greenhouse gases (e.g. SF6, HFCs, PFCs), emission factors are very difficult to establish in a generic way, since emissions are estimated in more enhanced methods. For these methods multiple input parameters are necessary, which are very difficult to find. Emissions are available though from the UNFCCC reports and other scientific databases, and these emissions are available for use in CREEA.

Furthermore, Tier 1 methods have been used to estimate emissions where – according to the Guidelines – Tier 2 or Tier 3 methods should have been used. This has been done because of the lack of activity data for some sources, and the limited differences. For instance for CO2, the emission factor will only depend on the fuel type, and the exact technology used is not relevant.

An overview of the methods to estimate greenhouse gas emissions used for this inventory can be found alongside with the relevant activity statistics in an Annex to this report.

4.2.1.2 EMEP/EEA Emission Inventory Guidebook

The EMEP/EEA Emission Inventory Guidebook (TFEIP, 2009), formally known as the EMEP/CORINAIR Guidebook, contains methods for estimating emissions from all major substances emitted to air[29]. The Guidebook is edited by the Task Force on Emission Inventories and Projections (TFEIP) and published by the European Environment Agency (EEA).

The latest version of the Guidebook has been published in 2009 and reflects the latest scientific information on emission factors of air pollutants for all relevant sources of anthropogenic emissions. The Guidebook describes methodologies to report emissions following the reporting requirements from the Convention on Long Range Transboundary Air Pollution (LRTAP) and the European Union's National Emission Ceilings Directive (NECD). Both these instruments require countries to annually report their emissions to both the LRTAP Convention and the European Union, using the methodologies described the EMEP/EEA Guidebook as the minimum method.

The Guidebook is organised following the NFR (Nomenclature for Reporting) structure, identical to the reporting requirements under the LRTAP Convention and the NECD. Furthermore, the Guidebook has emission estimation methodologies organised in Tiers, similar to the 2006 IPCC Guidelines (see above).

As for the IPCC Guidelines, in most cases simple Tier 1 or Tier 2 methods have been used in order to estimate the emissions, mainly because lack of worldwide available data prevented the use of more detailed methods (higher Tiers). However, for the most important sources, e.g. power plants and some larger industrial facilities in developed countries, more detailed methods (Tier 2) have been used, assuming a typical abatement levels for these countries.

The Guidebook covers all air pollutants (non-greenhouse gases) that are included in the protocols of the Convention on Long Range Transboundary Air Pollution. These pollutants include:
Main pollutants: NO_x, SO_x, CO, NMVOC, NH_3
Particulate matter: TSP, PM_{10}, $PM_{2.5}$
Priority heavy metals: Pb, Cd, Hg
Other heavy metals: As, Cr, Cu, Ni, Se, Zn
Persistent organic pollutants (21 substances)

With regard to persistent organic pollutants (POPs), the use of many of these substances is prohibited in developed countries. Therefore, these substances are not emitted to air

[29] This includes the air pollutants listed in the protocols, which are due to be reported under the LRTAP Convention and the NEC Directive.

anymore and as such also not included in the emissions. These substances are likely to be still emitted in developing countries, but unfortunately emission estimation methodologies are only available for a limited number of POPs.

4.2.1.3 Selection of emission factors

For each IEA flow and product, one (or more) emission factor(s) (and penetration grade) has to be selected.

The global emission inventory for CREEA is set up using the CRF and NFR source codes, as they are used in international emission reporting. These two source codes are very similar, only at detailed level differences exist. The codes have been harmonized for this inventory, to ensure consistency within the database and prevent errors or missing data. However, for the energy related emission factors, also the IEA flow and product codes are included and these are the codes that link the emission factors to selected industries.

To select the correct emission factors, link tables are needed between the emission factors in the guidance documents for emission inventory methodologies (based on CRF/NFR source codes) and the flow and product combinations used in the IEA energy statistics. In the tables below, these link tables are given.

IEA_flow	CRF/NFR	Source Category Name
EPOWERPLT	1.A.1.a	Public electricity and heat production
AUTOHEAT	1.A.1.a	Public electricity and heat production
MAINHEAT	1.A.1.a	Public electricity and heat production
AUTOELEC	1.A.1.a	Public electricity and heat production
AUTOCHP	1.A.1.a	Public electricity and heat production
MAINELEC	1.A.1.a	Public electricity and heat production
MAINCHP	1.A.1.a	Public electricity and heat production
EREFINER	1.A.1.b	Petroleum refining
EOILGASEX	1.A.1.b	Petroleum refining
EMINES	1.A.1.c	Manufacture of solid fuels and other energy industries
EBIOGAS	1.A.1.c	Manufacture of solid fuels and other energy industries
EBKB	1.A.1.c	Manufacture of solid fuels and other energy industries
ECHARCOAL	1.A.1.c	Manufacture of solid fuels and other energy industries
ECOALLIQ	1.A.1.c	Manufacture of solid fuels and other energy industries
ECOKEOVS	1.A.1.c	Manufacture of solid fuels and other energy industries
EGASWKS	1.A.1.c	Manufacture of solid fuels and other energy industries
ELNG	1.A.1.c	Manufacture of solid fuels and other energy industries
EGTL	1.A.1.c	Manufacture of solid fuels and other energy industries
ENONSPEC	1.A.1.c	Manufacture of solid fuels and other energy industries
EPUMPST	1.A.1.c	Manufacture of solid fuels and other energy industries
EPATFUEL	1.A.1.c	Manufacture of solid fuels and other energy industries
IRONSTL	1.A.2.a	Manufacturing industry, iron and steel
EBLASTFUR	1.A.2.a	Manufacturing industry, iron and steel
NONFERR	1.A.2.b	Manufacturing industry, non-ferrous metals

IEA_flow	CRF/NFR	Source Category Name
CHEMICAL	1.A.2.c	Manufacturing industry, chemicals
PAPERPRO	1.A.2.d	Manufacturing industry, pulp, paper and print
FOODPRO	1.A.2.e	Manufacturing industry, food processing, beverages and tobacco
CONSTRUC	1.A.2.f	Manufacturing industry, other sectors
MACHINE	1.A.2.f	Manufacturing industry, other sectors
NONMET	1.A.2.f	Manufacturing industry, other sectors
TRANSEQ	1.A.2.f	Manufacturing industry, other sectors
INONSPEC	1.A.2.f	Manufacturing industry, other sectors
TEXTILES	1.A.2.f	Manufacturing industry, other sectors
MINING	1.A.2.f	Manufacturing industry, other sectors
WOODPRO	1.A.2.f	Manufacturing industry, other sectors
WORLDAV	1.A.3.a	Civil aviation
DOMESAIR	1.A.3.a	Civil aviation
ROAD	1.A.3.b	Road transport
RAIL	1.A.3.c	Railways
DOMESNAV	1.A.3.d	Navigation
WORLDMAR	1.A.3.d	Navigation
TRNONSPE	1.A.3.e	Pipeline compressor and other transportation
PIPELINE	1.A.3.e	Pipeline compressor and other transportation
COMMPUB	1.A.4.a	Commercial/Institutional
RESIDENT	1.A.4.b	Residential
FISHING	1.A.4.c	Agriculture/Forestry/Fishing
AGRICULT	1.A.4.c	Agriculture/Forestry/Fishing
ONONSPEC	1.A.5	Other combustion

Using the CRF/NFR reporting codes, the relevant emission factors can be selected from the emission estimation guidance documents. To do this, also a link between the fuel types has to be established. Since there is no standardized fuel definition in the emission inventory guidance material, a one-by-one selection has been made, to select for each IEA flow & product combination the correct set of emission factors.

For most sectors, relatively simple default Tier 1 emission factors have been used, representing the emission assuming an average technology level. These average emission factors are developed specifically for sources which do not contribute very much to the national total emissions, and therefore a simple methodology to estimate the emission value can be justified. In contrast to these small sources, sources such as power plants, large industrial installations, or road transportation, contribute a significant amount to the national total emissions for a number of pollutants. For these sources, country specific information and/or technology breakdowns are necessary for estimating emissions, and country and/or technology specific emission factors are needed. However, the detailed data needed to apply such a detailed methodology are not always available, especially for non-EU countries.

In this study, we have applied the more detailed approach for these larger sources where possible. If this was not possible due to lack of data, we have applied the simpler Tier 1 methodology, and thereafter compared with other estimates at the detailed level (for the comparison see Chapter 5). Where significant differences were observed, these have been examined in more detail and based on this, an alternative emission factor was developed, which is thought to better represent the situation in the specific sector and country.

Road transport model

One of the most important sources of air pollution is road transportation. Since for road transport a lot of information is available on technologies and emissions, a more detailed model has been elaborated for its emissions, and emission factors are calculated separately for each country, fuel and pollutant based on the detailed data available.

As for the other combustion sources, the IEA values have been used as the baseline (IEA flow ROAD). For each country and each fuel, the energy use in road transportation has been disaggregated to a detailed level by using data from TML (Transport and Mobility Leuven) and their TREMOVE model (TML, 2011) for Europe. Apart from the TREMOVE model, a separate dataset (VPPT) (TML, 2012) has been obtained from TML, which contains information on the split of the energy use per fuel over vehicle types in regions around the world, including the non-European domain. In some cases, data for the specific year 2007 were not available and 2005 data have been used instead. This is reasonable since the data are only used for disaggregating the IEA energy use data.

In short, the approach followed for road transportation:

- For the activity data, TREMOVE data are used to disaggregate IEA energy use by fuel and country to the most detailed level (including vehicle category, vehicle type, vehicle technology and road type). For countries not included in TREMOVE, VPPT data from TML have been used to disaggregate the IEA data into vehicle categories. Then, these data are disaggregated further to the same level as TREMOVE by assuming for each country a representative distribution based on the available distributions from the countries included in TREMOVE. For instance, for the US an average distribution of the EU15 (western Europe) has been assumed, while for China the average distribution of the non-EU countries in TREMOVE has been assumed.
- Emission factors at the same level of detail are available from another FP7 project TRANSPHORM (focusing on the impact of transport of human health) and are developed by the University of Thessaloniki (AUTH, 2012). These emission factors are the state-of-the-art in Europe. The emission factors cover all relevant pollutants from road transport, including the non-exhaust emissions from gasoline evaporation and from wear. These emission factors are country specific as well and only available for EU Member States. For all countries not considered in this database, an average of the EU emission factors have been assumed (not crucial since they are already technology dependent). The emission factors are originally given in g/km. The conversion to kg/TJ has been made by taking the ratio of the CO2 emission factor from the emission factors (in g/km) and the CO2 emission factor from the IPCC Guidelines (in kg/TJ), and apply this to each emission factor.
- After preparing both the activity data (for all countries in the world), and the emission factors (also for all countries in the world), the two have been combined and the emissions have been calculated, whereafter the data have been aggregated over vehicle categories, types and technologies to receive the total activity (in TJ) and

emission (in kg) per pollutant for road transport by fuel and country. By dividing these two, the implied emission factor for the specific country is obtained.

Using this information, a detailed estimate of the emissions from road transport has been made for each country. To calculate the final emission factors,

The resulting emissions are shown in Chapter 5 of this report.

4.2.2 Calculation of air emissions from combustion uses

The procedure to calculate the air emission accounts related to combustion uses is very similar to the procedure to calculate the corresponding emission relevant energy use tables.

From the task above, emission factors in the format of the IEA balances (63 energy products x 85 items) are obtained for 27 different air pollutants. This emission factors are expanded to a 63 x 89 matrix to match the energy matrices in residence principle (c.f. Task 2 in Chapter 3.1.2).

A simple cell-by-cell multiplication of the emission relevant energy uses by the corresponding emission factors gives the combustion related emissions of a given pollutant in a 63 x 89 matrix format. To allocate these emissions to their corresponding CREEA industries and final use categories the same procedure applied for the emission relevant energy uses is applied as explained in Chapter 3.1.2.

4.3 Air Emissions from the Non-Combustion of Energy Products

4.3.1 Introduction and sources covered

Emissions from non-combustion of energy are resulting from the extraction, processing, transformation and distribution of fossil fuels. The main emissions occurring in this phase consist of CH_4, NMVOC and particulate matter, particularly during transport, storage and distribution (e.g. leakages) of fossil fuels, in solid, liquid as well as gaseous forms.

The IPCC Guidelines and the EMEP/EEA Guidebook consider a number of sources of emissions in the national greenhouse gas and air pollution inventories. These sources are given in Table 9, where also the links to the relevant IEA items are given, which are used as activity variable where the emission factor can be applied to.

Table 9: Overview of emission sources covered in the non-combustion of energy products, and their link to the IEA flow and product items

IEA_flow	IEA_product	CRF/NFR	Source Category Name
INDPROD	ANTCOAL	1.B.1.a	Coal mining and handling
INDPROD	BITCOAL	1.B.1.a	Coal mining and handling
INDPROD	BROWN	1.B.1.a	Coal mining and handling

IEA_flow	IEA_product	CRF/NFR	Source Category Name
INDPROD	COKCOAL	1.B.1.a	Coal mining and handling
INDPROD	HARDCOAL	1.B.1.a	Coal mining and handling
INDPROD	LIGNITE	1.B.1.a	Coal mining and handling
INDPROD	SUBCOAL	1.B.1.a	Coal mining and handling
INDPROD	GASCOKE	1.B.1.b	Coal to coke transformation
INDPROD	OVENCOKE	1.B.1.b	Coal to coke transformation
INDPROD	PETCOKE	1.B.1.b	Coal to coke transformation
INDPROD	CRUDEOIL	1.B.2.a	Oil production and distribution
TREFINER	CRUDEOIL	1.B.2.a	Oil refining
TOTTRANS	JETKERO	1.B.2.a	Oil products distribution
TOTTRANS	GASDIES	1.B.2.a	Oil products distribution
TOTTRANS	MOTORGAS	1.B.2.a	Oil products distribution
INDPROD	NATGAS	1.B.2.b	Gas production and distribution

4.3.2 Emission Factors

As for the emission factors for energy, the emission factors for these sources are taken from the IPCC Guidelines and the EMEP/EEA Guidebook (see sections 4.2.1.1 and 4.2.1.2 for more information).

For these sources, mostly Tier 1 emission factors have been applied. Since the quality of fuels and the control of (unintentional) releases differs a lot between different parts in the world, this does not accurately reflect the emissions in all cases.

Therefore, based on comparisons with other international emission datasets, emission factors have been aligned with these estimates where necessary to reflect better the official national total emissions from these sectors.

The resulting emissions are displayed in Chapter 5.

4.3.3 Allocation to CREEA products

The source categories in the CRF/NFR classification and the industries and IFU categories in CREEA do not match. Thus, an allocation matrix is needed to link the emissions from the non-combustion of energy products as obtained in CRF/NFR format and the EXIOBASE 2.0 categories.

To achieve full consistency over products, each of the CRF/NFR categories in the emission model has been linked to the corresponding product which is being manufactured, either on the supply or on the use side. For instance, the coal mining and handling is allocated to the supply of the various coal products, while the oil refining is allocated to the use of crude oil. This approach is different to the approach applied in EXIOPOL, where the allocation has been to industries. The reason to do so, is to ensure that the mass balances at product level can be made (WP4).

4.4 Air Emissions from Non-Energy Products

4.4.1 Introduction and sources covered

Emissions to air do not only arise from the combustion of fuels (chapter 3) and the extraction, transformation and distribution of fossil fuels (chapter 4.3). Processes in e.g. the manufacturing industry may not be related to combustion, but during industrial production processes chemical and physical reactions may lead to certain gases being formed and emitted into the air. For instance, CO2 is formed during the cement production as part of the main process reaction.

Two main sources of air emission can be distinguished:
- Industrial sources: mineral industry, chemical industry, metal industry, paper and pulp industry, food industry
- Solvent and other product use

These main sources are split into several processes and sources of emissions, for which both activity data (e.g. annual production figures) and emission factors (e.g. amount of emission per unit production) have been collected in order to calculate the emissions. A full overview of the detailed sources is available in the Annex to this report.

4.4.2 Emission Factors

As for the energy sections, relevant emission factors have been selected from the IPCC Guidelines for greenhouse gases, and the EMEP/EEA Guidebook for air pollutants. As for the energy sources, mostly Tier 1 emission factors are used representing a typical situation in a country. For selected sources which are relatively high emitters however, such as the iron and steel industry, more advanced methodologies have been applied to reflect the actual emissions resulting from each of the activities.

For the category "product use" (NFR sector 3), the methodology applied is different. Since it is very difficult to find the correct and consistent activity data for this sector, especially considering the global scale of CREEA, it has been chosen to apply the GAINS model approach for NMVOC emissions from this sector.

The GAINS model is developed by IIASA for analysing policy measures and impacts for both air pollutants and greenhouse gases, and provides a complete and consistent overview of activities and emissions for the European domain, but also for some other major world regions such as China and India. For the product use sector, the model considers a number of activities which are listed in the Annex to this report, for both the model gives activity data and emission factors. For the countries not included in the GAINS model, average emission factors from the other countries are assumed.

4.4.3 Activity data used in TEAM

In order to make the full emission inventory for the non-energy products, not only emission factors but also activity data are a necessary piece of information. In contrast to the energy emissions, there is no global dataset such as the IEA statistics which can be used, but all kinds of individual statistics have to be combined. The table in the Annex contains a full overview of the data sources used for the activity data.

Data have been collected for a set of 43 countries and for the rest of the world as a whole, however they are not always available. Especially for non-European or developing countries, data are often lacking or considered of insufficient quality. It has been chosen to use a single source representing the activity for a certain source to ensure consistency and transparency between countries. A gapfilling procedure has been applied to estimate activity data for missing countries, which is described in detail below.

In order to complete our database with activity rates, activity data for countries where no data are available are estimated using the countries' GDP as a proxy. This seems the most reasonable proxy parameter, since countries with higher industrial production shares often have also higher total GDP values. Of course this will not always be true, but in this case it is the best available.

The GDP values for the year 2007 have been collected from the World Bank (World Bank, 2012).

The search for data is not only done with respect to individual countries, but also towards world totals. In the CREEA project, next to individual countries, an estimate of emissions from "other" countries has to be made (in the form of 5 country groups). Because of the difficulty in finding data for many developing countries, it has been chosen to use total world activity rates where available, and calculate the activity rates for "other" countries as the difference between world and the individual countries considered. The distribution over the individual countries is performed using weighted GDP factors.

Thus, two different cases can be considered for estimating activity rates for countries for which these are not directly available:

- *Available world total activity rate*
  When the total activity rate in the world is known, this is used in the estimation of activity rates for specific countries. In this case, activity rates for countries in which it is not known are estimated by distributing the remaining activity rate (difference between the world total and the sum over all available activity rates) over all countries using their relative GDP as weighting factor. This ensures that the total activity rate for the world is always consistent with $AR_{world,source}(t)$. In formula:

$$\frac{AR_{country,source}(t)}{GDP_{country}(t)} = \frac{AR_{world,source}(t) - \sum_{ref.countries} AR_{country,source}(t)}{GDP_{world}(t) - \sum_{ref.countries} GDP_{country}(t)}.$$

  In this case, to the right of the equal sign is the ratio of "remaining" activity rates to be distributed over the "unknown" countries and the GDP of these countries, which represents an averaged activity rate per GDP. This averaged activity rate per GDP is then multiplied by a countries' GDP in order to estimate the activity rate.

- *Unavailable world total activity rate*
  The unknown activity rate $AR_{country,source}(t)$ is estimated for each year *t* by applying linear regression with constant offset (*y*=*a*+*b***x* with *a*=0):

$$\frac{AR_{country,source}(t)}{GDP_{country}(t)} = \frac{\sum_{ref.countries} AR_{country,source}(t)}{\sum_{ref.countries} GDP_{country}(t)}.$$

The right side of the equation consists of the ratio of the sum of all activity rates for all reference countries (defined as the countries for which relevant activity data are available) and the sum of the GDP for these reference countries. This ratio represents an averaged activity rate per GDP. This averaged value is applied to all countries for which the activity rate is unknown. In mathematical terms this method is identical to a linear regression through the origin. This is far from an ideal method, the R^2 values (indicating the linearity of the data) vary a lot between sources, and in some cases estimates for the whole world are based on a limited number of real values. However, since data are usually for the major sources and for major countries, the estimated emissions using GDP only make up a small part of the total emissions.

4.4.4 Allocation to CREEA products

As in the case of emissions from the non-combustion of energy products, the categories given for the emission factors and the EXIOBASE 2.0 categories do not match. To overcome this problem, the same approach has been used as in chapter 4.2.1. Therefore, each of the CRF/NFR categories has been linked to the corresponding product which is being manufactured, either on the supply or on the use side. For instance, the coal mining and handling is allocated to the supply of the various coal products, while the oil refining is allocated to the use of crude oil. This approach is different to the approach applied in EXIOPOL, where the allocation has been to industries. The reason to do so, is to ensure that the mass balances at product level can be made (WP4).

4.4.5 Emissions of SF6, HFCs and PFCs

Due to limitations in data availability, not all the emissions could be calculated using the TEAM model. For emissions from HFC, PFC and SF6, emissions cannot be calculated by combining activity data and emission factors in a generic way. The IPCC 2006 Guidelines give guidance for estimating these emissions on a country level, however this requires the use of multiple variables rather than one generic emission factors.

Because it is within CREEA not possible to collect all these data on global level, it has been chosen to apply a different approach, i.e. the direct use of the emission data reported in UNFCCC for these specific pollutants. Since only Annex I countries in UNFCCC report these emissions, data from the JRC EDGAR emission model have been used to complete this dataset.

These data have been supplied separately to WP7 and will be considered for the updated EXIOBASE database.

4.5 Air Emissions from Agriculture

This section of the report describes emission factors for agriculture. Emission factors for most of the relevant pollutants (CH_4, N_2O, NO_X, NO_3) are not calculated by the WP6 but provided by WP4. Therefore, these factors are not described in this report but in D4.2.

4.5.1 Introduction

Emissions of particulate matter from agriculture arise from both animal husbandry and from crop treatment. These two sources are briefly discussed below.

4.5.2 Emission Factors

Emission factors for PM from animal husbandry include both PM10 and PM2.5 emission factors for the different animal types. For crops, one generic emission factor is provided representing the PM emissions from crop treatment and agriculture activities on the famers' land. These exclude the PM emissions from the combustion of fuels, e.g. in tractors.

Other emission factors than PM are estimated in WP4, see D4.2 for details.

4.5.3 Activity data

For the activity data in the agricultural sector, FAOSTAT data are used on the number of animals and the amount of crops.

4.6 Air Emissions from Waste Management

Emission factors for waste treatment are not covered by this report but described in D4.2.

5 Air Emission Accounts, Air Emission Inventories, and their Numerical Differences

As explained in Chapter 2.2.1, air emission accounts and air emission inventories can lead to very different results due to the different accounting principles. On the one hand, differences on the country level arise from the mismatch between the non-residents' activities within a territory (accounted for in inventories[30], but not in accounts) and the residents' activities in a foreign country (accounted for in accounts, but not in inventories). Further, international marine and aviation bunkers are kept out of the country totals in inventories, while they are part of air emission accounts.

At the global level, both datasets differ due to the inclusion of the bunkers in the air emission accounts. If these emissions are subtracted, the global emissions need to be equal under the territory and residence principles.

The numerical differences between inventories and accounts are shown in the next section. Thus, Section 5.1 gives an overview of the general results by showing the ratio between combustion related, non combustion related and non energy emission for each pollutant. Section 5.2 shows a few examples of the differences between the results of emission accounts and inventories, while Section 5.3 compares the emissions resulting from multiplying the emission factors by the energy uses in the territory principle with other emission inventories.

5.1 CREEA Air Emissions

Within this project, a global emission database has been calculated, having state-of-the-art emission estimates for each selected country, industry, product and air pollutant. Figure 6 shows all the pollutants included in the inventory, and the contribution of the energy (combustion and non-combustion) and non energy to the total emissions calculated. The figure shows clearly that for most pollutants, combustion of (fossil or bio) energy is the most relevant source of the emissions. For selected pollutants such as CH4 and NMVOC, the non-combustion part of energy use plays a role, mainly in the form of leakages and other diffuse emissions. For non energy, the chlorinated hydrocarbons are the only from this source, while some other pollutants such as PM10 and CO also show major contributions which are largely related to biomass burning in tropical regions. Other air pollutants like CH4, N2O and NH3 emissions are largely related to agricultural activities.

[30] For readability, in the following sections the terms „inventories“ and „accounts“ refer to „air emission inventories“ and „air emission accounts“, respectively.

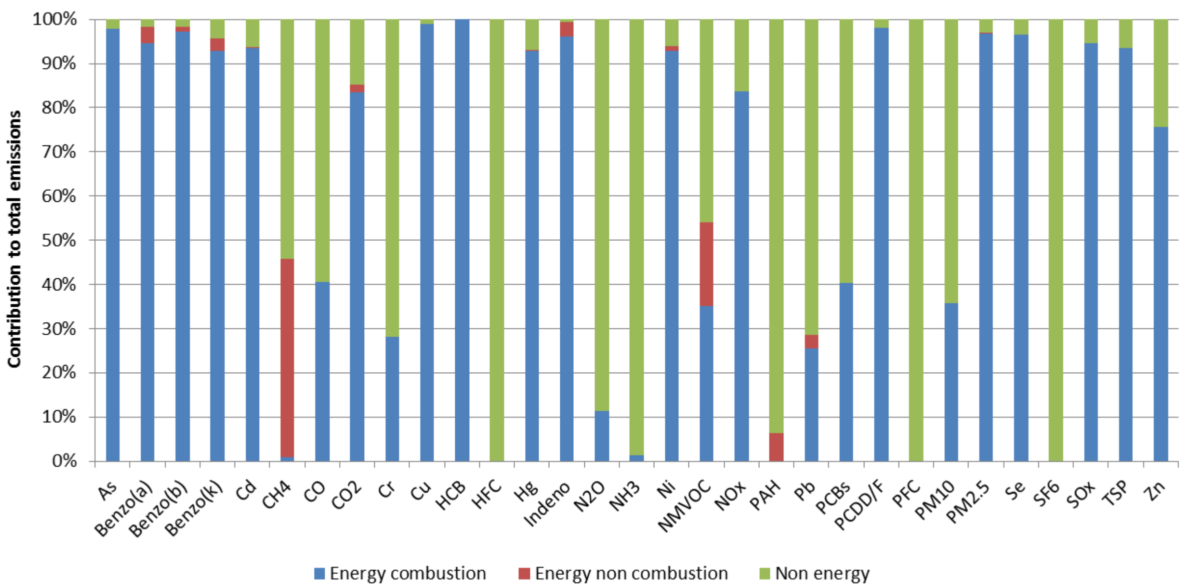


Figure 6: The contribution of energy (combustion and non combustion) and non energy to the total global emissions of CREEA, for each pollutant (n.b. excludes emissions from waste treatment)

5.2 Numerical Differences between Territory and Residence Principle in the Case of Combustion related Emissions

It has been mentioned several times the difference between the residence and the territory principle and how the results change depending on which one is applied. Figure 7 and Figure 8 show the numerical differences for CO2 and SOX from combustion[31]. The values for both principles have been obtained by multiplying energy uses according to the territory and to the residence principle by the emission factors obtained from Chapter 4.

[31] China and United States have not been included in the graph because they distort the results due to their high CO2 and SOX emissions.

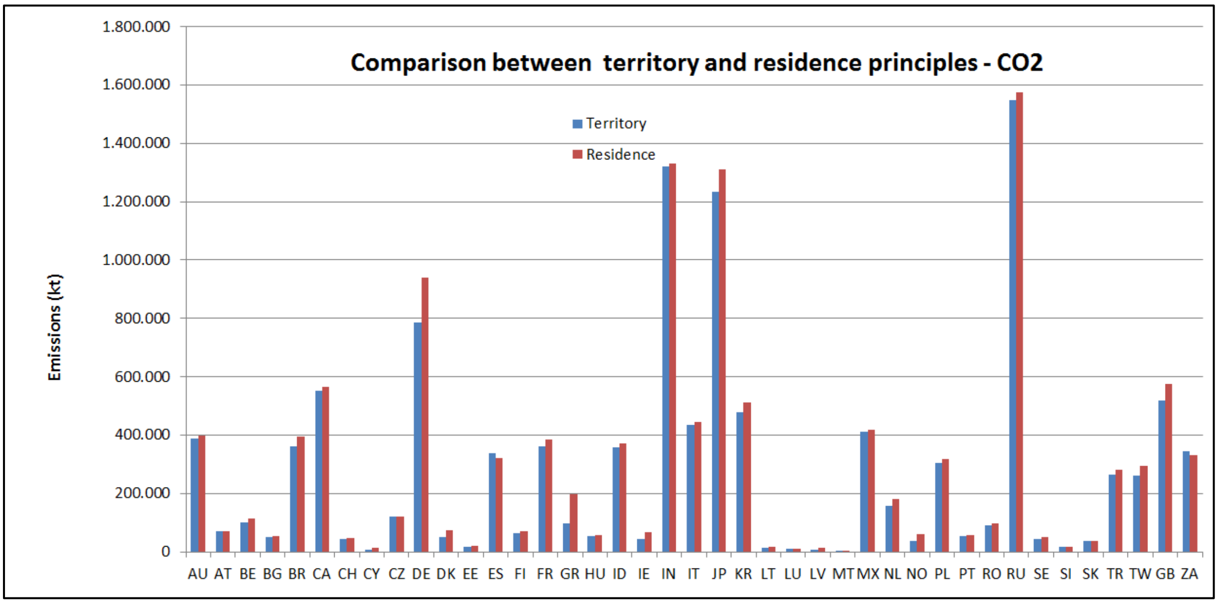


Figure 7: The differences between the combustion related CO2 emissions applying the territory and the residence principles

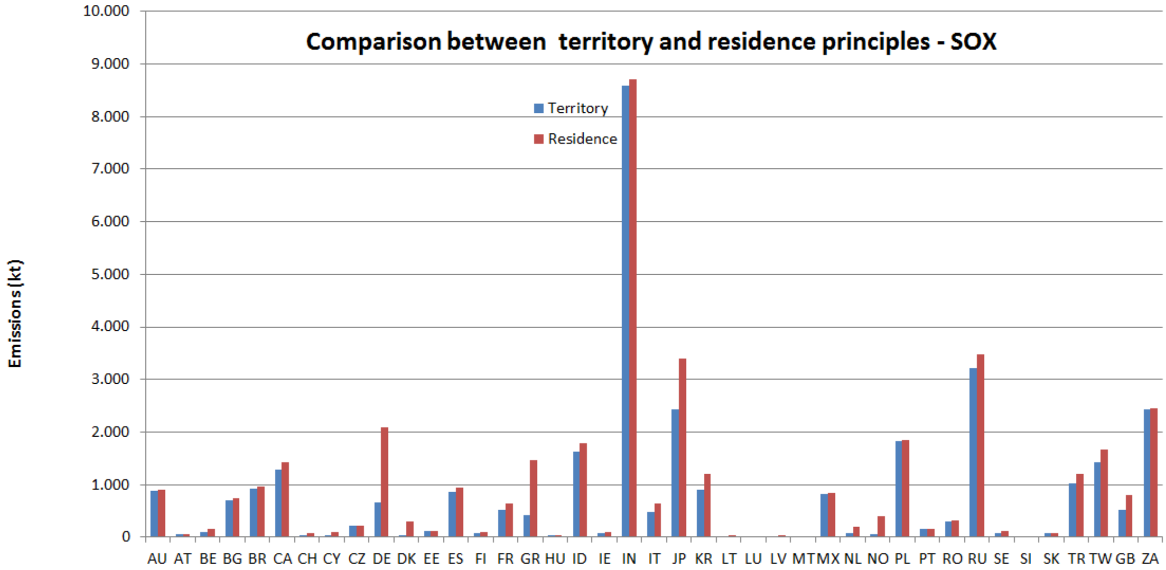


Figure 8: The differences between the combustion related SOX emissions applying the territory and the residence principles

For almost all countries the combustion related CO_2 emissions are higher under the residence principle. This is because the emission from international aviation and marine bunkers are not accounted for in country totals under the territory principle. Accordingly, the difference is higher in countries with large aviation and marine fleets (e.g. DE, DK, GR).

This fact can be better appreciated in Figure 8, which compares the SOX emissions, since shipping is a major source of this pollutant. Road transport can also be an important factor that explains the differences shown in the first graphs. Its relevance in the second is limited, since the use of cleaner fossil fuels in the road fleet has significantly decreased the SOX emissions in this area.

5.3 Verification of Emission Estimates

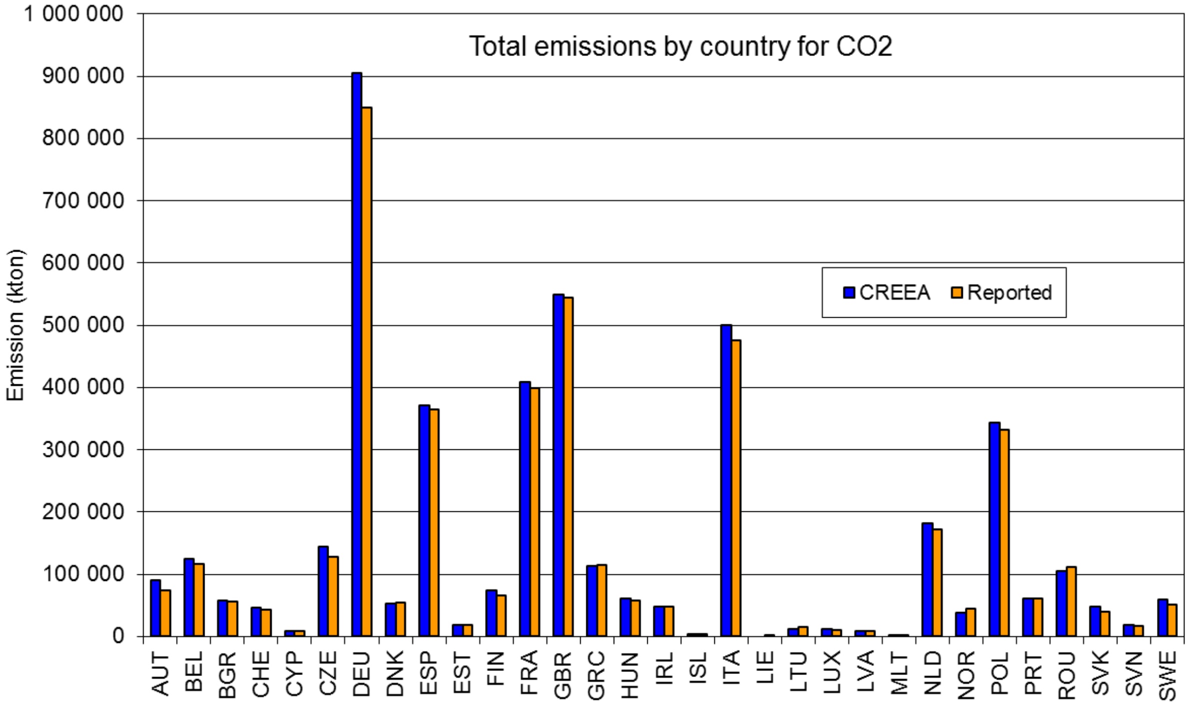
One of the primary deliverables of this task 6.1 is the emission factors by CREEA industry, product, country and pollutant, for the year 2007, as input to WP7. However, to check the emissions before sending out emission factors, and compare them to other datasets, we have also combined the selected emission factors with the relevant activity data in order to make a full emissions inventory and check the resulting emissions with other estimates. This section presents the results of this comparison.

Note that the IEA energy statistics applied to calculate the energy related emissions in this comparison are based on the territory principle, which might lead to deviations with the actual results (e.g. through the re-allocation of transport emissions).

To make the comparison, emissions from agriculture have been added for CH_4 and N_2O based on the UNFCCC reporting, complemented by EDGAR emission estimates at sectoral level where UNFCCC data were not available (for non Annex I countries). The waste sector is not taken into account in this comparison, therefore country totals in this comparison are slightly below the official country totals for all sectors.

Data have been compared to:
- National total emissions as reported by countries under the UNFCCC (for greenhouse gases) and CLRTAP (for air pollutants), for European countries only
- EDGAR (Emissions Database for Global Atmospheric Research): a scientific database with emission estimates for the whole world.

Figure 9 shows the comparisons with the nationally reported emissions for European countries. National reported emissions are taken from the EEA databases (http://www.eea.europa.eu/data-and-maps/) available online by mid-2012. Graphs are shown for CO_2 and NO_X, being two of the main air pollutants. The comparison shows quite good agreement between the two datasets as for the national totals. For Poland and NO_X there is an error in the reported emissions database where Poland was missing.



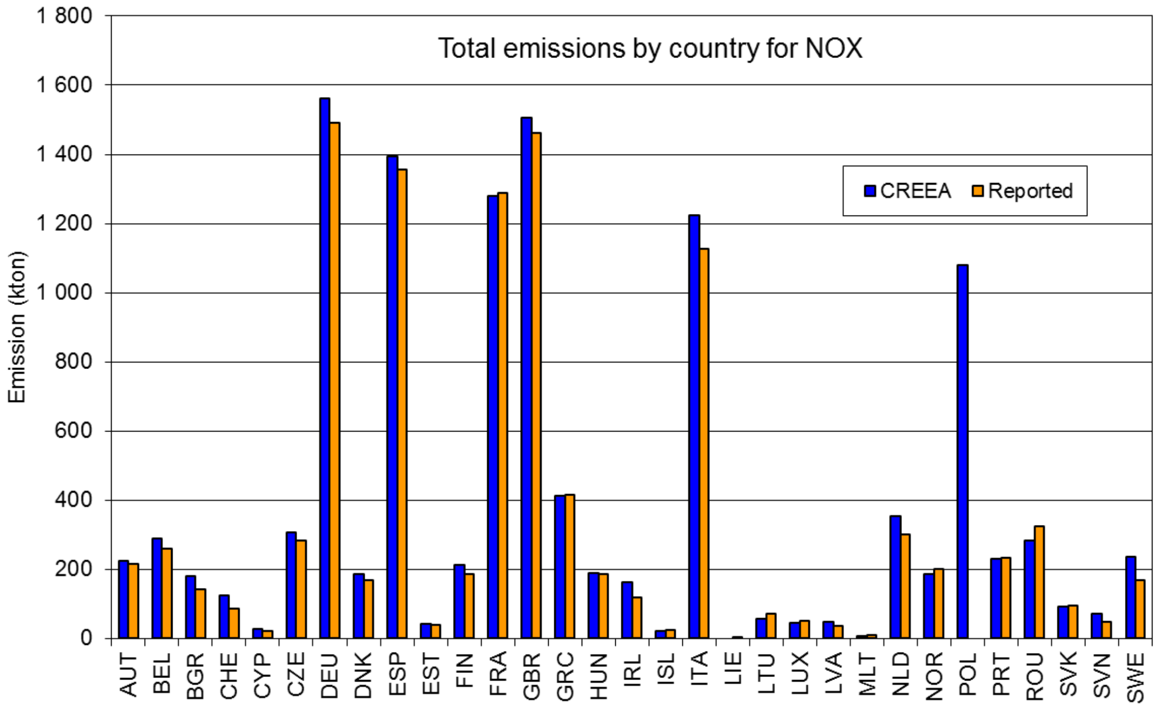


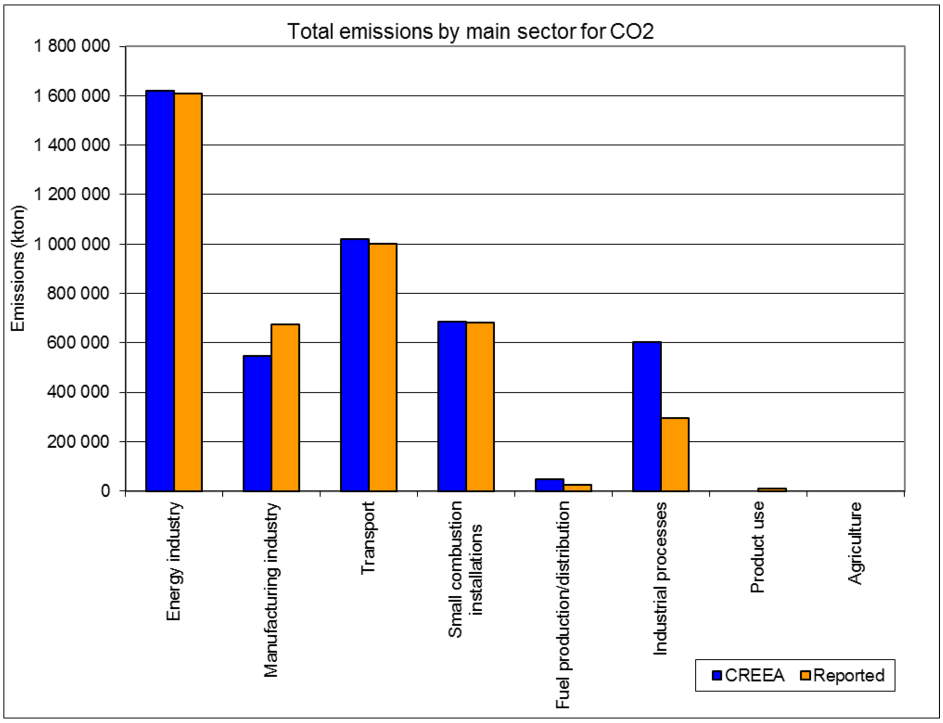
Figure 9: Comparison of CREEA emissions with national reported emissions to UNFCCC/CLRTAP (countries represented by their ISO3 code) for CO2 (upper panel) and NOx (lower panel)

Figure 9 shows a good match between the emissions of CREEA and national reported emissions for CO2 and NOX, although small deviations exist. These may be caused by:

- National inventories applying slightly different emission factors than applied in CREEA, reasons for this may be

- Activity data may have changed, i.e. a newer version of the IEA Energy Statistics with corrections or updates might result in an increase or decrease in the emissions.

To check the distribution over main sectors, the comparison has also been made by sector, for all countries. This is shown in Figure 10 for CO2 and NMVOC, respectively, as examples. It is shown that between sectors there are some deviations. For CO2, between manufacturing industry (fuel combustion) and industrial processes (non-combustion) there appears to be a mismatch.



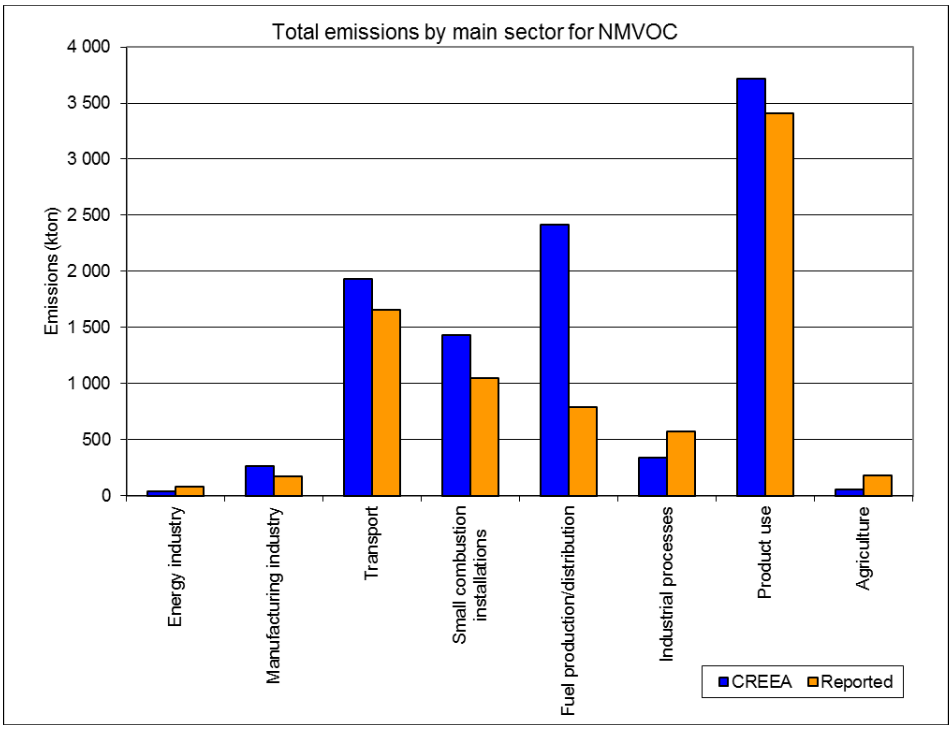
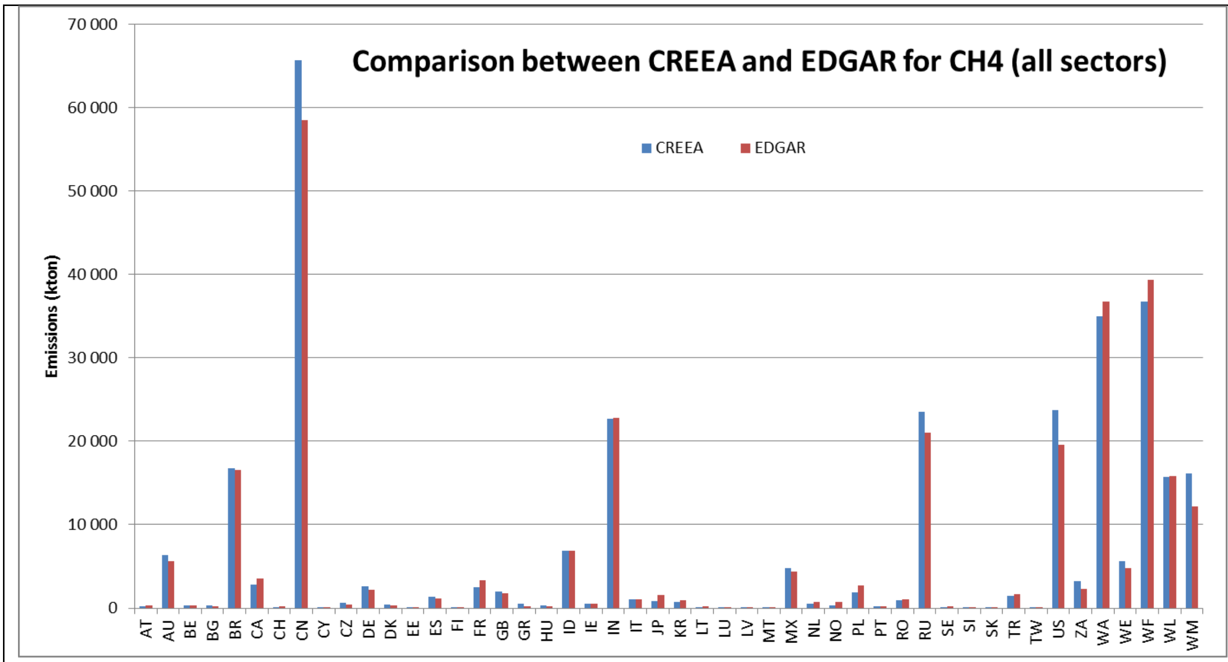


Figure 10: Comparison of CREEA emissions with national reported emissions to UNFCCC/CLRTAP by main sector (all countries together) for CO2 (upper panel) and NMVOC (lower panel)

At the global level, a comparison to EDGAR has been made. EDGAR v4.2 (JRC, 2012) is a well-known and often used emission inventory for the world as input to the scientific global atmospheric modelling community. Similarly to CREEA, it is a bottom-up approach which is largely based on the IEA energy statistics combined with emission factors. However, it does not have the sectoral disaggregation and only covers the main pollutants. For CH_4 and PM10, the comparison is shown in Figure 11. This also shows good agreement, although in selected countries differences of around 5% are observed for CH_4. For PM10 the difference is larger, but this is expected since PM10 emissions are often diffuse emissions and therefore difficult to estimate, and it is difficult to assess the level of technology especially in developing countries.

For PM10 at first glance the figure looks awkward, since by far the largest emission occurs in country WF (rest of Africa), this is due to the importance of biomass burning in this region.



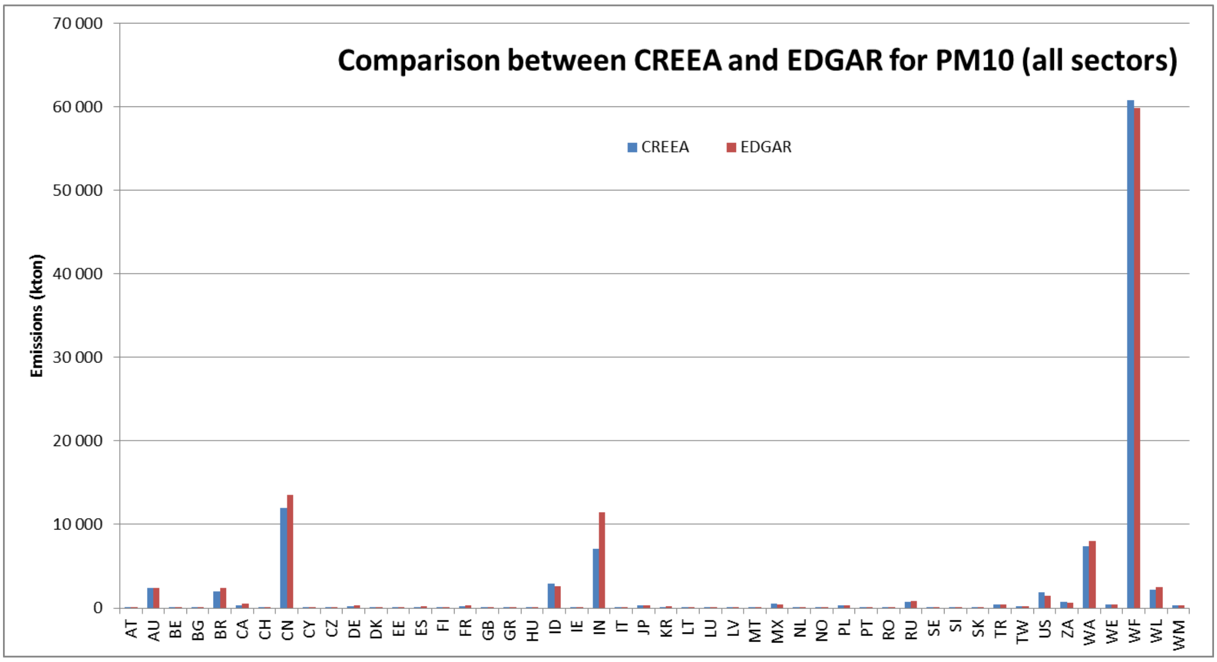


Figure 11: Comparison of CREEA emissions with EDGAR emissions for all 48 regions considered in CREEA (represented by their ISO2 code) for CH_4 and PM_{10}

Following the comparisons as shown in this paragraph, we have identified some areas where we have looked again at the emission factors and activity data applied, because of an apparent mismatch between the CREEA estimates and other estimates. These have been solved to the extent possible (e.g. taking into account that also the other estimates can be wrong).

6 Discussion

6.1 Update of Database towards EXIOBASE 2.0

The process of generating energy and air emission accounts has been further refined since EXIOPOL. Besides the general procedure, other changes refer to the product/industry classification used and countries covered.

The main change is the extension of the coverage of the energy accounts. While the former version of the accounts only covered the flows of energy within the economy, the current version also includes the physical extraction of energy from natural inputs, as well as the flows towards the environment in form of residuals, i.e. as losses and returns of energy to the environment. This task has been done following the indications given in the SEEA Energy manual.

As shown previously in Table 7 and Table 8, the matrix representing the energy products within the economy has been further split into relevant submatrices:

Supply
- Production of energy products (excluding own use)
- Production of energy for own use

Use
- Transformation of energy products
- End use of energy products
- Own end use of energy products, and
- End use of energy products for non energy purpose

From the above split, the vector "total energy consumption by resident units"[32] can be calculated, which is referred to as key indicator by Eurostat (2011, p. 31). In the SEEA terminology, this indicator is termed "Net domestic Energy Use".

This work thus shows for the first time an approach to estimate global energy accounts and air emission accounts consistent with the standard concepts and manuals of the System of Environmental-Economic Accounting (SEEA).

Besides, there were improvements in detailed data fields:
- The transport models used in EXIOPOL have been further refined, and now also bridge fishing activities from the territory to the residence principle
- A much more comprehensive LCI database has been used to allocate the energy flows in agricultural and industrial activities

[32] This indicator looks at how the (primary) energy provided through natural energy inputs, imported energy products, and energy recovered from residuals is 'used off' or made unavailable by end users, i.e. resident industries and households.

Furthermore, the product and industry classification has become more detailed, especially in terms of waste products. While the EXIOPOL classification covered 129 products and 129 industries, the CREEA classification contains 200 products and 163 industries. The classification, as well as a detailed overview of the waste products can be found in D4.1.

As for the country coverage, the 43 single countries addressed in EXIOPOL remain unaltered in CREEA. Nonetheless, the RoW has now been split in 5 regions that represent RoW Africa, RoW Asia and Pacific, RoW Middle East, RoW Europe and RoW Latin America.

6.2 Emission Factors

This report describes the emission factors (or emission coefficients) that were determined for use in CREEA. In the case of non combustion related energy use and non energy use, these emission factors are directly calculated by CREEA product and industry, respectively. In contrast, the emission factors are given by IEA product and item for combustion related air emissions. Since the latter cannot be used directly by other WPs, new ones are calculated once the emission relevant energy use and the combustion related air emissions were generated in CREEA format (cf. Chapters 3 and 4).

The delivery of emission factors rather than emissions to other WPs makes it possible to ensure the mass balances throughout the whole economy in the physical IOTs. At the same times this ensures that the emissions are based on the same physical data as the other parameters in EXIOBASE 2.0, e.g. the energy consumption and the production data.

Emission factors are supplied for all substances which are covered by the UNFCCC and CLRTAP, i.e. the two main international conventions on air emissions. The methodologies applied under these two conventions to create the air emission inventories are generally applicable to Annex I countries, e.g. the EU, USA, Canada, Japan, South Korea, etc., but not to non-Annex I countries such as the BRIC countries. Where possible this has been accounted for, however, due to limited data availability, the emission factors are often not country-specific. For some major sources, such as road transportation, a more sophisticated approach using transport models was used, accounting for differences in fleet composition in different countries and different regions in the world.

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Annex I

Transport models used to bridge the gap between the territory and the residence principle

Road Transport[33]

The total use of fuel related to road transport in a certain country can best be estimated on the basis of the composition of the vehicle fleet, the distances travelled by these vehicles, and their fuel consumption, according to the following equation:

$$TFU_R = \sum_{i=1}^{n} NV_i \cdot \overline{VKM}_i \cdot \overline{FU}_i$$

where:

TFU_R : annual total consumption of a given fuel (litres) by a domestic vehicle fleet

NV_i : number of vehicles (units)

$\overline{VKM}_i$: average distance travelled per vehicle (kilometres)

$\overline{FU}_i$: average fuel consumption per vehicle (litre/kilometre)

i : type of vehicle, which is defined by a certain fuel and consumption

Data on vehicle fleet by country of registration and vehicle movement were taken from Eurostat, UNECE, IRF and NSIs. Since the data on vehicle movement taken from Eurostat and UNECE refers only to the movements in national territory[34], two additional modules have been added to estimate the fuel consumption related to tourism (by cars and buses) and freight transport (by lorries and trucks). When data was available Eurostat's CO_2 bridge tables have been used to estimate the fuel consumption of a country's fleet according to the residence principle. Further, for islands and big countries with limited road access (e.g. China, India) it has been assumed that the fuel sold in the country (as given in the IEA) is the same as the fuel used by the road vehicle fleet registered in the reporting country.

[33] The item "road transport" in the RGEST/RGEUT (IEA code: "ROAD") "includes fuels used in road vehicles as well as agricultural and industrial highway use. Excludes military consumption as well as motor gasoline used in stationary engines and diesel oil for use in tractors that are not for highway use" (IEA 2011).

[34] The main datasets used were "Motor vehicle movements on national territory, by vehicles registration" in Eurostat and "Motor vehicle movements on national territory by country (...)" in UNECE.

International Maritime Transport[35]

Lloyds provides data on the number and type of ships (>1.000 GT) by the nationality of the owner and by the country of registration. In the case of maritime transport the country of registration of the ship is a misleading parameter, since a significant share of the vessels operates under a foreign flag (UNCTAD 2012). For this reason, it has been assumed that the nationality of the owner coincides with the one of the operator. Thus, the former has been chosen, as it is the one that fits better into the residence principle.
The fuel consumed by the ship fleet of a certain country used for international marine transport was estimated by combining the data available on the composition of its marine merchant fleet, i.e. cargo carrying ships (16 types) and ships of miscellanea activities (8 types) that exceed a gross registered tonnage of 1.000 tonnes[36] (Lloyd's Register Fairplay, 2008). These data were combined with data on the annual fuel consumption per ship type as given by IMO (2009), which are based on actual ship movement data for the year 2007. The IMO study provides average fuel consumption for ships of different types and sizes. Since the Lloyd's Register's database does not disaggregate the fleet data the same way, average values were taken for each ship type. In order to match the classifications of both sources, a basic bridge table was created.

The fuel consumption by maritime transport was calculated for each country according to the following equation:

$$TFU_M = \sum_{i=1}^{n} NS_i \cdot \overline{FU}_i$$

where:

TFU_M : annual total consumption of a given energy product M (tons)

NS_i : number of ships (units)

$\overline{FU}_i$: average annual fuel consumption per ship type (tons/year)

i : type of ship

The value for each country is then divided by the world value to calculate the distribution shares.

[35] The item "international marine bunkers" (IEA code: "MARBUNK") "covers those quantities delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded. The domestic/international split is determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship. Consumption by fishing vessels and by military forces is also excluded. See domestic navigation, fishing and non-specified other sectors´" (IEA 2011).

[36] The country distribution of the fuel consumption obtained for the fleet of merchant ships above 1.000 gross tonnage (GT) was assumed as representative for the international maritime transport.

International Air Transport[37]

The fuel consumed by the aircraft fleet of a certain country used for international air transport was estimated with the aid of data on fleet, annual distance flown and trips carried out (by airline), and average time flown (by airline and aircraft type). This information has been obtained from IATA (2008). When possible, the existing gaps in the airline fleets have been filled with alternative sources (e.g. airfleets database) or country/region average values.

The data on km and time flown provided by the IATA is given at airline level, while the fuel consumption factors provided by the EMEP/EEA guidebook (EMEP/EEA 2009) are given at aircraft level for different flight distances. Since the IATA statistics also provide data for the aircraft types and their daily flight time, the model built estimates an average flight in terms of distance flown for each aircraft in order to link both datasets.
A correspondence table has been generated based on EMEP/EEA (2009) to match the aircraft types included in the IATA statistics and the ones for which fuel consumption data are available. Further assumptions had to be made to match a few more categories.

The length of an average trip has been estimated as follows:

$$\bar{d}_{F,i} = \frac{\bar{t}_{D,i} \cdot \frac{d_{T,j}}{t_{T,j}}}{NA_i \cdot FA_i}$$

The average length obtained for a given aircraft have been multiplied by fuel consumption factors obtained from EMEP/EEA (2009):

$$TFU_A = \sum_{i=1}^{n} NA_i \cdot FA_i \cdot 365 \cdot \bar{d}_{F,i} \cdot FU_i(d)$$

[37] The item “international aviation bunkers” (IEA code: AVBUNK) “includes deliveries of aviation fuels to aircraft for international aviation. Fuels used by airlines for their road vehicles are excluded. The domestic/international split should be determined on the basis of departure and landing locations and not by the nationality of the airline. For many countries this incorrectly excludes fuel used by domestically owned carriers for their international departures” (IEA 2011).

where:

$\bar{d}_{F,i}$	:	average distance flown per aircraft per flight (km/flight)
$\bar{t}_{d,i}$	:	average daily time flown per aircraft (hour/day)
$d_{T,j}$	:	annual distance flown per airline (km/year)
$t_{T,j}$	:	annual time flown per airline (hour/year)
NA_i	:	number of aircrafts (units)
FA_i	:	flights carried out per aircraft (trips/day)
TFU_A	:	annual total consumption of a given energy product by international air transport (tons)
$FU(d)$	:	average annual fuel consumption per aircraft (tons/km)
i	:	type of aircraft
j	:	airline

These values have been added up to the ones referring to the other aircraft models in a country's airline and thus, the total fuel consumption per country has been calculated. The split between domestic and international fuel consumption has been made on the basis of the distance flown in domestic and international trips by each airline. The value for each country is then divided by the world value to calculate the distribution shares.

Fishing[38]

The procedure applied for fishing is the same as for international marine bunkers. In this case, the distribution calculated for fishing vessels bigger than 1.000 GT has been used for the item "Fishing" as a whole (both domestic and international), since the number of fishing ships per nationality of the owner is not available for ships below that size.

[38] The item "fishing" (IEA code: "FISHING") "includes fuels used for inland, coastal and deep-sea fishing. Fishing covers fuels delivered to ships of all flags that have refuelled in the country (including international fishing) as well as energy used in the fishing industry [ISIC Rev. 4 Division 03].´" (IEA 2011).

Annex II

Non-energy products list of sources covered

SourceCategory	SourceName	Activity data source
2.A.1	Cement production	USGS Minerals Yearbook
2.A.2	Lime production	USGS Minerals Yearbook
2.A.4	Soda ash production and use	USGS Minerals Yearbook
2.A.7.d	Glass and glass products	UN Industrial Commodities Statistics
2.B.1	Ammonia production	USGS Minerals Yearbook
2.B.2	Nitric acid production	Eurostat Prodcom
2.B.3	Adipic acid production	Eurostat Prodcom
2.B.4	Carbide production	Eurostat Prodcom
2.B.5.a	Ammonium nitrate	FAOSTAT
2.B.5.a	Ammonium sulphate	http://www.mapsofworld.com/minerals/world-sulphur-producers.html
2.B.5.a	Carbon black	Eurostat Prodcom
2.B.5.a	Chlorine production	Eurostat Prodcom
2.B.5.a	Dichloroethane	Eurostat Prodcom
2.B.5.a	Ethylbenzene	Eurostat Prodcom
2.B.5.a	Ethylene	Eurostat Prodcom
2.B.5.a	Ethylene oxide	Eurostat Prodcom
2.B.5.a	Formaldehyde	Eurostat Prodcom
2.B.5.a	Polyethylene high density	Eurostat Prodcom
2.B.5.a	Polyethylene low density (excl. linear)	Eurostat Prodcom
2.B.5.a	Polyethylene low density (linear)	Eurostat Prodcom
2.B.5.a	Polypropylene	Eurostat Prodcom
2.B.5.a	Polystyrene (expansible)	Eurostat Prodcom
2.B.5.a	Polystyrene (non-expansible)	Eurostat Prodcom
2.B.5.a	Polyvinylchloride	Eurostat Prodcom
2.B.5.a	Styrene	Eurostat Prodcom
2.B.5.a	Styrene-butadiene	Eurostat Prodcom
2.B.5.a	Sulphuric acid	Eurostat Prodcom
2.B.5.a	Titanium dioxide	Eurostat Prodcom
2.B.5.a	Urea	FAOSTAT
2.B.5.a	Vinyl chloride	Eurostat Prodcom
2.C.1	Pig iron production	USGS Minerals Yearbook
2.C.1	Steelmaking - Basic oxygen furnace	USGS Minerals Yearbook
2.C.1	Steelmaking - Electric furnace	USGS Minerals Yearbook

SourceCategory	SourceName	Activity data source
2.C.1	Steelmaking - Open hearth furnace	USGS Minerals Yearbook
2.C.2	Ferroalloys production	USGS Minerals Yearbook
2.C.3	Primary aluminium production	USGS Minerals Yearbook
2.C.5.a	Primary copper production	USGS Minerals Yearbook
2.C.5.a	Secondary copper for treatment, Re-processing of secondary copper into new copper	USGS Minerals Yearbook
2.C.5.b	Lead refinery production primary	USGS Minerals Yearbook
2.C.5.b	Lead refinery production secondary	USGS Minerals Yearbook
2.C.5.b	Secondary lead for treatment, Re-processing of secondary lead into new lead	USGS Minerals Yearbook
2.C.5.c	Nickel ores and concentrates	USGS Minerals Yearbook
2.C.5.d	Zinc smelter production primary	USGS Minerals Yearbook
2.C.5.d	Zinc smelter production secondary	USGS Minerals Yearbook
2.C.5.e	Other metal production, magnesium production	USGS Minerals Yearbook
2.D.1	Pulp	FAOSTAT
2.D.2	Beer	FAOSTAT
2.D.2	Beverages,-Alcoholic	FAOSTAT
2.D.2	Bovine-Meat	FAOSTAT
2.D.2	Fish,-Seafood	FAOSTAT
2.D.2	Freshwater-Fish	FAOSTAT
2.D.2	Marine-Fish,-Other	FAOSTAT
2.D.2	Meat	FAOSTAT
2.D.2	Meat,-Other	FAOSTAT
2.D.2	Molluscs,-Other	FAOSTAT
2.D.2	Mutton-&-Goat-Meat	FAOSTAT
2.D.2	Pigmeat	FAOSTAT
2.D.2	Poultry-Meat	FAOSTAT
2.D.2	Sugarcrops	FAOSTAT
2.D.2	Wine	FAOSTAT
3.A.1	Decorative paints	IIASA GAINS
3.A.1	Vehicle refinishing	IIASA GAINS
3.A.1	Vehicle refinishing (new installations)	IIASA GAINS
3.A.2	Manufacture of automobiles	IIASA GAINS
3.A.2	Manufacture of automobiles (new installations)	IIASA GAINS
3.A.2	Coil coating	IIASA GAINS

SourceCategory	SourceName	Activity data source
3.A.2	Industrial paint applications - General industry (continuous processes)	IIASA GAINS
3.A.2	Industrial paint applications - General industry	IIASA GAINS
3.A.2	Industrial paint applications - General industry (plastic parts)	IIASA GAINS
3.A.2	Leather coating	IIASA GAINS
3.A.2	Winding wire coating	IIASA GAINS
3.A.2	Wood coating	IIASA GAINS
3.B.1	Degreasing	IIASA GAINS
3.B.1	Degreasing (new installations)	IIASA GAINS
3.B.2	Dry cleaning	IIASA GAINS
3.B.2	Dry cleaning (new installations)	IIASA GAINS
3.C	Pharmaceutical industry	IIASA GAINS
3.C	Products incorporating solvents	IIASA GAINS
3.C	Polystyrene processing	IIASA GAINS
3.C	Polyvinylchloride produceduction by suspension process	IIASA GAINS
3.C	Synthetic rubber production	IIASA GAINS
3.C	Tyre production	IIASA GAINS
3.D.1	Printing, offset	IIASA GAINS
3.D.1	Printing, offset, new installations	IIASA GAINS
3.D.1	Flexography and rotogravure in packaging	IIASA GAINS
3.D.1	Flexography and rotogravure in packaging, new installations	IIASA GAINS
3.D.1	Rotogravure in publication	IIASA GAINS
3.D.1	Rotogravure in publication, new installations	IIASA GAINS
3.D.1	Screen printing	IIASA GAINS
3.D.1	Screen printing, new installations	IIASA GAINS
3.D.2	Domestic use of solvents (other than paint)	IIASA GAINS
3.D.3	Fat, edible and non-edible oil extraction	IIASA GAINS
3.D.3	Industrial application of adhesives (use of high performance solvent based adhesives)	IIASA GAINS
3.D.3	Industrial application of adhesives (use of traditional solvent based adhesives)	IIASA GAINS

SourceCategory	SourceName	Activity data source
3.D.3	Other industrial use of solvents	IIASA GAINS
3.D.3	Manufacturing of shoes	IIASA GAINS
3.D.3	Treatment of vehicles	IIASA GAINS
3.D.3	Wood preservation (not creosote)	IIASA GAINS
3.D.3	Wood preservation (creosote)	IIASA GAINS
4.B	Manure management, Asses	FAOSTAT
4.B	Manure management, Buffaloes	FAOSTAT
4.B	Manure management, Camels	FAOSTAT
4.B	Manure management, Cattle	FAOSTAT
4.B	Manure management, Chickens	FAOSTAT
4.B	Manure management, Ducks	FAOSTAT
4.B	Manure management, Geese and guinea fowls	FAOSTAT
4.B	Manure management, Goats	FAOSTAT
4.B	Manure management, Horses	FAOSTAT
4.B	Manure management, Mules	FAOSTAT
4.B	Manure management, Other Camelids	FAOSTAT
4.B	Manure management, Pigs	FAOSTAT
4.B	Manure management, Sheep	FAOSTAT
4.B	Manure management, Turkeys	FAOSTAT