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World Input-Output Database Environmental Accounts

Update 2000-2016

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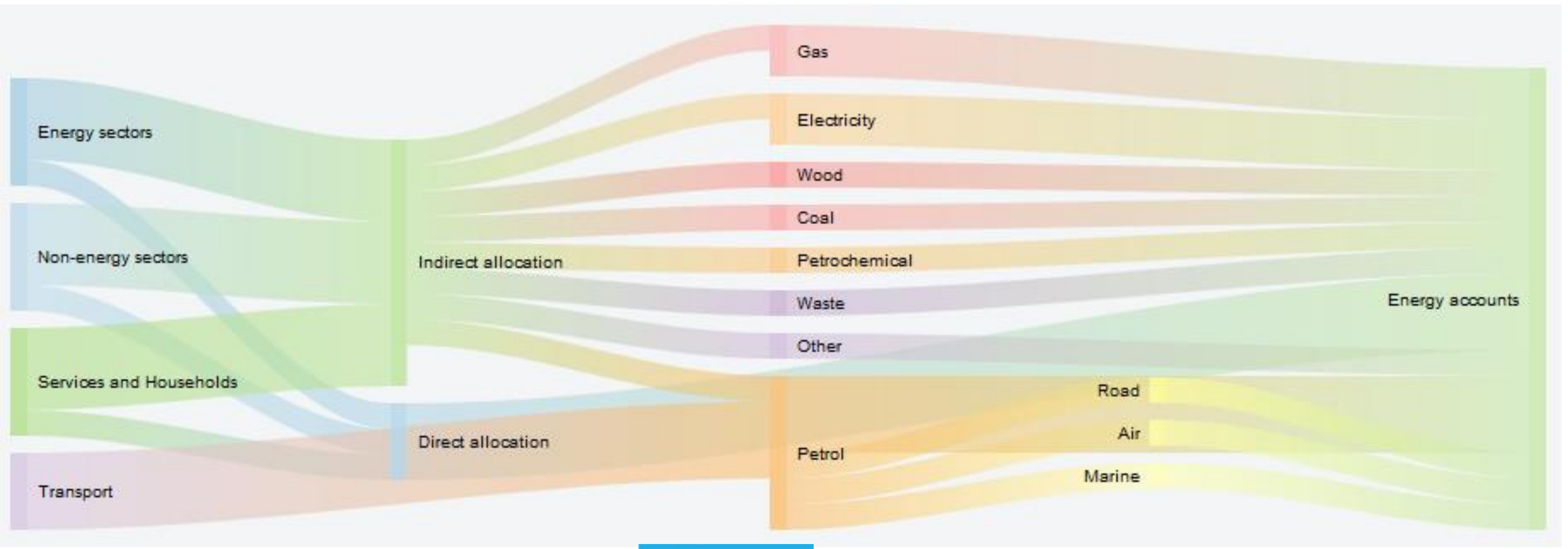

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Abstract

This report describes the approach adopted for the update of the World Input-Output Database (WIOD) environmental accounts for the period 2000-2016. In constructing the WIOD-based energy and emission accounts we follow closely the methodology developed by Genty et al. (2012), with some adjustments due to changes in system boundaries, which are further detailed. This report illustrates the data adjustment steps required to reconcile energy and economic data which stem, for example, from different accounting principles. Special care has been taken to address problems related to time series breaks in order to achieve a smooth transition between the years 2009 and 2010 at the intersection between the original and new WIOD releases. Results for EU countries are compared with other data sources such as the previous WIOD time series, the Physical Energy Flows Accounts (PEFA) and the National Accounts Matrices with Environmental Extensions (NAMEA) showing a satisfactory goodness of fit, with some exceptions. A final comparison of the inter-temporal structure across periods is proposed in order to identify possible reasons of changes in the patterns of gross energy use.

1 Introduction

With rising energy prices and increasing competition, efficient use of energy inputs in production processes of goods and services became a key performance indicator for industrial competitiveness. A comprehensive assessment of the role that energy plays in industrial competitiveness needs to inform on how energy prices and energy use affect production decisions.

Energy costs, energy productivity and energy intensity are important competitiveness indicators for both researchers and policy makers. One example is the calculation of real unit energy costs (RUEC) which allows decomposing the effect of real (energy) prices and energy intensity on industrial performances. Unit energy costs indicators were developed to assess energy competitiveness in the EU and Member States (European Commission, 2014). In the European Competitiveness Report 2014, WIOD energy accounts were used to analyse the changes over time in the energy intensity (energy use over value added) of major economies and to perform a decomposition analysis disentangling energy intensity effects and structural change effects (European Commission, 2014). The WIOD database has also been used for reporting on the state of the Energy Union as a source for key indicators in monitoring progress achieved towards the Energy Union objectives (European Commission, 2017).

In order to allow for the development of indicators such as the RUEC, national energy and economic data need to be updated, harmonised and made accessible to researchers and/or policy analysts. The Commission funded the project "ELIOD" (Environmental and Labour Accounts linked to a Global Input-Output Database) with this purpose. The project consists of the production of gross energy use data for the 28 European Countries, USA and Japan for the year 2010 – 2014. The time coverage was further extended to the period 2000-2016 and for all WIOD countries. As part of an update of the WIOD database, the aim of this project is to produce an updated series of energy uses by industry consistent with both the WIOD 2013 release classification (Genty et al., 2012) and the latest release of WIOD (2016) tables. Besides, carbon dioxide (CO_2) emissions associated to energy use are also obtained.

Section 2 introduces the concepts of environmental accounts and the System of National Accounts while Section 3 describes the data sources and other general considerations such as concepts and definitions of the different datasets used in the estimation (territorial and residential principle). This is particularly important because energy balances data and national Supply and Use Tables (SUTs) data use different accounting principles which need to be reconciled. Next, we present in Section 4 the WIOD methodology to estimate the gross energy accounts, including specific treatments for the changes in the classification of activities (NACE Rev.2 vs. NACE Rev.1.1). In Section 5, the estimation method for CO_2 emissions is detailed. In Section 6, our estimated energy uses are compared to officially published statistics whenever possible. For four countries (Denmark, Germany, the Netherlands and Austria) official NAMEA accounts statistics are available, so these have been used to compare our estimates. Furthermore, we compare our gross energy use estimates with the officially published statistics of the EUROSTAT Physical Energy Flow Accounts (PEFA) data. Section 7 concludes with some recommendations for future work.

2 Environmental Accounts and System of National Accounts

Energy accounts serve as a link between the System of National Accounts (SNA) framework and the energy balances statistics. They are part of the economy-wide material flow accounts, which record consistent compilations of the material inputs into national economies, changes of material stocks within the economy and the material outputs to other economies or to the environment. However, there is still some debate in the international community on the exact nature of the energy accounts. They are not operationally defined in any statistical standard or compilation guide (System of Economic and Environmental Accounts, SEEA, 2003 mentions them only briefly). As a result, countries are currently compiling their own energy accounts according to different concepts and methodologies. Currently, several groups are developing a coherent methodology with harmonised definitions, classifications and tables for energy accounts and related statistics, such as the United Nations Statistics Division (UNSD) and the Oslo Group on Energy Statistics.

Usually, energy accounts have both supply and use sides: an energy supply table shows the amount of energy products produced or extracted within a country and imported from abroad; an energy use table shows the intermediate use, the final use by households, and the exports abroad of energy products. Not all the final demand elements are present in the environmental satellite accounts: due to accounting convention, the use of inputs such as fuels is not registered in the government consumption but rather as intermediate input into the NACE Rev. 2 sectors 84, 85, 86 and 87[1]. Focussing on the energy use table only, this can serve as a bridge table that enables linking the energy information provided in the energy balances with the sector breakdown of the system of the integrated NAMEA (National Accounting Matrix including Environmental Accounts) accounts.

Energy balances and the SNA have been developed as independent statistical systems which are subject to their own definitions and classifications. Developing the Energy Accounts (EA) requires identifying and reconciling the differences between the two frameworks. Thus, EA are provided by energy commodity as given by the energy balances, but based on the same definitions and classifications as the SNA. As a result, EA make a direct comparison possible between economic and energy information.

All energy produced and consumed at the national level is reported in energy units in energy balances. Conversely, in the SNA the supply and use of energy is recorded in monetary units following the residence principle.

One additional difference between the two systems is that the transport sector in the energy balances is functionally defined, i.e. all energy consumed related to transport activities is assigned to items that are sometimes related to more than one NACE Rev.2 sector. To the contrary, the road transport from the EA needs to be assigned to specific sectors, i.e. road fuel consumption registered in the energy balances needs to be distributed across industries and households.

The recording of flows in energy balances follow the territorial definition of a country, whilst in the SNA, it is the residence principle.

Whilst the starting point in estimating the EA is the energy balances, there are main differences between energy balances and the SNA classification of activities that are pointed out in **Table 1** and explained in detail in this report.

An important difference stems from territorial versus residence principles. The residence principle implies that a resident is an institutional unit (person, company) whose economic activities take place in a territory. The national accounts framework allocates all emissions/energy use of a resident unit, be they physically in or out of the territory, to the territory of residence. By the territory principle all emissions/energy use of economic

[1] Where mentioned NACE Rev. 2 sectors refer to 84 Public administration and defence; compulsory social security; 85 Education; 86 Human health activities; 87 Social work activities

units are allocated to the country where they physically (geographically) take place, regardless of whether they are undertaken by residents or non-residents. Both accounting (residence) and inventory (territorial) frameworks co-exist as non-competing elements of analysis, having both definitions inherent advantages and disadvantages; however, these are very different frameworks and considerable effort is required to reconcile data from one framework to the other.

Table 1. Major differences between Energy statistics and SNA

Data source	**Energy Balances**	**National Accounts**
Industry breakdown	IEA/UNECE/Eurostat	NACE 2*-digit
Recording Principle	Territorial	Residential
Units	Physical and energetic	Mainly monetary
Classification	IEA/UNECE/Eurostat fuels	CPA 2*-digit
Balance	Supply = Consumption	Supply = Use

(*) Eurostat's National Accounts are published for 64 industries and products more aggregated that the "pure" 2-digit.

Source: Own elaboration

In practical terms, the methodological differences between energy balances and SNA result in the need to develop a concordance methodology; for instance, in the form of bridge tables, showing how to go from one framework to the other using additional data (e.g. domestic purchases abroad by resident units and purchases by resident units in the domestic territory). This includes elements such as international maritime transport with bunkering abroad (fuel purchases that are not included in the national statistical systems where the ships resides), fishing vessels operating abroad and foreign vessels in national waters. The same applies to international air transport or tourism activities.

Finally, a clarification is useful related to the use of the *gross vs net energy concept*. The gross energy use, which includes the energy intermediate consumption of energy by industries, allows answering questions related to the energy mix and to the substitution of energy inputs in electricity production over time. Perhaps even more importantly, the gross energy concept is fully consistent with the National Accounts framework on which WIOD is based: input-output tables do not only report value added and final use but also intermediate inputs. This issue sometimes generates confusion due to the different meaning of the concept of "final use" between National Accounts and energy statistics. While the gross energy concept implies counting intermediate energy inputs twice, on the other hand it records energy products in a way fully consistent with how inputs are recorded in the Use Tables of National Accounts.

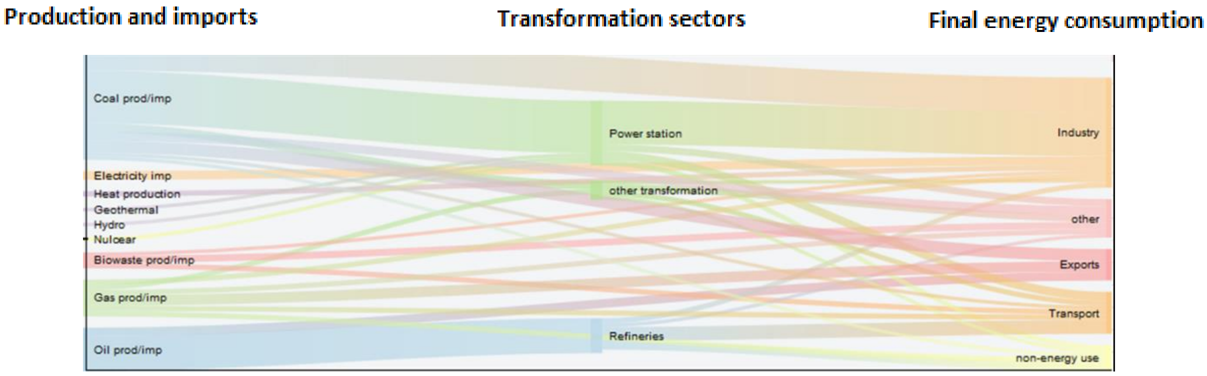
The net energy concept is useful for computing the total energy metabolism of an economy, as its records reflect the final use of energy and disregard the inputs that are only used for transformation. Oil inputs to refineries and fuel inputs to the power sector are not recorded. Nevertheless, this report only deals with gross energy use.

Energy accounts belong to the broader category of environmental satellites, which can cover different environmental themes such as the use of energy and other resources, the emissions of various substances, waste generation etc. In this case, the present update of WIOD environmental accounts includes energy use and CO_2 emissions. These emissions are crucial to derive the environmental impact of economic activities on global warming.

2.1 Energy balances

The energy balances as published by the IEA can be seen as a matrix, where the columns represent the different energy product categories and rows represent all the different “flows”. These are grouped in three main blocks: energy production and imports, energy transformation and final energy consumption. These blocks represent the overall energy flow from primary extraction and imports to final consumption in the economy (**Figure 1**).

Figure 1. Overall energy flow through an economy



Source: Own elaboration

The energy balances differentiate from the commodity balances in two ways:

1. All flows reflect a common energy unit
2. Double counting is avoided when summing all products together. For example, for secondary products (e.g. motor gasoline) the production appears in the production row in commodity balances, but is reported as an output of the relevant transformation (e.g. oil refineries) in an energy balance.

The methodological principle adopted by the IEA is that of "*primary energy equivalent*", meaning that the primary energy form is the first energy form downstream in the production process for which multiple energy uses are practical (IEA, 2005). For example, the first energy form that can be used as energy in the case of nuclear is the nuclear heat of the reactor, most of which is then transformed into electricity. The application of this principle leads to the choice of the following primary energy forms:

— Primary electricity hydro, wind, tide/wave/ocean and solar photovoltaic.

— Heat and secondary electricity (nuclear, geothermal and solar thermal).

— Once the primary energy form is identified for all electricity and heat generated from non-combustible sources, the IEA adopts the physical energy content method to compute the corresponding primary energy equivalent amounts: the primary energy equivalent is simply the physical energy content of the corresponding primary energy form.

The IEA energy balances are based on a “net” energy content, which excludes the energy lost to produce water vapour during combustion. All the elements of the energy balance are expressed on the same net basis to ensure comparability. The difference between the "net" and the "gross" calorific value for each fuel is the latent heat of vaporisation of the water produced during combustion of the fuel. For coal and oil, for example, the net calorific value is about 5% less than gross, for most forms of natural and manufactured gas the difference is 9-10%, while for electricity and heat there is no difference as they are not combusted.

2.2 Linking energy statistics and SNA classification in NAMEA framework

Energy, as an example of a variable included in environmental satellite accounts, is used together with monetary Supply and Use Tables (SUTs) to allow for energy-economic type analyses (Genty et al., 2012). A typical arrangement for the NAMEA satellite accounts is as depicted in **Figure 2**:

Figure 2. Environmental satellites in a SUT framework

	Product	**Industries**	**Final Demand**	
Products		$\mathbf{U}$	$\mathbf{y}$	$\mathbf{q}$
Industries	$\mathbf{V}$			$\mathbf{x}$
	$\mathbf{m}$	$\mathbf{w}$		
	$\mathbf{q}^T$	$\mathbf{x}^T$		
		$\mathbf{Rx}^T$	$\mathbf{Ry}^T$	

Source: Own elaboration

In **Figure 2**, the Make Table ($\mathbf{V}$ = transpose of the supply table) and the Use Table ($\mathbf{U}$) are highlighted in light grey. An element v_{ij} indicates the supply by industry i of product j for domestic production. Vector $\mathbf{m}$ denotes import of products (j). The vector $\mathbf{q}^T$ is the transposed total supply by products j, either domestically produced by industries or through imports. Vector $\mathbf{x}$ is the output by industries (i, domestic production).

The use matrix $\mathbf{U}$ 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. Vector $\mathbf{y}$ denotes final demand. An element y_i shows the use of product i by all components of the final demand (i.e. consumption by private households and government, gross fixed capital formation, exports). Vector $\mathbf{q}$ shows total products use. Vector $\mathbf{w}$ denotes the gross value added by industries (comprising several factor inputs such as wages, depreciation, other net taxes on production and gross operating surplus). Finally, the transposed vector $\mathbf{x}^T$ denotes inputs (sum of intermediate products and value-added) to industries.

A simple and convenient means of adding environmental variables, while keeping the system balanced, is to add them as an extension of the SUTs, using the so-called satellite accounts. Satellite accounts are thus exogenous vectors that are added using the same product and industry breakdown and accounting principles (i.e. residential vs territorial) as the SUTs they go with. This is illustrated in the form of matrix $\mathbf{R}^T$ (environmental dimensions in rows and industries in columns). Such accounting framework for environmental variables that sets data up to be added to Input-Output (IO) or SUTs, and consistent with IO data (residence principle) is generally denoted as NAMEA accounts. Since all environmental accounts published by National Statistics Institutes follow the publication of compatible national accounts, the terms NAMEA and environmental accounts are frequently used as synonyms. Currently, only Austria, Germany, Netherlands and Denmark publish long series of energy accounts.

Energy accounts are reported under different concepts, such as net energy concept, gross energy concept and emission relevant energy concept (see **Table 2**). All concepts are possible in a balanced accounting framework and sensible argumentation can be made for all of them in terms of supply and use. Accordingly, the gross energy supply is calculated as the sum of domestic production, of imports and of inventory changes (gross supply). Gross energy use is the sum of the intermediate consumption, final uses and exports (Genty et al., 2010).

Table 2. Inventory of data sources for environmental accounting

Country	Period	Energy concept	Data source
Denmark	1966-2014	Gross energy use	Statistics Denmark, Table Ene2ha: Energy Account In Common Units By Use And Type Of Energy, https://www.statbank.dk/
Belgium, Bulgaria, Czech Republic, Germany, Greece, Croatia, Lithuania, Latvia, Slovenia, Romania	2010, 2011, 2012, 2013	Energy use, Emission related energy use	EUROSTAT, Physical Energy Flow Accounts (PEFA): http://ec.europa.eu/eurostat/web/environment/physical-energy-flow-accounts
Germany	2000, 2005-2013	Gross energy use, Energy use	Destatis bank, Federal Statistical Office, Economy and Use of Environmental Resources, Energy (Preliminary), 2016
Austria	1999-2014	Gross energy use	Statistik Austria, Bundesanstalt Statistik Österreich, Energy Accounts as of 2008
Netherlands	1995-2013	Gross energy use, Net energy use	CBS, Statistics Netherlands, http://statline.cbs.nl/Statweb/dome/?LA=en, Environmental accounts; energy use by companies and households
Finland	2011	Total hybrid energy use for highly aggregated sectors	Statistics Finland, Economic and Environmental Statistics Environment and Energy, Final Technical Implementation Report Grant Agreement No 50904.2011.005-201 1 .293
Hungary	2006	Emission related energy use (NACE Rev.1.1)	Hungarian Central Statistical Office, Environmental statistics and accounts: environmental accounts, agreement number: 71401.2007. 014-2007.482
Norway	2005	Total energy use, emissions related energy use	Statistics Norway, 2008 Final Technical Implementation Report to Eurostat Grant Agreement,no71401.2007.014-2007.469
Portugal	2005	Emissions related energy use	Instituto Nacional de Estatistica Portugal, Environment Statistics And Accounts Environmental Accounts: Pilot Study on Energy Accounts Grant Agreement No 71401.2007.014-2007.479

Source: Own elaboration

2.3 The WIOD energy database

The scope of the WIOD energy accounts includes energy flows, but excludes energy assets, energy and environmental taxes/subsidies, permits, licenses. In order to link the energy balances with WIOD the following steps are required:

1. Bridging the sector breakdowns of the IEA/UNECE/Eurostat, reflecting the NACE Rev.2 - and then aggregating into the WIOD sector classification.
2. Splitting up the functionally defined transport sector of the IEA classification into the corresponding NACE Rev.2 sectors.
3. Transforming the balance equation as used in the energy balances into the balance equation as used in the SNA framework.
4. Adjusting the territory principle as used in energy balances to the residence principle as used in the SNA.
5. Evaluating the physical data with prices and adjusting the different monetary information.

3 Data sources and general considerations

Several EU countries publish official environmental and energy accounts that are compiled under various concepts (**Table 2**). Long time series (1995-2014) of gross energy uses are only available for Austria, Denmark and Germany although initiatives are gradually being developed for several other European countries (**Table 2**). Additionally, the reporting of data within the Eurostat Physical Flows of Energy Accounts (PEFA) is based on questionnaires that are submitted by Member States on a voluntary basis. According to Regulation (EU) 691/2011, starting from 2017 the provision will become mandatory to the national statistical institutes of the EU.

To reflect uniform and homogeneous energy flow information across EU countries, the present exercise estimates the energy accounts using the WIOD methodology (Genty et al., 2012). The methodology uses as data sources the WIOD Supply and Use Tables, the IEA's Energy Balances, fuel prices and information about vehicle fleets. The challenges and limitations of the data used as inputs are described in Sections 6.2 and 6.3.

3.1 Gross energy use data reported by National Statistical Institutes

The publicly available energy use data of four countries serve us for aligning and comparing the consistency of our own estimates.

Austria: The NAMEA tables of gross energy accounts for Austria are available in a disaggregated format including 88 sectors (NACE Rev.2) and 34 energy carriers, which needed to be aggregated to 64 sectors and 22 energy products.

Germany: They provide detailed and well-described NAMEA accounts for the years 2010 – 2013 including 22 energy products and 55 sectors (NACE Rev.2); they were disaggregated to 64 sectors.

Denmark: Energy accounts are publicly available at a level of detail of 129 sectors and 49 energy products.

Netherlands: Since only the total gross energy accounts were available, the values for the 22 energy carriers were estimated and then disaggregated to 64 sectors, by using the relevant information from the PEFA database (64 sectors * 25 relevant products) and the industries' totals of the Dutch energy NAMEA accounts.

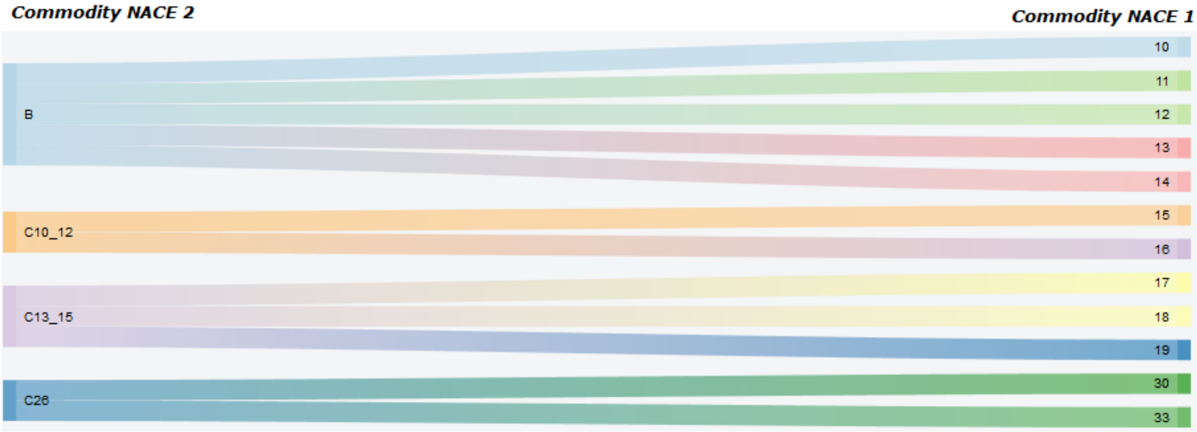
3.2 National Supply and Use Tables

The monetary values of the energy flows are reflected in the transactions of the National Supply and Use Tables (SUTs). For the purposes of the present exercise we used the latest version of the WIOD database (release 2016). The latest update captures the changes due to the transition to new classifications of economic activities (from NACE rev.1.1 to NACE rev.2), changes in the accounting principles, as well as changes in the ways of reporting economic activities (e.g. mining activities, see below).

Referring to the changes in accounting principles, the new European System of National Accounts ESA 2010 differs in scope and concepts from the ESA95, including R&D as investment (and not as intermediate inputs) and excluding from trade the value of goods sent abroad for processing (among other changes). All these modifications might introduce distortions with respect to the previous WIOD Energy Accounts. These changes in the ESA principles will not be tackled in the present exercise, as in the WIOD (2016) description of the database.

However, the changes in the NACE classification affecting the splitting of energy uses, needs to be specifically addressed. The change in NACE Rev.2 (**Figure 3**) corresponds to the aggregation of the coal and gas extraction, uranium and thorium extraction, metal ores and other mining and quarrying activities.

Figure 3. Changes in product classification between NACE Rev.1.1 and NACE Rev.2



Source: Own elaboration

Precise information for coal and gas commodities in monetary terms is needed in order to disaggregate sectors with insufficient level of detail or to re-allocate energy uses to their specific sector (Case a). Alternatively, inputs can be aggregated because of consolidation (Case b).

Case a. Coal and gas commodities are used as splitting keys of the energy use in sectors whenever the energy balances do not provide sufficient sectorial detail, such as Textiles, Miscellaneous Manufacturing, Services (**Figure 8**). In applying this disaggregation, it is assumed either that energy unit prices are constant or that for some energy products, they have identical shares as those given by the energy product shares of the corresponding IEA extended energy balance account.

Case b. National statistical offices usually record differently the energy commodities/ sectors within the energy balances. For instance, natural gas can be treated either as input or as an output and, hence, recorded either as commodity B (i.e. gas extraction) or commodity D (electricity generation). A uniform treatment of information would require specific corrections for such differences. Other corrections refer to energy sectors, such as those of "coking plant" that might be consolidated within the steel industry. Consequently, specific economic activities might disappear in cases such as: a) the transformation of coal to coke, which occurs in the same industry as an intermediate step, b) missing records for coal inputs to the refining sector (C19) and c) missing records for coke inputs to the iron and steel sector (C2).

Given their key role to disaggregate energy uses from energy balances, we estimated the expenditures of coal and gas separately for the whole period of our analysis. Several alternative approaches were tested, e.g. RAS, linear estimations and compound annual growth rate (CAGR), all having two steps in common:

— Forecasting the above mentioned NACE Rev.1.1 commodities (**Figure 3**) for 2005-2014 starting from the WIOD Supply and Use tables (release 2013, 1995-2009),

— Re-scaling such estimates using the aggregated data in NACE Rev.2.

The bi-proportional balancing of matrices (RAS) and linear estimations were tested for the disaggregation of the aforementioned commodities; however, because of abundant null values, the approach did not provide satisfactory results for all countries, commodities and years.

We used a deterministic approach to estimate the missing energy uses in specific years using compound annual growth rates (CAGR)[2] and the latest available data on uses of energy commodities. The metric implies calculating the CAGR for the use of each of the selected NACE Rev.1.1 commodities by sector between 1995 and 2009. If the latest available year was null, we used the previous year value as the basis for projections. For highly discontinued series, we used an average value rescaled over NACE Rev.2 aggregated commodities. These new estimates of energy use of commodities (coal, gas) over 2005-2014 constitute the first step to split energy balances records.

Other energy commodities from the Supply and Use Tables were used for the breakdown of energy flows but not always this could be a proper solution. For example, the use of refinery products (NACE Rev.2, code C19) to split unallocated residual residential fuel use might lead to an overestimation of the use of petroleum products. One way to deal with this issue is to complement the information from the Use Tables with data on the number of employees. Their representation across sectors would approximate the relative importance of specific activities. The data on employment by NACE Rev.2 sectors is collected from the National Accounts published by Eurostat.

3.3 Energy balances: limitations and proposed corrections

The IEA's extended energy balances report the consumption of 67 energy products and 95 processes (see Annex 1). Although more homogenous than national sources, the IEA data (IEA, 2016) reflects changes in the energy flows/products stemming from official national authorities. For example, Estonia started to report positive values of shale oil resources in 2014, which turned out to be more than 70% of its energy demand (IEA, 2016).

The information collected from the energy balances needs to be reallocated both in terms of energy products and energy flows mainly because they reflect differences in the recording of the energy statistics and National Accounts.

The energy balances need to undergo a redefinition of *industrial boundaries*, especially in the cases of unspecified energy use in the industry consumption (INONSPEC), in the transport consumption (TRNONSPEC) or in other energy consumption (ONONSPEC). The shares of such unspecified flows over the total final energy consumption of each European country are shown in **Figure 4**. In most cases, these represent from 1% to 3% of the total final consumption, with the exception of three countries that reported higher shares of unspecified consumption: Sweden (9%), UK (6%) and Malta (5%). In order to handle the case of missing sectors, the present methodology reallocates the non-specified energy consumptions using the pattern of derived/similar energy products.

Some of the energy balance's flows may not have a direct correspondence with the classification of sectors in the National Accounts framework. This is the case of energy *losses*, which were assigned by IEA fuel and NACE Rev.2 sector. For the current update, the shares of distribution losses were the ones already employed for the estimation of the energy uses in the WIOD release 2013 (1995-2009).

The most important differences are normally due to the fact that physical energy flows recorded in national energy balances use the territorial principle as recording method. And last but not least, 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 resident agent. **Figure 5** provides an overview of the weight of road transportation in total final consumption, computed under the territorial principle, i.e. including expenditures of non-residents on road fuels.

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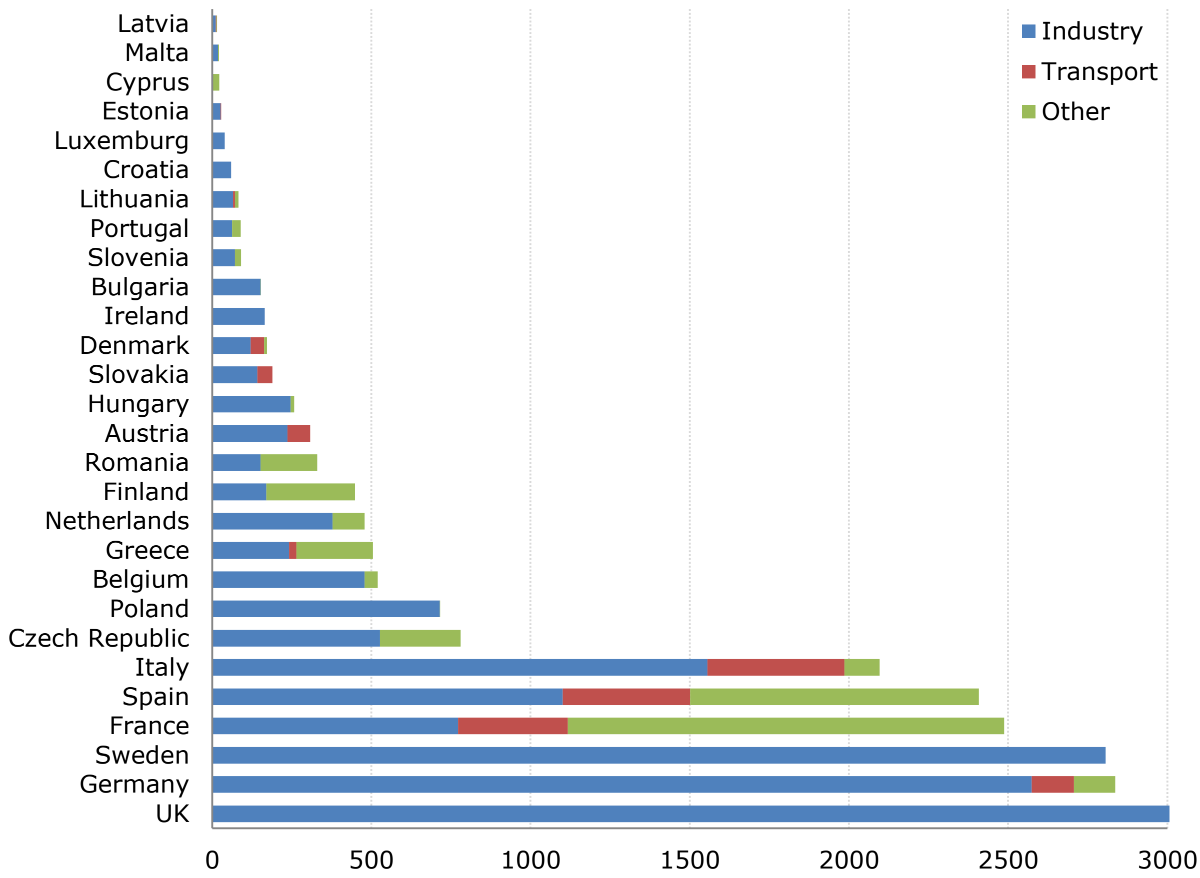
[2] Where $CAGR = (EV / BV)^{1/n} - 1$. EV is the ending value of the expenditure in each of the selected each of the selected NACE Rev.1.1 commodities. BV the beginning value of the expenditure each of the selected NACE Rev.1.1 commodities

Figure 4. Non-specified energy consumption flows by sector and country, 2014, ktoe



Note: UK overflow the chart because of its extremely high values (Industry = 6870, Other = 1117).

Source: Own elaboration

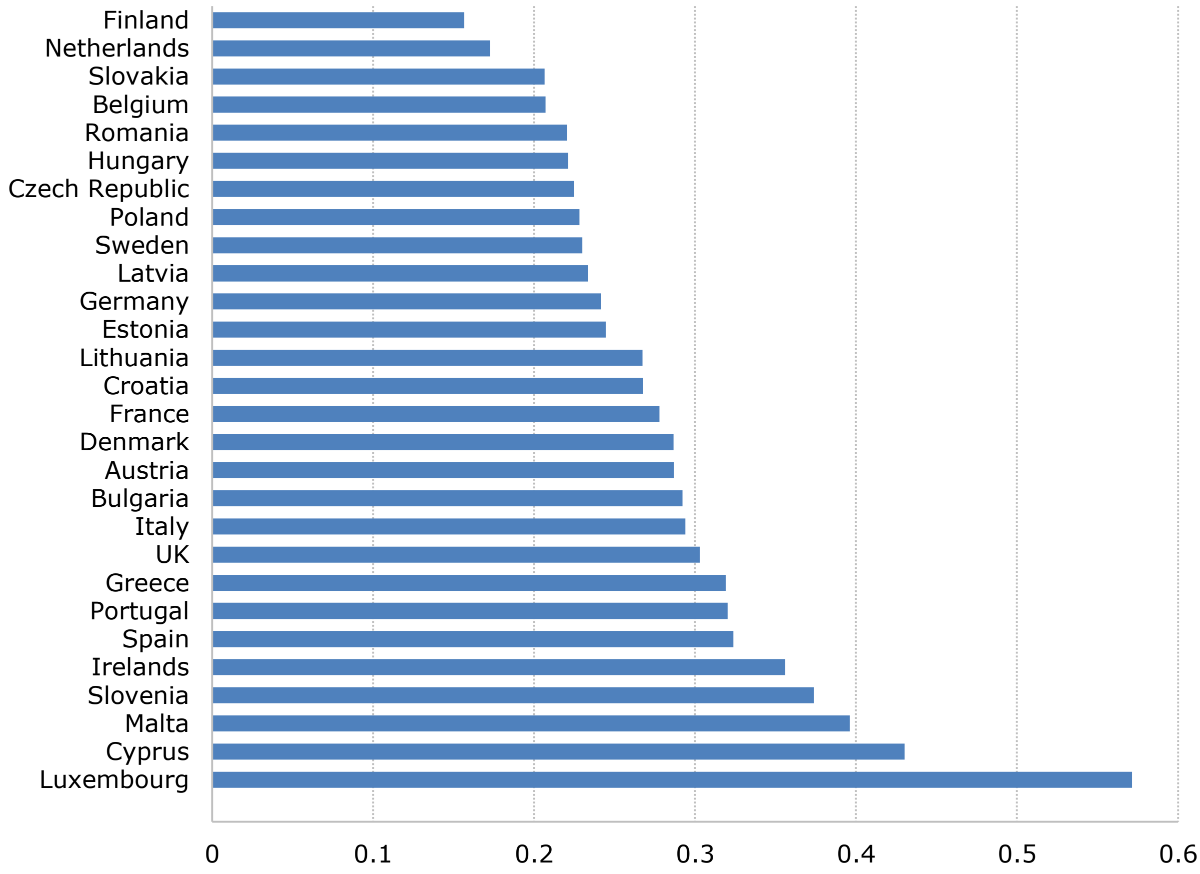
Figure 5 clearly shows a huge share registered under the IEA road consumption for small countries, such as Cyprus, Luxembourg and Malta. In the case of Luxembourg, fuels sales have been around 3 times larger than consumption by residents due to fuel tanking tourism associated to the relatively low price of fuels. In the cases of Cyprus and Malta, tourists' purchases of road fuels might be behind the large share of road consumption. These differences between national accounts and IEA balances were addressed with specific corrections, using the information on fuel prices, car shares, and purchases of non-residents and residents.

Fuel price information links the physical quantities from energy balances to the monetary values of the Use Tables. However, the information is very limited at the country level.

Detailed specific fuel price data in national currencies and tonnes of oil equivalents were collected from IEA's Beyond 2020 database (IEA, 2016). The dataset reports the prices of automotive diesel, coking coal, electricity, high sulphur fuel oil, light fuel oil, liquefied petroleum gas, low sulphur fuel oil, natural gas, premium leaded gasoline, premium unleaded 95 RON, premium unleaded 98 RON, regular leaded gasoline and regular unleaded gasoline.

This first set of information revealed many missing values both in terms of fuels coverage and geographical coverage, although with a better coverage for OECD countries. These data were used to compile information on prices of more aggregated fuels such as motor LPG, motor diesel, gasoline, light fuel oil, heavy fuel oil and converted from national currency units/tonnes of oil equivalents into USD/TJ. The Jet Fuel Price used the information on spot oil prices for three markets (NWW Rotterdam, USA and Singapore) to which a series of technical and exchange rate conversions were applied in order to obtain an estimation of the series of aviation fuel prices.

Figure 5. Road energy flows as shares of TFU (total final use), 2014



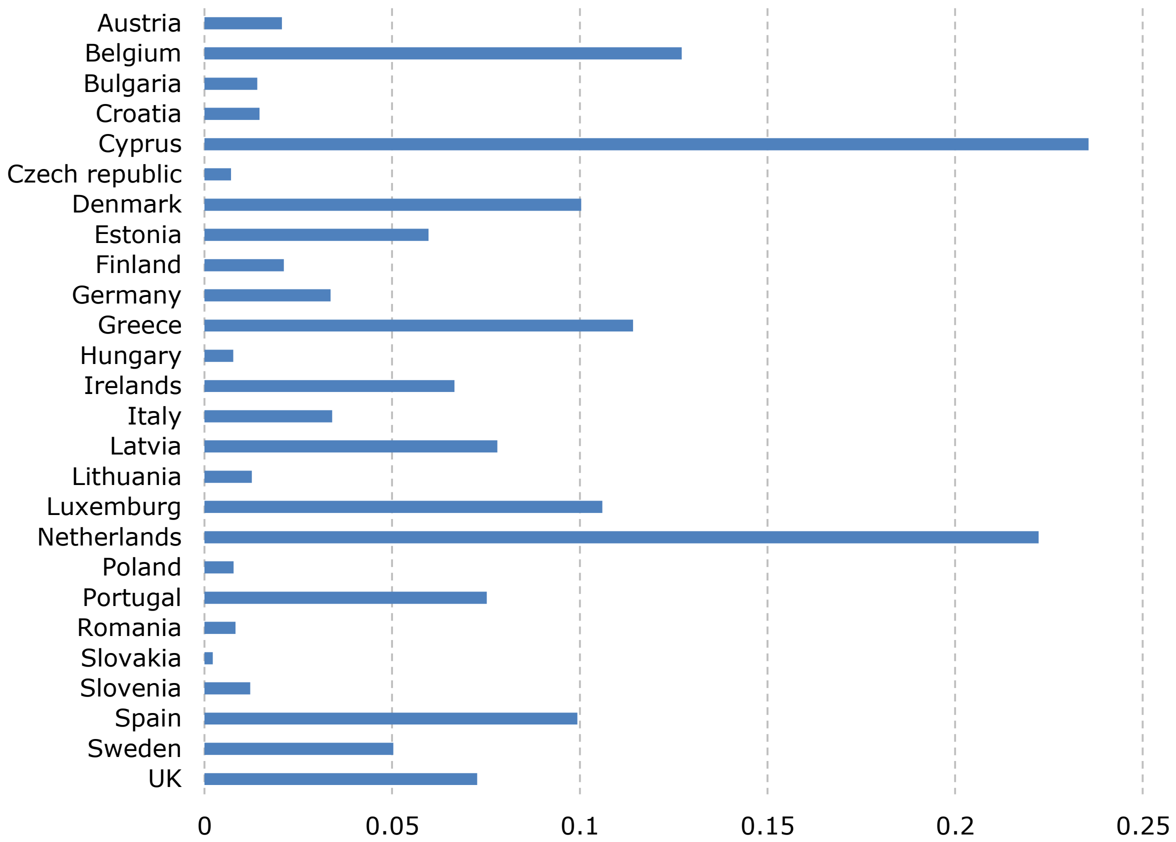
Source: Own elaboration

The information on the fuel uses of inland transport between households and industries is not differentiated in the energy balances. In order to construct this information, cross-country data on the stock of vehicles by type of fuel is useful. The Odyssee - Mure database collects the technical and economic transport data needed for the estimation of the household and industry transport expenditures, whilst accounting for different fuel efficiencies (Odyssee, 2016).

As the time series were incomplete for some countries and years, we made imputations by using linear estimations of car use shares as a function of fuel use shares given a certain relationship between fuel use and stock of cars (tables available on request). Transboundary driving household information was estimated by using the information provided by Use Tables in terms of purchases of non-residents in the domestic territory vs direct purchases of residents abroad, weighted by the proportion of tourist expenses on fuels.

Fuels used by ships and airplanes engaged in international transport are not included in the air and water sectors, but rather separately recoded in energy balances as international bunkering (**Figure 6**). These categories were reallocated to the corresponding transport sectors. Maritime fuels were allocated based on country specific bunker shares (EXIOPOL database) and the information present in the IEA energy balances (release 2011).

Figure 6. Maritime and aviation bunkering as share of Total Primary Energy Supply (TPES), 2014



Note: Malta is excluded from the chart because of its extremely high value (1.71)

Source: Own elaboration

The allocation of the aviation fuel implied an estimation of expenditures on non- jet kerosene petroleum fuels and jet kerosene; based on the monetary information from the Use Tables and the fuel price, the air transport fuel use was not only derived from the IEA bunker accounts but also by dividing the fuel expenditures from the Use Table by the corresponding jet fuel price[3].

3.4 CO_2 emissions data

For CO_2 emissions accounts, four types of data sources are used: NAMEA-air data reporting (based in the national accounting framework), emission relevant energy use accounts, emission factor data and air emission inventory data.

- NAMEA-air like data:

This type of data is only available for EU countries (Eurostat, 2019). Air emissions accounts are available in Eurostat, compiled by the "Environmental statistics and accounts; sustainable development" unit. We used the Air emissions accounts by NACE Rev.2 activity [*env_ac_ainah_r2*]. This data set reports emissions of Greenhouse Gases (GHG) and air pollutants broken down by 64 industries and households, with concepts and principles similar to national accounts. The complete data series starts in 2008.

[3] This procedure produces negative energy use for some countries and years when the values in the Use Table were not available or abnormally low. In these cases, we have either interpolated the value of the Use Table when it was available (Ireland 2010) or applied a fix ratio between jet and non-jet kerosene expenditures corresponding to the closest year with data (Norway 2000-2004; Switzerland 2000-2004, 2016; Croatia 2013-2014), or assumed the same expenditure as previous years when neither of the former options was possible due to lack of data (Croatia 2015-2016).

However, some countries have data already from 2000 onwards. We focused on CO_2 emissions (carbon dioxide without emissions from biomass) measured in thousand tonnes.

- Emission Relevant Energy Use accounts

For those countries and years for which NAMEA-air like data are not available, the CO_2 emissions estimation consists of two parts: the estimation of energy-related emissions and of non-energy related emissions. Energy accounts are used for the first part. In particular, we used the Emission Relevant Energy Use (in TJ) by sector and energy commodity. This matrix contains the use of energy that causes emissions directly. It is obtained from the Gross Energy Use excluding:

- Non-energy use of energy commodities (e.g. naphtha for basic chemicals production or bitumen for asphalt).

- Input of energy commodities for transformation into other fuels (e.g. coal transformed in coke and coke oven gas).

- Emission factor data:

To complete the estimation of energy-relevant emissions, emission factors are needed. In this case, emission factors come from two sources:

- 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). This document contains standard CO_2 emission factors by fuel, on energy basis in kg/TJ.

- Inventory from the United Nations Framework Convention on Climate Change (UNFCCC). Inventory submissions from Annex I parties include Common reporting format (CRF) tables: a series of standardized data tables containing mainly quantitative information, including country-specific emission factors by fuel and year in t C/TJ (UNFCCC, 2018).

- Air emission inventory data

Apart from providing emission factors, inventories also provide estimates of the CO_2 non-energy-related emissions. We used three different inventories depending on the country.

- For Annex I Parties, non-energy-related emissions are taken from the UNFCCC CRF tables (UNFCCC, 2018), which contain time series of CO_2 emissions from industrial processes in kt CO_2. In particular, this data is in the CRF Table 10s2: "Emission trends CO_2 from industrial processes".

- For China, South Korea, India, Indonesia and Taiwan, the European Commission's Emission Database for Global Atmospheric Research, EDGAR v4.3.2 (EC-JRC/PBL, 2016) is used. This database provides estimates of anthropogenic greenhouse gas emissions on a country-by-country basis (more information in Janssens-Maenhout et al., 2017). For non-energy-related emissions, we used the table "v432_CO_excl_short-cycle_org_C_1970_2012"[4], containing for CO_2 emissions 1970-2012 time series for fossil fuels by sector and country in kt.

EDGAR is also used as a reference for global emissions. In this case, we used the "EDGARv5.0_FT2017" dataset[5] containing 1970-2017 time series of fossil CO_2 emissions of all world countries including sources from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals and urea) and product use (more information in Muntean et al., 2018).

-For Mexico and Brazil, we used national inventories: "*Inventario nacional de emisiones de gases y compuestos de efecto invernadero (INEGYCEI)*" for Mexico (INECC, 2018) and "*Base de Dados de Estimativa de Emissoes de Gases de Efeito Estufa*" for Brazil (SEEG, 2018). Both provide time series of CO_2 emissions by industry.

[4] http://edgar.jrc.ec.europa.eu/overview.php?v=432_GHG
[5] http://edgar.jrc.ec.europa.eu/overview.php?v=booklet2018

4 Estimation method for the gross energy accounts

An inventory of the main global input-output databases comprising environmental extensions and a discussion of their strengths and weaknesses can be found in Tukker and Dietzenbacher (2013). Descriptions of each database can be found in Lenzen et al. (2013) for EORA, Tukker et al. (2009) for EXIOBASE, Dietzenbacher et al. (2013) for WIOD, Peters et al. (2011) for GTAP, Bruckner et al. (2012) for GRAM, and Meng et al. (2013) for the IDE-JETRO's Asian International Input-Output Tables.

For the scope of the present exercise, the update of the gross energy use accounts was done using the WIOD methodology as the basis (Genty et al., 2012). Relying extensively on Supply and Use Tables, this WIOD methodology could also be useful for other applications. Overall, it implies

— a redefinition of industrial boundaries through a technical redistribution of energy uses that reflects the energy mix of countries and

— a redistribution according to macro-economic boundaries.

The redefinition of industrial boundaries addresses the geographical mismatch between the territorial principle of the energy balances and the residence principle of the energy accounts.

Industrial boundaries include all relevant energy activities on the supply side (extraction, conversion, supply) and the use side (end use of energy commodities). In this endeavour the following <u>classifications and terms</u> are crucial:

1. Definition of industry aggregations,
2. Definition of energy commodities,
3. Physical Conversions (net vs. gross calorific values, efficiency of fuels).

The energy balances are reported with fewer sectors and more fuel types than generally needed by economic analyses. Additional information is required to achieve the level of sectoral detail of the NACE Rev.2 classification, meaning that one-to-many relationships need to be established (**Figure 7**). However many-to-many relationships can also occur. The method developed to obtain energy accounts from the energy balances consists of a series of steps which are briefly outlined below: if sectors and fuel uses are known for each country and year, the energy uses are directly allocated; otherwise, if one of the dimensions is not known (country, users, fuels or time) then additional disaggregation steps will be required for the estimation of their corresponding energy use. **Figure 8** sketches the approach to disaggregate many-to-many relationships by using some specific commodities of the Use Tables as splitting variables. Finally, the previously described corrections for sectors such as road, air and maritime transport restores the residence principle of the System of National Accounts. Annex 2 presents an inventory of the main allocation and corrective methods applied in order to redefine physical energy flows.

The mix of direct allocation and fuel/sector corrections includes:

1. Direct allocation,
2. Corrections for energy sectors,
3. Indirect allocations,
4. Other specific corrections,
5. Transport allocations,
6. Disaggregation of NAMEA fuels.

Figure 7. Direct allocation of energy use: one to one correspondence between energy balances and the National Accounts framework

Source: Own elaboration

4.1 Direct allocation

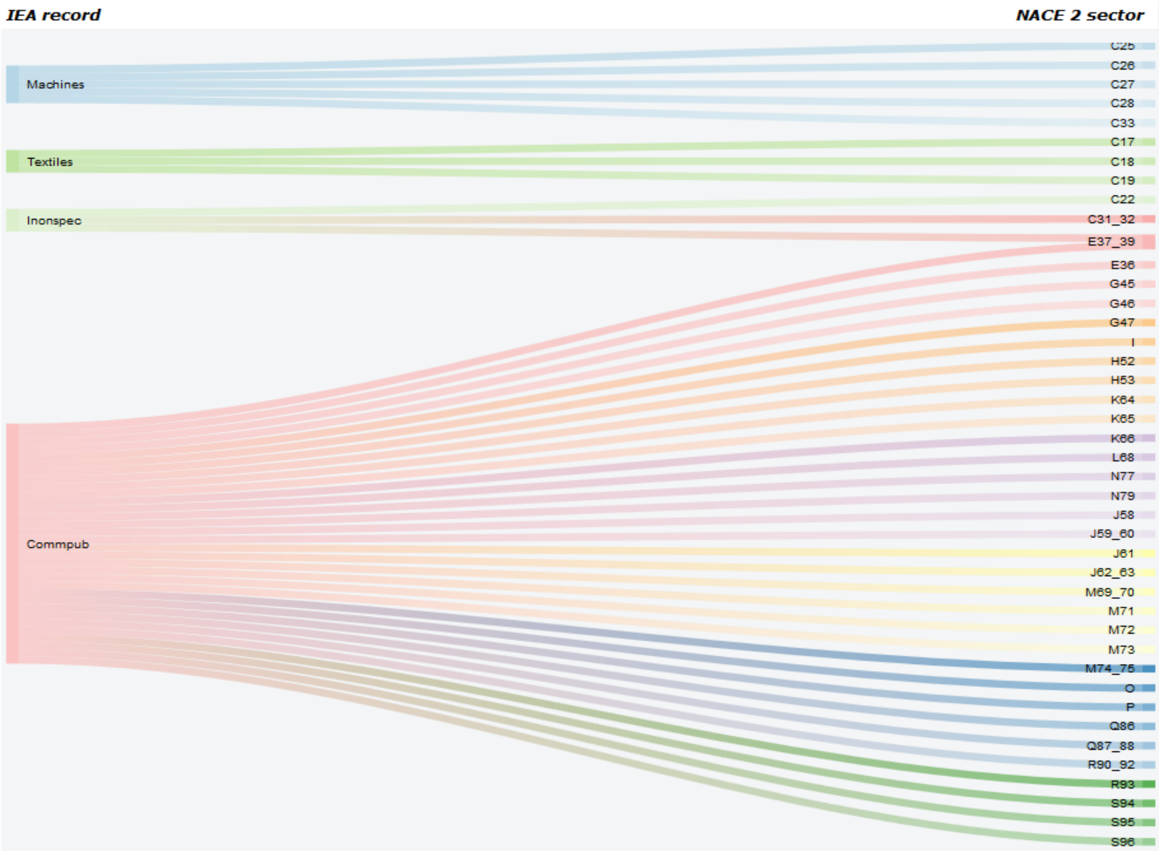
The direct allocation directly identifies the users of energy flows based on the technical knowledge of the productive processes. In some cases, the estimation of the energy use of specific industries from the energy balances' records is relatively straightforward. One example is the use of electricity or natural gas in the Construction sector.

4.2 Corrections for energy sectors

The energy transformation sectors incur in energy losses that are recorded separately in the energy balances. They correspond to losses due to the energy distribution through energy carriers. In the case of heat and electricity, these losses can be easily assigned to the electricity sector (sector D), disregarding short-distance losses incurred by auto-producers. For distribution losses related to other energy carriers (e.g. crude oil, coal), additional information is needed in order to allocate those flows to the energy accounts.

Inter-product transfers are another category that needs to be broken down into energy users provided that the energy flows are recorded together in the energy balances. This disaggregation method largely relies on the fuel mix and the consumption of energy commodities by the energy sectors as splitting variables for the energy flows.

Figure 8. Concordance between aggregate IEA energy balances' flows and NACE Rev.2 sectors: one-to-many correspondences



Source: Own elaboration

$$E(c, s, f, y) = B(c, h, f, y) \frac{U(c, p_f, s, y)}{\sum_{ss \epsilon h} U(c, p_f, ss, y)} \tag{1}$$

Equation (1) maps the IEA energy flows (B) into the energy accounts/sectors (E). Basically, we split the aggregated IEA energy flow (h) for a specific fuel (f), country (c) and year (y) using the share of the monetary use (U) of such fuel (f) by each energy sector (s) over their total use made by all energy sectors (ss, in particular B, C19 and D). (**Figure 9**).

The allocation of energy uses of fuels (e.g. natural gas) in auto-producing sectors[6] (waste management, pulp and paper, iron and steel, etc.) was done based on Equation (2) instead. It is in general also the case of specific sectors that auto-produce electricity and use specific energy commodities, such as waste, black liquor and coke oven gas. The intuition behind relates to the sale of surplus electricity to the grid and the supply of electricity between different establishments of the same firm.

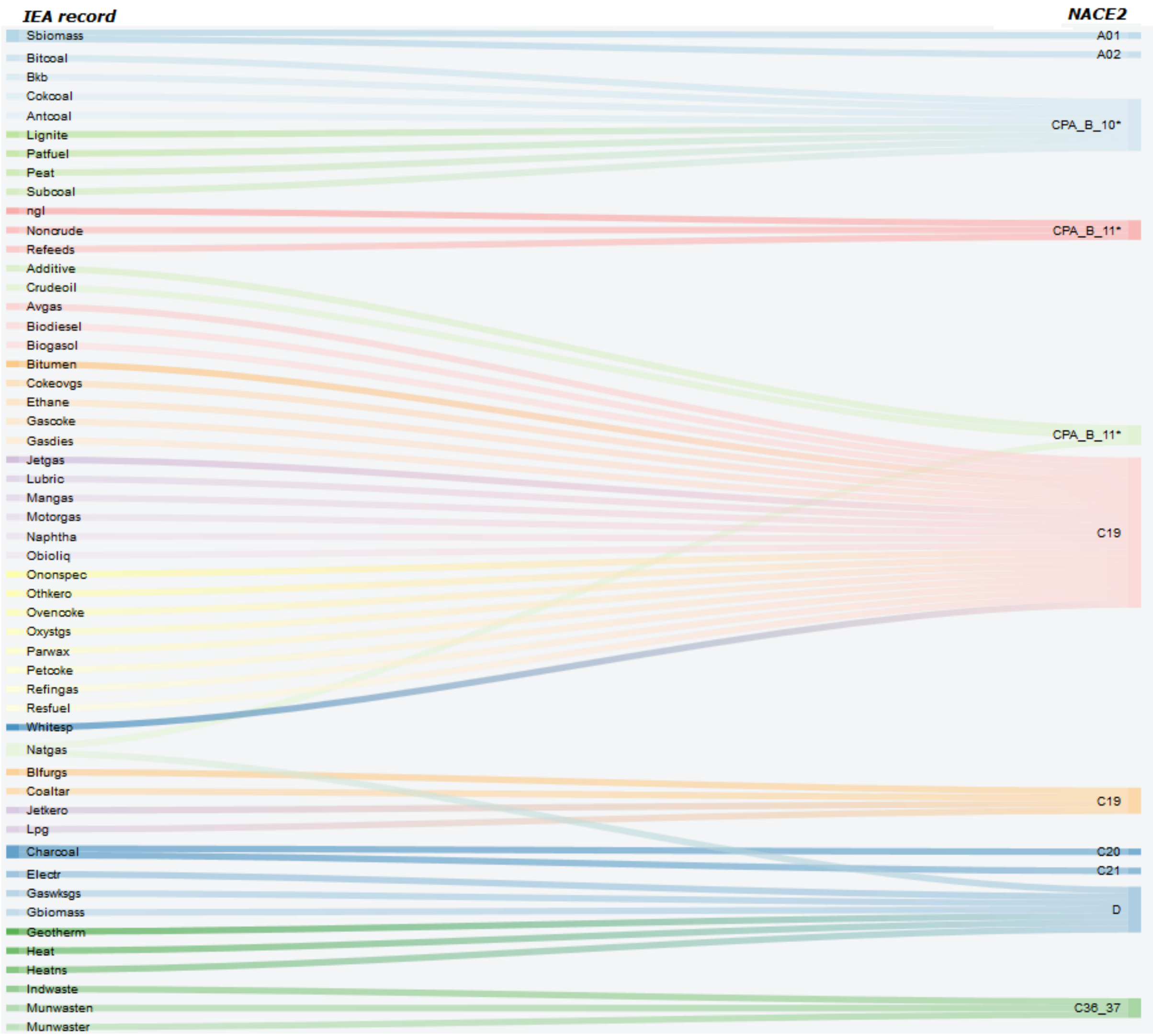
$$E_a(c, s_n, f_n, y) = B(c, h_a, f_n, y) \frac{S(c, p_D, s_n, y)}{\sum_y \sum_{s_n} S(c, p_D, s_n, y)} \tag{2}$$

Analogously to the former equation, Equation (2) maps the IEA energy flows (B) into the energy accounts/sectors (E). This equation splits the energy balance flow (h_a) for a specific country (c), year (y) and fuel type (f_n) using the share of the supply (S) of

[6] Excluding the power sector.

electricity (p_D) by each sector (s_n) over the total supply of electricity provided by all sectors (and summed over the years).

Figure 9. Concordance between energy balances' commodities and NACE/CPA products



Source: Own elaboration

4.3 Indirect allocation

Indirect allocation refers to the case where many users/sectors (NACE Rev.2) do not have a direct correspondence with the energy balances' flows (see **Figure 9** above). In order to estimate energy uses at NACE Rev. 2 level, Genty et al. (2012) introduced an indirect allocation method assuming a certain relationship between physical and monetary energy flows for the WIOD industries mentioned in **Figure 8**. This method uses information on the use of energy commodities assuming either that energy unit prices are constant across all sectors or that for some energy products, they have identical shares as those given by the energy product shares of the corresponding IEA extended energy balance account.

This method is particularly relevant for particular manufacturing sectors that are assumed to use an identical mix of heavy oil, light oil, and gasoline, and pay the same price for them. One additional specification should be made: although some fuels can be easily allocated to CPA commodities, additional assumptions were needed for specific fuels such as biodiesel, bio-gasoline, liquid biofuels, coke oven gas, blast furnace gas and oxygen steel furnace gas. As they show little similarity with the sectors in which they were classified (C20, C21 or D) and represent negligible shares, we assumed the same use shares as those of "other petroleum products", e.g. C19 (**Figure 9**). This is similar to the WIOD methodology (Genty et al., 2012).

4.4 Other specific corrections

There are other specific corrections related to auto-production activities and intra-industry transformations.

Transformation occurring in the same industry (i.e coal use).

Certain inputs are not recorded within the industry where they are used. Such is the case of the transformation of coal to coke occurring in the iron and steel industry (C24).

In order to reallocate the energy flows, Equation (1) is redefined to estimate the share of coal use in the refining (C19) and steel sectors (C24). Equation (3) maps the IEA energy flows (B) into the energy accounts/sectors (E). We split the aggregated IEA energy flow (h, TCOKEOVENS) derived from coal (f) for country (c) and year (y) using the share of the monetary use (U) of extracted coal (p_{B10}) by the refining and steel sectors (s_Y) over their total use made by both of them (in particular C19 and C24).

$$E\left(c, s_y, f_{COAL}, y\right) = B(c, h_{TCOKEOVS}, f_{COAL}, y)\frac{U(c,p_{B\_10},s_Y,y)}{\sum_Y U(c,p_{B\_10},s_Y y)} \tag{3}$$

Auto-production and wood

Wood can be used by several sectors such as forestry (secAtB), manufactured wood products (sec20) and pulp and paper (sec21t22) products. The energy use for forestry sectors was estimated using an adjusting factor (d) based on Austrian data. This factor provides an estimation of the intensity of purchases for wood-based fuels by the above wood related sectors.

Equation (4) maps the IEA wood-based energy flows (B) related to electricity and heat auto-production (AUTOELEC, AUTOCHP and AUTOHEAT) into the wood based energy accounts/sectors (E). We split the aggregated IEA energy flow (h) derived from wood (f) for country (c) and year (y) using the (adjusted) share of the monetary use (U) of forestry goods (p_{02}) by the forestry, wood sector and pulp and paper sectors (s_{wood}) over their total use made by all of them.

$$E(c, s_{wood}, f_{wood}, y) = B(c, h, f_{wood}, y)\frac{U(c,p_{02},s_{wood},y)d(s_{wood})}{\sum_{ss_{wood}} U(c,p_{02},ss_{wood},y)W(s_{wood})} \tag{4}$$

4.5 Allocation of fuels used in road transport

The reconciliation of the energy balances with the National Accounts framework entails shifting from the territorial to the residence principle.

Firstly, using the available information of the Use Tables, the *households' transportation expenditures* by road fuel use were calculated by difference between the households' (s_{HH}) purchases of refined products, p_{C19}, (from the Use tables, U) for a country (c) and year (y) and the households' (h_{HH}) purchases of non-road refined products for heating purposes (from IEA energy balances) for the same country and year[7]. The derived households' transportation expenditures were further adjusted by fuel efficiencies of diesel, LPG and petrol (road fuels, $f_{fuel\text{-}road}$), by the kilometres driven per year compared

[7] The price information used to estimate expenditures in non-road refined products by households produced a negative use of energy for Italy in 2015. To deal with this issue we substituted the abnormally high value of the price with the interpolation between 2014 and 2016.

to petrol cars, and by the private vehicle fleet share for a given road fuel, as described in the following equation. *P* stands for fuel prices.

$$E(c, s_{RESIDENT}, f_{Fuel_{road}}, y) = \frac{[U(c, p_{C19}, s_{HH}, y) - \sum B(c, h_{HH}, f_{C19}, y) * P(c, f_{C19}, y)] * eff(f_{Fuel_{road}}) * Car\_share(c, f_{Fuel\_road}, y)}{\sum_{ff_{C19}} eff(ff_{Fuel_{road}}) * Car\_share(c, ff_{Fuel\_road},) * P(c, ff_{C19}, y)} \quad (5)$$

Secondly, the expenditure for road fuels of the transportation sectors, i.e. land transport and pipelines, auxiliary transport activities and post and telecommunications was calculated as:

$$E(c, s_{transport}, f_{Fuel\_road}, y) = \frac{[U(c, p_{C19}, s_{transport}, y) - \sum B(c, h_{transport}, f_{C19}, y) * P(c, f_{C19}, y)]}{P(c, ff_{C19}, y)} \quad (6)$$

The energy use flow compliant with the resident principle (*E*) was calculated as the difference between the expenditures of transport sectors ($s_{transport}$) in refined products (p_{C19}) for a country (c) and year (y) and the corresponding purchases of other refined products, excluding diesel, divided by the commercial diesel price as from the IEA database, as described in Equation (6).

Lastly, the use of transport fuels not allocated either to the households (i) or to the transport sectors (ii) represents a residual category in the IEA energy flow ROAD. This residual was distributed over the rest of the sectors of the economy by using employment as a proxy variable for the intensity use of the different sectors.

Because of heterogeneous databases (IEA energy balances, Use Tables, energy prices, car fleet composition) the method produced inconsistent results in a number of cases and specific corrections were implemented accordingly. When this method did not produce meaningful shares across the different sectors (households, transport sectors and other sectors), or meaningful shares of fuel used, simple interpolations were used: average shares of comparable countries or European averages.

4.6 NAMEA energy use

The published official NAMEA energy accounts are our primary source data and prevail over other related estimates such as the WIOD estimates, which are primarily used only to further disaggregate and complement missing fuels/sectors. Countries publishing energy accounts often report energy commodities/energy sectors at a more aggregated level. For instance, wind, solar and geothermal energy flows are often aggregated in the broader category "renewable energies". Hence, these aggregated categories are further disaggregated using both the information from the national energy accounts (E^{NSI}) and our estimates $E^{estimated}$ (see Equation 7) for a specific country (c), year (y), sector (s) and fuel (f). The same logic is applied for some of the sectors where all energy flows are aggregated into one single category (e.g. financial sectors or services in general). Also, missing years (e.g. 2014, for Germany) were inferred using the national energy accounts in a particular year and the growth rate of estimates derived from the energy balances.

$$E(c, s, f_{wind}, y) = E^{NSI}(c, s, f_{renewables}, y) * \frac{E^{estimated}(c, s, f_{wind}, y)}{E^{estimated}(c, s, f_{renewables}, y)} \quad (7)$$

5 Estimation method for the CO_2 emissions accounts

CO_2 emissions include energy and non-energy-related emissions. The former originate from fuel combustion, while the latter relate to industrial processes. Overall, CO_2 emissions consist of the sum of energy ($CO2en$) and non-energy-related emissions ($CO2nen$). That is:

$$CO2(c,s,t) = CO2en(c,s,t) + CO2nen(c,s,t) \tag{8}$$

Where *c* is the country, *s* represents the industry and *t* represents the year.

For some countries and years, official CO_2 emissions data by sector are available (NAMEA-air data from Eurostat). Since this data includes both energy and non-energy-related emissions, the only data processing required is minor changes in the aggregation of figures to match the WIOD industry classification (e.g. grouping industries "R" and "S" into one "R_S" single category). This is the case of Belgium, Denmark, United Kingdom, Hungary, Ireland, Italy, Latvia, Malta, the Netherlands, Portugal, Slovakia, Switzerland and Turkey for the whole period (2000-2016); and of Austria, Bulgaria, Cyprus, the Czech Republic, Germany, Spain, Estonia, Finland, France, Greece, Lithuania, Luxembourg, Poland, Romania, Slovenia, Sweden, Norway and Croatia for the period 2008-2016.

In the case of Slovenia, Norway and Switzerland zero emissions are reported in some industries (e.g. E36 in Slovenia, C20 and C21 in Norway, C19 in Switzerland) where one would expect positive emissions, while the emissions of other industries seem inflated (e.g. E37-E39 in Slovenia, C19 in Norway, C20 in Switzerland). This suggests that some industries' emissions are grouped together and registered under one of those industries. Air Emission Accounts Questionnaires with additional information on how emissions are registered were provided by EUROSTAT for these countries[8]. This information is crucial to distribute emissions across the correct industries. But it does not inform about how much corresponds to each industry. To solve this problem, we used the shares obtained from the estimation of emissions made as if there was not official data. This procedure is detailed next.

For countries and years without official data on CO_2 emissions, **the first step** is to estimate energy-related emissions as:

$$CO2en(c,s,t) = \sum_f EREU(c,s,f,t) * EF(c,f,t) \tag{9}$$

Where *EREU* is Emission Relevant Energy Use (see Section 3.4.) from our estimated Energy Accounts, *EF* is the emission factor and *f* is the WIOD fuel or energy commodity.

Note that for four countries (Austria, Germany, Denmark and the Netherlands) estimations have been calibrated with official data. We used these calibrated estimations for all countries except of Germany, because for this country the projection method used for the years missing in the official data produces a peak in emissions in 2007 that is not observed in other emission databases (e.g. EXIOBASE, WIOD Release 2013). To circumvent this problem, we decided to use non calibrated estimates of emission relevant energy use for Germany, since these produce a path of emissions much closer to that of those other sources.

[8] In the case of industry "G. Wholesale and retail trade; repair of motor vehicles and motorcycles" of Slovenia, Air Emission Accounts Questionnaires do not provide additional information on where the emissions are registered. Then, reflecting official data, we register zero emissions for this industry although our estimation method would result in positive emissions.

Some countries report specific emission factors by fuel and year in their CRF tables. Whenever available, we used this data, which is contained in the CRF "TABLE 1.A(b) SECTORAL BACKGROUND DATA FOR ENERGY. CO_2 from fuel combustion activities". For some reporting countries, however, there are data gaps. To fill in these gaps, the average of the emission factor of each fuel across the available years of that country is used.

For non-reporting countries (non-Annex I Parties), standard emission factors provided in the IPCC Guidelines are used. These emission factors are only dependent on the energy commodity or fuel, and are homogeneous across countries and years.

Table 3 shows the correspondence between WIOD and IPPC fuels adopted to use emission factors either from CRF inventories or IPCC Guidelines:

Table 3. Correspondence between IPCC and WIOD fuels

WIOD fuels	CRF/IPCC fuels
HCOAL	Anthracite
BCOAL	Lignite
COKE	Coke oven coke
CRUDE	Crude oil
DIESEL	Gas/Diesel oil
GASOLINE	Motor gasoline
JETFUEL	Jet kerosene
LFO	Gas/Diesel oil
HFO	Residual fuel oil
NAPHTA	Naphta
OTHPETRO	Other petroleum products
NATGAS	Natural gas
OTHGAS	Liquified Petroleum Gases*
WASTE	Municipal waste (Non-biomass fraction)
OILSHALE	Oil shale and tar sands

(*) In the case of industry C24 "Manufacture of Basic Metals", OTHGAS corresponds to the average of coke oven gas, Blast furnace gas and Oxygen steel furnace gas. In the case of industry C19 "Manufacture of coke and refined petroleum products" OTHGAS corresponds to Refinery gas.

Source: Own elaboration

Other WIOD fuels (BIOGASOL, BIODIESEL, BIOGAS, OTHRENEW, ELECTR, HEATPROD, NUCLEAR, HYDRO, GEOTHERM, SOLAR, WIND and OTHSOURC) are assigned zero as CO_2 emission factors.

This methodology implies the assumption that emissions depend on the fuel (country and year), but not on the sector where fuels are used. Being CO_2 emissions stoichiometrically related to the carbon content of the fuel (in the absence of carbon sequestration), this can be considered a minor approximation as long as the WIOD fuel combusted is homogeneous across the sectors using it[9]. This would however be very different in the case of estimating emissions of air pollutants such as NO_X, SO_2 or fine dust, which are generated through non-stoichiometric processes and/or are controlled with secondary abatement techniques.

The **second step** is to add non-energy-related emissions. As already detailed in the data sources section, non-energy-related emissions come from different inventories depending on the country. **Table 4** is the correspondence table followed to match the different industry classifications in those sources:

Table 4. Correspondence between sectors for non-energy-related emissions in different classifications

WIOD	CRF	INECC	GEE Brasil	EDGAR
C23 - Manufacture of other non-metallic mineral products	A. Mineral industry	2A Industria de los minerales	Produção de Amônia Produção de Carbureto de Cálcio Produção de Metanol Produção de Eteno Produção de Cloreto de Vinila Produção de Óxido de Eteno Produção de Acrilonitrila Produção de Negro-de-fumo Produção de Ácido Fosfórico	2A1 - Cement production 2A2 - Lime production 2A3 - Limestone and dolomite use 2A7 - Production of other minerals 2A4 - Soda ash production and use
C20 - Manufacture of chemicals and chemical products	B. Chemical industry	2B Industria química	Produção de Cal Produção de Vidro Produção de Cimento Consumo de Barrilha	2B - Production of chemicals
C24 - Manufacture of basic metals	C. Metal industry	2C Industria de los metales	Produção de Ferro Gusa e Aço Produção de Magnésio Produção de Alumínio Produção de Ferroligas Produção de Outros Não-Ferrosos	2C - Production of metals

Source: Own elaboration

Since the period 2013-2016 is missing in EDGAR, projections are required to fill the gap. We projected 2013 and 2014 figures using growth rates of WIOD (2016 Release) gross

[9] The unique exception is OTHGAS, which can consist of a different mix of energy commodities depending on the industry. To tackle this, as noted in Table 3, we considered different correspondences depending on the industry.

output volume indices (GO_QI) by country and industry. Since no gross output data is available in WIOD for 2015 and 2016, we could calculate neither the corresponding growth rates nor emissions. So the gap persists for 2015-2016 non-energy-related emissions in these countries. Nevertheless, this only needs to be so until WIOD provides estimates for 2015-2016.

Finally, as mentioned above, the Rest of the World (RoW) emissions are rescaled to match EDGAR estimates of global emissions by applying the ratio between the RoW as residual between EDGAR global emissions and WIOD countries' emissions by year and the RoW estimated emissions by year, namely:

$$CO2(RoW,s,t) = \frac{EDGAR_{world}(t) - \sum_{c,s} CO2(c,s,t)}{\sum_{s} CO2(RoW,s,t)} * CO2(RoW,s,t) \qquad (10)$$

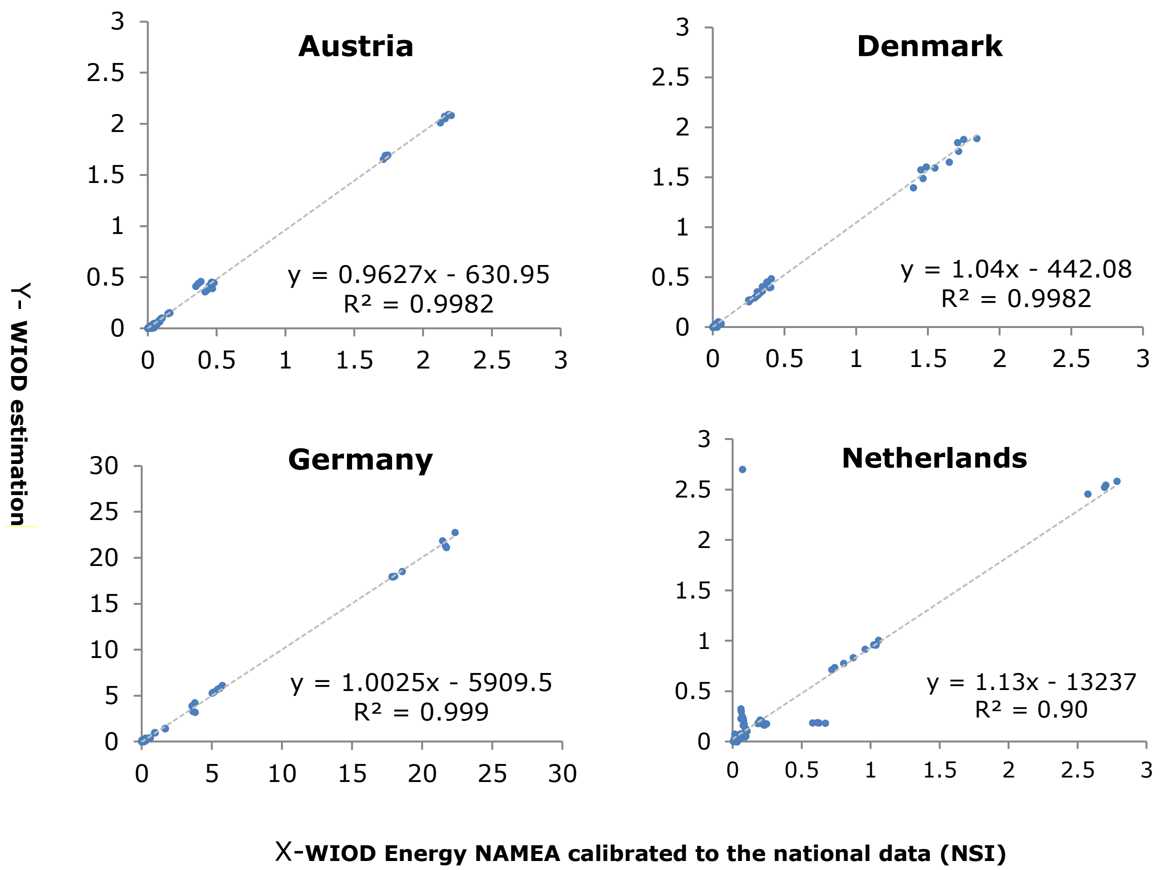
6 General discussion and consistency of the estimations

In this section, we confront our results to other available data sources. First, we mirror our estimated patterns of physical energy flows with the publicly available data from the National Statistical Institutes. Although this comparison can only be done for four countries for the whole period, it is one of the few opportunities to test the consistency of our estimations.

6.1 Comparison of estimations with available data sources

We measure the deviations between our estimated energy accounts and those published by the National Statistical Institutes of Austria, Denmark, Germany and the Netherlands. **Figure 10** shows a satisfactory goodness of fit for all regressions, with R-squared ranging from 0.90 for the Netherlands (excluding the mining sector) and 0.99 for the other countries.

Figure 10. Estimated versus disclosed data (millions): goodness of fit



Source: Own elaboration based on data from WIOD and PEFA tables from Eurostat

Excluding the mining sector, the Dutch estimates are overestimated by 13%. The difference comes from the approach used for the disaggregation of energy use by carriers and sectors (see Section 2) in terms of gross energy flows, used in order to have comparable results with the rest of the countries.

Beyond this overall evaluation of the goodness of fit, a closer examination of the results for specific industries is also needed to identify the strengths and weaknesses of our methodology.

We have also explored for the manufacturing industries the extent to which our estimates are comparable to the values registered in the energy balances and the PEFA tables. In terms of energy products, WIOD includes additional energy inputs (e.g. hydro, solar, wind) that are reported differently in the PEFA tables; moreover, the allocation of energy commodities is different in terms of the treatment of energy carriers. Besides, the PEFA tables were only available for 10 countries, among which only Belgium had a time series from 2010 to 2014 (Eurostat, 2014). Bearing all this in mind, we proved that for most of the countries the differences between our estimations and the two other sources were small. The largest difference corresponds to Lithuania, although still being our estimates also consistent with the former WIOD time series (release 2013).

Regarding emission accounts, our results are confronted with the official NAMEA-air like data that served as data source (when available), just to double check that the estimation process has not overwritten these figures. This way we could ensure that the estimated CO_2 emission accounts are fully consistent with official statistics on emissions.

6.2 Analysis of time structural patterns

The analysis of time structural patterns is based on the use share of energy products over their total use for each year (t) throughout the period 1995-2014. We use different use shares by energy product (I1), country (I2) and sector (I3):

$$I1_{i,t} = \frac{\sum_{k=1}^{40}\sum_{j=1}^{32} E_{i,j,k,t}}{\sum_{i=1}^{29}\sum_{k=1}^{40}\sum_{j=1}^{32} E_{i,j,k,t}} \tag{11}$$

$$I2_{j,t} = \frac{\sum_{k=1}^{40}\sum_{i=1}^{29} E_{i,j,k,t}}{\sum_{i=1}^{29}\sum_{k=1}^{40}\sum_{j=1}^{32} E_{i,j,k,t}} \tag{12}$$

$$I3_{k,t} = \frac{\sum_{j=1}^{32}\sum_{i=1}^{29} E_{i,j,k,t}}{\sum_{i=1}^{29}\sum_{k=1}^{40}\sum_{j=1}^{32} E_{i,j,k,t}} \tag{13}$$

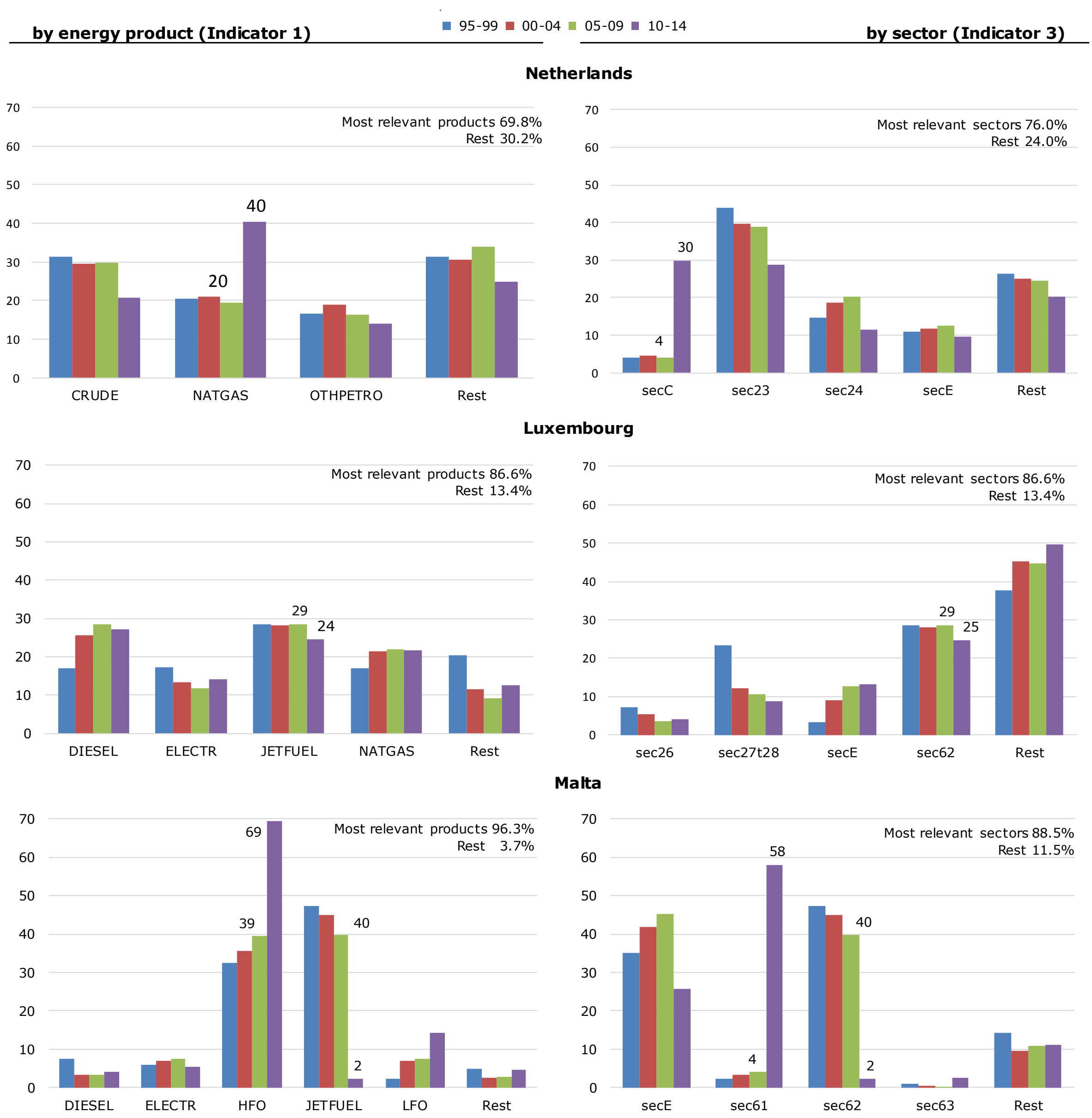
After obtaining the yearly structure for each indicator, the entire period is divided into four periods of five years each and the average structure is estimated for each period.

By comparing the use structures of the four periods, we can investigate whether there was some country-specific event that might have affected the use of energy flows or whether the assumptions made in the estimations might have led to inconsistent results.

In a WIOD based classification, the database comprises 32 countries, 34 sectors and 23 energy accounts, which resulted in around 37,000 time series to analyse. Consequently, the analysis in this section only provides an initial insight at aggregated level; a more detailed analysis of all series is out of the scope of this report but can be requested to the authors.

Figure 11 shows for some selected countries the composition of the most relevant energy products used by all sectors in three specific countries (Left-hand side of the figure, Indicator $I1$) and the energy use for all energy products in four specific sectors plus remaining sectors together (Right-hand side of the figure, Indicator $I3$) in the four periods, with a view to identifying the main changes in the consumption structure across periods.

Figure 11. Structural use of energy products by product and sector



Source: Own elaboration

For Indicator *I*1, the Netherlands shows a striking increase of the use share of NATGAS from around 19.6% in the three first periods to 40.4% in the fourth period.

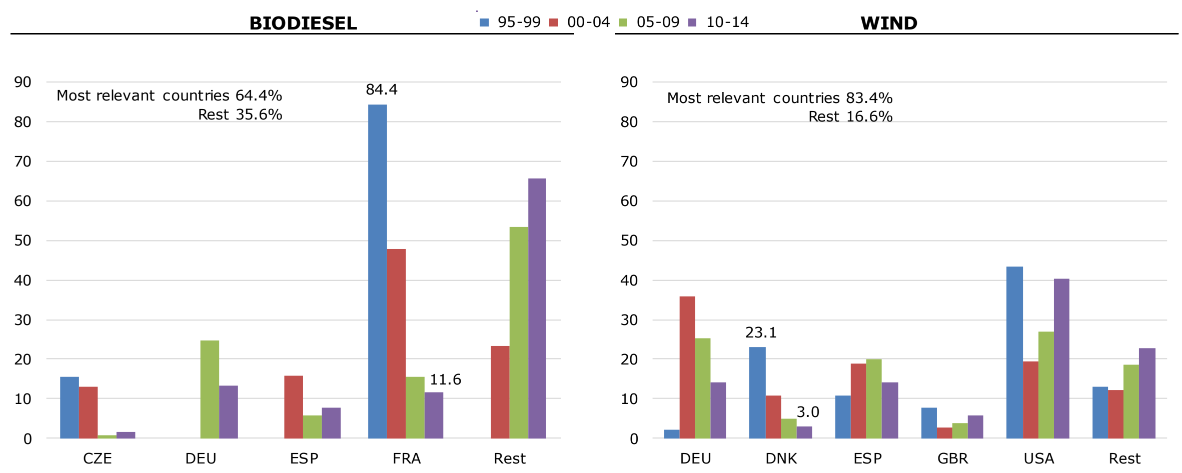
This result is in line with the result of the indicator *I*3 in which the share of total energy used by the Mining and Quarrying sector (secC on the right hand side graph for the Netherlands in 11) also increases from 3.9% in the third period to 29.8% in the last period.

For Luxembourg, the decrease of 4 percentage points in the share of energy used in the Air Transport sector (Sec62) during the last two periods is directly connected with the decrease of 4 percentage points in the share of Jet-fuel consumption.

Malta also shows a close relationship between the pattern of HFO and Jet-fuel consumption and the use of energy in the Air and Water Transport sectors, respectively. The share of HFO use almost doubles (from 39.4% to 69.5%) in the last period compared to the three previous periods, and at the same time the share of energy use in the Water Transport sector increases from 4.0% to 58.2%. The Jet-fuel use share, conversely, decreases from 39.7% to 2.3% in the last period, while the energy use share in the Air Transport sector decreases by the same proportion.

Figure 12 shows Indicator $I2$, i.e. the pattern for specific fuel use by country as a share over the total energy use for all sectors together. The two fuels presented in **Figure 12** have been selected because of the significant structural changes shown. France shows a strong progressive decrease in the Biodiesel use share, from 84.4% to 11.1% of the total for all countries, dropping from first to second overall biodiesel consumer after Germany.

Figure 12. Structural demand of all sectors for each country by fuel



Source: Own elaboration

A similar pattern is seen for Wind energy use in Denmark, where the decrease is from 23.1% to 3% of the total from the first to the last period. It is not clear if these patterns can be related to the situation of first movers in the deployment of certain technologies (biofuels and wind energy) progressively losing their dominant position while other countries catch up or it can be associated to the assumptions made.

Most of the patterns during the four periods and for the three indicators estimated present reasonable results that respond to the implementation of policies in some countries that produces changes in the pattern of the consumption of energy. More information can be requested to the authors for a number of specific cases. Those analysed in this section represent the cases with the greatest gap between periods and they may be related to a specific problem associated with the lack of information or methodological procedures. These breaks can also help identifying which statistics need to be improved. In the next section some of the limitations and ongoing improvements are briefly presented.

6.3 Current limitations and ongoing improvements

For a number of countries there was not enough information on physical energy flows or monetary energy use able to help estimating the energy accounts in the same manner as in the methodology set out by Genty et al. (2012).

For example, there was no information for coal in the Use Tables for Estonia. Moreover the country presented a discontinuity in the lignite series of the energy balances in 2009, which was actually used by the former WIOD estimates (release 2013). These two considerations alone serve to explain the difficulties in constructing the series for coal uses. However, a deeper investigation on the way each country reported energy balances has allowed us identifying a different allocation for coal based on oil shales information, which led to remove the above discontinuities in the coal patterns.

Substantial discontinuities have also been identified in the datasets when estimating the use of aviation fuel. For example, Luxembourg reports in 2009 a value for the use of aviation fuels in air transport activities several times smaller in the new WIOD Use Tables (NACE Rev.2) than the same value in the former WIOD Use Tables (NACE Rev.1.1). Such discontinuities could not be obviated and are mirrored in the energy use patterns. A similar pattern is seen also for Malta.

Discontinuities that might not be related to data issues were also identified for certain countries (e.g. Italy and Lithuania). For example, in Italy the consumption of heavy fuel oil is reduced by 50% every 5 years. This pattern has been identified by the IEA[10] and is consistent with the progressive substitution of oil with natural gas in the power generation. Another relevant example is the disappearance of nuclear fuel inputs in Lithuania after the closure of its single nuclear reactor in 2009.

For the identified discontinuities in energy use patterns we have been able to find explanations that were related to the switch in the NACE classifications of sectors and to the methods used to estimate purchases or sales of energy products. We have tried to identify and to limit the number of inconsistencies as much as possible, although there might still be room for improving our gross energy use estimates.

And last but not least, it should be noticed that the time structural patterns analysed in this section rely on Use Tables at current prices of the WIOD release 2016. We are fully aware that price effects of fuels can notably change these results. So, we would rather recommend repeating the analysis with deflated Use Tables, whenever they will be published in the future.

[10] https://www.iea.org/publications/freepublications/publication/italy_2010.pdf, page 5

7 Conclusion

The current work updates the WIOD series of environmental accounts. Wherever available, official environmental accounts were used (NAMEA) and complemented with estimates from the IEA data (e.g. renewables energies). However, the necessary data on energy accounts was not available for all countries and thus the energy accounts were estimated using the former WIOD methodology (Genty et al., 2012). Our estimation of gross energy use accounts incorporates changes in the classification of activities (NACE Rev.2 and NACE Rev.1.1). The estimation of a bridge layer of emission relevant energy use has enabled to make the link with CO_2 emissions, when NAMEA-air like data was not available. In these cases, air emission inventories (UNFCCC, EDGAR or national inventories) have been used to complete energy-related CO_2 emissions with non-energy-related emissions when necessary. The time series data were tested and compared with officially published energy use statistics to check their consistency in terms of energy use/consumption by countries and/or sectors and changes of classification and system boundaries. We found a satisfactory goodness of fit for most observations when comparing our estimates with official statistics. Where larger mismatches were found (e.g. Netherlands) we suspect that differences might stem from the fact that official NAMEA's gross energy accounts used net energy data to disaggregate gross energy uses for sectors/fuels at the desired level. A comparison of our estimated monetary physical energy flows with those monetary energy purchases of the Use Tables reveals a similar pattern for both, which gives reliability to our estimates.

The time breaks found in the comparison of series most likely point to the change in the classifications of activities. This finding implies that part of the uncertainty associated with the estimated gross energy accounts might be due to the underlying data. In Owen et al. (2014), a comparison of CO_2 emissions results between different MRIO databases (including WIOD) revealed that part of the differences in emissions results can be attributed to differences in collecting energy data (Owen, et al., 2014). Further improvements in data transparency and alignment of data compilation practices in National Statistical Institutes would therefore be beneficial.

The analysis of structural changes in the use of fuel by country and sectors was done by dividing the time series into four time periods. Then, a comparison was made between the overall energy use composition in the economy as well as changes in the consumption of individual fuels by sectors. It was found that most changes over time are likely due to changes in the consumption patterns of energy, which could be influenced by policies, changes in the economy and other factors. However, it would be necessary to analyse this issue more deeply, such as performing a detailed structural decomposition and using deflated Use Tables. However, the data also reveals some sharp changes in individual fuel consumption by country. Whether these changes are due to data consistency, estimation methods or other factors such as energy policies would need further investigation.

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List of abbreviations and definitions

CO_2	Carbon dioxide
CPA	Classification of Products by Activity
EDGAR	Emission Database for Global Atmospheric Research
EE	Environmental Extensions
ESA2010	European System of National and Regional Accounts 2010
EU	Energy Uses
GAMS	General Algebraic Modelling System
GJ	Gigajoule
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
n.a.	not available
NACE	Statistical Classification of Economic Activities in the European Community (by its initials in French)
NAMEA	National Accounting Matrix with Environmental Accounts
PEFA	Physical Flows of Energy Accounts
PJ	Petajoule
Rev	Revision
RUEC	Real Unit Energy Cost
SNA	System of National Accounts
SUT	Supply and Use Tables
TJ	Terajoule
UNFCCC	United Nations Framework Convention on Climate Change
WIOD	World Input Output Database

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Annexes

Annex 1. Energy commodities (plus losses) in the WIOD satellite accounts

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

Annex 2. Method of allocation of energy use by sector

Sectors	Method of allocation
Agriculture, Hunting, Forestry and Fishing	Direct allocation+ Correction Autoproduction: wood and wood products + Indirect allocation
Mining and Quarrying	Direct allocation + Indirect allocation
Food, Beverages and Tobacco	Indirect allocation
Textiles and Textile Products, Leather, Leather and Footwear	Indirect allocation
Wood and Products of Wood and Cork	Direct allocation+ AUTOPRODUCTION: wood and wood products
Pulp, Paper, Paper , Printing and Publishing	Indirect allocation
Coke, Refined Petroleum and Nuclear Fuel	Direct allocation+ Sec27/OVENCOKE
Chemicals and Chemical Products	Direct allocation + fuel correction
Rubber and Plastics	Indirect allocation
Other Non-Metallic Mineral	Indirect allocation
Basic Metals and Fabricated Metal	Indirect allocation
Machinery, Nec	Indirect allocation
Electrical and Optical Equipment	Indirect allocation
Transport Equipment	Indirect allocation
Manufacturing, Nec; Recycling	Indirect allocation
Electricity, Gas and Water Supply	Direct allocation+ Sec27/OVENCOKE Non-specified energy/transformation
Construction	Direct allocation
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	Indirect allocation
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	Indirect allocation
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	Indirect allocation
Hotels and Restaurants	Indirect allocation
Inland Transport	Transport allocation
Water Transport	Transport allocation
Air Transport	Transport allocation
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	Indirect allocation
Post and Telecommunications	Indirect allocation+ correction NEOTHER
Financial Intermediation	Indirect allocation+ correction NEOTHER
Real Estate Activities	Indirect allocation+ correction NEOTHER
Renting of M&Eq and Other Business Activities	Indirect allocation+ correction NEOTHER
Public Admin and Defence; Compulsory Social Security	Indirect allocation+ correction NEOTHER
Education	Indirect allocation+ correction NEOTHER
Health and Social Work	Indirect allocation+ correction NEOTHER
Other Community, Social and Personal Services	Indirect allocation+ correction NEOTHER
Private Households with Employed Persons	Indirect allocation+ correction NEOTHER
Extra-territorial organizations and bodies	Indirect allocation+ correction NEOTHER
Final consumption expenditure by households	Transport correction+ NEOTHER + Household uses of road fuels (Petrol, Diesel and LPG) +Household expenditure of non-road fuels

Annex 3. NACE Rev.2 classification

Code	Description
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10-C12	Manufacture of food products, beverages and tobacco products
C13-C15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31_C32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35	Electricity, gas, steam and air conditioning supply
E36	Water collection, treatment and supply
E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59_J60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommunications
J62_J63	Computer programming, consultancy and related activities; information service activities

Annex 3. NACE Rev.2 classification (continuing)

Code	Description
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68	Real estate activities
M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74_M75	Other professional, scientific and technical activities; veterinary activities
N77	Rental and leasing activities
N78	Employment activities
N79	Travel agency, tour operator reservation service and related activities
N80-N82	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
O84	Public administration and defence; compulsory social security
P85	Education
Q86	Human health activities
Q87_Q88	Social work activities
R90-R92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
R93	Sports activities and amusement and recreation activities
S94	Activities of membership organisations
S95	Repair of computers and personal and household goods
S96	Other personal service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extra-territorial organisations and bodies

Annex 4. List of sectors covered in the WIOD database

Code	Description
secAtB	Agriculture, Hunting, Forestry and Fishing
secC	Mining and Quarrying
sec15t16	Food, Beverages and Tobacco
sec17t18	Textiles and Textile Products
sec19	Leather, Leather and Footwear
sec20	Wood and Products of Wood and Cork
sec21t22	Pulp, Paper, Paper , Printing and Publishing
sec23	Coke, Refined Petroleum and Nuclear Fuel
sec24	Chemicals and Chemical Products
sec25	Rubber and Plastics
sec26	Other Non-Metallic Mineral
sec27t28	Basic Metals and Fabricated Metal
sec29	Machinery, Nec
sec30t33	Electrical and Optical Equipment
sec34t35	Transport Equipment
sec36t37	Manufacturing, Nec; Recycling
secE	Electricity, Gas and Water Supply
secF	Construction
sec50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
sec51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
sec52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
secH	Hotels and Restaurants
sec60	Inland Transport
sec61	Water Transport
sec62	Air Transport
sec63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
sec64	Post and Telecommunications
secJ	Financial Intermediation
sec70	Real Estate Activities
sec71t74	Renting of M&Eq and Other Business Activities
secL	Public Admin and Defence; Compulsory Social Security
secM	Education
secN	Health and Social Work
secO	Other Community, Social and Personal Services
secP	Private Households with Employed Persons
secQ	Extra-territorial organizations and bodies
secTOT	Total intermediate consumption
FC_HH	Final consumption expenditure by households

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