# National Accounts-based allocation of energy-related GHG emissions by end use

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**Abstract**
By using an end-use approach, emissions in energy sectors are re-allocated to the end users of energy in order to investigate the link between energy use in an economy and emissions in the energy sectors. An end-use approach differs from a consumption-based accounting approach in which not only emissions in energy production, but also emissions in non-energy production are re-allocated to final consumers. The allocation of emissions to end users is usually done by an iterative procedure on the basis of energy usage data in physical units obtained from energy statistics. This paper presents an input-output-based end-use approach by using data on energy use in monetary terms obtained from National Accounts. The approach is illustrated with the calculation of the greenhouse gas (GHG) emissions by end-use in the EU-27 in 2006. About 41% of EU-27 GHG emissions, which occurred in the energy sectors, were re-allocated to manufacturing and commercial and residential sectors mainly. The paper goes into the main differences between the two end-use allocation methods, which are the use of monetary versus physical data on energy usage, treatment of transport emissions and sectoral classification. After that, further applications of the National Accounts-based end-use approach are sketched and a preliminary time-series analysis of GHG emissions by end use in EU-27 in the period 2000-2006 is presented. The paper ends with some recommendations.

**Keywords:** End-use approach, energy sectors, GHG emissions, input-output analysis

## Introduction

An end-use approach enables the investigation of trends in emissions related to energy consumption per sector in order to identify decoupling of energy use and emissions in an economy (Abbott et al., 2010). In an end-use approach, energy-related emissions are allocated to end-users in order to display which end-users are responsible for the emissions in the energy sectors. For instance, the emissions in the electricity sector are allocated to the non-energy users of electricity such as manufacturing or households. Emissions at the extraction of coal, natural gas or other energy sources that are used in electricity plants are allocated to these end users of electricity as well. Figure 1 shows this re-allocation of emissions by end use for a fictitious example. The emissions in the energy system as reported in emission inventories (in the example 30 Mt) were allocated to non-energy production sectors, final consumers and exports on the basis of their energy use. Furthermore, emissions in energy sectors abroad, for example related to electricity imports were allocated to domestic end users (non-energy sectors and final consumers) as well.

In order to sketch the position of the end-user approach in relation to other accounting approaches, Figure 1 also shows the re-allocation of emissions in a consumption-based accounting (CBA) approach. In a CBA approach not only emissions in energy production, but also emissions in non-energy production are re-allocated to final consumers (households and government) and exports (for production and consumption abroad). Domestic consumption related emissions in other countries are also included. The calculation of the carbon footprint is an example of such an approach in which global emissions are allocated to final consumption per country (ESR, 2009). Thus, where the end-use approach considers the link between emissions and consumption of energy, the consumption-based approach considers the link between emissions and consumption of all goods and services. This paper will not further discuss the CBA approach, but will focus on the end-use approach.

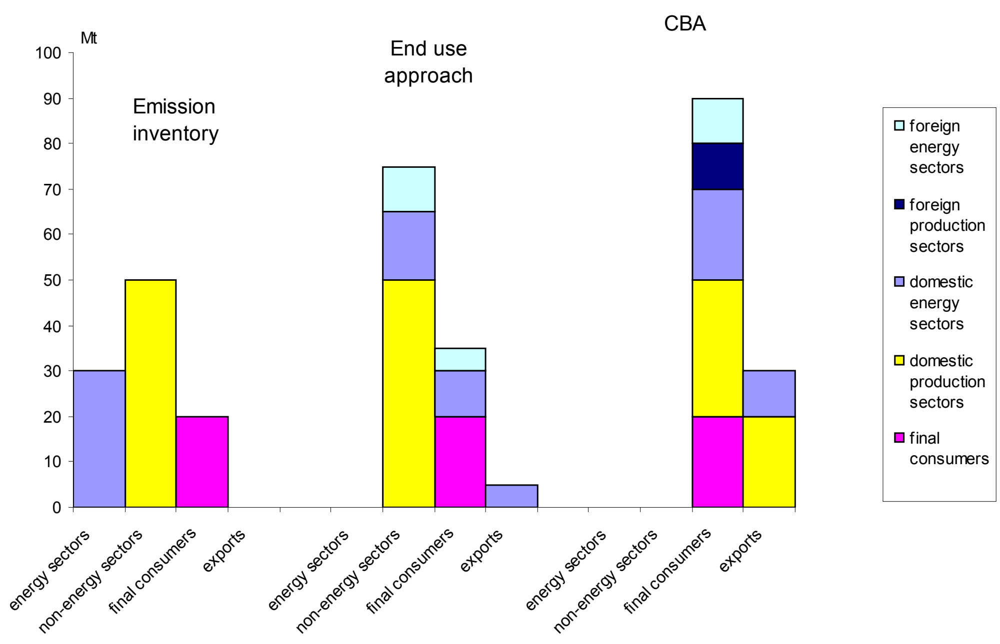


**Figure 1 Allocation of GHG emissions in emissions inventories, the end-use approach and consumption-based accounting (CBA).**

The European Environment Agency (EEA) presented an allocation of energy-related greenhouse gas (GHG) emissions by end use for the EU-27 (EEA, 2010). A key objective of this allocation was to better analyse the link between GHG emissions and the final energy demand driving the source of emissions taking into account the energy supply between countries in the EU-27. The re-allocating of energy-related GHG emissions to end users presented by EEA was carried out with a method developed for the UK by AEA Technology, the so-called UK end-use model (Abbott et al., 2010). The re-allocating in the UK model is based on emission data obtained from UNFCCC[1] GHG emission inventories and energy data from Eurostat energy statistics. The data on energy use in the energy database are in physical terms. This paper presents end-use emissions based on the National Accounts (NA) that include both information on emissions in economic sectors (in NAMEAs[2]) and information on supply of energy from energy sectors to other sectors (in economic input-output tables). Thus, the approach presented in this paper re-allocates emissions by using monetary data on energy use. Since not all end users pay the same energy price this might lead to differences in the re-allocation of end-use emissions between the UK end-use model and the NA-based approach.

Another important difference between the underlying data sets and therefore in both approaches is the treatment of transport emissions (see e.g. Mould and Abbott, 2010). In the energy and emission inventories, transport emissions are allocated to the drivers of transport. For example, all passenger car energy use is aggregated in energy balances (per fuel type), while in contrast, in a NAMEA, emissions related to this transport type are allocated to households (private transport) and all industries (salesmen, construction workers, etc.). Similarly, in a NAMEA, mobile emissions by farm tractors are allocated to agriculture.

Another difference between the data in a NAMEA and in energy statistics is the sectoral detail. In a NAMEA, the detail in sectors in business and other services is larger; where the energy statistics distinguish only one aggregated service sector, in the Eurostat input-output tables and environmental accounts, twenty trade, business and other service sectors are distinguished. The same sectoral classification in economic, energy and emission data in National Accounts enables an analysis of emissions in relation to, for instance value added or employment at the sectoral level. Contrary, energy statistics are more specific in fuel use. For instance, electricity, gas, steam and hot water supply are all aggregated in the National Accounts classification. This means that it is not possible to accurately distribute the indirect emissions according to the fuel used. In the UK end-user method, it is possible to separately allocate these emissions according to the fuel used.

Since there are different classification schemes, re-allocation of energy related GHG emissions will differ between both approaches. Since these classification schemes serve different applications, both methods can co-exist.

**Application to GHG emissions in the EU-27, 2006**

The method for re-allocating energy-related GHG emissions to end users based on NA data was applied to the GHG emissions (carbon dioxide, methane and nitrous oxide) in the EU-27 in 2006 (see Appendix A for the data details and Appendix B for the methodological details on this application). Emissions related to energy imports into the EU-27 were not considered; however, the application includes the emissions related to intra-trade of energy between individual EU

[1] United Nations Framework Convention on Climate Change.
[2] National Accounting Matrix with Environmental Accounts.

countries. Figure 2 shows total EU-27 GHG emissions by end use for some aggregated end-use categories. In Appendix C the outcomes of the re-allocation are presented at the most detailed level of the calculations (table C.1).

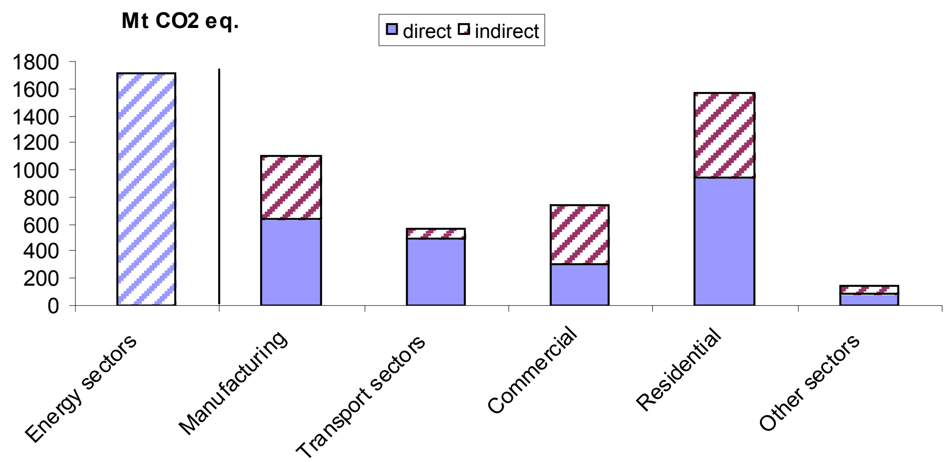


**Figure 2 GHG emissions in the energy transformation sector and re-allocated to end-use sectors in EU-27 in 2006.**

Total GHG emissions in the energy transformation sectors were 1706 Mt in the EU-27 in 2006 according to the Eurostat NAMEA data (table A.2). More than 80% of these emissions were $CO_2$ emissions in electricity production. Furthermore, methane emissions in coal mining and at the extraction of oil and natural gas contributed significantly. These energy-related emissions, which are reflected by the far most left bar, were allocated to end users (depicted in the figure by the indirect emissions of end users). The energy transformation emissions were mainly allocated to the residential and commercial sectors and to manufacturing. A small amount of GHG emissions (54 Mt $CO_2$ eq. is 1% of indirect emissions) were allocated to exports of the EU-27. They are not included in Figure 2.

Figure 3 shows the re-allocation of the emissions in an alternative way. The direct and allocated indirect emissions of end users are depicted as the share in total EU-27 GHG emissions. Indirect GHG emissions summed up to 41% of all GHG emissions in EU-27. Commercial sectors, inclusive institutional sectors, had relatively high indirect emissions compared to direct emissions due to their high electricity use in offices and other buildings.

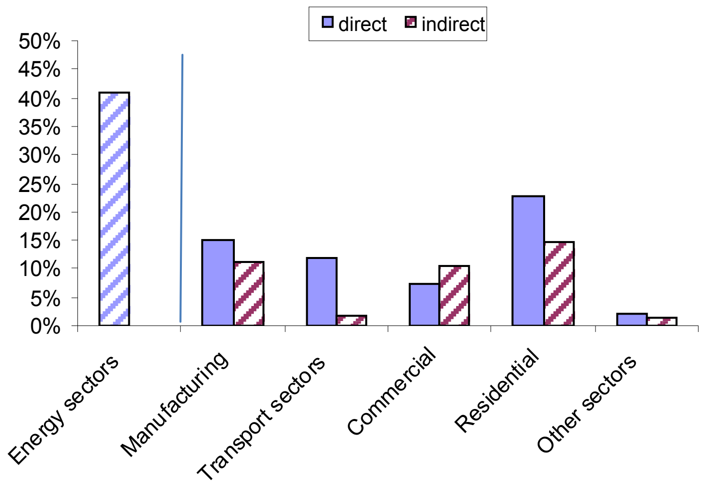


**Figure 3 GHG emissions in the energy transformation sector and re-allocated to end-use sectors in EU-27 in 2006 (as percentage of total GHG emissions).**

### Overall comparison with the results of the UK model based on energy statistics

The EEA paper (EEA, 2010) showed end-user emissions for the EU-27 based on the UK end-use model. These results concern all combustion emissions and fugitive emissions in the energy transformation system in 2008. For a comparison between the results of the energy-statistics approach and those of the NA-based approach, we obtained the 2006 outcomes from the UK end-use model by AEA Technology (Abbott et al., 2011). Table 1 shows the differences in outcomes for both approaches at the aggregated level as presented in the EEA paper. The indirect emissions column shows the allocation of the emissions in the energy transformation sector to the non-energy sectors (as share of total emissions). The sum of direct and indirect emissions equals end-use emissions.

**Table 1 Shares of direct, indirect and end-use emissions in this study and the UK end-use model, 2006.**

| | NA-based approach | | | UK end-use model | | |
|---|---|---|---|---|---|---|
| | direct | indirect | end use | direct | indirect | end use |
| Energy transformation | 41% | 0% | 0% | 42% | 0% | 0% |
| Manufacturing | 15% | 11% | 26% | 16% | 12% | 28% |
| Transport sectors / transportation | 12% | 2% | 14% | 24% | 4% | 27% |
| Commercial | 7% | 10% | 18% | 5% | 9% | 14% |
| Residential | 23% | 15% | 37% | 12% | 12% | 24% |
| Other sectors | 2% | 1% | 4% | 2% | 3% | 5% |
| Exports from EU-27 | | 1% | 1% | | 2% | 2% |
| Total | 100% | 41% | 100% | 100% | 42% | 100% |

The table shows that the allocation on the basis of monetary flows from national accounts and the allocation on the basis of energy use obtained from energy statistics give different answers. The differences are analysed in this section. An important difference between both approaches is the treatment of transport emissions. In energy statistics, energy use of all transport activities, e.g. in manufacturing, services and residential, is summed up to energy use of transportation. Transportation had a share of 24% in direct GHG emissions in the EU-27 in 2006. In a NAMEA, transport emissions are allocated to the economic sectors where these emissions occur. Emissions of private car transport are allocated to the residential sector and emissions of tractors to agriculture. Emissions in the transport sectors concern emissions in specific transport companies only. Furthermore, NAMEAs report on emissions of aviation, marine transport, etc. of domestic (EU-27) companies that take place outside the territory. For all sectors, the distinction between stationary and mobile emissions is lost, but the allocation of transport emissions is more in accordance with economic activities.

These differences concerning transport explain the differences in the direct emission shares in the table largely. Especially, the shares in direct emissions in the non-transport sectors ‘commercial’ and ‘residential’ are higher in this study than in the UK end-use model since in this study part of transportation emissions are allocated to non-transport sectors. Shares in emissions in ‘energy transformation’ and ‘manufacturing’ are slightly smaller in this study since the total emissions in this study are a bit higher than in the GHG emission inventories to UNFCCC because of additional transportation emissions in the NAMEAs. These sectors have relatively low shares of mobile emissions. A detailed comparison between both datasets in order to check if they are consistent is beyond this paper. Transportation has relatively low energy-related indirect emissions. Therefore, the ratio between direct and indirect emissions per sector is in this study higher than in the UK end-use model.

In the UK end-use model, emissions are allocated to end users on the basis of energy use. In the NA-based approach emissions are allocated on the basis of energy deliveries obtained from input-output tables, which are in monetary values. When all end users pay the same energy price this should lead to similar allocations of indirect emissions, but in practice there are differences between energy prices per end user. Households and medium sized enterprises often meet higher energy prices than basic industries or transport sectors and therefore the re-allocation of emissions to these end users is larger. Consequently, re-allocation of emissions to manufacturing and transport sectors is smaller. This is highlighted in the table by the lower shares of manufacturing and the transport sector and the higher shares of the commercial and residential sectors in indirect emissions as calculated in this paper. Specific information on energy prices per sector might improve the re-allocation of emissions, but it was not checked if this information is available at the desired level.

**Further application of the method**

This paper presented the end-use GHG emissions in the EU-27 as an example of an application of the NA-based end-use approach. If the data were available, this approach could also be applied to study the re-allocation of emissions between individual EU-27 countries or time-series analysis.

In the UK end-user study on the EU-27, all energy flows between individual countries were considered in order to re-allocate the energy-related emissions to end users in individual countries as well. The NA-based end-use approach can be extended in a similar way in which the bilateral flows of energy between single countries are included. Such an application including all interactions between countries requires a more sophisticated approach that consists of a multi-regional description of the energy sectors in all countries in the EU-27 (see Appendix B for a short description on elaborating this). The multi-regional approach requires input-output data for all individual countries.

The NA-based approach might be used for time series analysis as well, for instance for an investigation of the changes in emissions with a structural decomposition analysis (SDA). An SDA decomposes the changes in the emissions in the energy system to changes in the structure of the energy system and changes in the energy use by end users. As an example of a time series analysis we applied the NA-based end-use approach to the year 2000 as well and calculated the changes in direct and indirect emissions in the period 2000-2006. Figure 4 shows these changes in end-use emissions in the EU-27 in this period. GHG emissions in the energy supply sectors increased with almost 80 Mt CO2 eq. Almost 45% of this change in emissions was re-allocated to the commercial sector where direct GHG emissions in this sector increased with about 7 Mt. This indicates a higher share of electricity use in the commercial sector. The manufacturing sector managed to decrease the direct emissions, but the indirect emissions in this sector increased with slightly 3% showing a shift of emissions from end-use sector to energy sector. An SDA of the changes in emissions was beyond the scope of this paper.

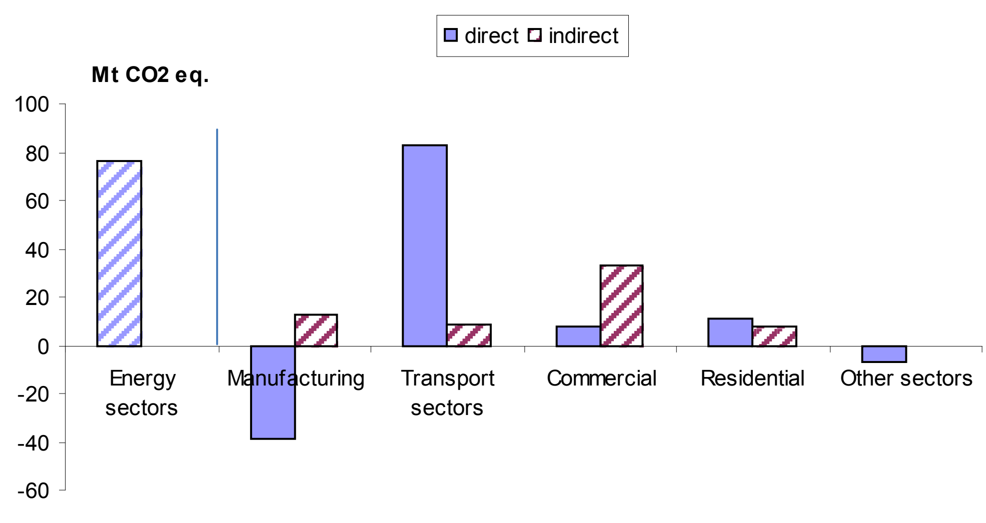


**Figure 4 Changes in GHG emissions in the energy transformation sector and re-allocated to end-use sectors in EU-27 in the period 2000-2006.**

Both regionalisation of the EU-27 emissions and a detailed time series analysis could be applied if the data were available. However, the availability of input-output tables is very different for countries in the EU-27. Most countries publish their tables every 5 years. Only Denmark, Germany, France, Luxembourg, The Netherlands and Finland produce input-output tables more frequently. The years 2000 and 2006 in the time series example were chosen because of data availability as well. Eurostat input-output tables for the EU-27 were only available for the period 2000-2006. Data on emissions in the Eurostat NAMEA for EU-27 were available for a longer period, namely 1995-2008. With the publication of the World Input-Output Database (WIOD), in April 2012, a multi-regional input-output framework came available covering all EU-27 countries and 13 major regions for the period from 1995 to 2009 (Timmer, 2012). However, these input-output tables are with 35 industries (of which two are energy sectors) more aggregated than the Eurostat tables. A far more detailed multi-regional input-output database, which also came available early 2012, is Exiobase with 43 countries and 129 industries. This database enables a detailed end-use calculation for the year 2000.

In general, input-output tables are constructed from supply and use tables (SUTs). Since most countries annually publish these SUTs, it might be interesting to investigate the possibilities to retrieve the data required for the NA-based end-use approach on these SUTs. Furthermore, the WIOD includes national and international SUTs (35 industries by 59 products) as well.

**Recommendations**

This paper explored the possibilities for a method for re-allocating energy-related emissions based on NA data, namely input-output and emission data. Such a method was developed, explained and applied to energy-related GHG emissions in the EU-27. Furthermore, the method was compared with the original method that was implemented in the UK end-use model. On the basis of our findings we make the following recommendations:

- Further research is required to investigate the effects of differences in energy prices between sectors on the re-allocation of indirect emissions. The re-allocation based on monetary deliveries assumes the same price for all sectors. A sensitivity analysis in which energy prices in the residential and commercial sectors are twice as high as energy prices in other sectors might be useful. Another starting point might be a comparison of the shares in energy use based on the input-output tables with shares in energy use based on energy statistics.
- A more detailed multi-regional approach is required in order to include all interactions of energy transfers between individual EU-27 countries in the end-use re-allocation of GHG emissions. Such an approach consists of a multi-regional description of the energy flows between energy sectors in all countries in the EU-27. The multi-regional approach is shortly sketched in Appendix B. It might be useful to elaborate a multi-regional analysis of the EU-27 end-use emissions and to compare the outcomes with those of the UK end-use model.
- The availability of Eurostat input-output tables is very different for countries in the EU-27. The WIOD offers a complete set of multi-regional input output tables at a more aggregated

level for the period 1995-2009. It might be interesting to explore the application of the WIOD for the end-use calculations, especially to what extent the lack of detail in industries influences the results. Furthermore, it might be interesting to investigate the possibilities to retrieve the data required for the NA-based end-use approach on supply and use tables supplied by WIOD or Eurostat.

- In case of large-scale application of the NA-based end-use approach, inclusion of the approach in the models of ETC/SCP might be worth considering. The ETC/SCP models for calculating consumption-based emissions in EU-27 and in individual countries contain all the information required for national end-use calculations, like input-output tables and NAMEA data. Therefore, it might be useful to investigate if these models can be extended with a module for calculating end-use emissions in a standard way. The re-allocation of domestic energy-related emissions should be easy, but since the ETC/SCP models have not a multi-regional character yet, a multi-regional re-allocation of energy-related emissions will be a more challenging task.

**References**


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**Appendix A Details of the application of the NA method for EU-27**

For the application of the NA-method to the energy-related GHG emissions in the EU-27 the following data were retrieved from the online Eurostat databases (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes; date of download: August, 10, 2011):

- Input-output table for domestic output at current prices, 60 branches - EU aggregates [naio_18_agg_60] – rows of the energy sectors only, 2006 data
- Air Emissions Accounts by activity (NACE industries and households) [env_ac_ainacehh] – $CO_2$, $CH_4$ and $N_2O$; 2006 data

The branches in the input-output table correspond with the industries in the emission accounts (NAMEA), so there is no mismatch in sectoral detail.

The following energy sectors were considered in the analysis:

- Mining of coal and lignite; extraction of peat
- Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
- Mining of uranium and thorium ores
- Manufacture of coke, refined petroleum products and nuclear fuel
- Electricity, gas, steam and hot water supply

Table A.1 shows, in the rows, the supply of EU-27 energy sectors to energy sectors and to end users in million euro's. For example, total supply of sector 1 (coal mining, etc.) is 15,634 million euro of which 5,480 million euro is directly supplied to end users. Imports of energy to the EU-27 energy sectors were not considered, so emissions in foreign energy sectors upstream in the supply chain of energy production, for instance at the extraction of coal in Australia, were not re-allocated to end users.

**Table A.1 Supply of energy per energy sector in the EU-27 in 2006 (in million euro's.)**

| | 1 | 2 | 3 | 4 | 5 | end users | total |
|---|---|---|---|---|---|---|---|
| 1 | 386 | 28 | 0 | 1062 | 8677 | 5480 | 15634 |
| 2 | 5 | 3652 | 0 | 46925 | 23700 | 19580 | 93862 |
| 3 | 0 | 0 | 2 | 0 | 0 | 41 | 43 |
| 4 | 177 | 176 | 2 | 32648 | 11776 | 290680 | 335459 |
| 5 | 1106 | 2044 | 10 | 3563 | 108539 | 396503 | 511764 |

With:

1. Mining of coal and lignite; extraction of peat
2. Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
3. Mining of uranium and thorium ores
4. Manufacture of coke, refined petroleum products and nuclear fuel
5. Electricity, gas, steam and hot water supply

Total GHG emissions in energy sectors in EU-27 in 2006 are listed in Table A.2. These emissions were re-allocated to end users by the approach described in Appendix B. In the re-allocation process there were no corrections made on the basis of energy prices.

**Table A.2 Total greenhouse gas emissions in energy sectors in EU-27 in 2006 (according to NAMEA)**

| | | Mt |
|---|---|---|
| 1 | Mining of coal and lignite; extraction of peat | 40.5 |
| 2 | Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying | 44.9 |
| 3 | Mining of uranium and thorium ores | 0.4 |
| 4 | Manufacture of coke, refined petroleum products and nuclear fuel | 166.4 |
| 5 | Electricity, gas, steam and hot water supply | 1454.0 |
| | Total energy sectors | 1706.3 |

**Appendix B End-user approach based on National Accounts data**

The method to calculate end-use emissions is illustrated with a fictitious example concerning two energy sectors and three end-use sectors. Figure B.1 shows the supply of energy between the energy sectors and to the end users. All supply is expressed in the value of the deliveries, thus in monetary units. The real money flows will go in the opposite direction.

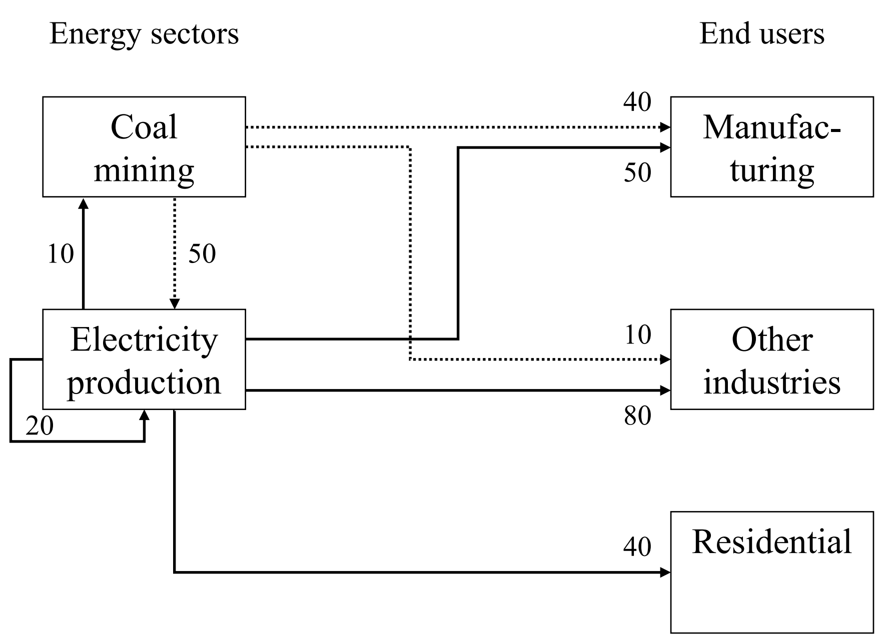


**Figure B.1 Fictitious example of flows of coal (dashed lines) and electricity (solid lines) between energy sectors and to end users (in million euros).**

In the example, coal mining delivers 40 million euros of coal to manufacturing and 10 million euros of coal to Other industries. Furthermore, 50 million euros of coal are delivered to electricity plants. Thus, 50% of the GHG emissions in coal mining could be allocated directly to end users. The electricity sector produces 200 million euros of electricity in total of which 170 (= 50+80+40) million euros are supplied to end users. So 85% of GHG emissions in electricity production can be allocated directly to the end users. Since coal mining supplies 50 million euros to the electricity sector, 85% of the emissions related to this supply in the coal-mining sector have to be allocated to the end-users of electricity. On the other hand, 50% of the emissions in electricity production for supplying 10 million euros of electricity to the coal mining sector are allocated to the end-users of coal mining.

It is possible to re-allocate emissions to end users in such an iterative way until the additional contributions become very small. This approach is feasible in a small example, but may be more challenging in a real application. Therefore, the NA-based method presented in this paper uses a mathematical formalism to re-allocate emissions that is based on economic input-output analysis. For a standard textbook on input-output analysis see e.g. Miller and Blair (2009).

The method concerning the re-allocation of emissions in the energy system consists of two main steps:

1. The first step concerns the unravelling of the flows between the energy sectors. Which part of the emissions in electricity production has to be allocated to the electricity consumption of end users and which part of these emissions has to be allocated to the coal consumption of the end users? Similar questions can be posed for the emissions in the coal mining sector. At the end of this step, the amount of emissions that have to be allocated to coal consumption and to electricity consumption are known. Thus this step concerns the calculation of total energy-related emissions, including emissions upstream in the energy supply chain, for energy production for end-users per energy sector.
2. In the second step the total emissions per energy sector are re-allocated to the individual end users that consume coal and electricity, respectively. Thus all energy-related emissions related to coal production are distributed over the consumers of coal and the same for electricity.

In the NA-based end-use approach, the allocation in both steps is based on economic data. We now explain the steps in the method using the example in figure B.1.

The first step concerns the distribution of emissions over energy sectors taking into account the interlinkages between the sectors in the energy system. Table B.2 shows an input-output table of the energy system with in the rows the supply from the two energy sectors to energy sectors and end-users in million euros. Total supply of the coal mining sector is 100 million euros of which 50 million euros concern deliveries of coal to end-users.

**Table B.1 Input-output table of the energy system in million euros**

| | coal mining | electricity | end users | total output |
|---|---|---|---|---|
| coal mining | 0 | 50 | 50 | 100 |
| electricity | 10 | 20 | 170 | 200 |
| other input | 90 | 130 | | |
| total input | 100 | 200 | | |

The columns in the input-output table of the energy system describe the inputs to the energy sectors. For instance, the coal mining sector requires 10 million euro of electricity to produce 100 million euros of coal, which is 0.1 euro of electricity to produce one euro of coal. For producing one euro of electricity, 0.25 euro coal (= 50/200) and 0.1 euro electricity (=20/200) are required. This information can be combined in a matrix of direct inputs, A. The matrix of direct inputs for the energy system in the fictitious example in table B.2 is:

| €/€ | coal mining | electricity |
|---|---|---|
| coal mining | 0 | 0.25 |
| electricity | 0.1 | 0.1 |

For producing these direct, first order inputs, second and higher order inputs from the energy sectors are required. An input-output analysis determines the total inputs (including the indirect, higher order inputs) from the direct inputs in sectors. These total requirements are presented in the so-called Leontief inverse matrix **L** which is derived from the matrix of direct requirements **A** as follows:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$$

with **I** the identity matrix. The Leontief inverse matrix shows for each energy sector the total production that is needed to produce one unit of final demand. A row of the Leontief inverse matrix contains the production of the corresponding sector required so that all sectors can deliver one unit of final demand. A column of the Leontief inverse matrix contains the production of all sectors needed for the production of one unit of final demand of the sector that corresponds with the column. The Leontief inverse matrix for the fictitious example is:

| €/€ | coal mining | electricity |
|---|---|---|
| coal mining | 1.029 | 0.286 |
| electricity | 0.114 | 1.143 |

For the supply of one euro of the coal mining sector to end users, the coal-mining sector itself has to produce 1.029 euro's (that is the one euro itself and .029 additional euros because of the interlinkages in the energy system) and the electricity sector 0.114 euro's. For the supply of one euro of electricity, the coal mining sector has to produce 0.286 euro's and the electricity sector 1.143 euro's.

Besides, total production of the coal mining sector, which is 100 million euros, consists of a production of 51.4 (= 1.029*50) million euros to coal consumption of end users and 48.6 (= 0.286*170) million euros to electricity consumption of end users. The GHG emissions in the coal mining system are allocated to the end users in the same proportions. Total production of the electricity sector is 200 million euros of which 5.7 (= 0.114*50) million euros is for coal consumption of end users and 194.3 (=1.143*170) million euros for electricity consumption of end users. Emissions in the electricity are allocated accordingly.

The emissions in the energy system for the supply to the end users are calculated by using the Leontief inverse matrix of the energy sectors as follows. Suppose direct emissions in the coal-mining sector are 50 Megatonnes (Mt) and direct emissions in the electricity sector are 400 Mt. The emission per euro of supply is 0.5 (= 50/100) tonnes in the coal-mining sector and 2.0 (= 400/200) tonnes in the electricity sector.

The standard input-output formalism for the relationship between direct emissions and total emissions per unit of supply to end users is:

$$\mathbf{e} = \mathbf{d}\,\mathbf{L}$$

with **e** the row vector of total emission intensities, the so-called emission multipliers, and **d** the row vector of direct emission intensities. Total emissions in the energy system for the supply of one euro of the coal-mining sector are then 0.74 (= 0.5*1.029 + 2.0*0.114) tonnes. Total emissions in the energy system for the supply of one euro of the electricity sector are then 2.43 (= 0.5*0.286 + 2.0*1.143) tonnes. Total emissions in the energy sectors re-allocated to the end users are the product of the emission multipliers with the supply to end users:

$$E = \mathbf{e}\,\mathbf{y} = \mathbf{d}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y}$$

with **y** the vector of supply to end-users.

Total emissions in the energy sectors re-allocated to the end users are 37.1 (= 0.74*50) Mt for the supply of the coal-mining sector and 412.9 (= 2.43*170) Mt for the supply of the electricity sector. The example shows that emissions allocated to the end-users of electricity are slightly higher than the 400 Mt emitted in the electricity sector, since part of the coal-mining emissions are caused by the use of coal in electricity production. The re-allocated emissions sum up to total emissions of 450 Mt in the energy sectors.

The second step in the NA-based end-use approach is the distribution of the re-allocated emissions to different end-users. Suppose the deliveries to the end users are as described in table B.2.

**Table B.2 Consumption of energy by end users per energy sector in million euro's**

| | manufacturing | other industries | residential | total |
|---|---|---|---|---|
| coal mining | 40 | 10 | 0 | 50 |
| electricity | 50 | 80 | 40 | 170 |

The energy-related emissions are re-allocated to the end-users proportionally with the supply of energy. Table B.3 shows the re-allocation of energy-related emissions to end-users.

**Table B.3 Re-allocation of energy-related emissions by end use (in Mt)**

| | manufacturing | other industries | residential | total |
|---|---|---|---|---|
| coal mining | 29.7 | 7.4 | 0.0 | 37.1 |
| electricity | 121.4 | 194.3 | 97.1 | 412.9 |
| total | 151.1 | 201.7 | 97.1 | 450.0 |

So allocation of energy-related emissions to end users is carried out by multiplying the vector of emission multipliers of the energy sectors with the matrix of energy consumption by end users. Finally these energy-related emissions are added to the direct emissions of end users. Overall, the formalism for calculating end-user emissions **m** is:

$$\mathbf{m} = \mathbf{d}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{Y} + \mathbf{n}$$

where

**Y** is the matrix of energy demand by end users

**n** is the row vector of direct emissions of end users

This Appendix discussed the application of the NA-based approach to an individual country or region in which all domestic energy-related emissions were allocated to end-users. Such an approach does not take into account emissions related to energy imports from other countries. If imports and exports of energy between individual countries in a region, for example EU-27, have to be considered, as is done in the UK end use model, a more sophisticated approach is required. Such a more sophisticated model consists of a multi-regional description of the energy sectors in all countries in the EU-27. This description consists of a table of 135 (= 5*27) rows and columns depicting the direct inputs from other energy sectors. Instead of the single-region table of the energy system, this multi-region table is used for the calculation of the Leontief inverse matrix.

The diagonal 5x5 blocks of the big matrix display the intermediate inputs and outputs from the domestic energy supply systems. These blocks have to be based on the domestic input-output tables. The off-diagonal blocks represent the imports and exports of energy between EU-27 countries at the level of 5 sectors. These blocks have to be constructed since the input-output tables for imports only contain aggregated figures over all countries. Bilateral trade data at the level of individual countries might be used for the construction of the off-diagonal blocks. Since in general, trade data on imports and exports are not consistent, a re-balancing of the big matrix will be required.

## Appendix C GHG emissions by economic activity before and after re-allocation

Table C.1 consists of the direct GHG emissions per sector at the most detailed level and the re-allocation of the GHG emissions in the energy supply system to end users. The direct GHG emissions concern all emissions inclusive the emissions not related to energy, like industrial process emissions, emission in agriculture and emissions in landfills. Therefore, total emissions in this table are higher than the GHG emissions presented in Figure 2.

**Table C.1 Greenhouse gas emissions by economic activity before and after the re-allocation procedure in Mt $CO_2$ eq.**

| | Direct | Indirect | End use |
|---|---|---|---|
| Agriculture, hunting and related service activities | 541.4 | 28.2 | 569.5 |
| Forestry, logging and related service activities | 16.9 | 1.7 | 18.5 |
| Fishing | 5.8 | 1.7 | 7.5 |
| Mining of coal and lignite; extraction of peat | 40.5 | 0.0 | 0.0 |
| Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying | 44.9 | 0.0 | 0.0 |
| Mining of uranium and thorium ores | 0.4 | 0.0 | 0.0 |
| Mining of metal ores | 1.4 | 2.1 | 3.4 |
| Other mining and quarrying | 7.0 | 6.8 | 13.8 |
| Manufacture of food products and beverages | 84.7 | 57.5 | 142.2 |
| Manufacture of tobacco products | 0.4 | 0.6 | 1.0 |
| Manufacture of textiles | 17.0 | 13.6 | 30.6 |
| Manufacture of wearing apparel; dressing; dyeing of fur | 2.2 | 3.5 | 5.7 |
| Manufacture of leather and leather products | 1.9 | 2.1 | 4.0 |
| Manufacture of wood and wood products | 9.7 | 10.0 | 19.7 |
| Manufacture of pulp, paper and paper products | 41.7 | 31.7 | 73.4 |
| Publishing, printing and reproduction of recorded media | 9.4 | 9.6 | 19.1 |
| Manufacture of coke, refined petroleum products and nuclear fuel | 166.4 | 0.0 | 0.0 |
| Manufacture of chemicals, chemical products and man-made fibres | 199.4 | 73.7 | 273.1 |
| Manufacture of rubber and plastic products | 14.4 | 23.5 | 37.9 |
| Manufacture of other non-metallic mineral products | 264.1 | 42.3 | 306.4 |
| Manufacture of basic metals | 249.8 | 56.3 | 306.1 |
| Manufacture of fabricated metal products, except machinery and equipment | 20.3 | 27.6 | 48.0 |
| Manufacture of machinery and equipment n.e.c. | 16.8 | 25.2 | 42.0 |
| Manufacture of office machinery and computers | 0.6 | 1.6 | 2.2 |
| Manufacture of electrical machinery and apparatus n.e.c. | 7.6 | 12.4 | 20.0 |
| Manufacture of radio, television and communication equipment and apparatus | 2.5 | 4.6 | 7.1 |
| Manufacture of medical, precision and optical instruments, watches and clocks | 3.3 | 4.3 | 7.6 |
| Manufacture of motor vehicles, trailers and semi-trailers | 15.7 | 21.4 | 37.1 |
| Manufacture of other transport equipment | 5.4 | 6.7 | 12.1 |
| Manufacture of furniture; manufacturing n.e.c. | 12.3 | 8.0 | 20.3 |
| Recycling | 2.5 | 1.6 | 4.0 |
| Electricity, gas, steam and hot water supply | 1454.0 | 0.0 | 0.0 |
| Collection, purification and distribution of water | 4.0 | 12.7 | 16.7 |
| Construction | 65.2 | 33.2 | 98.5 |
| Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel | 19.4 | 17.8 | 37.1 |
| Wholesale trade and commission trade, except of motor vehicles and motorcycles | 35.5 | 45.3 | 80.8 |
| Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods | 33.7 | 54.6 | 88.2 |

| | | | |
|---|---|---|---|
| Hotels and restaurants | 16.5 | 36.4 | 52.9 |
| Land transport; transport via pipelines | 218.0 | 44.5 | 262.5 |
| Water transport | 107.6 | 4.7 | 112.3 |
| Air transport | 149.4 | 9.1 | 158.5 |
| Supporting and auxiliary transport activities; activities of travel agencies | 21.9 | 15.1 | 36.9 |
| Post and telecommunications | 14.3 | 16.8 | 31.1 |
| Financial intermediation, except insurance and pension funding | 5.6 | 8.6 | 14.2 |
| Insurance and pension funding, except compulsory social security | 2.2 | 3.1 | 5.2 |
| Activities auxiliary to financial intermediation | 2.3 | 3.8 | 6.1 |
| Real estate activities | 14.5 | 40.8 | 55.3 |
| Renting of machinery and equipment without operator and of personal and household goods | 14.4 | 9.2 | 23.6 |
| Computer and related activities | 4.3 | 8.2 | 12.4 |
| Research and development | 2.3 | 6.6 | 8.9 |
| Other business activities | 21.0 | 43.3 | 64.3 |
| Public administration and defence; compulsory social security | 35.9 | 40.8 | 76.6 |
| Education | 21.9 | 28.5 | 50.3 |
| Health and social work | 31.6 | 35.7 | 67.4 |
| Sewage and refuse disposal, sanitation and similar activities | 160.7 | 8.0 | 168.7 |
| Activities of membership organization n.e.c. | 3.9 | 3.9 | 7.8 |
| Recreational, cultural and sporting activities | 11.7 | 16.2 | 27.9 |
| Other service activities | 8.2 | 8.9 | 17.1 |
| Activities of households | 0.3 | 0.0 | 0.4 |
| Extra-territorial organizations and bodies | 0.7 | 0.0 | 0.7 |
| Residential | 947.1 | 613.9 | 1561.0 |
| Other final demand (government consumption and exports) | | 58.4 | 58.4 |
| Total | 5234.4 | 1706.3 | 5234.4 |