WIOD
Deliverable 4.6, Documentation

FINAL DATABASE OF ENVIRONMENTAL SATELLITE ACCOUNTS: TECHNICAL REPORT ON THEIR COMPILATION

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2 Introduction and objective

WIOD – World Input-Output Database – is a project financed by the European Union's Seventh Framework Programme for research and technological development, aiming to develop databases, accounting frameworks and models that enable to understand some of the worldwide trade-offs between socio-economic and environmental developments.

The project started on May 1st 2009 and ends on April 30th 2012.

At the core of the database stand the economic linkages between industries in the countries covered, portrayed by a set of harmonized supply and use tables (SUTs), alongside with data on international trade in goods and services, and integrated into sets of inter-country input-output tables.

In order to expand the analytical potential of the dataset to wider range of research themes, a set of socio-economic and environmental satellite accounts are developed. The environmental (including energy) satellite accounts are the matter of Work Package 4 (WP4) of the project, led by the IPTS. First deliverable of WP 4 (Deliverable 4.1), prepared in mid 2009 and amended in early 2010, described the scope, data requirements and sources of environmental indicators for the environmental satellites. It also reviewed the general linkages to the supply and use tables. Second deliverable of WP 4 (Deliverable 4.2), prepared in end 2010, described the work accomplished in the work package during the first 15 months since project inception, which resulted in the delivery of a first operational version of the energy and environmental satellites dataset (preliminary database of environmental satellite accounts). This second deliverable was a milestone as it documented the fundamentals of the data framework delivered for first analyses and further integration in the analytical and modelling work packages (chiefly WP 7, "Applications of the database: environmental aspects" and WP 9, "Policy assessments making use of the new database").

This report (Deliverable 4.6) updates Deliverable 4.2 with describing the final database of environmental satellite accounts. Changes compared to the previous version include the consideration of new data available, further refinements in the methodology of energy use and air emission compilation and extensions to additional variables (land use, material use and water use).

3 Overall data coverage and concepts in the WIOD energy and environmental satellites

3.1 WIOD data coverage

The environmental satellites are defined such as to cover the broadest range of environmental themes as reasonably achievable while maintaining a data quality that is well grounded in the empirical availability of primary data. In general terms, the variables cover: use of energy; emission of main greenhouse gases; emission of other main air pollutants; use of mineral and fossil resources; land use; and water use. Other environmental domains, such as waste generation and emission of pollutants to soil and water, are stricken out due to severe data gaps.

In the case of air emissions, they may serve to derive different environmental impact categories for analysing environmental themes of international relevance. Three impacts, for which operational characterisation methods are internationally well established, are of utmost importance, namely: global warming, acidification, and tropospheric ozone formation potential (note that the first one is global, and the last two are rather regional but in many cases of international relevance). We then collect in WIOD all the main air pollutant emissions needed to derive these three environmental impact categories: CO_2, CH_4, N_2O, NMVOC, CO, NO_x, SO_x and NH_3 (see Table 1 for the pathway between the air pollutants and the environmental impact categories). Some secondary air pollutants usually considered when computing the global warming potential like SF_6, CFCs and HFCs are not covered in WIOD due to severe data gaps for allocating the emissions to specific industries. However, it is worth mentioning that these latter pollutants usually play a minor role in the global warming results.

Table 1. Pathway between air pollutants and environmental impact categories

Air pollutant	Global warming	Acidification	Ozone formation
CO_2	X		
CH_4	X		X
N_2O	X		
CO			X
NMVOC			X
NO_x		X	X
SO_x		X	
NH_3		X	

Among the variables covered, we distinguish for the sake of clarity core variables and additional variables: core variables are energy use and emissions to air while additional variables are materials extraction, land use, and water use. Such enhanced attention to energy and air emissions (especially greenhouse gases) is justified by a number of factors. Firstly, the use of energy is usually treated as a factor of production in Economy-Energy-Environment (E^3) models such as those used in WIOD's work package 9, and this warrants the definition of detailed links between expenditure for energy inputs and those energy inputs in physical terms; secondly, due to the long standing existence of reporting obligations (such as in the framework of IEA and UNFCCC), these themes enjoy a relatively fortunate situation in terms of data availability; thirdly, because analyses related to the emission of greenhouse gases (such as in climate change mitigation scenarios) do not need to take into account local aspects in the same fashion that is necessary when dealing for instance with emission to water (where the adequate geographical dimension would likely be the river basin rather than the country), and this enables meso-scale models to claim full policy relevance.

The core of the environmental database is thus constituted by energy and air emission accounts.

Energy accounts include:

- **Gross energy use** (in TJ) by sector and energy commodity (see Annex 2 and 4 for full classification thereof); this matrix, once commodity aggregation and conversion prices are applied, is directly related to expenditures for energy inputs as from the use tables and the production functions used in models.
- **Emission relevant energy use** (in TJ) by sector and energy commodity; this matrix is related to gross energy use but excludes the non-energy use of energy commodities (e.g. naphtha for plastics production, asphalt for road building) and the input of energy commodities for transformation (e.g. the coal that is transformed into coke and coke oven gas, in order to avoid double counting of emissions). The emission relevant energy use is the direct link between energy use and energy-related emissions.

Air emission accounts include:

- **CO_2 emissions** (in 1000 tonnes) by sector and energy commodity; this matrix is obtained by applying CO_2 emission coefficients to emission relevant energy use and then adding process-based emissions. Such detailed data framework (as opposed to providing only aggregate CO_2 emissions per sector) is important if one wants to be able to simulate the environmental impact of energy mix changes, such as for instance of a substitution of gas for coal in the power sector.
- **Non-CO_2 emissions** (in tonnes) by sector (see Annex 5 for full list of emissions); in the case of emissions other than CO_2 the achievement of a full matrix distinguishing among different fuels is either irrelevant (some emissions, such as methane are chiefly related to biomass fermentation or the use of refrigerators, not to the use of energy) or not feasible within the boundaries and resources of WIOD[1]. The dataset includes seven substances: N_2O, CH_4, NO_X, SO_X, NH_3, NMVOC and CO.

The additional variables (other environmental extensions) of the WIOD environmental satellite accounts cover materials extraction, land use and water use.

Materials extraction accounts include:

- **Used materials** (in 1000 tonnes) by extraction sector and type of materials (see Annex 6 for a full list of materials); used materials represent the amount of extracted resources, which enters the economic system for further processing or direct consumption.

[1] The case of CO2 is in this respect easy because CO2 emissions (with the exception of technologies such as carbon capture and storage, incidentally not yet commercially available) are strictly determined by the carbon content of the fuel, which is actually fairly constant across countries and years being determined by variations in fuel quality. The estimation of other emissions, conversely, requires (much) additional specific information regarding fuel quality, combustion technologies and abatement technologies. Sulphur Oxide emissions, for instance, depend on the Sulphur content of the fuel and on the desulphurisation technology; Nitrogen Oxide emissions depend on combustion technology (flame temperature, air-fuel ratio) and abatement technique.

- **Unused extraction** (in 1000 tonnes) by extraction sector and type of materials; unused extraction refers to materials that never enter the economic system and thus can be described as physical market externalities. This category comprises overburden and parting materials from mining or by-catch and wood harvesting losses from biomass extraction.

Land use accounts include:

- **Use of land** (in 1000 hectares) by agriculture and forest sector by type of land (see Annex 6 for a full list of types of lands).

Water use accounts include:

- **Use of water** (in 1000 cubic meters) by sector and type of water (see Annex 6 for a full list of types of water).

3.2 Environmental satellites in a SUT framework

Environmental satellites are environmental variables of relevance for analysis, expressed mainly in physical units, which are juxtaposed to the monetary SUT framework. A typical arrangement for the satellites is as depicted in Figure 1.

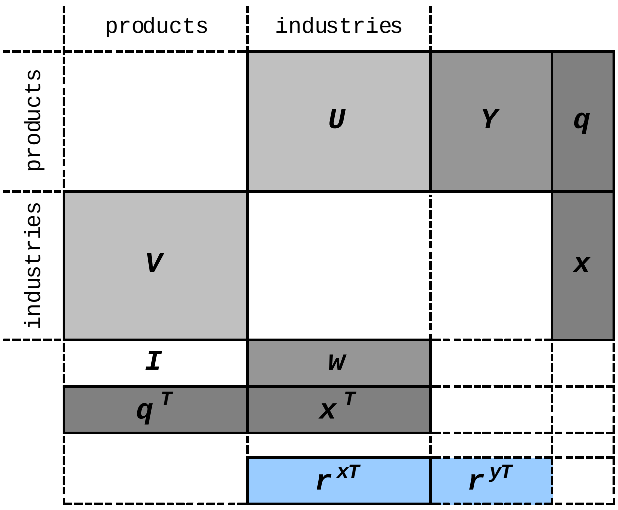

Figure 1. Environmental satellites in a SUT framework (Moll et al., 2008)

In Figure 1, marked in light grey are the make table (V = transpose of the supply table) and use table (U). An element V_{ij} indicates the supply by industry i of product j for domestic production. Vector I denotes import of products j. The vector q^T is the transposed total supply by products j, either domestically produced by industries or through imports. Vector x is the output (i) by industries (domestic production).

The use matrix U denotes the inter-industry part of the use table, where each element U_{ij} indicates the use of product i by industry j, including imported intermediate commodities. Matrix Y denotes final demand. An element Y_{ij} shows the use of product i by component j of final demand (e.g. consumption by private households and government, gross fixed capital formation, exports). Vector q shows total products use by industry and components of final demand. The vector w denotes the gross value added by industries (comprising several factor inputs such as wages, depreciation, and surplus).

Finally, the transposed vector x^T denotes input (intermediate products and value-added) to industry.

The SUT framework as illustrated in Figure 1 is balanced. It is expressed solely in monetary units, and the monetary input equals the monetary output of industries (x, x^T) and the product supply in monetary units equals the product use in monetary units (q, q^T). These identities are an important prerequisite for the mathematical Leontief-type models.

A simple and convenient means of adding the environmental variables, while keeping the system balanced, is to juxtapose them as an extension of the SUT, using so-called satellite accounts. Satellite accounts are thus external vectors, juxtaposed using the same product and industry breakdown as the SUT they accompany.

Figure 1 illustrates the treatment of an environmental variable (e.g. CO_2-emissions) in the form of vector r^T. The juxtaposed vector comprises two parts, one related to industries r^X representing direct environmental factor inputs (e.g. CO_2-emissions) by industry j, the remaining being the factor inputs associated to the components of final use, r^Y.

This framework accepts as many extensions as environmental variables of interest one needs to add. The presented framework is directly suitable for analysis using e.g. input-output models of Leontief type, using industry technology or commodity technology assumptions.

The accounting framework for environmental variables that sets data up to be juxtaposed to IO or SUT tables, and is consistent with IO data (residence principle) is sometimes named NAMEA (national accounting matrices including environmental accounts). Since all environmental account data published by National Statistics Institutes follow the publication of compatible national accounts, the terms NAMEA and environmental accounts are frequently used as synonyms.

Compared to an environmental extended IO system based on symmetric tables, the EE-SUT (Environmentally Extended SUT) offers the flexibility of recording the supply and use of residuals either by industries or by products; this distinction will be useful in the definition of the environmental satellite accounts related to the production of goods and services and to their use.

The total environmental load related to the consumption of products is in fact customarily broken down in three main components: production phase (including raw material production, manufacture of the product, and distribution), use phase, and post-consumer phase (waste management). Let us take an automobile as an illustrative example:

1) The environmental loads of the production phase are everything related to the production of steel and other materials, their assembly in the car as a product, and the sale of the car.; Direct impacts occur within the industries of car manufacture (sector 34) and sale (sector 50), while the indirect impacts occur in the industries that produce the car's raw materials (e.g. metals, rubber, glass, plastics). Attribution of those impacts to the good and its consumption is not part of the satellite accounts but is effectuated by applying a model (such as the demand-driven Leontief model). In the EE-SUT framework, it will be convenient to record these environmental loads as industry-related.

2) The use phase impacts are mainly those related to driving the car and are largely associated to the combustion of fuel in the engine. The consumer purchases the

fuel from NACE sector 23, but the emissions are not occasioned in sector 23; they are ascribed instead to the consumer. Strictly speaking, these impacts are not due to the fuel alone but to the *combination* of fuel and vehicle for the purpose of driving around, and the emission of pollutants depends not only on the characteristics of the fuel but also on the technology of the vehicle. It is for this reason that use phase emissions are often associated not to products but – with a further modelling step – to consumption purposes as in COICOP-classified statistics (driving, cooking, recreation, etc.). However, from the point of view of accounting it is very convenient to associate emissions to the product flow most closely related to each emission, and let a further modelling step (such as a bridge matrix between products consumed – CPA – and consumption purposes – COICOP) take care of the attribution to consumption purposes just like we let the Leontief model attribute production phase emissions to the consumption of products. In the automobile example, we will associate some emissions to the amount of fuel purchased, not because it is the fuel alone that emits, *but because the amount of fuel purchased has a direct relationship with the amount of substances emitted, e.g* in the case of CO_2 which is emitted in stoichiometric relation with the carbon content of the fuel. Of course, when the stoichiometric relation does not govern emissions (take for instance the case of NO_x, highly dependent on the flame conditions and combustion technology), the situation is more complex and has to be modelled with additional variables.

3) The post-consumer phase environmental impacts are those related to the disposal of the automobile: used tyres and spare parts for reuse or recycling, shredding and scrappage of the end-of-life vehicle. These processes are related to waste accounts and as such bear relation with a series of specific issues that will be addressed later in Section 6.

Having made the distinction between environmental loads of the production phase (only relevant for industries) and of the use phase (relevant both for industries and final consumers), we finally remark that not all the final demand elements of the environmental satellite accounts need be filled: final consumption by households has associated environmental account entries, final consumption by government and not-for-profit organisations does not due to accounting conventions: government consumption records expenditure for services provided (for public administration services CPA75, for education CPA80, for health CPA85, etc.), while the use of inputs such as fuels is not in the government consumption but in the input structure of the sectors NACE75, NACE80, NACE85 etc; other final uses do not have associated emissions either: investments do not because they are not clearly associated to flows responsible for emissions in the calendar year; exports do not because the use of those goods – and the emissions associated – in accordance to the overarching residence principle shall be booked to the importing country.

3.3 Environmental data in a National Accounts framework (NAMEA): the challenges

Most if not all environmental variables that are needed to fill the data framework described above stem from sources (e.g. energy statistics, water statistics, etc.) that use a different framework, not compatible with national accounts. Data transformations are therefore necessary to achieve conceptual consistency with the SUTs.

The most relevant differences between a national accounting framework and other national statistics are presented in Table 2, for the specific case of energy accounts and energy statistics.

Table 2. Differences between a national accounting framework and national statistics (energy)

	National accounting framework	National statistics and balances	Bridging	Particular issues dealt with in the bridge table
Ways of defining a country's boundaries	Economic definition: **residence principle**;a resident is an institutional unit (person, company) whose economic activities take place in a territory. The national account framework allocates all emissions etc. of a resident unit, be these physically in or out of the territory, to the territory of residence.	Geographic definition: **territorial principle**. This framework allocates all emissions etc. of economic units to the country where they physically (geographically) take place, regardless of whether they are undertaken by residents or non-residents.	Energy use on national territory (+) Residents in the rest of the world including especially • Road transport • Air transport • Water transport (-) Non-residents on domestic territory including especially • Road transport • Air transport • Water transport = Energy use by resident units (i.e., the national accounts definition)	* TRANSPORT ROAD: • Foreign (tourist and company) cars driving and fueling in national territory • National (tourist and company) cars driving and fueling abroad AIR: • Foreign plane's LTO and bunkering in national territory • National plane's LTO and bunkering in foreign territory WATER: • Foreign vessels sailing and bunkering in national territory • National vessels sailing and bunkering in foreign territory In particular fishing vessels and goods vessels * EMBASSIES * DEFENCE
Classification and terminology	Breakdown level: ISIC rev 4 for sectors (=NACE) Energy products follow CPC (central product classification) or perhaps better COICOP that includes purpose/intended use and makes possible to distinguish non-energy use of energy carriers	By sector	Exact definitions of sectors that include all relevant energy activities on the supply side (extraction, conversion, supply) and use side (end use of energy commodities). Exact definitions of energy commodities: Which commodities are assets, stocks, inventories, reserves, transactions, flows and losses? Handling of low vs. high calorific values in statistics. Conversion. Handling of gross/net accounts and avoidance of double counting	
Sources			Not always coincident due to interpretation of terminology, collection by different national entities, etc	

LTO: Landing and take-off

Both accounting (residence) and inventory (territorial) frameworks co-exist as non-competing elements of analysis, both definitions having inherent advantages and disadvantages; however, these are very different frameworks and considerable effort is required to accommodate data from one framework to the other.

In practical terms, the difference means that bridge tables showing how to go from one framework to the other using additional data need to be developed, for instance accounting the activity of resident units in the rest of the world and the activity of non-resident units on domestic territory. This covers elements such as international maritime transport with bunkering abroad (fuel purchases that are not included in the national statistical systems where the ships are resident), fishing vessels operating abroad and foreign vessels in national waters. International air transport poses similar problems.

Additional data collections and estimations have been carried out to address activities of resident units abroad complementing the statistics, chiefly in relation to tourism statistics and to the annual purchases of fuels by international shipping and transport carriers.

3.4 Concepts and Structure of the WIOD environmental database

3.4.1 Energy

Energy accounts are compiled using extended energy balances from IEA (2011a) as a starting point, achieving the specification of energy accounts as explained above using additional information to bridge between territory and residence principles and to allocate IEA accounts to the target classification and accounting concepts (distribution of transport activities and autoproduced electricity among industries). A rather general illustration of the layers in energy accounts is provided in Figure 2 (Olsen, 2007).

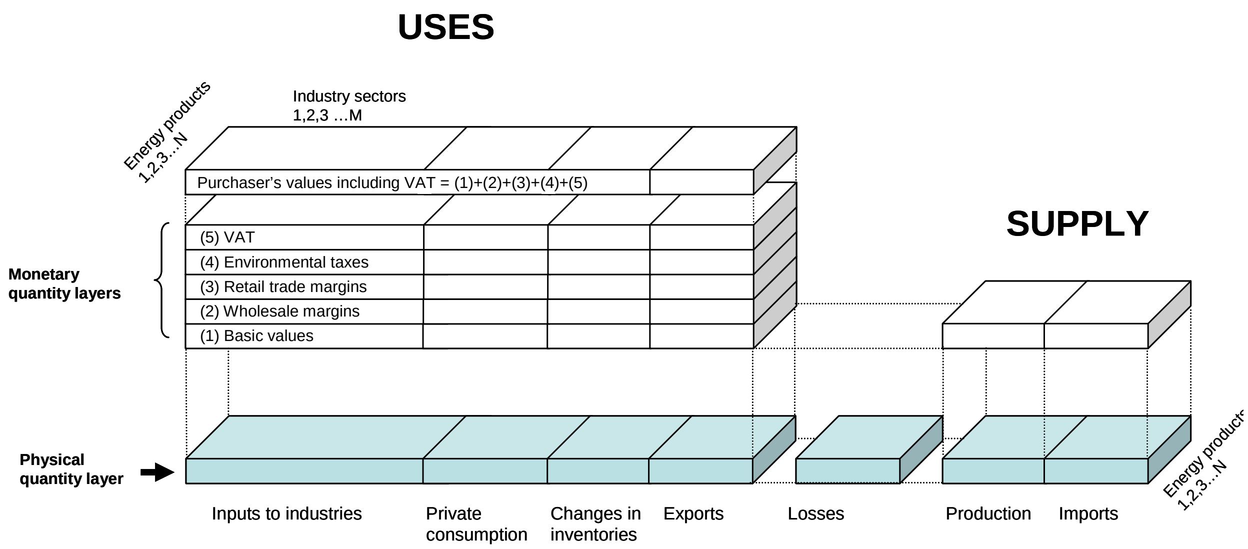

Figure 2. Composition of energy accounts including the relationship between the physical and monetary layers (Olsen, 2007).

The scope of the WIOD energy accounts includes energy flows but excludes energy assets, energy and environmental taxes/subsidies, permits, licenses.

The very first step in deriving energy accounts from international energy balances, as provided by the IEA, is to establish a correspondence key linking energy balance items and NACE entries plus households. Some of the energy balance items can directly link to the production of certain NACE entities, but in some cases the energy balance item is related to more than one industry. For instance, the energy balance item “road transport” needs to be distributed over all industries plus households. Likewise, the energy balance item “commerce and public services” needs to be distributed over a number of services. For this splitting the use of auxiliary variables is needed; although it is common practice to use for this purpose very aggregate indicators such as employment or production output, this would be sub-optimal and would not make use of all the data available. The use table at NACE 60 classification provides useful (monetary) information on the use of at least four aggregate energy commodities: coal, oil & gas, refinery products and electricity & gas. Note the redundancy: gas appears twice, as a resource together with crude oil, and as distribution of gas as public utility together with electricity (and district heating). Without dwelling on the details of the most correct accounting system or on how the different accounting practices are then reflected in the accounting of trade and transport margins of natural gas, in the practice some countries record natural gas inputs as inputs of oil & gas, some others as inputs of electricity & gas. Empirically, one can do little more than allowing sufficient flexibility in the data transformation protocols to accommodate the different accounting practices. Note also that the potential similar problem with refinery products does NOT occur: crude oil is always input to refineries and refineries only. Other users purchase refinery products and refinery products only.

Losses are also a relevant part of the energy accounts and an important element in the assessment of energy efficiency. They reflect the efficiency of the transformation of primary (e.g. crude oil) to other forms of energy (e.g. electricity), and the losses incurred to deliver energy to the final users. All losses should be recorded and allocated to the supplier. In some country energy NAMEAs, losses are recorded separately and by sectors like an "additional" fuel. Transformation losses are provided in the IEA balances, even though there may be some differences of interpretation and classification, e.g. some countries report positive losses from refineries (indeed as an energy *gain*, the process energy being recorded separately). Distribution losses are also provided in the IEA balances as a separate flow, and represent the losses due to the distribution of energy carriers, mainly but not only heat and electricity. In the case of heat and electricity, these losses can be easily assigned to sector 40, disregarding short-distance losses incurred by autoproducers. For distribution losses related to other energy carriers (e.g. crude oil, coal), additional information is needed.

An *excursus* follows regarding the main concept of energy accounts that is most appropriate to the WIOD framework. Indeed those national authorities that compile energy accounts apply different concepts, sometimes publishing more than one type of energy NAMEA. We distinguish in fact the following two main concepts:

1) Net energy concept;
2) Gross energy concept.

Both concepts are possible in a balanced accounting framework. In the case of gross energy supply and use, the following equation holds:

Gross supply: Domestic production + Imports + Inventory changes
=

Gross use: Intermediate consumption + Final uses + Exports

In the case of net energy supply and use, we have:

Net supply: Direct extraction + Imports + Inventory changes = Net use: Final uses + Losses due to conversion + Exports

The net energy concept is useful for computing for instance the total energy metabolism of an economy, as there is never any double counting: one only records the final use of energy and disregards the inputs that are only for transformation. Some illustrative implications are:

- Oil inputs to refineries are not recorded:
    - The TJ contained in that oil are mainly recorded in the oil products used by transport, by the chemical sector, etc.
    - Additionally, the refineries record the transformation losses and energy use necessary to run the refinery.
- Fuel inputs to the power sector are not recorded:
    - The power sector basically records the energy transformation loss (what is lost due to conversion efficiency and grid transmission losses).
    - Note that information on the energy mix is lost: how much gas goes in, how much coal, how much uranium.
    - The TJ contained in the electricity produced are recorded in the use of electricity by all sectors and households.

In the gross energy concept one has double counting, but on the other hand one records energy carriers in a way fully consistent with how inputs are recorded in the Use table of national accounts. Some illustrative implications are:

- Oil input to refineries is recorded:
    - The TJ contained in that oil are recorded twice: in the oil products used by transportation, chemical sec, etc., and in oil input to refineries.
- Fuel inputs to the power sector are recorded:
    - The power sector records the entire inputs of energy commodities: how much gas goes in, how much coal, how much uranium.
    - The TJ contained in the electricity produced are recorded in the use of electricity by all sectors and households. This energy, in terms of net TJ, is therefore counted twice across the economy.

When computing emissions, one needs not count them twice: electricity has no direct emissions, crude oil has no direct emissions, etc. More specifically, it is convenient – if not necessary – to develop an additional layer of "emission relevant energy use" as a bridge between gross energy use and emissions, where the part of the gross energy use that does not cause direct emissions is removed, such as in the following cases:

- The use of energy carriers that are not burned for energy (non-energy use of energy commodities: naphtha for the production of base chemicals, bitumen for asphalt) is eliminated.
- Likewise, the share of fuels that are transformed in other fuels is eliminated (this applies to chemical transformations but not to fuels "transformed" into electricity). The typical case is cokeries: when coal is transformed in coke and coke oven gas, part of the coal is consumed for energy and produces CO2. That is the part that is emission relevant. The remaining energy is stored in coke and coke oven gas. Conversely, since coke and coke oven gas are only used for final energy consumption (final in the sense intended by energy statisticians, not final consumption as in national accounts), their use is entirely emission relevant.

As a general principle and based on the modelling orientation of the WIOD project, the primary focus of the WIOD energy accounts is on the concept of gross energy use. It would be in fact impossible, otherwise, to account for such fundamental energy questions as the energy mix and the substitution over time of energy inputs in electricity production; furthermore, the gross energy concept is fully consistent with the framework of national accounts: in an input-output table not only the value added and net output are recorded, but also all intermediate inputs. This issue sometimes generates confusion due to the lexical discrepancies between national accounts and energy statistics, where the qualification "final" in the final use of energy in the energy balances and in the final use of products in national accounts are different.

- Note that the framework described only deals with the energy demand side (energy supply will not be reported).

Figure 3 presents a schematic representation of the energy accounts in WIOD for a country. Time series includes year 1995 to 2009. The WIOD sectors and energy commodities included are listed in Annex 2 (listing) and 4 (coding), respectively. The reference IEA energy sector and commodity lists are presented in Annex 3.

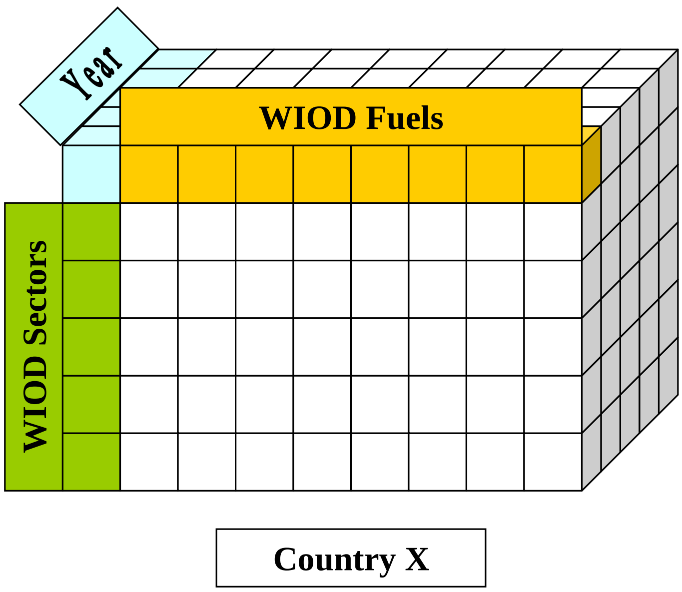

Figure 3. Schematic generic representation of energy account data in the WIOD satellite database

The energy account data of the WIOD satellite database are presented in Excel format where each year is recorded as a single sheet in which there is a single row (WIOD sectors) and column (WIOD fuels) dimension.

3.4.2 Air emissions

3.4.2.1 Structure

Regarding emissions, we distinguish energy-related air emissions from non-energy-related air emissions. Energy-related air emissions result directly from the use of energy through fuel combustion. Non-energy-related air emissions are not directly linked to the combustion processes and encompass:

- Fugitive emissions from fuels
- Industrial processes, including mineral, chemical, metal and other production industries
- Product uses, including paints, degreasing/dry cleaning products, chemicals and other products
- Agriculture, including manure, agriculture soils and field burning
- Waste, including landfills, wastewater and incineration
- Other human-related sources

Due to differences in data availability, we have also to distinguish CO_2 from non-CO_2 emissions. In the case of CO_2, WIOD environmental extensions provide both detailed and total sectoral emissions (like for energy). We mean by detailed sectoral emissions the sectoral emissions due to the use of each energy commodity listed in Annex 4, non-energy-related emissions being reported separately as a single item. For any other air pollutant, only total sectoral emissions are reported.

Figure 4 depicts the generic schematic representation of the NAMEA-air emissions in WIOD for a country. Time series includes year 1995 to 2009. The WIOD sectors and air emissions included are listed in Annex 2 and Annex 5, respectively.

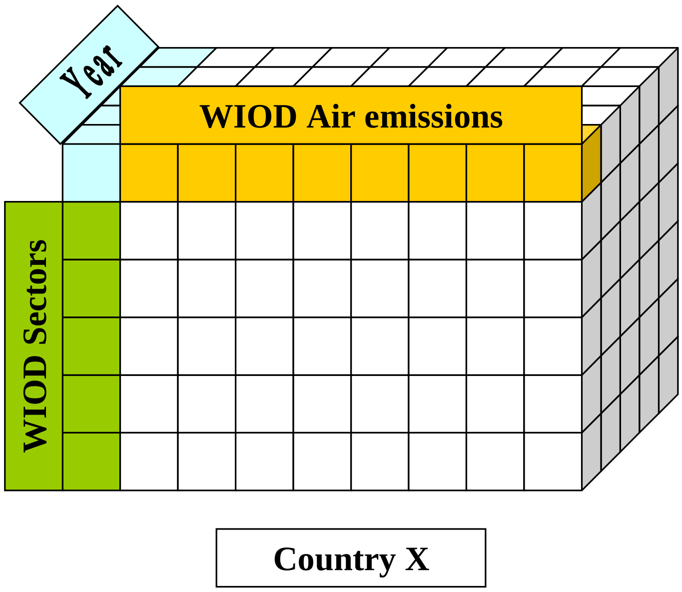

Figure 4. Schematic generic representation of the structure of air emission account data in WIOD

The air emission account data of the WIOD satellite database are presented in Excel format where each year is recorded as a single sheet in which there is a single row (WIOD sectors) and column (air emissions) dimension.

In addition for CO_2, we have the following details depicted in Figure 5 (NE stands for non-energy emissions and ε for statistical difference between official and WIOD total estimates). In practice, statistical difference may arise for EU27 countries only for which official air NAMEAs are published by EUROSTAT. The statistical difference mainly comes from the use of different estimation methodologies and data sources.

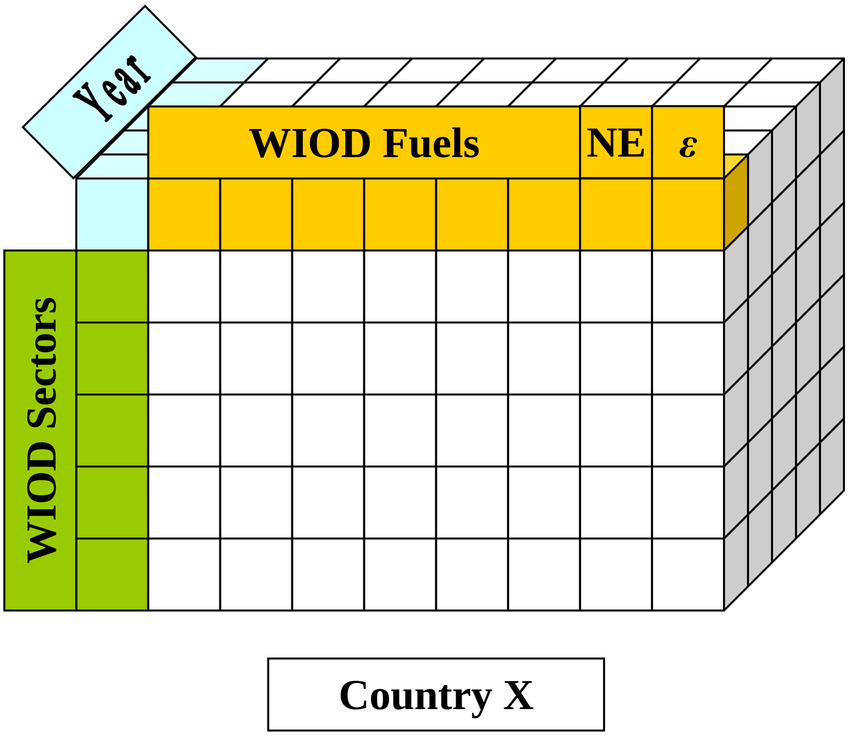

Figure 5. Schematic representation of the structure of CO_2 emissions in WIOD

3.4.2.2 Concept

For any given country, two main situations regarding air emission data may happen: either NAMEA-air like data are available and only minor manipulations of the emission data will be needed to fit the WIOD sector format; or NAMEA-air like data are not available, which means that NAMEA-air emissions need to be estimated from other data sources. In the latter case, according to the recently published Manual for air emission accounts (Eurostat, 2009a), NAMEA-type data on air emissions (greenhouse gases, acidifying gases etc.) can be generated using two main methodological approaches:

- The "inventory-first approach", which starts from the air emission inventories. Air emission inventories are air emission compilations following certain guidelines as agreed under international conventions.
- The "energy-first approach", which starts with detailed energy accounts. In a first step energy accounts are generated broken down by detailed energy products and sector divisions. In a second step, air emissions are calculated applying standard emission factors (e.g. drawn from IPCC guidelines).

To compute air emission accounts, we implemented different methodologies depending on the pollutant and the country considered. In a general way, we applied the following strategy for any given pollutant (by order of priority):

1. If NAMEA-air like data were available, we used them to match the WIOD breakdown format;
2. In the case of unavailability, we estimated the emissions with an energy-first approach when most emissions of the pollutant considered are linked to fuel combustion. This concerns CO_2, NO_x, SO_x, NMVOC and CO. Note that in this case, energy- and non-

energy-related emissions were tackled together, except for CO_2 for which non-energy-related emissions were estimated separately with an inventory-first approach;

3. When NAMEA-air like data were unavailable and most pollutant emissions are not linked to the use of energy (this concerns N_2O, CH_4 and NH_3), emission data (both energy- and non-energy-related) were estimated based on an inventory-first approach.

3.4.3 Other environmental extensions

3.4.3.1 Materials extraction

Compared to other environmental categories, the extension of the SUT with data on material extraction is not problematic. On the one hand, European and global data sets are available and can be used directly. On the other hand, the link to the SUTs is straightforward, as only a few sectors are involved in the extraction of primary materials.

In the structure of WIOD, only data on Domestic Extraction of materials (DE) is necessary, and there is no need to compile physical import and export data. For the calculation of indirect (or embodied) material requirements, input-output analysis on the international level has to be applied, using the economic core of the data base (monetary SUTs) plus monetary trade data (see also Giljum et al, 2007 for a description of multi-regional IO-materials models).

For each of the countries and years covered by the WIOD, it includes information on the Domestic Extraction (DE) Used and Unused by type of material, expressed in 1000 tonnes. The DE covers the annual amount of solid, liquid and gaseous raw materials (except for water and air) extracted or move from the natural environment by humans or human-controlled means of technology (i.e., those involving labour) insofar as they are considered resident units. The term DE-Used refers to the amount of extracted resources, which enters the economic system for further processing or direct consumption. These materials consist of biomass, construction and industrial minerals, gross ores, and fossil fuels. The DE-Unused refers to materials that never enter the economic system and thus can be described as physical market externalities. This category comprises overburden and parting materials from mining or by-catch and wood harvesting losses from biomass extraction (Eurostat, 2009c).

For both the DE-Used and DE-Unused extraction, the WIOD distinguishes 12 different types of materials: *Biomass animals*, *Biomass feed*, *Biomass food*, *Biomass forestry*, *Biomass other*, *Fossil coal*, *Fossil gas*, *Fossil oil*, *Fossil other*, *Minerals construction*, *Minerals industrial*, and *Minerals metal*.

3.4.3.2 Land use

The land accounts compile the land area used by economic activities. Land is a natural resource different than materials and energy for statistical data compilation purposes. Materials and energy are flows physically processed into goods and resulting in residuals. On the contrary, land constitutes a natural asset that is used but is not consumed as such, in the sense that it is not physically incorporated into products and does not flow through the economic system. Land area can be considered as a natural stock providing various services to human activities. Yet, land area is a key resource, since it is used for producing most of the food consumed worldwide and also holds infrastructures and building. Moreover, land is a relatively fixed and ultimately it is constrained by the Earth's total land surface.

Agriculture and forestry are the most important economic activities whose output is directly dependent on land area use. Agriculture and forestry use land to grow biomass, a renewable material resource which is further processed into goods. Many other activities are dependent on land to a much less extent (mining, non-biomass renewable energy). For others, the output has no direct relationship to land area use. The use of land for housing and infrastructures imposes a constraint on the total availability.

From an accounting perspective, land can be classified into 5 types:

- *Arable land*: is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for *Arable land* are not meant to indicate the amount of land that is potentially cultivable.
- *Permanent crops land*: is the land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under "forest"). Permanent meadows and pastures are excluded from land under permanent crops.
- *Permanent meadows and pastures*: is the land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).
- *Productive forest area*: is the forest area actually used for productive purposes.
- *Built-up area*: denotes land use for settlements and infrastructures.

At the moment of compiling the WIOD, there was no international data on *Build-up area*. Thus, the coverage of WIOD is limited to: *Arable land*, *Permanent crops*, *Permanent meadows and pastures*, and *Productive forest area*, measured in 1000 hectares. However, these four categories represent most of the total area used by human activities.

3.4.3.3 Water use

The statistical treatment of water in the WIOD is based on the concepts of blue, green and gray water of the Water Footprint approach (Hoekstra et al., 2011). Conventional national water use accounts are restricted to statistics on water withdrawals within their own territory. This would include the use of surface and ground water by the different economic activities and final users (the so-called blue water). The approach proposed by Hoekstra et al., extends these statistics by including data on rainwater use (green water) and volumes of water use for waste assimilation (gray water), giving a broader perspective of humans' appropriation of freshwater.

Therefore, the WIOD covers the use of water (measured in 1000 m3) distinguishing three different types:

- *Blue water*: refers to consumption of surface and ground water
- *Green water*: is the volume of rainwater consumed, mainly in crop production.
- *Gray water*: is the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

4 Data sources

This section discusses the data sources used in the estimation of the WIOD energy and environmental satellite accounts. The variables discussed are those listed in Section 3:

- Energy use, broken down into several energy commodities including different fossil fuels and primary energy sources, transformation processes, and final use.
- Air emissions, both energy-related and non-energy related, covering the environmental impact areas of global warming (CO_2, N_2O, CH_4), acidification (SO_2, NO_X, NH_3) and tropospheric ozone formation (CO NMVOC, CH_4, NO_x) .
- Other environmental extensions, including materials extraction, land use and water use.

The data, for reasons of homogeneity with the national accounting principles of the SUTs, is organised in compliance with the accounting principles of NAMEA-energy, NAMEA-air, NAMEA-materials, NAMEA-land and NAMEA-water (SEEA, 2003)

An assessment of the data quality of the data sources is also presented along with the practical pitfalls for use and transformation to the national accounting framework and harmonisation with the WIOD framework.

The scope of time, commodity and industry breakdown, and geographical coverage is common for all variables:

- Time scope: 1995-2009
- Country coverage: 40 countries including EU27 Member States plus 13 non-EU countries (Australia, Brazil, Canada, China, India, Indonesia, Japan, South Korea, Mexico, Russia, Taiwan, Turkey and USA) and the remaining regions of the world aggregated into a single region RoW (Rest of the World) .
- Sector/product breakdown: 36 sectors, including 35 industries[2] plus households, and 59 product groups (see Annex 2 for details)

The overarching principle of the data collection effort was to include, to the extent possible, all known and accessible official data published by national statistical institutes (NSIs) in a format similar to the target WIOD format (NAMEA-energy, NAMEA-air, NAMEA-materials, NAMEA-land and NAMEA-water). Whenever NAMEA data were not available, other statistics covering the same variables were collected to be converted to the NAMEA standard by means of the estimation procedures described in Section 5 and with the help of the required auxiliary data.

4.1 Use of other WIOD data

The objective of the whole WIOD database is to have a fully integrated worldwide dataset consisting of harmonized SUTs, bilateral trade matrices and inter-country input-output tables completed by socioeconomic and environmental accounts. To guarantee the consistency of the WIOD database, the construction of the environmental accounts fully relies on the other

[2] Note that extra-territorial organisations and bodies are not included in WIOD.

parts of the WIOD database, including the SUTs, sectoral gross output deflators, employment data, etc.

4.2 Energy data sources

Generally, national data on energy are available in the form of energy statistics and energy balances compiled as inventories using the territorial principle. All countries covered by WIOD compile energy statistics – albeit of inhomogeneous quality – and these are yearly surveyed by the International Energy Agency (IEA). According to a survey conducted by the UNSD (2009), some 30-35 countries worldwide have also developed, for at least one year, energy accounts based on a national accounting framework and using a residence principle though at different industry/product breakdown levels; however, our factual experience is that only a handful of countries (around 7-8) published and made available the results.

The WIOD countries were screened for the availability of official energy accounts, and if publicly available, this information was collected and used to align the WIOD estimates to the official figures available: where official information is available, it was considered to supersede the standard WIOD estimate; the WIOD estimate was then be used only to achieve the harmonised target concept (e.g. gross energy vs. net energy), sector classification, energy product classification and time series coverage. See more on the protocols of the methodological approach in Section 5.

In practice we could collect useful data only for the following WIOD countries: Austria, Denmark, Germany, The Netherlands, Australia and Canada. Belgium also published a draft NAMEA-energy (Gilis and Vandille, 2006), but this work was stricken out from the list of useful data sources because it is only available for 2002 as most recent year, it is based on the net energy concept only, and it is very incomplete.

As regards energy statistics and energy balances, data are available from all WIOD countries. All WIOD countries report to the yearly joint survey of IEA/OECD/ESTAT/UNECE, which uses harmonised methodologies and definitions. We used the latest version available (IEA, 2011a). However, there are some limitations to the level of harmonisation: Annex 3 lists the full classification of energy commodities and energy flows of the IEA Extended Energy Balances, but many countries (thereby including some very advanced countries) use a more aggregate (and country specific) classification of flows, which required adaptations in the estimation protocols described in Section 5. Among the WIOD countries, this applied to: Australia, Brazil, Canada, India, Indonesia, Japan, Luxembourg, Malta, Mexico, Turkey, United Kingdom and United States.

The IEA energy balances use, however, commodity balances and technology- and/or process-based classifications which are in certain cases difficult to link to economic activities as used in National Accounts (e.g. NACE or CPA divisions): for instance, the energy balances report energy use for all road transport – irrespective of the economic agent doing the transport activity – as one aggregate figure per each fuel, whereas in the national accounts framework this figure needs to be broken down by agent (households, transport services, and all other industries). The “Energy Statistics Manual” jointly published by OECD, IEA, and Eurostat (IEA/Eurostat/OECD, 2004) is the main reference for the concepts and classifications of energy balances and statistics.

In addition to classification, terminology and source differences between statistics and accounts (c.f. Table 2), the major concern in the transformation is related to conceptual differences between energy statistics and the System of National Accounts (SNA), and the transformation from the territory principle to the residence principle. Hence, one needs to add activities of residents operating abroad (e.g. international transport services provided by domestic residents) and deduct activities of foreign entities operating on the national territory (e.g. tourists driving a car in the respective country). Specific sources of information for such data are:

- International bunkering: The IEA provides the flows of fuels related to international bunkering, separately for aviation and marine transport. The attribution by country of these fuels is however dependent on information on the flagship of the transportation companies operating on each national territory. The project EXIOPOL (2011) endeavours to use vessel flagship information for this purpose. The EXIOPOL results were then used in WIOD when computing maritime bunkering while for aviation bunkering, we used an alternative method that relies instead on the monetary information of the use tables and on price information from the IEA (see Section 5).
- Energy prices: this information is crucial to link monetary entries from the Use tables to physical quantities. An extensive dataset on fuel prices – albeit far less complete than the energy balances in physical quantities – is available as a part of the IEA's Beyond 2020 database (IEA, 2011b). A number of data gaps (missing year, missing fuel quality) were filled by extrapolation using information from – whenever possible – neighbouring countries of similar development level.
- Cross-border driving of privately owned vehicles: Tourism terms of trade statistics were used for estimation of transboundary household driving. The necessary data was obtained from a joint OECD-Eurostat survey.
- Car fleet information for private transport: In order to be able to attribute transport fuels (chiefly petrol and gasoil) among household usage and industries, we used car fleet (stock) information from ODYSSEE (2011) and average fuel efficiency information from the Well to Wheels study (JRC/CONCAWE/EUCAR, 2008).

4.3 Air emission data sources

The dataset includes eight major air pollutants: CO_2, CH_4, N_2O, NMVOC, CO, NO_X, SO_X and NH_3.

Despite the publication of international guidelines (SEEA, 2003), there is currently no harmonised emission data reporting at the international level within the national accounting framework. Indeed, NAMEA-air data reporting (based on the national accounting framework) is mostly on the voluntary basis and emission data are rather collected into international air emission inventories for which the countries are committed.

As explained in Section 3.4.2, we may use for air emissions three types of data sources, depending on the country and the pollutant considered: NAMEA-air like data, air emission inventory data and emission factor data along with the energy accounts.

4.3.1 NAMEA-air like data

Regarding EU countries, NAMEA-air data are available for a number of Member States and have been collected by Eurostat from NSIs by different surveys (the last one took place in

2010)[3]. However, there are a lot of gaps in all these data, in terms of country, year and pollutant coverage and NACE sector breakdown. Only seven countries, indeed, reported a full NAMEA-air dataset compatible with the WIOD sector breakdown (disaggregated enough to match the WIOD sectors): Denmark, France, Italy, Netherlands, Austria, Portugal, Sweden and UK. The remaining EU countries have gaps in pollutant and/or year coverage and /or present data more aggregated than requested for the WIOD sector breakdown. In particular, the following countries do not report any NAMEA-air data (for any pollutant and any year): Belgium, Cyprus, Finland, Latvia, Malta and Slovak Republic.

Facing this situation, Eurostat ran a project in 2009 with the collaboration of the Wuppertal Institute to fill all the gaps in order to achieve a full EU27 dataset for air pollutants at NACE 60-sector breakdown (thus compatible with WIOD breakdown). Note that this full EU27 NAMEA-air dataset (Eurostat, 2012a) covers all the WIOD air pollutants over a time series from 1995 to 2008 (2009 is not included).

For the non-EU countries, official national air emission accounts are seldom. Among the 13 non-EU countries covered by WIOD, only Canada has been identified to publish national environmental accounts[4]. However, the air emissions are aggregated altogether and only data on greenhouse gas emissions as a whole are released in CO_2-equivalents (no details by pollutants), which limits the use of these data to checking purpose only. Australia is aiming at completing their national environmental accounts[5] but any publication of this work has not been released so far.

4.3.2 Air emission inventory data

Conversely to the NAMEA situation, a number of air emission inventories with harmonised and regularly updated datasets are available. There are two main international convention based air emissions inventories of relevance for WIOD:

- Inventory from the United Nations Framework Convention on Climate Change (UNFCCC)[6]. This collects data on: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, CO, NMVOC, NO_x, SO_2.
- Inventory from the Convention on Long-Range Transboundary Air Pollution (CLRTAP)[7]. This collects data on: CO, NMVOC, NO_x, SO_2, NH_3, PM_{10}, plus nine heavy metals and 17 POPs.

The coverage of UNFCCC inventory starts from 1990 to 2009 and includes all the WIOD countries except: Brazil, China, South Korea, India, Indonesia, Mexico and Taiwan (as non-Annex I Parties, these countries do not need to report). For these 7 non-reporting countries, only parsimonious (year coverage) and sparse (sectoral coverage) data may be available: Brazil (1990, 1994), China (1994), South Korea (1990, 2001), India (1994), Indonesia (1990-1994) and Mexico (1990, 1992, 1994, 1996, 1998, 2000, 2002).

[3] Data are available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.
[4] Available at: http://www.statcan.gc.ca/start-debut-eng.html.
[5] See Wentworth Group of Concerned Scientists (2008): http://www.wentworthgroup.org/docs/Accounting_For_Nature.pdf.
[6] UNFCCC (1994), signed by 193 countries, sets an overall framework for intergovernmental efforts to tackle climate change. Data are reported to UN and are available at: http://unfccc.int/2860.php.
[7] The aim of CLRTAP (1979), ratified by 50 countries from Europe and North America, is to limit, reduce and prevent air pollution including long-range transboundary air pollution. Data are reported to UNECE and EMEP and are available at: http://www.unece.org/env/lrtap/welcome.html.

The coverage of CLRTAP inventory starts from 1980 onwards (2009). In terms of country, coverage, the CLRTAP inventory is quite similar to the UNFCCC inventory and the UNFCCC non-reporting countries are also not covered by the CLRTAP inventory. For computing the data, we then gave the preference to the UNFCCC inventory.

In addition to these two convention based inventories, another emission inventory was used for the compilation of the environmental extensions in WIOD: the Emission Database for Global Atmospheric Research (EDGAR)[8]. This research database developed jointly by the Netherlands Environmental Assessment Agency (PBL), TNO Built Environment and Geosciences, the JRC and the Max Plank Institute for Chemistry stores global emission inventories of greenhouse, acidifying and ozone depleting gases. The latest version (EDGAR, 2011) covers all the WIOD countries over the period 1970-2008 and includes the following pollutants: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, CO, NMVOC, NO_x, SO_2 and NH_3.

As other data sources we can mention, for instance, the inventory from the Montreal Protocol on substances that deplete the ozone layer (MP)[9] or the European Pollutant Release and Transfer Register (E-PRTR)[10] developed under the Integrated Pollution Prevention and Control legislation. However these data sources have not been used for the WIOD database for different reasons. The MP inventory focuses only on the production and consumption of ozone depleting substances (CFCs, HCFCs, Halons, Methyl Bromide and other substances) without addressing the air emissions themselves. In addition, none of the WIOD air pollutants are covered by the MP inventory. Regarding E-PRTR, the air (and water) emission data on 91 substances have to be reported by selected facilities (the biggest polluters, hence not representative for the national economy level) every three years (2001, 2004 and 2007) and only if emissions are above defined threshold values. Therefore gaps are numerous in terms of time, pollutant and sector (in particular non-industrial sectors) coverage with severe consistency problems, which makes the data of limited use for WIOD.

4.3.3 Emission factor data and energy accounts

A main source for the emission factor comes from the technical guidance documents prepared for the compilation of national emission inventories under international conventions (UNFCCC, CLRTAP). This includes in particular the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Data from these documents are also completed by country-specific emission factors that each country may include in their required UNFCCC emission reporting[11].

Regarding energy account data, they come from the WIOD output on energy accounts as described in this document (See in particular Section 3.4.1 for main concepts, Section 4.1 for data sources and Section 5.1 for estimation methods).

[8] Data are available at: http://www.pbl.nl/en/themasites/edgar/index.html.
[9] MP (1989), a protocol to the Vienna Convention for the Protection of the Ozone Layer and signed by 195 countries, aims at protecting the ozone layer by phasing out the production of ozone depleting substances. Data are reported to UNEP and are available at: http://ozone.unep.org/.
[10] Formerly EPER, see: http://prtr.ec.europa.eu/.
[11] See footnote 6.

4.4 Data sources for the other environmental extensions

4.4.1 Materials extraction

In the last two decades, a number of academic, research and statistical institutions[12] have been working towards the standardisation of the methodology for Material Flow Accounting and Analysis (MFA). These efforts resulted in the publication of a series of methodological guidebooks for economy-wide MFA by Eurostat (Eurostat, 2001 and 2009).

At the moment of the compilation of the WIOD, there were two main data sources for the DE of materials: Eurostat and the database of material flows of Sustainable Europe Research Institute (SERI) and Wuppertal Institute for Climate, Environment and Energy.

Eurostat has compiled MFA data sets for the EU-27 countries on DE-Used among other indicators[13], classified according to Eurostat's guidelines (Eurostat, 2009). The data sets cover the time period 2000-2007 for all EU Member States, Turkey, Switzerland and Norway. Some countries have also provided data for the years 1995-1999 and for 2008-2009 but no estimates for missing data have been made. The database does not include information on DE-Unused.

The first global dataset in a time series was compiled in the framework of the "MOSUS" FP5 project (see www.mosus.net). In the context of MOSUS, resource extraction data, disaggregated by more than 200 raw material categories, was compiled for 188 countries in a time series from 1980 to 2002, taking into account changes in frontiers due to splitting up of former USSR, Czechoslovakia, Yugoslavia and PDR of Ethiopia, as well as reunification of Germany in 1990. The method for compiling data also followed the above-mentioned Eurostat (2001) handbook on economy-wide MFA. This database was developed mainly from international statistics (SERI, 2010).

The database has been regularly updated and improved and is available at the website www.materialflows.net, hosted by SERI in cooperation with Wuppertal Institute. By March 2012 the database covered the period 1980-2008, including information on the DE (Used and Unused) of 12 material categories[14] and for 223 countries. The SERI/Wuppertal database has been used in the FP6 project EXIOPOL and is being used in the FP7 project CREEA (Compiling and Refining Environmental and Economic Accounts).

4.4.2 Land use

FAOSTAT[15], the statistical system of the Food and Agriculture Organisation of the United Nations (FAO) hosts the main international data source for agricultural and forestry land use, covering all the countries of WIOD excluding Taiwan, for the period 1961-2008.

4.4.3 Water use

At the moment of the compilation of WIOD, there were no international data sets able to meet the geographical and temporal requirements of the database. Consequently, water accounts

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[12] Institute of Social Ecology (SEC/IFF), Wuppertal Institute, Sustainable Europe Research Institute (SERI), Eurostat or OECD among others.
[13] This database also includes the following indicators: Imports, Exports, Domestic Material Consumption (DMC) and Direct Material Input (DMI)
[14] The full database covers 317 material commodities
[15] http://faostat.fao.org/site/291/default.aspx

were estimated following different methods depending on the data available. The main data source for the water accounts is the series of studies on the calculations of water footprints conducted by Mekonnen and Hoekstra (2010a,b, and 2011a,b).

4.5 Summary

Table 3 presents the main blocks of background data to be combined and processed to achieve the final database of energy and air emissions satellite accounts.

Table 3. Main blocks of background data to be combined in WIODs environmental database

Country	NAMEA-(energy and-air(Eurostat, NSIs) 1995-2008	UNFCCC inventory submissions 1990-2009	EDGAR emission data 1970-2008	IEA data (energy balances, fuel prices 1960-2009	MFA (SERI, Eurostat) 1980-2008	FAO land data 1961-2008	EU FP6 EXIOPOL 2000 only
EU27	✓*	✓	✓	✓	✓	✓	✓
CANADA	✓**	✓	✓	✓	✓	✓	✓
JAPAN	NO	✓	✓	✓	✓	✓	✓
AUSTRALIA	✓**	✓	✓	✓	✓	✓	✓
TURKEY	NO	✓	✓	✓	✓	✓	✓
USA	NO	✓	✓	✓	✓	✓	✓
INDIA	NO	NO	✓	✓	✓	✓	✓
CHINA	NO	NO	✓	✓	✓	✓	✓
BRAZIL	NO	NO	✓	✓	✓	✓	✓
MEXICO	NO	NO	✓	✓	✓	✓	✓
INDONESIA	NO	NO	✓	✓	✓	✓	✓
SOUTH KOREA	NO	NO	✓	✓	✓	✓	✓
TAIWAN	NO	NO	✓	✓	✓	NO	✓
RUSSIA	NO	✓	✓	✓	✓	✓	✓

* NAMEA-air available for all EU countries (from Eurostat), NAMEA-energy only for Austria, Denmark, Germany, The Netherlands (from NSIs).
** Only NAMEA-energy (NAMEA-air not detailed by pollutant for Canada and not yet available for Australia)

As depicted in Table 3, the information in the blocks has different degrees of coverage:

IEA energy balances	→	For all countries and all years
SERI MFA	→	For all countries and some years
EDGAR emission inventories	→	For all countries and some years
UNFCCC emission inventories	→	For some countries and all years
Energy NAMEA	→	For some countries and some years
Air emissions NAMEA	→	For some countries and some years
Eurosat MFA	→	For some countries and some years
FAO	→	For some countries and some years
EXIOPOL	→	For all countries and one year only

In addition, the following information is necessary:

Use tables	→	For all years and all countries. At purchasers' prices and basic prices, in current and constant prices (output of the WIOD project)
Supply tables	→	For all years and all countries
IEA energy commodity prices	→	For all years and all countries (some extrapolations necessary due to data gaps)
Transport statistics	→	Additional information as required especially for Marine shipping
Tourism statistics	→	Some information is available for most countries and years

5 The WIOD data set: estimation methods

This section describes the methods and procedures adopted for the estimation of a complete data set of energy-environment satellite accounts in WIOD. Since completeness is an overarching aim in the compilation of the WIOD database, estimations are made such as to leave no gaps in the following dimensions:

- Geographical coverage: full set of 40 WIOD countries plus + RoW;
- Time coverage: full time series 1995-2009;
- Sectoral coverage: all 35 WIOD industries plus final consumption;
- Energy commodity coverage: 61 IEA energy commodities; for the sake of treatability the data is aggregated to 26 energy commodities plus one entry for losses (see Annex 3); this implies for instance that only two grades of coal are distinguished (brown and hard), discarding finer distinctions such as among bituminous, sub-bituminous and anthracite varieties;
- Energy commodities for non-energy use (chemical feedstock, asphalt, lubricants, solvents);
- Energy related emissions, explicitly related to the use of energy specific energy commodities, as well as non-energy related air emissions. The WIOD classification of air emissions is listed in Annex 5;
- Additional variables (water consumption, land use, extraction of natural resources).

Energy use, energy-related emissions, non energy-related emissions, materials extraction, land use and water use are addressed separately, as they bear specific methodological issues.

5.1 Energy use

Energy use is the first of the variables addressed as it plays a particularly important role in explaining the link between economic activity and environmental pressure. As described in Section 3.4.2.2, two main routes are possible to make the bridge from the energy balance to the air emissions NAMEA: an energy-first approach and an inventory-first approach.

The energy-first approach uses as intermediate step the energy NAMEA, displaying the use of fuels by industrial sector according to the definitions of the national accounts framework; subsequently, the NAMEA-energy is converted into the air-emissions NAMEA by applying the appropriate emission factors.

In the inventory-first approach, one never compiles the NAMEA-energy. Energy statistics or balances are first converted into the emission inventory as for UNFCCC reporting, and then the emissions are allocated to NACE sectors and bridged to the appropriate accounting principles.

Although in the statisticians' community there is no clear agreement on which of the two approaches is preferable, the strong modelling orientation of the WIOD project makes an inventory-first approach a far less appealing option than the energy-first route, the reason being that the NAMEA-energy is not a fancy by-product but key information for the empirical basis of IO modelling and of the E3 models of WIOD WP 9.

The methodology developed to process the heterogeneous information listed in Section 4 into harmonised and consistent satellite accounts is described below and was developed such as to be as standard as possible for all countries; the consequence of this approach is that in a first step the method uses only the information that is available for all countries (Extended Energy Balances, Supply and Use tables, Energy prices, tourism information, car fleet composition), and the additional information than is available for some countries (such as NAMEA-energy and NAMEA-air) comes into play only in a second stage by means of calibration steps.

This strategy has the additional advantage of allowing for an estimate of error in the case of those countries for which calibration is not possible, by measuring the deviations between the fully calibrated tables and the tables ahead of calibration in the case of those countries for which superior data availability makes calibration possible. For energy use tables, this was formally done for the countries (Austria, Denmark, Germany and Netherlands) for which energy accounts of good quality were available. The tests allowed gaining additional insights and working a number of improvements. The final results, reported in more detail in Section 6, indicated small (<1%) deviations of the aggregate figures, modest deviations (<5%) in the energy-intensive sectors and larger deviations in other industries and in the services (typically 30-40%).

5.1.1 From Energy Balances to Energy Accounts

Harmonised "minimum information" method applied to all countries. The main underlying concept is the reconciliation/combination of the physical information of IEA energy balances with the monetary information of the use tables, in particular with the information of inputs of energy related commodities in monetary terms (expenses for inputs of refinery products, of electricity and gas, etc.). In most cases the IEA sectors (flows) are more aggregate than the NACE sectors of the use tables, and additional information is required to split a single figure for energy use in a broad sector aggregate (IEA) to a number of NACE sectors. However, the contrary can also happen, and does happen in a limited number of cases related to the WIOD choice of sectoral aggregation compared to the NACE 2-digit classification. In particular:

- WIOD aggregates NACE 27 with NACE 28, whereas in the IEA basic metals are individually identified and NACE 28 is part of a broader aggregate of manufacturing industries. This generates an unpleasant many-to-many correspondence problem.

- WIOD aggregates NACE 40 with NACE 41. This generates a problem when seeking proxy information to determine the autoproduction of electricity in NACE 41 (collection, purification and distribution of water).

It is thus more convenient to work at the full NACE 2-digit level and aggregate subsequently. Time series of WIOD Supply and Use tables are therefore disaggregated to the full 2-digit NACE level using supporting information on gross output and on the use of intermediates from EU KLEMS. This is actually only a rough disaggregation that should be understood as an aid to gain some data quality at the WIOD classification level. It should never be considered sufficient to produce data of adequate quality at the full NACE 2-digit level and as a result, the intermediate results prior to final aggregation (WIOD sectors) are not included in the WIOD database.

The method developed to obtain energy accounts starting from energy balances operates a series of steps (hereafter listed as steps 5.1.1.1 through 5.1.1.7) along the whole time series 1995-2009 and at the level of each country. The procedure has been automated and programmed in GAMS (General Algebraic Modelling System).

5.1.1.1 Direct allocation of energy use by sectors where classification matches between IEA and NACE-WIOD

It concerns: Agriculture, Fisheries, Mining, Energy extraction, Food, Paper and printing, Refineries, Chemical industry, Non metallic mineral products, Metals, Transport equipment, Power sector, Construction, Transport sectors other than land transport, Residential sector (households). The sector concordance where direct allocation is possible is worked out as follows (Table 4):

Table 4. Concordance between IEA balances flows and NACE sectors

IEA Energy balance flow	→	Energy use of NACE sector	WIOD sectors
AGRICULT	→	NACE 01, 02	AtB
FISHING	→	NACE 05	AtB
MINES, OILGASEX	→	NACE 10, 11	C
MINING	→	NACE 13, 14	C
FOODPRO	→	NACE 15, 16	15t16
WOODPRO	→	NACE 20	20
PAPERPRO	→	NACE 21, 22	21t22
BKB, COALLIQ, GTL, NUC, PATFUEL, REFINER, COKEOVS*	→	NACE 23	23
CHEMICAL, PETCHEM	→	NACE 24	24
NONMET	→	NACE 26	26
BLASTFUR, COKEOVS*, IRONSTL, NONFERR	→	NACE 27	27t28
TRANSEQ	→	NACE 34, 35	34t35
CHARCOAL, GASWKS, LNG, POWERPLT, PUMPST, MAINCHP, MAINELEC, MAINHEAT, BLENDGAS, BOILER, ELE, HEAT	→	NACE 40	E
CONSTRUC	→	NACE 45	F

RAIL, PIPELINE	→	NACE 60	60
DOMESNAV, MARBUNK**	→	NACE 61	61
DOMESAIR, AVBUNK**	→	NACE 62	62
BIOGAS	→	NACE 90	O
RESIDENT	→	Households	HH

Standard IEA account prefixes E for energy and T for transformation (e.g. EBLASTFUR, TBLASTFUR) are omitted for brevity

* See text for allocation of coke oven inputs between industries 23 and 27

** Seaport and airport bunker fuels are based on a territorial principle. See text

Sector matching notwithstanding, the procedure requires making a number of choices and operations where the application of the residence principle requires a major deviation from the energy statistics and where the energy statistics flows do not match with special cases of the national accounting framework; this was particularly important in the following cases:

- **Allocation of coke oven inputs between sector NACE 23 and NACE 27**. NACE 23, in principle, in addition to refineries includes the processing of nuclear fuel and cokeries. Since the IEA balances record inputs to cokeries for energy transformation separately from the inputs to blast furnaces, the allocation is apparently obvious. However, it may happen (and it happens) that the coking plant is not a separate reporting entity in the national accounts but reports jointly with the steel industry it belongs to. In this case, there are no coal inputs to NACE 23 and no coke inputs to NACE 27. Since the transformation of coal to coke occurs in the same industry, the intermediate step is not accompanied by an economic transaction and disappears from the statistics. The same principle was applied in the transformation of energy balances into WIOD energy accounts, in order to avoid double counting and to enable the user to meaningfully integrate economic accounts and energy accounts in further analysis. The key for allocation was thus inputs of coal (CPA 10) into NACE 23 and NACE 27: the inputs to IEA TCOKEOVS were allocated to the two industries proportionally to their inputs of CPA 10, and among the inputs of coke into IEA TBLASTFUR, the proportion equal to the input of coal into NACE 23 was assigned to NACE 27, whereas the remaining proportion was *discarded*.

  To summarize, let us call ***E*** the WIOD NAMEA-energy and ***B*** the IEA energy balance. Let ***t*** be the year, ***s*** the WIOD sector, ***f*** the WIOD energy commodity (fuel), ***h*** the IEA balance flow. ***U*** is the use table, defined over WIOD sectors ***s*** and CPA products ***p***. The inputs of coal into WIOD sectors 23 and 27 (more precisely, 27t28) are calculated as:

$$\begin{cases} E(c,s_{23},f_{COAL},t) = B(c,h_{TCOKEOVS},f_{COAL},t)\dfrac{U(c,p_{10},s_{23},t)}{U(c,p_{10},s_{23},t)+U(c,p_{10},s_{27},t)} \\ E(c,s_{27},f_{COAL},t) = B(c,h_{TCOKEOVS},f_{COAL},t)\dfrac{U(c,p_{10},s_{27},t)}{U(c,p_{10},s_{23},t)+U(c,p_{10},s_{27},t)} \end{cases} \qquad \text{Eq. 5.1}$$

  And the inputs of coke into WIOD sector 27 are calculated as:

$$E(c,s_{27},f_{COKE},t) = B(c,h_{TBLASTFUR},f_{COKE},t)\frac{U(c,p_{10},s_{23},t)}{U(c,p_{10},s_{23},t)+U(c,p_{10},s_{27},t)} \qquad \text{Eq. 5.2}$$

- **International marine and airport bunkers**. These data entries are among those where the deviations between the territorial and the residence principle are largest, since carriers of all nationalities are served jointly. See point 1.5 below for a discussion of the workaround.

5.1.1.2 Splitting of energy use by commodity in sectors where the IEA balances do not have sufficient sectoral detail

It concerns: Textiles, Miscellaneous manufacturing and Services. Splitting key is the input of energy commodities (CPA 10, 11, 23, 40) in monetary terms from the use table. It is assumed therefore that the NACE sectors that are below an aggregate IEA heading (such as different service sectors) a) pay the same price per energy unit, and b) consume energy products below an aggregate CPA heading (such as different refinery products) with identical shares given by the energy product shares of the corresponding IEA extended energy balance account (Final Energy Consumption of Other Sectors in the case of services). The concordance between more aggregate IEA balance flows and NACE sectors is worked out as follows (Table 5):

Table 5. Concordance between aggregate IEA balances flows and NACE sectors

IEA Energy balance flow	→	Energy use of NACE sector
TEXTILES	→	NACE 17, 18, 19
MACHINE	→	NACE 28, 29, 30, 31, 32
INONSPEC	→	NACE 25, 33, 36, 37
COMMPUB	→	NACE 41, 50, 51, 52, 55, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93

The concordance between IEA fuels and CPA energy-related commodities (used as key for splitting the physical flows) is worked out as follows (Table 6):

Table 6. Concordance between IEA balance energy commodities and CPA products related to the consumption of energy

IEA Energy commodity	→	CPA energy-related commodity
SBIOMASS	→	CPA 01 + CPA 02
ANTCOAL, BITCOAL, BKB, COKCOAL, LIGNITE, PATFUEL, PEAT, SUBCOAL	→	CPA 10
ADDITIVE, CRUDEOIL, NGL, NONCRUDE, REFFEEDS, NATGAS*	→	CPA 11
AVGAS, BIODIESEL[1)], BIOGASOL[1)], BITUMEN, BLFURGS[2)], COALTAR, COKEOVGS[2)], ETHANE, GASCOKE, GASDIES, JETGAS, JETKERO, LPG, LUBRIC, MANGAS, MOTORGAS, NAPHTHA, OBIOLIQ[1)], ONONSPEC, OTHKERO, OVENCOKE, OXYSTGS[2)], PARWAX, PETCOKE, REFINGAS, RESFUEL, WHITESP	→	CPA 23
CHARCOAL	→	CPA 24
ELECTR, GASWKSGS, GBIOMASS, GEOTHERM, HEAT,	→	CPA 40

HEATNS, NATGAS*	
INDWASTE, MUNWASTEN, MUNWASTER	→ CPA 90

1) Biofuels (formally CPA 24) are assumed to have the same pattern use as petroleum products (CPA 23).
2) Coal gases (formally CPA 40) are assumed to have the same pattern use as coke products (CPA 23).
* See text for association of natural gas to CPA 11 or CPA 40

Biofuels (biodiesels, biogasoline and other liquid biofuels) are formally classified as CPA 24 (chemicals). However biofuels represent a very marginal share of the whole use of chemical products and the sectoral chemical use cannot be deemed to be representative of the sectoral biofuel use (most chemical uses are completely unrelated to biofuel use). Alternately, it has been assumed that biofuel use, which is somehow related to gasoline and diesel/gasoil consumption, follows the same pattern as petroleum product use (CPA 23). In the same idea, coal gases (coke oven gas, blast furnace gas and oxygen steel furnace gas) are formally classified as CPA 40 (electrical energy, gas, steam and hot water). However coal gases represent a very marginal share of the whole use of electricity and natural gas commodities and the sectoral coal gas use is not directly linked to electricity and natural gas use. Alternately, it has been assumed that coal gas use, which is to a certain extent related to coke consumption[16] follows the same pattern as coke product use (CPA 23).

In Table 6, we have also to note the redundancy of natural gas: depending on the practice followed by the individual NSI, deliveries of natural gas can be accounted either in the resource (commodity CPA 11), or in the distribution service (commodity CPA 40). The estimation method was adjusted such as to allow flexibility in this respect. The two cases are easily identified by examining the use tables: in the first case the row of the use table corresponding to CPA 11 is filled with non-zero entries, in the second case the only non-zero entry is at the crossing with sector NACE 40, with the possible exception of sector NACE 24 (chemicals) and few more.

To summarize, let ***s*** be one of *n* WIOD sectors ***ss*** that are part of a more aggregate IEA flow ***h*** (as from Table 5), and let us designate as $\boldsymbol{p_f}$ the CPA product that includes the energy commodity ***f*** (as from Table 6). The inputs of energy commodity ***f*** in WIOD sector ***s*** are calculated as:

$$E(c,s,f,t) = B(c,h,f,t)\frac{U(c,p_f,s,t)}{\sum_{ss\in h} U(c,p_f,ss,t)} \qquad \text{Eq. 5.3}$$

5.1.1.3 Allocation of electricity and heat autoproduction to all industrial sectors

The IEA balances have separate accounts for the production of electricity and heat from electricity, heat and CHP plants from entities producing mainly energy commodities (main production, NACE sector 40) and from other entities (autoproduction). In the NAMEA framework the autoproduction part must be split among all NACE sectors. Autoproduction of electricity and heat by specialised fuels is directly assigned to specific sectors (e.g. autoproduction by waste to the waste management sector, autoproduction by blast furnace gas to the basic metals sector). Table 7 shows this assignment for all specialised fuels.

[16] A significant part of coal gases, which are by-product of coke making and/or coke using, is reused within the same sector in which it has been produced.

Table 7. Concordance between specialised IEA energy commodity for autoproduction and specific NACE sector

Specialised IEA energy commodity for autoproduction	→	**Specific NACE sector**
CHARCOAL, SBIOMASS	→	NACE 02, 20 & 21*
BITCOAL, LIGNITE, PEAT, SUBCOAL	→	NACE 10
COKEOVGS, CRUDEOIL, ETHANE, PETCOKE, REFINGAS, REFFEEDS	→	NACE 23
COKCOAL, OVENCOKE, BLFURGS, OXYSTGS	→	NACE 27
GASCOKE, GASWKSGS	→	NACE 40
NUCLEAR	→	NACE 75
GBIOMASS, INDWASTE, MUNWASTEN, MUNWASTER	→	NACE 90

* see text below for further allocation to the three sectors

Charcoal and solid biomass (noted as $\boldsymbol{f_{wood}}$) are a special case. They are considered as specialised fuels but are assumed to be used by three different sectors: forestry (secAtB), wood products (sec20) and pulp and paper (sec21t22). Let us call $\boldsymbol{ss_{wood}}$ these three sectors. The splitting key is the input of energy commodity CPA 02 (forestry products) in monetary terms from the use table. However most CPA 02 use by these three sectors is nonenergy related (wood is mostly used as a raw material which enters in the composition of the final products). To circumvent the difficulty with taking into account that only a small share of CPA 02 purchase is actually for wood fuels, a weighting factor $\boldsymbol{W}$ computed on the basis of Austrian data has been associated to CPA 02 ($\boldsymbol{p_{02}}$) purchase of each of the three sectors. The inputs $\boldsymbol{E_a}$ of charcoal and solid biomass only for electricity and heat autoproduction are calculated as follows:

$$E_a(c, s_{wood}, f_{wood}, t) = B(c, h_a, f_{wood}, t)\frac{U(c, p_{02}, s_{wood}, t)W(s_{wood})}{\sum_{ss_{wood}} U(c, p_{02}, ss_{wood}, t)W(s_{wood})} \qquad \text{Eq. 5.4}$$

where $\boldsymbol{s_{wood}}$ is any one of the three WIOD sectors $\boldsymbol{ss_{wood}}$ and ***ha*** is any one IEA energy flow related to the electricity and heat autoproduction (AUTOELEC, AUTOCHP and AUTOHEAT).

For all the other fuels, which are of general use, such as natural gas, a practical splitting key can be the supply of commodity 40 from the supply table. Note that this data represents not only the sale of surplus electricity to the grid from those establishments but also the supply of electricity within the same firm, as long as the production of electricity occurs in a different establishment (belonging to the same firm) than the one consuming electricity, and as long as the statistical authority applies consistently this accounting convention; in practice it is common, however, that empirical hurdles cause part of these flows to be unrecorded. The use of this disaggregation key bears therefore the assumption that the share of power generation not captured in the supply table is equal for all industries that autoproduce electricity. In order to circumvent the statistical volatility due to the fact that part of the recorded supply of electricity as non diagonal output is related to the sales of surplus electricity, for this purpose the supply tables were averaged along the whole WIOD time series (1995-2009).

To summarize, let $\boldsymbol{s_n}$ be any one WIOD sector excluding the power sector and the other sectors mentioned above (waste management, pulp and paper, iron and steel, etc.) that autoproduce electricity with specific energy commodities (waste, black liquor, coke oven gas). Likewise, let f_n be any one energy commodity excluding those specific ones. S is the supply of products at basic prices (ideally in constant prices). The inputs E_a of energy commodity f_n in WIOD sector s_n only for electricity and heat autoproduction are calculated as:

$$E_a(c, s_n, f_n, t) = B(c, h_a, f_n, t) \frac{S(c, p_{40}, s_n, t)}{\sum_t \sum_{s_n} S(c, p_{40}, s_n, t)} \quad \text{Eq. 5.5}$$

5.1.1.4 Allocation of fuels used in road transport

This task requires two operations: a) to split total energy for road transport to all NACE sectors and to private consumers; and b) to correct for the mismatch between territorial and residence principle. Both operations can be completed either in a single step or in two, depending on the supporting information available; in particular, different cases apply to the following groups of users:

- **Households:** the procedure is aided by using the information of monetary expenditure for refinery products (CPA 23) from the use table at purchasers' prices (current prices) divided by fuel prices. This method already corrects for the residence principle for the sectors where it is applied, because the use tables are already conformant. More precisely, the household expenditure for commodity 23 includes both purchases of transport fuels at the gas station and the purchases of other refinery products, chiefly for heating and less prominently for cooking (e.g. gas cookers not connected to a public gas utility but fuelled by butane bottles); these inputs, recorded in the IEA flow RESIDENT, were priced by the corresponding IEA fuel price (non-commercial light fuel oil where more specific price information were not available) and subtracted from the total household expenditure for CPA 23. The residual identifies the household expenditure for transport fuels and is converted in physical units by dividing with a composite fuel price that takes into account the fuel share (diesel, LPG and petrol) in the vehicle fleet passenger transport. This information was obtained from the database Odyssee. Since this database only covers European countries, for non European countries (and Lithuania) the diesel and LPG vehicle shares were extrapolated on the basis of a regression between diesel (LPG) vehicle shares in European countries and share of total diesel (LPG) to road transport fuel consumption from the IEA statistics (which is available for all WIOD countries). Note that petrol shares were then computed as a residual. Actual data were used for South Korea (Kim *et al.*, 2006). Additional information on fuel consumption for average diesel and Otto-cycle cars was taken from the Well-to-wheels study (JRC/CONCAWE/EUCAR, 2008).

  To summarize, let f_{p23} be any one energy commodity included in CPA 23 commodity (see Table 6) and f_r any of the ff_r road fuels (diesel, LPG and petrol); let P be the price of energy commodities obtained from the IEA database. We also define α as an adjustment factor to petrol taking into account the differential of the car motor efficiency and the kilometres driven per year compared to petrol cars ($\alpha_{\mathbf{petrol}} = 1$); K is the household vehicle fleet share for a given road fuel . The inputs E_r of road fuels for driving by households (HH) are calculated as:

$$E_r(c,s_{HH},f_r,t)=\frac{\left[U(c,p_{23},s_{HH},t)-\sum_{f_{p23}}B(c,h_{RESIDENT},f_{p_{23}},t)P(c,f_{p_{23}},t)\right]\alpha(f_r)K(c,f_r,t)}{\sum_{ff_r}\alpha(ff_r)K(c,ff_r,t)P(c,ff_r,t)} \quad \text{Eq. 5.6}$$

Note that the final results aggregate LPG into a more generic fuel (OTHPETRO).

- **Road transport sector** (and two additional sectors that are road transport intensive enough for transport fuels to entirely dominate the inputs of refinery products: **auxiliary transport activities** and **post and telecommunications**). Again, instead of allocating a portion of the IEA entry ROAD, the physical quantity compliant with the resident principle was calculated as expenditure for commodity 23 from the use table at purchasers' prices (less the purchases of other refinery products than diesel) divided by the commercial diesel price as from IEA database. Note that in IEA classification diesel and LFO are merged together into *gasoil* and then cannot be differentiated. Then, this method assumes that a) expenditure for gasoil as heating fuel (LFO) is insignificant in these industries compared to gasoil as transport fuel (diesel), and b) that the use of petrol in these industries is insignificant compared to diesel. These assumptions were by and large verified in the NAMEA-energy data available from NSIs[17].
- The residual amount of fuels, corrected for the residence principle (see below), in the IEA flow ROAD is split among **all other sectors** using as key the number of employees (purchase of commodity 23 is impractical due to too many other commodities included in that expenditure – chemical feedstock, heating oil, coke, agricultural fuel – for which it is very difficult to obtain reliable prices). Correction for the residence principle is necessary because not *all* sectors' fuel consumption is obtained by pricing transactions of the use table. The correction is obtained with the aid of tourism terms of trade statistics (Eurostat-OECD); since detailed statistics on the expenditure *structure* of outgoing and incoming tourists are largely unavailable, it is assumed that the fuel consumption share of outgoing tourists is identical to that at home.

This procedure has the advantage that it makes the most of the information available (IEA balances, use tables, energy prices, car fleet composition). It has however a drawback: since the amount of fuels to be split among non road transport intensive sectors is obtained as a residual, it only works if key but heterogeneous sources of information (IEA balances and use tables) are mutually consistent and if road fuel prices are reliable. The initial tests indicated that the fuel prices required are sufficiently reliable and the results are in good agreement with the published energy NAMEA for those countries that do make this information available (AUT, GER, DNK, NLD). However, those are among the countries with the overall best statistics. In a number of cases the method produced inconsistent results along the time series and had to be replaced by second-best options. First, when considering the road fuels as a whole, it appeared that for some countries the estimation does not provide meaningful shares between the different sectors (households, transport sectors and other sectors). Where the detected problems only concerned point estimates in time, simple interpolations were applied

[17] For instance, for Germany in 2005 LFO makes up less than 2% of gasoil input in sector NACE 60, and petrol represent about 2% of the fuel input.

to circumvent the problematic years and new estimations were produced on that basis.[18] When the whole time series was affected, average shares drawn from countries as close as possible and with consistent results were used instead and new estimations were produced on that basis.[19] Second, when looking at each time series of each road fuel, some results for some countries, years and fuels were inconsistent. In that case, the inconsistent results were calibrated to the available emission data for a benchmark year and projected along the time series according to the aggregate flow in the IEA account ROAD of the fuel road under consideration.

5.1.1.5 Air and Maritime transport (correction for residence principle)

Separate entries are available in the IEA balances for Air and Marine bunkering. These fuel deliveries are recorded by the territorial concept, i.e. total deliveries in the country in the calendar year. The correction to the residence principle implies, in principle, removing all fuels delivered to foreign carriers and adding all the bunkering fuels delivered abroad to national carriers (method **5.a**). This would require the collection of data on fuel bunkering worldwide and carrier flagship information worldwide. The effort required is large and the results very much dependent on the quality of the underlying data, which comes with a big question mark as specific data is expected to be scarce.

We adopted therefore an alternative method **5.b** that does not require carrier flagship information and that is based, instead, on the expenditure for commodity CPA 23 from the use tables and on the conversion to physical flows by price relations. On the encouraging side, the commodity mix is limited: international marine shipping uses heavy fuel oil as eminently predominant fuel, and airlines use almost exclusively jet fuel; the prices required are thus only jet kerosene for airlines and heavy (and light) fuel oil for maritime shipping. On the less encouraging side, there are significant potential problems related to the price measurements; indeed large transport operators such as airlines are well known to use hedge positions to diminish their exposure to price fluctuations, implying that the spot price is not necessarily the correct measurement of the fuel price paid by the sector in the calendar year[20]. Initial tests gave indeed mixed results, indicating that method 5.b could be empirically viable for Air transport but not for Maritime shipping. Actual air transport energy uses were used when available (e.g. for Australia).

As least sophisticated but most robust alternative we thus resort to method **5.c** for maritime transport, which consists in obtaining for one point in time the ratio between fuel use by national carriers and bunker fuel deliveries in the country. This is possible as a single point in time estimate is available from the project EXIOPOL. With keeping that ratio as constant, we can project along the time series with the supply of maritime transport services by the maritime transport sector in constant prices. In that case, it is assumed a fully constant energy use per output, which may be acceptable in maritime transport where room for innovation is limited. In general, use of fuels makes up approximately 10% in input structure of maritime transport. Note that we did not use the purchase of petroleum fuels by maritime transport sector to project the time series since the results were quite mixed in this case. .

[18] This applied to the following countries: MLT, POL, SVK and SVN.

[19] This applied to the following countries: BEL, BGR, CYP, CZE, EST, FIN, GRC, LTU, MLT, LVA, POL, ROU, SVK, SVN, BRA, CHN, IND, IDN, MEX, RUS and TUR.

[20] A rough correction estimated by comparing the results with cases where NAMEA-energy was available (AUS, DEU, DNK, NLD, AUS and CAN) was systematically applied to take into account that the actual prices paid by the air companies for jet fuel should be lower (actual prices estimated to be 20% lower than the spot prices).

In the cases where a NAMEA-air is available, it is also possible to calibrate fuel use on CO2 emissions from NAMEA-air (method **5.d**) along the time series. Given the predominance of a single product (kerosene or HFO) in the use of fuels from industries NACE 61 and NACE 62, one could envisage to apply this method to both maritime and air transport sectors, for at least all European countries (where NAMEA-air are available). After all, the method is extremely simple to apply and circumvents the problem of price measurement errors. Unfortunately, the data quality of NAMEA-air for these specific sectors was found to have large variations by Member State: in many cases the country seems to report essentially the same value to the NAMEA survey and to the UNFFFC, which is based on the territorial principle, takeoff and landing only for aviation, etc.. Thus it was chosen not to apply method **5.d** to any sector but to keep the estimates from method **5.b** (air transport) or **5.c** (maritime transport), which present the advantages of preserving the consistency between the SUTs and the environmental extensions as well as a formal link between the energy commodity prices and the energy uses.

5.1.1.6 Defence

In principle emissions related to military spending are part of the NAMEA concept. In practice this information is largely covered by military secret. Fuel consumption by the military is in principle included in the IEA energy balances under the heading "Final Energy Consumption, Non Specified (Other)", based on the territory principle. An undesirable consequence is that fuel use in military missions abroad is not accounted for. The EXIOPOL project assessed this situation and concluded that data shortages prevent the development of empirically sound solutions to this issue; consequently, in WIOD we did not treat this instance in any special fashion.

5.1.1.7 Embassies

Information on NACE sector Q (Extra-territorial organisations and bodies) is often missing in input-output accounts from NSIs. As is also the case in the EXIOPOL project, WIOD neglects this issue.

5.1.2 Calibration of WIOD estimates to official national data

This additional step is included when official NAMEA-energy information is available for the country. Despite the optimistic assessment drawn in WIOD deliverable 4.1 (Villanueva *et al.*, 2009) from the results of an UNSD survey, in reality there are only a very limited number of countries that publish energy accounts. The procedure described in this section could be applied to the European countries Austria, Denmark, Germany and the Netherlands. This procedure is worked out along the following steps (which are applied sequentially in the given order if more than one is necessary):

5.1.2.1 Aggregation/ disaggregation of national NAMEA industries to the target WIOD sectoral classification

Aggregation does not require additional information and is relevant in those cases where the national energy accounts have more detail than WIOD's 35 sectors. This in practice only occurs for Germany, as the German NAMEA is produced with a classification distinguishing 69 industries, slightly more detailed than NACE 2-digit.

Conversely, when the national NAMEA needs to be disaggregated, this is done with the shares computed with the WIOD NAMEA ahead of calibration, estimated as described above (cf. 5.1.1.1 – 5.1.1.7). This method achieves the target WIOD classification while ensuring that at the aggregate level of the official NSI data, correspondence with official data is fully maintained. Let us call $\boldsymbol{E^{NC}}$ the WIOD NAMEA before calibration, $\boldsymbol{E^{C}}$ the calibrated WIOD NAMEA and $\boldsymbol{E^{NSI}}$ the national NAMEA from NSI. With the same notation as before, let, $\boldsymbol{s_n}$ be a sector of the national NAMEA such that n WIOD sectors ***ss*** are part of $\boldsymbol{s_n}$[21]. The sector-wise calibration is worked out as:

$$E^{C}(c,s,f,t) = E^{NSI}(c,s_n,f,t)\frac{E^{NC}(c,s,f,t)}{\sum_{ss\in s_n} E^{NC}(c,ss,f,t)} \qquad \text{Eq. 5.7}$$

5.1.2.2 Aggregation/disaggregation of energy commodities to standard energy commodity divisions of the WIOD satellite accounts (see Annex 4 for energy commodity classification)

Aggregation does not require additional information and is relevant in those cases where the national energy accounts have more detail than WIOD's 25 energy commodities. This in practice only occurs for Denmark, as the Danish NAMEA is produced with a classification distinguishing 31 energy commodities.

Conversely, when the national NAMEA needs to be disaggregated, this is done with the shares computed with the WIOD NAMEA ahead of calibration, estimated as described above (1.1-1.7). This method achieves the target WIOD classification while ensuring that at the aggregate level of the official NSI data, correspondence with official data is fully maintained. Let $\boldsymbol{f_m}$ be an energy commodity of the national NAMEA such that m WIOD energy commodities ***ff*** are part of $\boldsymbol{f_m}$[22]. The commodity-wise calibration is worked out as:

$$E^{C}(c,s,f,t) = E^{NSI}(c,s,f_m,t)\frac{E^{NC}(c,s,f,t)}{\sum_{ff\in f_m} E^{NC}(c,s,ff,t)} \qquad \text{Eq. 5.8}$$

5.1.2.3 Extrapolation of missing years

In certain cases the national energy NAMEA is available but not for the full yearly time series. The official NAMEA is then projected to the WIOD time series definition using shares computed with the WIOD NAMEA ahead of calibration, estimated as described above (1.1-1.7). This method achieves the target WIOD time series scope while ensuring that the official NSI data is unaffected at the points in time where official data is available. Let $\boldsymbol{t_l}$ be a year of the national NAMEA such that l WIOD years need to be projected from $\boldsymbol{t_l}$. The projection along the time series is worked out as:

[21] For instance: the national NAMEA may only contain aggregate transport services independent of mode aggregating NACE sectors 60, 61 and 62. In this case s_n is the aggregate transport sector, *ss* are sectors NACE 60, NACE 61 and NACE 62. The scalar n is 3.

[22] For instance: the national NAMEA may only identify a single variety of coal instead of brown and hard coal as in WIOD. In this case f_m is the aggregate coal commodity, *ff* are the commodities brown coal and hard coal. The scalar m is 2.

$$E^{C}(c,s,f,t)=E^{NSI}(c,s,f,t_{l})\frac{E^{NC}(c,s,f,t)}{E^{NC}(c,s,f,t_{l})} \qquad \text{Eq. 5.9}$$

5.2 Air emissions

As explained in Section 3.4.2.2, we implemented different methodologies to compute air emission accounts depending on the data availability. By order of priority, we used:

1. NAMEA-air like data
2. Energy-first approach
3. Inventory-first approach

Table 8 shows the implemented methodology according to the pollutant and the country considered. For EU27 countries, we used NAMEA-air data for all pollutants (except for detailed CO_2 emissions). For the non-EU countries, we applied an energy-first approach for NMVOC, CO, NO_x and SO_x (most emissions of these air pollutants are linked to the use of energy) and an inventory-first approach for CH_4, N_2O and NH_3 (most emissions of these air pollutants are not linked to the use of energy). Regarding total CO_2 in the non-EU countries as well as detailed CO_2 emissions in any countries, we applied an energy-first approach for energy-related emissions and an inventory-first approach for non-energy-related emissions.

Table 8. Implemented methodology according to the pollutant and the country

Pollutant	Country	NAMEA-air	Energy-first	Inventory-first
CO_2 (detail)[1)]	EU27		X	X
	Non-EU		X	X
CO_2 (total)[2)]	EU27	X		
	Non-EU		X	X
NMVOC	EU27	X		
	Non-EU		X	
CO	EU27	X		
	Non-EU		X	
NO_x	EU27	X		
	Non-EU		X	
SO_x	EU27	X		
	Non-EU		X	
CH_4	EU27	X		
	Non-EU			X
N_2O	EU27	X		
	Non-EU			X
NH_3	EU27	X		
	Non-EU			X

[1)] Detailed sectoral CO_2 emissions (by energy commodity);
[2)] Total sectoral CO_2 emissions.

As for energy accounts, the method developed to obtain air emission accounts operates a series of steps along the whole time series and at the country level, respecting the priority order exposed below (NAMEA-air like data > energy-first approach > inventory-first approach). As well, the procedure has been automated and programmed in GAMS (General Algebraic Modelling System), at the full NACE 2-digit level with a subsequent aggregation at the WIOD breakdown.

5.2.1 NAMEA-air like data

As mentioned in Section 4.3.1, the NAMEA-air data available concern only EU27 countries. The original data submitted by NSIs to Eurostat have a lot of gaps in terms of country, year and pollutant coverage and NACE sector breakdown. However, these data have been gap-filed by Eurostat (2009b), so that a full EU27 dataset with the eight WIOD pollutants, from 1995 to 2008, at NACE 60-sector breakdown is available.

Starting from this gap-filed dataset, data have been aggregated to the 36 WIOD sectors according to the correspondence between NACE and WIOD sectors given in Annex 2.

5.2.2 Case of CO_2 emissions

For detailed sectoral CO_2 emissions, we computed energy-related and non-energy-related emissions, separately. We applied an energy-first approach for energy-related (combustion) emissions (see Section 5.2.3.2) and an inventory-first approach for non-energy-related emissions (see Section 5.2.4.2). In addition, we detailed the energy-related CO_2 emissions by energy commodity.

Total sectoral CO_2 emissions was worked out as follows. For non-EU countries, they are simply the sum of our estimated energy and non-energy related sectoral emissions. However, in the case of EU27 countries, official NAMEA-air data are available for total sectoral CO_2 emissions (though no details by energy commodity). These official data are then used as the basis for the WIOD total sectoral CO_2 emissions in EU countries. Any discrepancy between these official sectoral emissions and the sum of our estimated energy and non-energy related sectoral emissions is reported as a statistical difference (ε), which is included in the detailed CO_2 emissions as a separate entry. In the case of non-EU countries, ε is void. Therefore, for any given country c and year t, the sectoral CO_2 emissions A_{CO_2} can be written as:

$$A_{CO_2}(s,c,t) = \sum_f A^E_{CO_2}(f,s,c,t) + A^{NE}_{CO_2}(s,c,t) + \varepsilon(s,c,t) \qquad \text{Eq. 5.10}$$

where $A^E_{CO_2}$ and $A^{NE}_{CO_2}$ are the energy-related and non-energy-related CO_2 emissions, respectively.

5.2.3 Energy-first approach

In the case of energy-first approach, air emissions are estimated based on energy accounts. The estimation of CO_2 and non-CO_2 emissions are dealt separately since in WIOD they differ to a certain extent, though the estimation is based on the same basic principle. This basic principle assumes a simple emission model with a linear relationship between the emissions and a given type of activity:

Emissions (pollutant) = Activity level × Emission Factor (pollutant)

where the activity is directly linked to the energy accounts (at least for the emissions related to combustion) and the emission factor is specific to the pollutant but also depends on the fuel and the economic sector as well as some technical aspects.

5.2.3.1 Estimation of non-CO_2 emissions (NMVOC, CO, NO_x and SO_x)

The energy-first approach for non-CO_2 emissions concerns NMVOC, CO, NO_x and SO_x. Based on the emission model described above, we developed it for non-CO_2 emissions as follows: we assume a "soft" link between the annual air emissions A_p of a pollutant *p* (in tonnes) and the sectoral activity, without detailing the energy use mix of this sector nor separating energy-related and non-energy-related emissions. We retained as sectoral activity the relevant energy use W^r (in TJ) of the sector, i.e. all energy uses generating air pollutant emissions by the sector. As a result, the pollutant emission factor F_p (in tonne/TJ) is assumed to be linked only to the sector *s* and reflects both energy-related and non-energy-related emissions. In mathematical terms, we have the following straightforward formula:

$$A_p(s,c,t) = F_p(s,c,t) \times W^r(s,c,t) \qquad \text{Eq. 5.11}$$

where W^r represent all emission-relevant energy uses from the energy accounts computed in WIOD (see Section 5.1) minus Electricity, Heat, Nuclear, Hydroelectric, Geothermal, Solar, Wind power and Other sources which do not generate any emissions.

We have to keep in mind that the emission factor $F_p(s, c, t)$ actually depends on the fuel mix used by the sector, the pollutant content of the different fuels, the industrial processes involved (non-energy related emissions) and the abatement techniques implemented by the sector, but all these elements will remain implicit. As the non-CO_2 emission factors by sector, country and year are not available, we estimated them based on EU data as follows:

$$F_p(s,c,t) = F_p^{EU}(s,t) \times scaling(s,c,t) \qquad \text{Eq. 5.12}$$

where F_p^{EU} is a representative (average) European emission factor and *scaling* a scaling factor which scales the emission factor in order to force the model to replicate some reported total emissions (more details below).

This simple model assumes that non-EU country emission factors basically followed the same evolution as in Europe, while keeping flexibility through the scaling factor for any needed adjustment. Emission factors for EU countries were computed based on their NAMEA-air and NAMEA-energy by reverting Eq. 5.11 as follows:

$$F_p(s,c,t) = \frac{A_p(s,c,t)}{W^r(s,c,t)} \qquad \text{Eq. 5.13}$$

In addition, we distinguished developed and less developed/developing non-EU countries. We assumed that developed non-EU countries faced the same evolution as in old MS (in terms of emission factors) while the evolution in less developed/developing non-EU countries was more similar to the one in new MS. Therefore, emissions factors are based on EU15 (old MS) representative values for Australia, Canada, Japan and USA and on EU12 (new MS) representative values for other non-EU countries. Representative values mean, here, average values from which outliers (due to data quality problem) have been excluded.

In the final version of the WIOD database, the scaling factor was calibrated in such a way that the sum of our estimated sectoral emissions matches some target total (over all sectors) emissions. The general formula for this scaling factor is:

$$scaling(s,c,t) = scaling(c,t) = \frac{A_p^*(c,t)}{\sum_s F_p^{EU}(s,t) \times W^r(s,c,t)} \qquad \text{Eq. 5.14}$$

where A_p^* are the target total emission to match.

A_p^* should be the residence-based total national emissions. In practice, A_p^* is approximated as follows. It is the sum of the estimated bunkering emissions[23] plus:

- territory-based UNFCCC total emissions for reporting non-EU countries (Australia, Canada, Japan, Russia, Turkey and USA);
- territory-based EDGAR total emissions for non-reporting non-EU countries countries (Brazil, China, South Korea, India, Indonesia, Mexico, Taiwan and RoW).

Note that the scaling factor in Eq. 5.14 scales all the sectors exactly in the same way (it is not dependant on the sector). Other scaling factors were also considered and but were finally not retained due to data quality issues. Two alternatives are presented below.

If we consider that sectoral emission data in NAMEA format are available but only for a single year t_0 (like EXIOPOL data), we can construct for this benchmark year the scaling factor in such a way that these sectoral emissions are replicated. The expression of the scaling factor for t_0 is:

$$scaling_{t_0}(s,c) = \frac{A_p^{t_0}(s,c,t_0)}{F_p^{EU}(s,t_0) \times W^r(s,c,t_0)} \qquad \text{Eq. 5.15}$$

where $A_p^{t_0}$ represents the given sectoral emissions (in NAMEA format) to match in t_0.

One option to derive the scaling factor over the time period is to assume that the “bridge” matrix $scaling_{t_0}$ defined for the benchmark year is also applicable for other years, then assuming a constant scaling factor over time. The underlying assumption is that, for any non-EU country, each sectoral emission factor needs to be scaled by a specific constant value (based on the benchmark year) whereas its evolution in time (in differential terms) is still the

[23] Without any further information, the national non-CO_2 emissions due to bunkering are estimated based on the global non-CO_2 emissions due to bunkering (aviation or maritime) from EDGAR and the country shares of relevant energy use by the sector of interest (NACE 61 or 62, respectively) derived from WIOD (energy accounts).

same as for European countries. Under these assumptions, the scaling factor would be merely expressed as:

$$scaling(s,c,t) = scaling_{t_0}(s,c) \qquad \text{Eq. 5.16}$$

A second option to derive the scaling factor over time is to take on board the reported total emissions over the period (like UNFCCC and EDGAR data) and then combine the two previous approaches of Eq. 5.14 and Eq. 5.15. Any differential between target and NAMEA-format total emissions for the benchmark year (due for instance to the territory vs. residence principle) is assumed to be the same over the whole period. Here, the underlying assumption is that, for any non-EU country, each sectoral emission factor needs to be scaled by a specific constant value (based on the benchmark year) but its evolution in time (in differential terms) combines two trends: the trend of the European sectoral emission factor and the general trend from a "virtual" total emission factor (over all sectors) in the non-EU country considered. Under these assumptions, the scaling factor would then be expressed as:

$$scaling(s,c,t) = scaling_{t_0}(s,c) \times \frac{\sum_s A_p^{t_0}(s,c,t_0)}{A_p^*(c,t_0)} \times \frac{A_p^*(c,t)}{\sum_s \left(\frac{F_p^{EU}(s,t) \times W^r(s,c,t)}{F_p^{EU}(s,t_0) \times W^r(s,c,t_0)} A_p^{t_0}(s,c,t_0) \right)} \qquad \text{Eq. 5.17}$$

The consequences of the different scaling methods are summed up in Table 9.

Table 9. Consequences of the different scaling methods

Scaling method	Consequences
Eq. 5.14	**Over the period:** Target total emissions are replicated; no constrains on sectoral emissions.
Eq. 5.16	**Benchmark year:** NAMEA-format sectoral (and total) emissions are replicated **Other years:** No constrains.
Eq. 5.17	**Benchmark year:** NAMEA-format sectoral (and total) emissions are replicated. **Other years:** Target total emissions are replicated, taking into account the differential between NAMEA-format and target total emissions for the benchmark year; no constrains on sectoral emissions.

5.2.3.2 Estimation of energy-related CO_2 emissions

For energy-related CO_2 emissions, we used an emission model similar to the one for non-CO_2 emissions, where the sectoral activity, here, is the emission-relevant energy use W by the sector and broken down by energy commodity. Detailed (by energy commodity) energy-related CO_2 emissions $A_{CO_2}^E$ are computed as follows:

$$A_{CO_2}^E(f,s,c,t) = F_{CO_2}(f,s,c,t) \times W(f,s,c,t) \qquad \text{Eq. 5.18}$$

where *f* is any fuel (energy commodity) from the list of Annex 4.

W comes directly from the energy accounts. Regarding CO_2 emission factors, we used information from 2006 IPCC Guidelines (IPPC, 2006) and reported UNFCCC data. We first made a correspondence between the WIOD and the UNFCCC fuels (see Table 10).

Table 10. Correspondence between the WIOD and the UNFCCC fuels

WIOD fuel	UNFCCC fuel
HCOAL	Anthracite
BCOAL	Lignite
COKE	Coke Oven/Gas Coke
DIESEL	Gas / Diesel Oil
GASOLINE	Motor Gasoline
JETFUEL	Jet Kerosene
LFO	Gas / Diesel Oil
HFO	Residual Fuel Oil
NAPHTA	Naphtha
OTHPETRO	Other Oil
NATGAS	Natural Gas (Dry)
OTHGAS	Other Gaseous Fossil
WASTE	- Municipal Wastes (non-biomass fraction) - Industrial Wastes

Note that the other WIOD fuels (CRUDE, BIOGASOL, BIODIESEL, BIOGAS, OTHRENEW, ELECTR, HEATPROD, NUCLEAR, HYDRO, GEOTHERM, SOLAR, WIND and OTHSOURC) as well as losses do not cause any emissions and as a result their emission factors were assumed to be zero.

Next, since CO_2 emissions are linked by stoichiometric relation to the carbon content, we assumed that the emission factors for any given country are the same over all the sectors (CO_2 emission factors depend on the fuel but not on the sector in which the fuel is used). For simplification, we assumed in the specific case of WASTE that manufacturing sectors may use only industrial wastes and other sectors, including NACE 90, only municipal wastes (the corresponding emission factor was then assigned accordingly).

When country-specific emission factors by type of fuel were available, which is the case for each UNFCCC reporting country, we used this information for emission factors (in the case of Malta, emission factors are available only for 2009; we then assumed that these emission factors were constant over the WIOD time horizon). For non-reporting countries as well as for some specific fuels (OTHGAS and WASTE), we used the corresponding default values provided by the IPCC Guidelines (IPPC, 2006). Note that in the case of non-reporting EU countries (namely Cyprus), we preferred to compute some average European values instead of using the default IPCC values. Table 11 summarises the basic data sources for emission factors by country.

Table 11. Basic sources of factor emission data by country

Group of countries	Data
EU26[a)]	Own UNFCCC reporting
Cyprus	EU26[a)] average

Reporting non-EU countries[b)]	Own UNFCCC reporting
Non-reporting non-EU countries[c)]	Default IPCC values

[a)] EU27 minus Cyprus;
[b)] Australia, Canada, Japan, Russia, Turkey and USA;
[c)] Brazil, China, South Korea, India, Indonesia, Mexico, Taiwan and RoW.

5.2.4 Inventory-first approach

The inventory-first approach concerns CH_4, N_2O and NH_3 emissions as well as non-energy related CO_2 emissions.

In the case of inventory-first approach, air emissions are estimated based on air emission inventories. However, the air emission inventories generally use classifications with CRF (Common Reporting Format) categories defined on a technology and/or process basis which are widely compatible with the classification used in energy balances and statistics but differ to a certain extent from the NACE sectors defined on an economic activity basis. In our case, there is no straightforward way to go from the CRF categories from UNFCCC/EDGAR to the NACE sectors. The following explains how we proceeded for the allocation procedure in general. Note that in some very specific cases (for some CRFs of some countries) we had to deviate from this general procedure to correct some inconsistencies.

As a starting point, for a pollutant *p*, we have the following model:

$$A_p(s,c,t) = A_p^E(s,c,t) + A_p^{NE}(s,c,t) \quad \text{Eq. 5.19}$$

where A_p^E and A_p^{NE} are the energy- and non-energy-related emissions, respectively.

In the following, energy- and non-energy-related emissions are addressed separately. Note that for CO_2, only non-energy-related emissions are concerned.

5.2.4.1 Estimation of energy-related emissions (CH_4, N_2O and NH_3)

- **Methodology**

We applied the following steps to estimate A_p^E (steps 5.2.4.1.1 to 5.2.4.1.4):

5.2.4.1.1 Direct allocation of sectoral emissions where classification matches between UNFCCC/EDGAR CRFs and NACE-WIOD sectors

It concerns: Agriculture & Fisheries, Food, Paper & printing, Refineries, Chemicals, Metals, Transport sectors other than road transport, Power sector and Residential sector (households). The sector concordance where direct allocation is possible is worked out as follows (Table 4):

Table 12. Concordance between UNFCCC/EDGAR CRFs and NACE sectors

UNFCCC/EDGAR CRF	NACE sectors
1.A.4.c. Agriculture/Forestry/Fisheries	NACE 01, 02, 05
1.A.2.e. Food Processing, Beverages and Tobacco	NACE 15, 16
1.A.2.d. Pulp, Paper and Print	NACE 21, 22

1.A.1.b. Petroleum Refining 1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries	NACE 23
1.A.2.c. Chemicals	NACE 24
1.A.2.a. Iron and Steel 1.A.2.b. Non-Ferrous Metals	NACE 27, 28
1.A.1.a. Public Electricity and Heat Production	NACE 40
1.A.3.c. Railways 1.A.3.e. Other Transportation	NACE 60
1.A.3.d. Navigation[a)]	NACE 61
1.A.3.a. Civil Aviation[a)]	NACE 62
1.A.4.b. Residential	Households

[a)] Note that the emissions from these CRFs, based on territory principle, have not been corrected according to the residence principle in this preliminary version.

5.2.4.1.2 Splitting of sectoral emissions in sectors where the UNFCCC/EDGAR CRFs do not have sufficient sectoral detail

It concerns: other manufacturing, services and miscellaneous. Splitting key is the relevant energy use from the energy account. It is assumed that the air emissions from NACE sectors that are below an aggregate UNFCCC/EDGAR CRF category (such as different service sectors) are proportional to their relevant energy use W^r as defined in Section 5.2.3.1. The concordance between more aggregate UNFCCC/EDGAR CRF category and NACE sectors is worked out as follows (Table 13):

Table 13. Concordance between aggregate UNFCCC/EDGAR CRFs and NACE sectors

UNFCCC/EDGAR CRF	**NACE sectors**
1.A.2.f. Other Manufacturing Industries and Construction	NACE 10, 11, 12, 13, 14, 17, 18, 19, 20, 25, 26, 29, 30, 31, 32, 33, 34, 35, 36, 37, 45
1.A.2 Manufacturing Industries and Construction[a)]	NACE 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35 ,36, 37, 40, 45
1.A.4.a. Commercial/Institutional	NACE 41, 50, 51, 52, 55, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93, 95
1.A.5. Other	All NACE including HH

[a)] When no details are given for Manufacturing Industries and Construction categories.

5.2.4.1.3 Allocation of emissions from road transport

Splitting key is the use of diesel and motor gasoline from the energy account. It is assumed that the road transport emissions from all NACE sectors (reported under a single CRF category) are proportional to their use of diesel and motor gasoline. The concordance between road transportation CRF category and NACE sectors is worked out as follows (Table 14):

Table 14. Concordance between aggregate road transportation CRFs and NACE sectors

UNFCCC/EDGAR CRF	NACE sectors
1.A.3.b. Road Transportation	All NACE including HH

- **Data sources**

Table 15 shows the data sources for air emission inventory by pollutant and country.

Table 15. Emission inventory data sources by pollutant and country for energy-related emissions

Pollutant	Group of countries	Data
CH_4, N_2O	Reporting non-EU countries[a)]	UNFCCC data
	Non-reporting non-EU countries[b)]	EDGAR data
NH_3	Non-EU countries	EDGAR data

[a)] Australia, Canada, Japan, Russia, Turkey and USA;
[b)] Brazil, China, South Korea, India, Indonesia, Mexico, Taiwan and RoW.

5.2.4.1.4 Allocation of emissions from international bunkering (aviation and maritime transport)

Global emissions from aviation and maritime bunkering are available from EDGAR. The splitting key between countries is the country shares of relevant energy use by NACE 61 (in the case of maritime bunkering) or NACE 62 (in the case of aviation bunkering) derived from WIOD (energy accounts). It is assumed that the international transport emissions from NACE 61 and NACE 62 sectors are proportional to their use of relevant energy use (chiefly HFO and LFO for NACE 61 and jet fuel for NACE 62).

5.2.4.2 Estimation of non-energy-related emissions (CH_4, N_2O, NH_3 and CO_2)

- **Methodology**

We applied the following steps to estimate A_p^{NE} (steps 5.2.4.2.1 to 5.2.4.2.3):

5.2.4.2.1 Direct allocation of sectoral emissions where classification matches between UNFCCC/EDGAR CRFs and NACE-WIOD sectors

It concerns: Agriculture, some Mining processes, some Energy extraction processes, Food, Paper & printing, some Refineries processes, Chemicals, Non metallic minerals, Metals, Power sector, Transport sectors and Waste. The sector concordance where direct allocation is possible is worked out as follows (Table 16):

Table 16. Concordance between UNFCCC/EDGAR CRFs and NACE sectors

UNFCCC/EDGAR CRF	NACE sectors
4. Agriculture	NACE 01
1.B.1.a. Coal Mining and Handling	NACE 10

1.B.2.a.i. Oil Exploration 1.B.2.a.ii. Oil Production 1.B.2.b.i. Natural Gas Exploration 1.B.2.b.ii. Natural Gas Production / Processing 1.B.2.c.i. Venting	NACE 11, 12
2.D.2. Food and Drink	NACE 15, 16
2.D.1. Pulp and Paper	NACE 21, 22
1.B.1.b. Solid Fuel Transformation 1.B.2.a.iv. Oil Refining / Storage 1. B. 2. c.ii. Flaring	NACE 23
2.B. Chemical Industry	NACE 24
2.A. Mineral Products	NACE 26
2.C. Metal Production	NACE 27, 28
1.B.2.b.iv. Natural Gas Distribution	NACE 40
1.B.2.b.iii. Natural Gas Transmission[a)] 1.B.2.a.v. Distribution of Oil Products[a)]	NACE 60
1.B.2.a.iii. Oil Transport[a)]	NACE 61
6. Waste	NACE 90

[a)] Note that the emissions from these CRFs, based on territory principle, have not been corrected according to the residence principle in this preliminary version.

5.2.4.2.2 Splitting of sectoral emissions in sectors where the UNFCCC/EDGAR CRFs do not have sufficient sectoral detail

It concerns: Solvent use and some miscellaneous processes. The splitting key depends on the CRF considered and encompasses: purchase of chemicals, all energy uses and employment. It is assumed that the air emissions from NACE sectors that are below an aggregate UNFCCC/EDGAR CRF category (such as different service sectors) are proportional to the splitting key. The concordance between more aggregate UNFCCC/EDGAR CRF category and NACE sectors and the splitting key used is shown in Table 17:

Table 17. Concordance between aggregate UNFCCC/EDGAR CRFs and NACE sectors

UNFCCC/EDGAR CRF	**NACE sectors**	**Splitting key**
3. Solvent and Other Product Use	All NACE including HH	Purchase of chemicals (from SUT)
1.B.2.b.v. Other Natural Gas Leakage at industrial plants and power stations	NACE 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35 ,36, 37, 40, 45	Energy use (from energy account)
1.B.2.b.v. Other Natural Gas Leakage in residential and commercial sectors	NACE 01, 02, 05, 41, 50, 51, 52, 55, 60, 61, 62, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93, 95, HH	Energy use (from energy account)
2.G. Other Industrial Processes	All NACE excluding HH	Employment (from WIOD)

5.2.4.2.3 Allocation of miscellaneous emissions

The allocation of some miscellaneous CRF categories was done on a country-by-country basis due to the heterogeneity of the actual content of those categories. This includes the following CRF categories (Table 18):

Table 18. UNFCCC/EDGAR CRFs and NACE sectors with no direct concordance

UNFCCC/EDGAR CRF	NACE sectors
1. B. 1. c. Other Solid Fuels 1.B.2.a.vi. Oil Other 1.B.2.d. Fugitive Emissions Other Sources	Country-by-country basis

- **Data sources**

Table 19 shows the data sources for air emission inventory by pollutant and country.

Table 19. Emission inventory data sources by pollutant and country for non-energy-related emissions

Pollutant	Group of countries	Data
CH_4, N_2O	Reporting non-EU countries[a)]	UNFCCC data
	Non-reporting non-EU countries[b)]	EDGAR data
NH_3	Non-EU countries	EDGAR data
CO_2	EU26 countries[c)]	UNFCCC data
	Cyprus	EU26[a)] share data
	Reporting non-EU countries[a)]	UNFCCC data
	Non-reporting non-EU countries[b)]	EU26[a)] share data

[a)] Australia, Canada, Japan, Russia, Turkey and USA;
[b)] Brazil, China, South Korea, India, Indonesia, Mexico, Taiwan and RoW;
[c)] EU27 minus Cyprus.

In the case of CO_2, when data were missing for a country (Cyprus and non-reporting non-EU countries), we assumed that:

- the share of non-energy-related total emissions over all emissions (both non-energy- and energy-related) is the same as in Europe;
- the sectoral structure of non-energy related emissions (share of sectoral over total non-energy-related emissions) is the same as in Europe.

We used the aggregate EU26 (EU27 minus Cyprus) as representative European values. For missing values, we then have the general formula:

$$A_{CO_2}^{NE}(c,s,t) = \left(A_{CO_2}^{E}(c,s,t) \times \frac{S_{tot}^{EU26}(t)}{1 - S_{tot}^{EU26}(t)} \right) \times S_{\sec}^{EU26}(s,t) \qquad \text{Eq. 5.20}$$

where: S_{tot}^{EU26} represents the share of non-energy-related total emissions over all emissions and $S_{\sec}^{EU26}$ the sectoral structure of non-energy-related emissions, for aggregate EU26.

5.2.4.3 Correction of EDGAR-based estimates of CH_4, N_2O and NH_3 emissions

In the case of CH_4, N_2O and NH_3 emissions, most emissions are not linked to the use of energy but come from processes which occur in a very limited number of sectors:

- CH_4 emissions come chiefly from agriculture and waste (biomass fermentation) and mining activities (fugitive emissions from natural gas and coal production);
- N_2O emissions come mainly from agriculture (nitrification/denitrification processes of nitrogen compounds);
- NH_3 emissions come chiefly from agriculture and households (nitrification/denitrification processes of nitrogen compounds).

Most CH_4, N_2O and NH_3 emissions come from primary sectors (agriculture and mining) for which the computed emissions should be the same on territory or residence principle basis. Therefore, it is fair enough to assume that the total national emissions for these three pollutants should be about the same on a territory basis (inventory emissions) or residence basis (NAMEA emissions). However, when comparing for EU countries the NAMEA-based estimates (the ones which are reported in the WIOD database) with EDGAR-based estimates, they may differ significantly. It was then decided, in the case of non-EU countries, to apply a correcting factor on the EDGAR-based estimates of sectoral CH_4, N_2O and NH_3 emissions to take into account these discrepancies. In practical terms, for each NACE sector, a median correcting factor was computed on the basis of EU observations (ratio NAMEA-based estimates/EDGAR-based estimates) assuming that the discrepancies observed for EU countries also apply for non-EU countries. Note that no correcting factor was applied to the following sectors: NACE 02, 05, 10 and 71 (implausible corrections for insignificant emissions). NACE 61 and 62 were neither corrected since these sectoral emissions are computed in a different way (see Section 5.2.4.1.4).

Table 20 shows, by pollutant, which non-EU countries are concerned by the correcting procedure.

Table 20. Correction of EDGAR-based estimates of CH_4, N_2O and NH_3 emissions

Pollutant	Group of countries	Data
CH_4, N_2O	Non-reporting non-EU countries[a)]	EDGAR data
NH_3	Non-EU countries	EDGAR data

[a)] Brazil, China, South Korea, India, Indonesia, Mexico, Taiwan and RoW;

5.3 Materials extraction

For incorporating material extraction as an environmental variable in WIOD, the data sets from both Eurostat and SERI/Wuppertal have been used. The Eurostat database is the main source for the DE-Used in the EU-27 countries while the SERI/Wuppertal data set constitutes the base for the DE Used and Unused in the non EU-27 countries, and for the DE-Unused in the EU-27.

In contrast to other environmental extensions, such as emissions of greenhouse gases, which are generated practically in all economic sectors, raw materials are only extracted by a very limited number of industries. In the case of the WIOD, there are only two sectors extracting materials: "Agriculture, Hunting, Forestry and Fishing" and "Mining and Quarrying" and, consequently, the 12 categories and materials have been allocated to these two sectors. Table

21 shows the correspondence of the 12 material categories of the database and the WIOD sectors.

Table 21. Correspondence between material categories and WIOD sectors

Eurostat and SERI/Wuppertal material category	WIOD correspondence	
	Material code	Sector code
Biomass animals - Used	Biomass_animals_Used	AtB
Biomass feed - Used	Biomass_feed_Used	AtB
Biomass food - Used	Biomass_food_Used	AtB
Biomass forestry - Used	Biomass_forestry_Used	AtB
Biomass other - Used	Biomass_other_Used	AtB
Fossil coal - Used	Fossil_coal_Used	C
Fossil gas - Used	Fossil_gas_Used	C
Fossil oil - Used	Fossil_oil_Used	C
Fossil other - Used	Fossil_other_Used	C
Minerals construction - Used	Minerals_construction_Used	C
Minerals industrial - Used	Minerals_industrial_Used	C
Minerals metals - Used	Minerals_metals_Used	C
Biomass animals - Unused	Biomass_animals_Unused	AtB
Biomass feed - Unused	Biomass_feed_Unused	AtB
Biomass food - Unused	Biomass_food_Unused	AtB
Biomass forestry - Unused	Biomass_forestry_Unused	AtB
Biomass other - Unused	Biomass_other_Unused	AtB
Fossil coal - Unused	Fossil_coal_Unused	C
Fossil gas - Unused	Fossil_gas_Unused	C
Fossil oil - Unused	Fossil_oil_Unused	C
Fossil other - Unused	Fossil_other_Unused	C
Minerals construction - Unused	Minerals_construction_Unused	C
Minerals industrial - Unused	Minerals_industrial_Unused	C
Minerals metals - Unused	Minerals_metals_Unused	C

Note: AtB: Agriculture, Hunting, Forestry and Fishing; C: Mining and Quarrying.

In the construction of the material accounts, as we pointed before, we have faced a number of situations in which for some countries and years data was not available. In such cases we have proceed as follows:

1. If data is not available for an EU-27 member state for a year before 2009:
   1.1. Calculate the growth rate of the total DE-Used and for the total DE-Unused for that country and year in the SERI/Wuppertal database.
   1.2. Apply the resulting growth rates to the latest available year of the total DE-Used and total DE-Unused from EUROSTAT.
   1.3. Disaggregate the resulting total DE-Used and total DE-Unused by material using the shares of the latest available year in the Eurostat database.
2. If data is not available for 2009:
   2.1. Calculate the real growth of the gross output of the corresponding extracting sector from the WIOD Socioeconomic Accounts (WIOD-SEA)
   2.2. Apply the resulting growth rates to the sectoral material extraction by material of 2008.

Finally, note that from a practical perspective, a sufficient number of disaggregated material categories and extracting sectors could be required in order to investigate the economic driving forces inducing the extraction and use of some specific materials. In the case of the WIOD, the reduced number of material extraction sectors could affect the quality of the results for some specific analysis. In such cases, we would recommend to re-allocate the materials not to the extraction sector itself, but to the sector receiving specific material inputs at the 1st stage of processing (see Schoer, 2006). As Schoer (2006) suggests, a wrong assignment in the first steps of production will lead to larger errors than a biased allocation at later production stages, as the processing of materials in the first production steps follows rather specific processes with particular input relations. Conversely, in later production stages, the original raw materials are mixed into semi-finished and finished products and distributed over a much larger number of sectors. Example of this type could be the re-allocation of the crude oil extraction to *Coke, Refined Petroleum and Nuclear Fuel* instead of *Mining and Quarrying*.

5.4 Land use

FAOSTAT classifies the use of land as *Agricultural area*, *Forest area* and *Other land*. The first category is further split into three subcategories: *Arable land*, *Permanent crops land*, and *Permanent meadows and pastures*, which correspond directly to sector "Agriculture, Hunting, Forestry and Fishing" (code AtB in WIOD).

Under the category *Forest area*, FAOSTAT does not distinguish if the forest is used for economic activities (e.g. plantations primarily used for forestry or rubber-wood plantations) or for other non-economic purposes (e.g. nature reserves or other protected areas). This distinction is important from a statistical viewpoint, because only the forest area actually used for productive purposes should be included in the satellite accounts. Therefore, the information on forest area of FAOSTAT is not useful for the WIOD.

In order to include forest area we followed the method suggested by Lugschitz, et al. (2011), and have estimated the forest area on the basis of the Global Forest Resource Assessment 2005 published by FAO (2006). This document reports the total forest area of 229 countries (excluding Taiwan) and the respective shares of those areas used for production purposes. In cases where the share of the forest area used for production purposes is unknown, we used regional averages, distinguishing 12 world regions. We used these figures to calculate the forest area for production purpose in 2005, for all the WIOD countries excluding Taiwan. These figures were extrapolated to the rest of the years using the total forest productivity of 2005 and the total extraction of biomass from forestry from the materials accounts of WIOD. The total forest productivity (*F_prod*) in 2005 was calculated as the ratio of used and unused biomass from forestry to forest area for productive purposes:

$$F\_prod_{2005} = \frac{Biomass\_Forestry\_Used_{2005} + Biomass\_Forestry\_Unsed_{2005}}{Forest\_area_{2005}} \qquad \text{Eq. 5.21}$$

Finally, as FAO does not record statistics for Taiwan, data for this country was directly taken from the Directorate-General of Budget, Accounting and Statistics of Taiwan (DGBAS, 2011).

5.5 Water use

The procedure followed for estimating water use for crop production is as follows:

1. We compiled crop specific blue, green and grey water intensities by country from Mekonnen and Hoekstra (2010b) in m³/tonne crop harvested. These figures are the average value for the period 1996-2005. We denote the water intensity by:

$$W\_crop\_int(c, crp, w) \qquad \text{Eq. 5.22}$$

where *crp* is the crop, *c* the country, and *w* the type of water.

2. We estimate the use of water (*W _crop_est*) for each of the years (*t*) of the period 1995-2009 by multiplying the average water intensities times the crop production by country (*P*) from FAOSTAT:

$$W\_crop\_est(c, crp, w, t) = W\_crop\_int(c, crp, w) \times P(c, crp, t) \qquad \text{Eq. 5.23}$$

$$W\_crop\_est\_tot(c, w, t) = \sum_{crp} W\_crop\_est(c, crp, w, t) \qquad \text{Eq. 5.24}$$

where *W_crop_est_tot* is the total water use estimated for crop production by country, water type and year.

3. We calculated the average value by country and water type of the estimated water use for the sub-period 1996-2005.

$$W\_crop\_avg(c, w) = \sum_{t=1995}^{2006} W\_crop\_est\_tot(c, w, t) \Big/ 10 \qquad \text{Eq. 5.25}$$

4. We calculate a scaling factor (*Scaling_crop*) for matching the total average figures calculated for the period 1996-2005 with the total results reported by Mekonnen and Hoekstra (2010b), called as *W_crop_MH*:

$$Scaling\_crop(c, w) = W\_crop\_MH(c, w) \big/ W\_crop\_avg\left(c, w\right) \qquad \text{Eq. 5.26}$$

5. Finally, we scaled the estimated total values by country using the scaling factor:

$$W\_crop(c, w, t) = W\_crop\_avg(c, w, t) \times Scaling\_crop(c, w) \qquad \text{Eq. 5.27}$$

A similar procedure was used for estimating the water use for maintaining the live stock, including water intake from grazing, service water and drinking water. In this case we used the average water intensities by country, animal and water type from Mekonnen and Hoekstra (2010a) for the period 1996-2005 in m3 per ton of animal. We also used the number of live animals by specie, country and year from FAOSTAT that where converted into weight using conversion factors from the same authors. The estimated figures were also scaled to fit the results of Mekonnen and Hoekstra (2010a).

The sum of the water for crop production and for maintaining livestock was aggregated and allocated to sector "Agriculture, Hunting, Forestry and Fishing" (code AtB of WIOD).

In the case of Taiwan, the use of water in the agricultural sector was estimate using the annual water intensity of the gross output of "Agriculture, Hunting, Forestry and Fishing" in constant prices and the output in constant prices of Taiwan. The water use in the rest of the world was also estimate on the gross output at constant prices and the results were scaled to match the values reported by Mekonnen and Hoekstra (2010a and 2010b).

The WIOD database includes an estimation of the use of water for hydropower generation. This water refers to (blue) the water evaporated from manmade reservoirs to produce electric energy. Mekonnen and Hoekstra (2011b) estimated the average water use of 35 hydropower plants around the world to be 68 m3/GJ. We use this factor together with the electricity production by country and year reported by IEA to estimate the water use for hydropower generation. This water was allocated to the sector "Electricity, Gas and Water Supply" of WIOD (code E in the database).

Mekonnen and Hoekstra (2011a) report estimations of the average water use of industrial production (excluding hydropower) by country and water type for the period 1995-2006. We distributed that water to WIOD sectors according to the share of water use in the EXIOPOL database. Finally, we used these figures to calculate the average water intensity by country, industry and water type of the gross output at constant prices for the period 1995-2006. This intensity was extrapolated to the whole series, obtaining the water use of the industrial sector. The water use in Taiwan and in the rest of the world was calculated using the average water intensity of the other WIOD countries and the sectoral output at constant prices of Taiwan.

Finally, we estimated the water use by households on the basis of the average domestic water supply reported in Mekonnen and Hoekstra (2011a) for 1995-2006 and the average population for that period. The resulting water use per capita was extrapolated to the population of the rest of the years covered by WIOD.

6 Results and discussion on data quality

In this section we elucidate the results of the work undertaken by means of a series of indicators that can be related to the quality of the estimations. Starting with energy, the most straightforward indicator can be drawn by measuring – for the case of those countries that do publish an official national NAMEA – the deviation of the final WIOD Energy NAMEA calibrated to the NSI data (E^C in the nomenclature of Section 5) from the "standard" WIOD estimation (E in the nomenclature of Section 5) that is assumed as final in the more common case where official NAMEA-energy data are not available. In so doing we implicitly take the official NAMEA-energy as "true". Note that for the sample countries that publish an official NAMEA-energy the measured error does *not* apply, as the results are successively calibrated. Instead, we assume that the error so measured is representative of the error affecting the NAMEA-energy estimated for the remaining countries. Figure 6, Figure 7, Figure 8 and Figure 9 plot E vs E^C for Austria, Denmark, Germany and the Netherlands, respectively, in log scale along with a linear fit and coefficient of correlation R^2. The figures plot the entire sample (all WIOD sectors, WIOD years for which calibrated WIOD Energy NAMEA are based on actual official NAMEA-energy[24]) also including energy use of households, total of

[24] In details: Austria: 1999-2008; Denmark: 1995-2009; Germany: 1995, 2000, 2005-2008; Netherlands: 1995, 2000-2007. Extrapolated years (missing official NAMEA-energy) are not considered here in the plots.

all industries and total of industries plus households (the latter will then be the cloud of points at the top right corner of each plot):

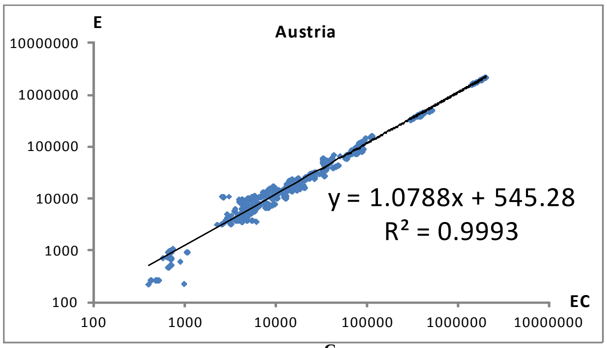

Figure 6. E vs. E^C for Austria

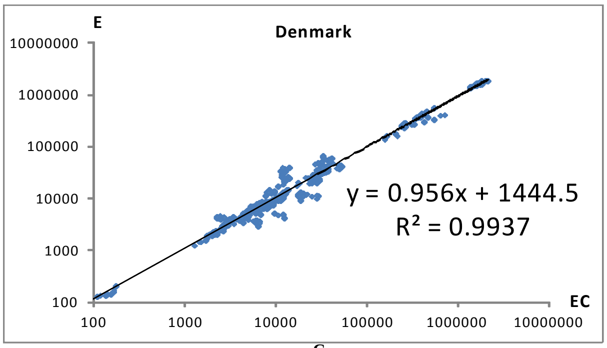

Figure 7. E vs. E^C for Denmark

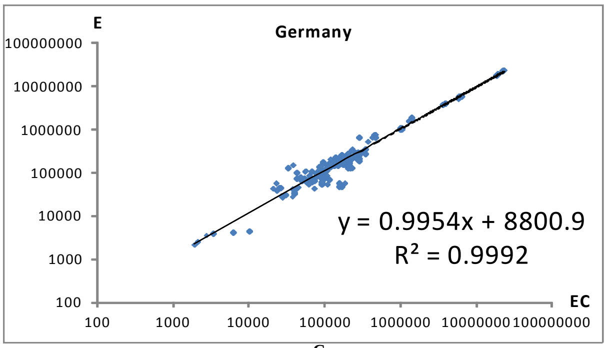

Figure 8. E vs. E^C for Germany

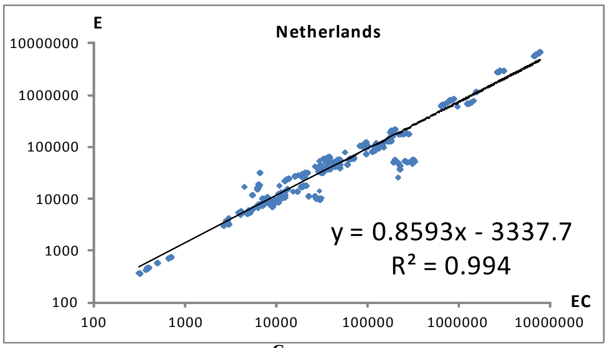

Figure 9. E vs. E^C for The Netherlands

The R^2 is in all cases greater than 0.99. The linear coefficient of the fit is close to 1 for Germany (0.99) and Denmark (0.96). For Austria and the Netherlands, the linear coefficient of the fit tends to diverge from 1. Austrian estimates without calibration are a bit overestimated (by about 7% on average) while Dutch estimates without calibration are underestimated (by about 14% on average). In the Dutch case, this divergence should come from the fact that gross energy use is in fact derived from the official net energy use built by Statistics Netherlands

If one assumes a similar confidence for the estimated NAMEA-energy for all the remaining WIOD countries (leaving aside the specific Dutch case), one will bring home a relatively cheerful picture. However, we also need to take into account that the countries that publish a NAMEA-energy are also among those that can benefit from the efforts of the most advanced statistical institutes, and in those cases there is a good level of integration between different kinds of statistics. Smaller countries and developing countries in many cases cannot produce statistics of comparable quality, and those additional uncertainties in the input data (IEA balances, supply and use tables) must also be factored in. A discussion of such data quality issues –aided by a comparison with CO2 emission data – is presented further on.

Another data integrity issue that is of special relevance for the use of the WIOD database for analysis and for E^3 modelling is the concordance between the information on inputs of energy in money terms from the use tables and the same information in physical terms from the energy satellite accounts. Indeed in earlier sections we have argued that among the truly central tasks of the whole work package 4 is the reconciliation of the information of the use tables with that of the energy balances. We have also pointed out that discrepancies in different data sources make it impossible to achieve a complete reconciliation unless one is prepared to make changes (and significant changes) either in the use tables, or in the energy balances, or in the energy prices, or in all of them. As an alternative that circumvents inconsistencies while at the same time respecting all official data sources in the database, the work package 4 partners have proposed to accept a certain degree of discrepancy and provide a “soft” link between energy use in monetary terms and in physical units through appropriate deflators that are developed in work package 7.

More in detail, the empirical mismatch between use tables and NAMEA-energy can be elucidated by calculating energy inputs in monetary terms for the four commodities corresponding to CPA 10, 11, 23 and 40 starting from the NAMEA-energy, applying energy prices at the most detailed level known and finally grouping to the final four-commodity aggregation. This is shown in Figure 10, Figure 11, Figure 12 and Figure 13 for four representative cases (four energy intensive industries) in Austria, following the long term price increase trend that accompanies the WIOD time series.

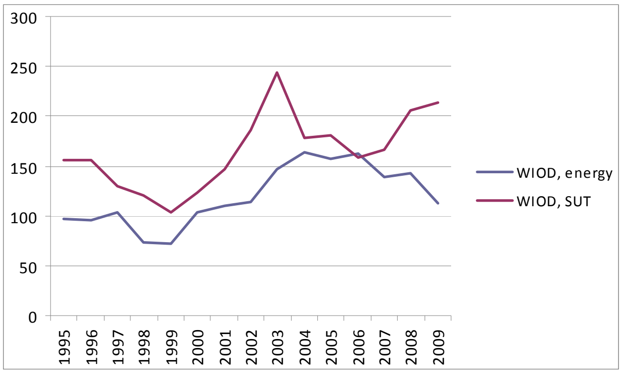

Figure 10. Energy input in € from Use table vs. calculated from physical energy input. CPA 10 into sector E

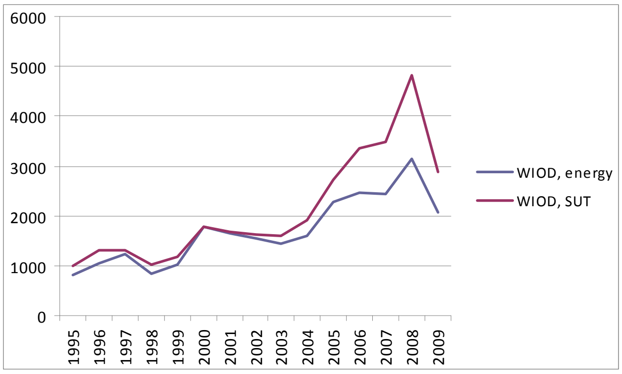

Figure 11. Energy input in € from Use table vs. calculated from physical energy input. CPA 11 into sector 23

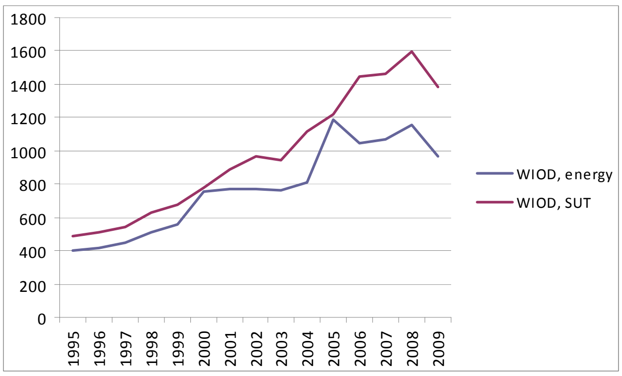

Figure 12. Energy input in € from Use table vs. calculated from physical energy input. CPA 23 into sector 60

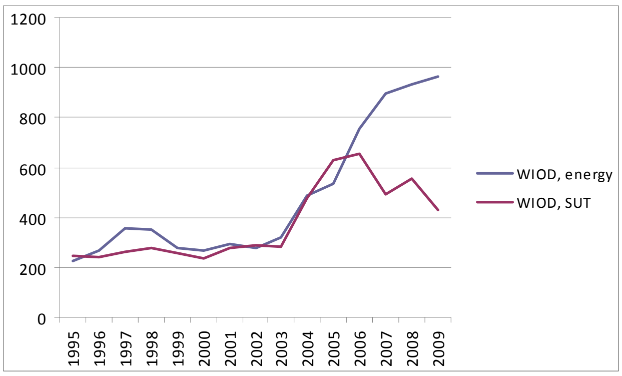

Figure 13. Energy input in € from Use table vs. calculated from physical energy input. CPA 40 into sector 27-28

Figure 10 is useful to frame the problem: it is evident that the same information obtained from both parts of the WIOD database is not entirely the same: the general development is similar, but in absolute terms the coal product purchase differs over time between the use table and the energy account. We can also notice the differing behaviour after 2006: increase with the use table information while decrease with the energy data. Figure 12shows an improved situation: the development is very similar in both cases, with acceptable deviations, except for the period after 2006 with the sharp energy price increase. Figure 11 and Figure 13 show better cases where the mismatch between the two sides of the database is limited. Basically there is no problem until 2004-2005 when the energy prices start increasing with a higher rate; then in the first case, the development is comparable but of different magnitude; in the second case, the rapid price development, which appears in the SUT, is not detectable in the energy data.

One needs to keep in mind, in any case, that Figure 10 to Figure 13 depict the situation in an advanced country with well developed statistics. In other countries the situation may well be different, and indeed a number of cases have been detected, in which energy commodity inputs from the use tables show unseemly break points or are otherwise inconsistent with any sensible price level or price development. In those cases more inventiveness, cunning or bravery will be unavoidably required from the researcher engaged in analysis.

In Figure 14, Figure 15 and Figure 16 we show a country comparison of 2008 energy intensities calculated as the ratio of total gross energy use in TJ over gross output in million USD in three energy intensive sectors: NACE 24 (chemicals), NACE 26 (non metallic mineral products) and NACE 62 (aviation), respectively.

The chemical industry (Figure 14) shows a significant degree of variability, with countries like Bulgaria, Estonia, Romania and Russia, having the highest energy intensity[25]. A significant degree of variability is plausible taking in consideration, among other things, the broad variability of output of the chemical sector in different countries, spanning basic chemicals as well as specialty chemicals and pharmaceutical products. However, we also detect a few instances of unseemly low energy intensity, in particular Cyprus, Denmark, Ireland and Malta.

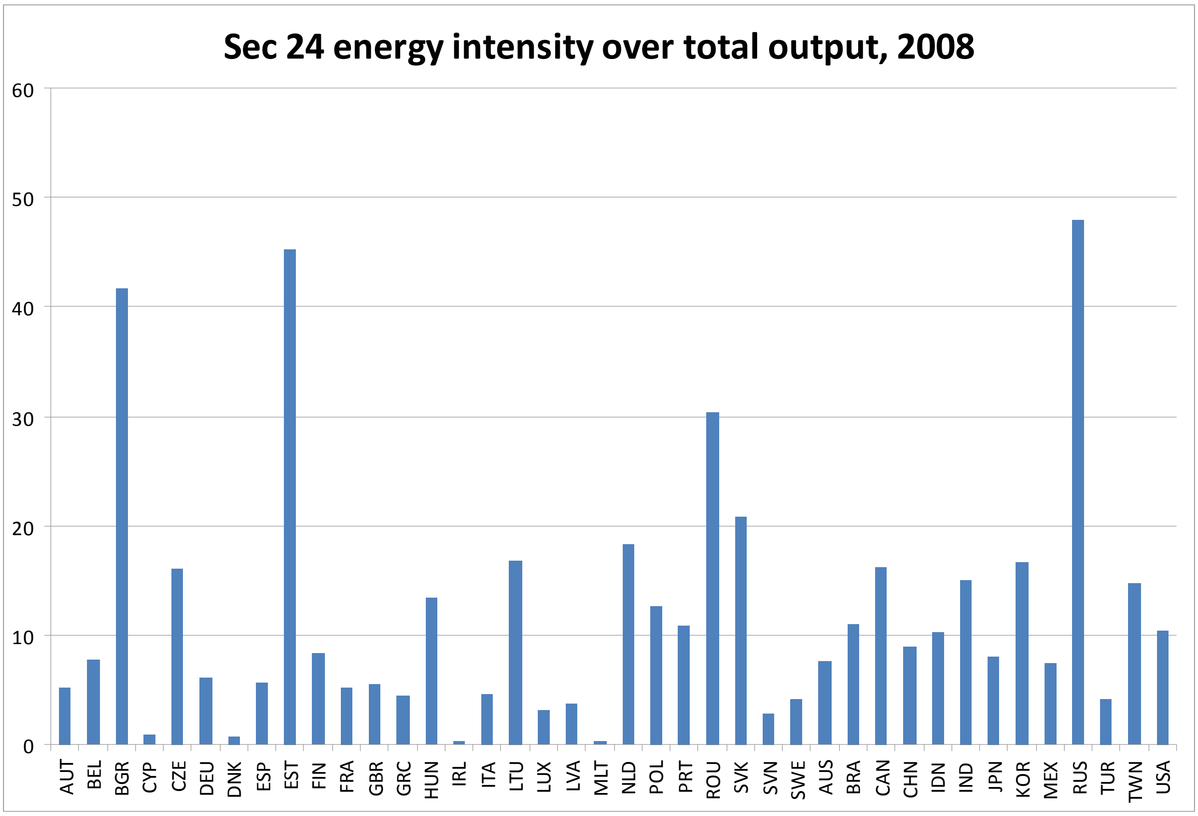

Figure 14. Energy intensity of industry NACE 24 in 2008 across WIOD countries

[25] Total energy use in the energy intensity calculation includes energy commodities used as petrochemical feedstock

The industry "non metallic mineral products" (Figure 15), which includes cement, glass, tiles, etc., shows a rather regular pattern, with advanced countries showing relatively low energy intensity and developing countries relatively high; Indonesia, China, India, Russia and Bulgaria are the five countries with highest energy intensity. Again, the case of Malta seems problematic, with an apparent energy intensity that is extremely low. The reason for such artefact in industries 24 and 26 indicates most likely incomplete reporting to the energy statistics questionnaires. Note that Canada shows also an apparent energy intensity extremely low.

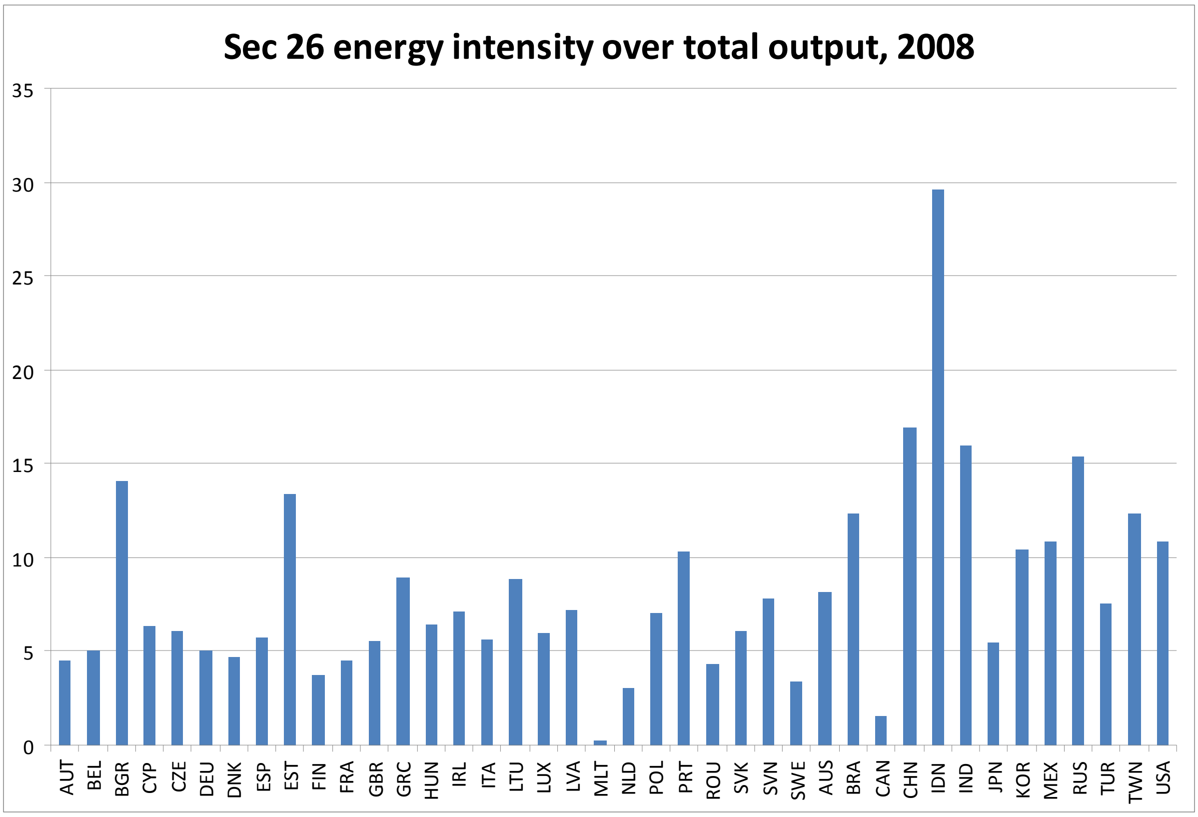

Figure 15. Energy intensity of industry NACE 26 in 2008 across WIOD countries

The aviation industry (Figure 16) shows a much lower variability than the former two industries. This is not surprising considering the largely homogeneous technology in use in this global industry. There are however a few outliers: Cyprus, Greece and Indonesia. Again, this observation seems to indicate incomplete reporting in the relevant statistics. However, since the estimation method used for energy use of the aviation industry (point 5.b in Section 5.1.1.5) relies not on IEA statistics but on the monetary entries of the use table, in this case the indication points at underestimated flows in the WIOD SUTs.

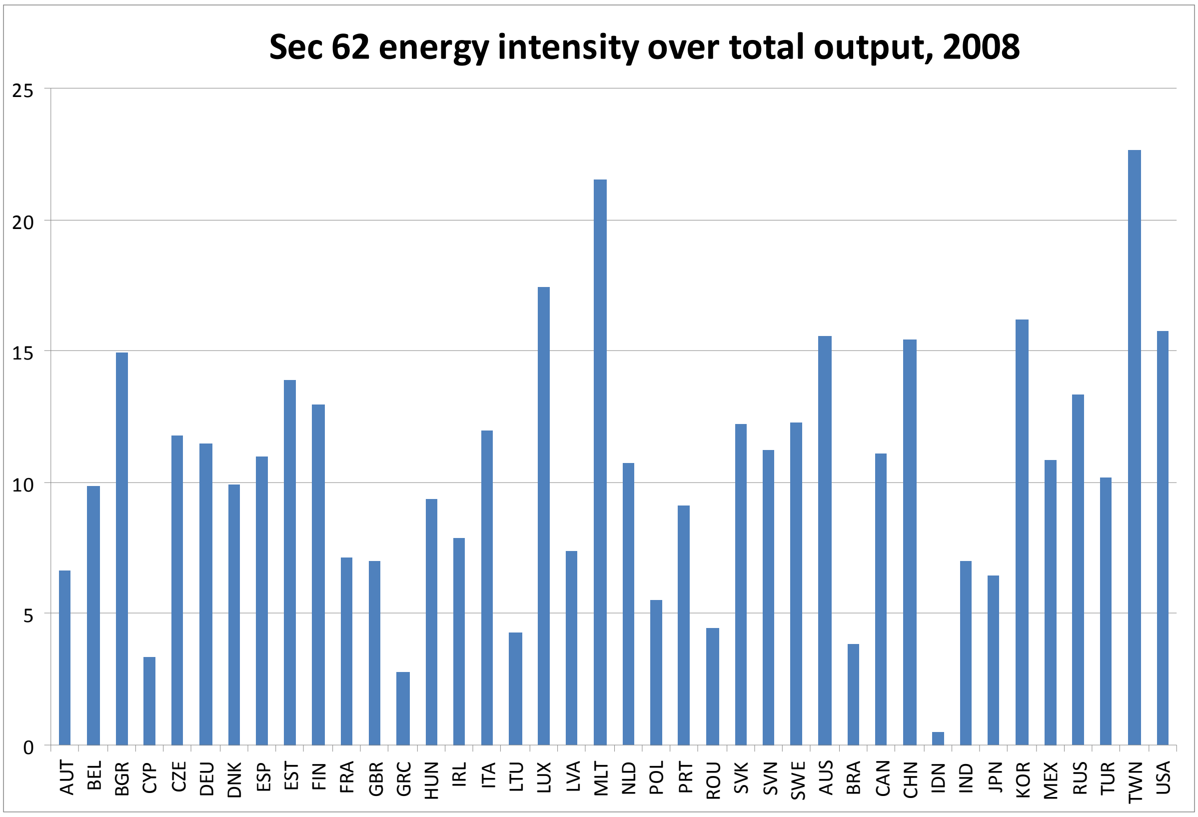

Figure 16. Energy intensity of industry NACE 62 in 2008 across WIOD countries

7 Conclusion

This report documents the compilation of the environmental accounts for WIOD.

As a matter of fact, energy use and air emission accounts are the core of the environmental satellites. Giving priority to these variables is justified by their political prominence, by the availability of highly detailed data, by the considerable effort required to process such highly detailed data and by their central role in the models developed or used in the analytical and modelling work packages of WIOD. Nevertheless, additional variables have been considered for WIOD and the following environmental satellites are also included in the database: material extraction, land use and water use.

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Annex 1: 3-digit classification for material flows (domestic extraction) as applied in Eurostat MFA-questionnaire 2007

A.1 Biomass
A.1.1 Primary crops
A.1.1.1 Cereals
A.1.1.2 Roots, tubers
A.1.1.3 Sugar crops
A.1.1.4 Pulses
A.1.1.5 Nuts
A.1.1.6 Oil bearing crops
A.1.1.7 Vegetables
A.1.1.8 Fruits
A.1.1.9 Fibres
A.1.1.10 Other crops (Spices Stimulant crops, Tobacco, Rubber and other crops)
A.1.2 Crop residues (used)
A.1.2.1 Straw
A.1.2.2 Other crop residues (sugar and fodder beet leaves, other)
A.1.3 Fodder crops incl grassland harvest
A.1.3.1 Fodder crops
A.1.3.2 Biomass harvested from grassland
A.1.4 Grazed biomass
A.1.5 Wood
A.1.5.1 Timber (Industrial roundwood)
A.1.5.2 Wood fuel and other extraction
A.1.6 Fish capture, crustaceans, molluscs and aquatic invertebrates
A.1.7 Hunting and gathering

A.2 Metal ores (gross ores)
A.2.1 Iron ores
A.2.2 Non-ferrous metal ores
A.2.2.1.a Copper ores - gross ore (t)
A.2.2.1.b Copper ores - metal content (t)
A.2.2.2.a Nickel ores - gross ore (t)
A.2.2.2.b Nickel ores - metal content (t)
A.2.2.3.a Lead ores - gross ore (t)
A.2.2.3.b Lead ores - metal content (t)
A.2.2.4.a Zinc ores - gross ore (t)
A.2.2.4.b Zinc ores - metal content (t)
A.2.2.5.a Tin ores - gross ore (t)
A.2.2.5.b Tin ores - metal content (t)
A.2.2.6.a Gold, silver, platinum and other precious metal ores - gross ore (t)
A.2.2.6.b Gold, silver, platinum and other precious metal ores - metal content (t)
A.2.2.7.a Bauxite and other aluminium ores - gross ore (t)
A.2.2.7.b Bauxite and other aluminium ores - metal content (t)
A.2.2.8.a Uranium and thorium ores - gross ore (t)
A.2.2.8.b Uranium and thorium ores - metal content (t)
A.2.2.9.a Other metal ores - gross ore (t)
A.2.2.9.b Other metal ores - metal content (t)

A.3 Non metalic minerals
A.3.1 Ornamental or building stone
A.3.2 Limestone, gypsum, chalk, and dolomite
A.3.3 Slate
A.3.4 Gravel and sand
A.3.5 Clays and kaolin
A.3.6 Chemical and fertilizer minerals
A.3.7 Salt
A.3.8 Other mining and quarrying products n.e.c.
A.3.9 Excavated soil, only if used (e.g for construction work)

A.4 Fossil energy carriers
A.4.1 Brown coal incl. oil shale and tar sands
A.4.2 Hard coal
A.4.3 Petroleum
A.4.4 Natural gas
A.4.5 Peat

Annex 2: List of 37 sectors and 59 product groups covered in the WIOD database

Table A.2.1. List of 37 sectors (36 industries plus households) covered in the WIOD database

WIOD Code	Sectors	Corresponding NACE code
AtB	Agriculture, Hunting, Forestry and Fishing	01, 02, 05
C	Mining and Quarrying	10, 11, 12, 13, 14
15t16	Food, Beverages and Tobacco	15, 16
17t18	Textiles and Textile Products	17, 18
19	Leather, Leather and Footwear	19
20	Wood and Products of Wood and Cork	20
21t22	Pulp, Paper, Paper , Printing and Publishing	21, 22
23	Coke, Refined Petroleum and Nuclear Fuel	23
24	Chemicals and Chemical Products	24
25	Rubber and Plastics	25
26	Other Non-Metallic Mineral	26
27t28	Basic Metals and Fabricated Metal	27, 28
29	Machinery, Nec	29
30t33	Electrical and Optical Equipment	30, 31, 32, 33
34t35	Transport Equipment	34, 35
36t37	Manufacturing, Nec; Recycling	36, 37
E	Electricity, Gas and Water Supply	40, 41
F	Construction	45
50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	50
51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	51
52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	52
H	Hotels and Restaurants	55
60	Other Inland Transport	60
61	Other Water Transport	61
62	Other Air Transport	62
63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	63
64	Post and Telecommunications	64
J	Financial Intermediation	65, 66, 67
70	Real Estate Activities	70
71t74	Renting of Machinery and Equipment and Other Business Activities	71, 72, 73, 74
L	Public Admin and Defence; Compulsory Social Security	75
M	Education	80
N	Health and Social Work	85
O	Other Community, Social and Personal Services	90, 91, 92, 93
P[1)]	Private Households with Employed Persons	95
Q[2)]	Extra-Territorial Organizations and Bodies	99
HH	Households	HH

[1)] Due to conventions, any environmental extension related to that sector is aggregated and reported under sector "Households".
[2)] This sector is void in WIOD.

Table A.2.2. List of 59 products covered in the WIOD database

CPA code	Products
01	Products of agriculture, hunting and related services
02	Products of forestry, logging and related services
05	Fish and other fishing products; services incidental of fishing
10	Coal and lignite; peat
11	Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying
12	Uranium and thorium ores
13	Metal ores
14	Other mining and quarrying products
15	Food products and beverages
16	Tobacco products
17	Textiles
18	Wearing apparel; furs
19	Leather and leather products
20	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials
21	Pulp, paper and paper products
22	Printed matter and recorded media
23	Coke, refined petroleum products and nuclear fuels
24	Chemicals, chemical products and man-made fibres
25	Rubber and plastic products
26	Other non-metallic mineral products
27	Basic metals
28	Fabricated metal products, except machinery and equipment
29	Machinery and equipment n.e.c.
30	Office machinery and computers
31	Electrical machinery and apparatus n.e.c.
32	Radio, television and communication equipment and apparatus
33	Medical, precision and optical instruments, watches and clocks
34	Motor vehicles, trailers and semi-trailers
35	Other transport equipment
36	Furniture; other manufactured goods n.e.c.
37	Secondary raw materials
40	Electrical energy, gas, steam and hot water
41	Collected and purified water, distribution services of water
45	Construction work
50	Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel
51	Wholesale trade and commission trade services, except of motor vehicles and motorcycles
52	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods
55	Hotel and restaurant services
60	Land transport; transport via pipeline services
61	Water transport services
62	Air transport services
63	Supporting and auxiliary transport services; travel agency services
64	Post and telecommunication services
65	Financial intermediation services, except insurance and pension funding services
66	Insurance and pension funding services, except compulsory social security services
67	Services auxiliary to financial intermediation
70	Real estate services
71	Renting services of machinery and equipment without operator and of personal and household goods
72	Computer and related services
73	Research and development services
74	Other business services
75	Public administration and defence services; compulsory social security services
80	Education services
85	Health and social work services
90	Sewage and refuse disposal services, sanitation and similar services
91	Membership organisation services n.e.c.
92	Recreational, cultural and sporting services
93	Other services
95	Private households with employed persons

Annex 3: List of Energy flows and Energy commodities in the International Energy Agency statistics (Beyond 2020 database).

Table A.3.1. List of 91 energy flows in the IEA statistics

IEA Code	FLOW
SUPPLY	
INDPROD	Production
IMPORTS	Imports
EXPORTS	Exports
BUNKERS	International marine bunkers
STOCKCHA	Stock changes
TPES	total primary energy supply
TRANSFER	Transfers
STATDIFF	Statistical differences
TRANSFORMATION SECTOR	
TOTTRANF	Transformation sector
MAINELEC	Main activity producer electricity plants
AUTOELEC	Autoproducer electricity plants
MAINCHP	Main activity producer CHP plants
AUTOCHP	Autoproducer CHP plants
MAINHEAT	Main activity producer heat plants
AUTOHEAT	Autoproducer heat plants
THEAT	Heat pumps
TBOILER	Electric boilers
TELE	Chemical heat for electricity production
TBLASTFUR	Blast furnaces
TGASWKS	Gas works
TCOKEOVS	Coke ovens
TPATFUEL	Patent fuel plants
TBKB	BKB plants
TREFINER	Petroleum refineries
TPETCHEM	Petrochemical industry
TCOALLIQ	Coal liquefaction plants
TGTL	Gas-to-liquids (GTL) plants
TBLENDGAS	Plants for blended natural gas
TCHARCOAL	Charcoal production plants
TNONSPEC	Non-specified (transformation)
ENERGY SECTOR AND DISTRIBUTION LOSSES	
TOTENGY	Energy Sector
EMINES	Coal Mines
EOILGASEX	Oil and Gas extraction
EBLASTFUR	Blast furnaces
EGASWKS	Gas works
EBIOGAS	Gasification plants for biogas
ECOKEOVS	Coke ovens
EPATFUEL	Patent fuel plants
EBKB	BKB plants
EREFINER	Petroleum refineries
ECOALLIQ	Coal liquefaction plants
ELNG	Liquefaction/ regasification plants
EGTL	Gas-to-liquids (GTL) plants
EPOWERPLT	Own use in electricity, CHP and heat plants
EPUMPST	Used for pumped storage

ENUC	Nuclear industry
ECHARCOAL	Charcoal production plants
ENONSPEC	Non-specified (energy)
DISTLOSS	Distribution losses
FINAL CONSUMPTION	
TFC	Total final consumption
TOTIND	Industry sector
IRONSTL	Iron and steel
CHEMICAL	Chemical and petrochemical
NONFERR	Non-ferrous metals
NONMET	Non-metallic minerals
TRANSEQ	Transport equipment
MACHINE	Machinery
MINING	Mining and quarrying
FOODPRO	Food and tobacco
PAPERPRO	Paper, pulp and print
WOODPRO	Wood and wood products
CONSTRUC	Construction
TEXTILES	Textile and leather
INONSPEC	Non-specified (industry)
TOTTRANS	Transport sector
INTLAIR	International aviation
DOMESAIR	Domestic aviation
ROAD	Road
RAIL	Rail
PIPELINE	Pipeline transport
DOMESNAV	Domestic navigation
TRNONSPE	Non-specified (transport)
TOTOTHER	Other sectors
RESIDENT	Residential
COMMPUB	Commercial and public services
AGRICULT	Agriculture/forestry
FISHING	Fishing
ONONSPEC	Non-specified (other)
NONENUSE	Non-energy use
NEINTREN	Non-energy use ind./transf./energy
NECHEM	Feedstock use in petchemical industry
NETRANS	Non-energy use in transport
NEOTHER	Non-energy use in other sectors
ELECTRICITY OUTPUT (GWh)	
ELOUTPUT	Electricity output in GWh
ELMAINE	Main activity producer electricity plants
ELAUTOE	Autoproducer electricity plants
ELMAINC	Main activity producer CHP plants
ELAUTOC	Autoproducer CHP plants
HEAT OUTPUT (GWh)	
HEATOUT	Heat output in TJ
HEMAINC	Main activity producer CHP plants
HEAUTOC	Autoproducer CHP plants
HEMAINH	Main activity producer heat plants
HEAUTOH	Autoproducer heat plants

Table A.3.2. List of 61 energy commodities in the IEA statistics

IEA Code	FLOW
COAL AND PEAT	
ANTCOAL	Anthracite
COKCOAL	Coking coal
BITCOAL	Other bituminous coal
SUBCOAL	Sub-bituminous coal
LIGNITE	Lignite/brown coal
PEAT	Peat
PATFUEL	Patent fuel
OVENCOKE	Coke oven coke and lignite coke
GASCOKE	Gas coke
CAOLTAR	Coal tar
BKB	BKB/peat briquettes
CRUDE, NGL, REFINERY FEEDSTOCKS	
CRUDEOIL	Crude oil
NGL	Natural gas liquids (condensate)
REFFEEDS	Refinery feedstocks
ADDITIVE	Additives/blending components
NONCRUDE	Other hydrocarbons
PETROLEUM PRODUCTS	
REFINGAS	Refinery gas
ETHANE	Ethane
LPG	Liquefied petroleum gases
MOTORGAS	Motor gasoline
AVGAS	Aviation gasoline
JETGAS	Gasoline type jet fuel
JETKERO	Kerosene type jet fuel
OTHKERO	Kerosene
GASDIES	Gas/diesel oil
RESFUEL	Heavy fuel oil (residual fuel)
NAPHTA	Naphtha
WHITESP	White spirit & SBP
LUBRIC	Lubricants
BITUMEN	Bitumen
PARWAX	Paraffin waxes
PETCOKE	Petroleum coke
ONONSPEC	Non-specified petroleum products
GASES	
NATGAS	Natural gas
GASWKSGS	Gas works gas
COKEOVGS	Coke oven gas
BLFURGS	Blast furnace gas
OXYSTGS	Oxygen steel furnace gas and other recovered gases
MANGAS	Coal gases non-specified
COMBUSTIBLE RENENWABLES AND WASTES	
INDWASTE	Industrial waste
MUNWASTER	Municipal waste (renewable)
MUNWASTEN	Municipal waste (non-renewable)
SBIOMASS	Primary solid biomass
GBIOMASS	Biogases
BIOGASOL	Biogasoline
BIODIESEL	Biodiesels

OBIOLIQ	Other liquid biofuels
RENEWNS	Non-specified primary biomass and waste
CHARCOAL	Charcoal
ELECTRICITY AND HEAT	
HEATNS	Heat output from nonspecified combustible fuels
NUCLEAR	Nuclear
HYDRO	Hydroelectric
GEOTHERM	Geothermal
SOLARPV	Solar photovoltaics
SOLARTH	Solar thermal
TIDE	Tide, wave and ocean
WIND	Wind power
HEATPUMP	Heat pumps
BOILER	Electric boilers
CHEMHEAT	Heat from chemical sources
OTHER	Other sources
ELECTR	Electricity
HEAT	Heat

Annex 4: List of Energy commodities in the WIOD system of satellite accounts.

Table A.4.1. List of 26 energy commodities (plus losses) in the WIOD satellite accounts

WIOD Code	IEA Code	FLOW
COAL		
HCOAL	ANTCOAL + BITCOAL + COKCOAL + PATFUEL + SUBCOAL	Hard coal and derivatives
BCOAL	BKB + CAOLTAR + LIGNITE + PEAT	Lignite and derivatives
COKE	GASCOKE + OVENCOKE	Coke
CRUDE & FEEDSTOCKS		
CRUDE	CRUDEOIL + NGL + REFFEEDS + ADDITIVE + NONCRUDE	Crude oil, NGL and feedstocks
PETROLEUM PRODUCTS		
DIESEL	GASDIES(1)*	Diesel oil for road transport
GASOLINE	MOTORGAS	Motor gasoline
JETFUEL	AVGAS + JETGAS + JETKERO	Jet fuel (kerosene and gasoline)
LFO	GASDIES(2)*	Light Fuel oil
HFO	RESFUEL	Heavy fuel oil
NAPHTA	NAPHTA	Naphtha
OTHPETRO	BITUMEN + ETHANE + LPG + LUBRIC + ONONSPEC + OTHKERO + PARWAX + PETCOKE + REFINGAS + WHITESP	Other petroleum products
GASES		
NATGAS	NATGAS	Natural gas
OTHGAS	BLFURGS + COKEOVGS + GASWKSGS + MANGAS + OXYSTGS	Derived gas
RENEWABLES & WASTES		
WASTE	INDWASTE + MUNWASTEN + MUNWASTER	Industrial and municipal waste
BIOGASOL	BIOGASOL + OBIOLIQ	Biogasoline also including hydrated ethanol
BIODIESEL	BIODIESEL	Biodiesel
BIOGAS	GBIOMASS	Biogas
OTHRENEW	CHARCOAL + RENEWNS + SBIOMASS	Other combustible renewables
ELECTRICITY & HEAT		
ELECTR	ELECTR	Electricity
HEATPROD	HEAT + HEATNS	Heat
NUCLEAR	NUCLEAR	Nuclear
HYDRO	HYDRO	Hydroelectric
GEOTHERM	GEOTHERM	Geothermal
SOLAR	SOLARPV + SOLARTH	Solar
WIND	WIND	Wind power
OTHSOURC	BOILER + CHEMHEAT + HEATPUMP + OTHER + TIDE	Other sources
LOSSES		
LOSS	DISTLOSS	Distribution losses

(1) Includes only GASDIES for road transport
(2) Includes all GASDIES except GASDIES for road transport
* GASDIES [IEA] = DIESEL + LFO [WIOD]; GASDIES includes diesel oil for diesel compression ignition (cars, trucks, marine, etc.), light fuel oil for heating purpose, and other gas oil used as petrochemical feedstock.

Annex 5: Air emissions in the WIOD satellite accounts

The substances included in the database comprise a core set of air emissions linked directly to three environmental impact categories, namely (examples of emission sources in italic):

Greenhouse gas emissions, needed to derive Global Warming Potentials:

- **CO_2** (carbon dioxide): *fossil fuel combustion, cement, minerals, refineries*
- **CH_4** (methane): *agriculture, waste disposal*
- **N_2O** (nitrous oxide): *fertilizers and inorganic industry, combustion*

Emissions of acidifying substances, needed to derive Acidification Potentials:

- **NO_x** (nitrogen oxides): *fossil fuel combustion, cement and metal production*
- **SO_x** (sulphur oxides): *fossil fuel combustion, ore conversion, refineries*
- **NH_3** (ammonia): *agriculture, fertiliser and organic chemical industry*

Emissions of substances potentially causing Tropospheric Ozone Formation:

- **CO** (carbon monoxide): *fossil fuel combustion*
- **NMVOC** (non-methane volatile organic compounds): *fossil fuel combustion, solvents*
- **CH_4** (methane): *agriculture, waste disposal*
- **NO_x** (nitrogen oxides): *fossil fuel combustion, cement and metal production*

Annex 6: Other environmental extension in the WIOD satellite accounts

Table A.6.1. List of materials in WIOD

WIOD Code	FLOW
BIOMASS	
Biomass_animals_Used	Animal biomass (used)
Biomass_animals_Unused	Animal biomass (unused)
Biomass_feed_Used	Feed biomass (used)
Biomass_feed_Unused	Feed biomass (unused)
Biomass_food_Used	Food biomass (used)
Biomass_food_Unused	Food biomass (unused)
Biomass_forestry_Used	Forestry biomass (used)
Biomass_forestry_Unused	Forestry biomass (unused)
Biomass_other_Used	Other biomass (used)
Biomass_other_Unused	Other biomass (unused)
FOSSIL FUELS	
Fossil_coal_Used	Coal (used)
Fossil_coal_Unused	Coal (unused)
Fossil_gas_Used	Natural gas (used)
Fossil_gas_Unused	Natural gas (unused)
Fossil_oil_Used	Crude oil (used)
Fossil_oil_Unused	Crude oil (unused)
Fossil_other_Used	Other fossil fuels (used)
Fossil_other_Unused	Other fossil fuels (unused)
OTHER MATERIALS	
Minerals_construction_Used	Non-metallic minerals for construction (used)
Minerals_construction_Unused	Non-metallic minerals for construction (unused)
Minerals_industrial_Used	Other non-metallic minerals (used)
Minerals_industrial_Unused	Other non-metallic minerals (unused)
Minerals_metals_Used	Metals (used)
Minerals_metals_Unused	Metals (unused)

Table A.6.2. List of types of land in WIOD

WIOD Code	FLOW
Arable_area	Arable land
PermanentCrops_area	Permanent crops
Pastures_area	Permanent meadows and pastures
Forest_area	Productive forest area

Table A.6.3. List of types of water in WIOD

WIOD Code	FLOW
Water_blue	Blue water
Water_green	Green water
Water_gray	Gray water