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Calculation methods for energy efficiency and energy consumption variations at country, region and city levels

Méthode de calcul pour l'efficacité énergétique et les variations de consommation d'énergie aux niveaux national, régional et urbain

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 301, *Energy management and energy savings*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Due to the increasing role of energy efficiency improvements and of controlling the energy consumption growth in international climate and energy policies, there is a need for harmonization of methods to evaluate the impact of these policies at the international level.

This document is concerned with the evaluation of energy consumption and energy intensity changes through explanatory factors, as well as the calculation of an energy efficiency index, at national and regional levels. The practical application can be different due to specific restrictions, such as methodologies, availability of data at lower levels of disaggregation, or difficulty in understanding and communicating.

The methods presented here can provide valuable insights into trends in energy use and factors linked to those trends. Still, not all aspects of the phenomena that affect energy use are accounted for by the methods in this document, as these methods are primarily descriptive. While the analysis presented here can reveal patterns or shifts in patterns of energy use, they do not necessarily reveal causality, an aspect that can also require additional analysis.

The user should be aware of some issues associated with the methods presented in this document. Some of these arise from analytic issues. For example, whether to combine all fuels in a sector into a single energy variable or to treat them separately is a question best addressed by clear reference to the purpose of the analysis using the methods presented here. Other aspects are phenomena not explicitly included in the methods presented here. An example is the role of the prices of energy or other goods, which can require additional methods.

This document is composed of three different calculation methods:

— evaluation of structure effects in the variation of energy intensity;

— calculation of energy efficiency indices;

— decomposition analysis of energy consumption variation.

Energy intensity is often considered as an indicator of energy efficiency at aggregate level when limited data are available. Their use as a proxy for energy efficiency can be improved by removing from their variations changes in economic structures: this is the objective of the first part of this document.

With more detailed data on energy consumption available by subsectors or energy uses (e.g. space heating) or by modes of transport (e.g. cars), it is possible to assess energy efficiency trends through a more accurate indicator than energy intensity, called "energy efficiency indices": this is the objective of the second method of calculation presented in this document.

The variation of energy consumption can be related to change in economic activity, to energy savings as well as to other explanatory factors: the purpose of the third method of calculation described in this document is to present the method of decomposition of changes in energy consumption. It makes use of indicator-based savings, i.e. energy savings calculated according to the indicator-based method, as described in ISO 17742.

This document considers all end-use sectors, such as industry, transport, households, services (also known as the "tertiary sector") and agriculture. It does not generally incorporate the energy supply sectors, such as power plants, refineries or coal mines. However, the integration of the power sector can be considered in the decomposition of the primary energy consumption to account for the effect of variations in energy efficiency and energy mix in the power sector.

Energy consumption considered in this document excludes feedstock energy, such as oil feedstock used to produce plastics or natural gas used as a feedstock for the production of fertilisers, as they are not affected by energy efficiency policies.

This document can be used by any interested parties (decision-makers, companies, researchers, NGOs, etc.) that want to understand changes in the energy intensity or the energy consumption, as well as to assess energy efficiency by sector over a specific period.

This document is part of a set of documents developed by TC 301 (see Figure 1) and builds on the general principles outlined in ISO 17743, including reporting and system boundaries, and on the energy savings calculations presented in ISO 17742.

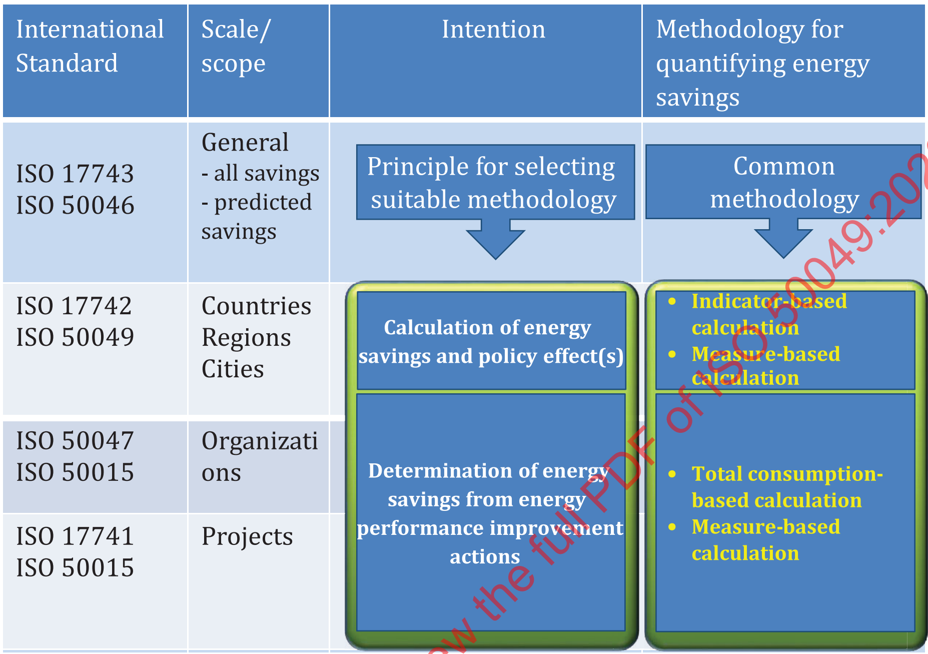


Figure 1 — Relationship between documents

The document covers more precisely three types of calculation methods based on energy efficiency indicators. Compared to ISO 17742, it details more advanced methodologies that facilitate a more comprehensive understanding of changes in: a) energy intensity, b) energy efficiency and, finally, c) energy consumption. The evaluation of energy efficiency trends relies on the calculation of energy efficiency indices. Variations in energy consumption are explained from a decomposition into different explanatory factors, one of which being energy savings. Therefore, this document complements ISO 17742 on energy savings calculation methods. More specifically, it complements how ISO 17742 deals with indicator-based methods. For each calculation method, examples of specific calculations are presented separately in Annexes A to C.

When applying this document, the user can choose between different options of the methods proposed. In order to be transparent in the way results have been obtained, the user of this document should specify the methodology used when presenting the results.

The general methodologies to evaluate trends in energy intensity, energy efficiency and energy consumption and its link to energy savings are presented in Clause 4. The calculation of the influence of structural changes in the energy intensity variation is described in Clause 5. The calculation method for the energy efficiency index is described in Clause 6. Finally, the method of decomposition of the energy consumption is given in Clause 7. Annexes A to C provide examples to illustrate various types of calculations. Annex D presents the methodology of climatic corrections, as most of these calculations should be done with energy efficiency indicators adjusted to a normal climate.

Calculation methods for energy efficiency and energy consumption variations at country, region and city levels

1 Scope

This document gives guidelines for methods for analysing changes in energy efficiency and energy consumption, and for measuring energy efficiency progress, for countries, regions and cities. It is composed of three different calculation methods:

— evaluation of structure effects in the variation of energy intensity;

— calculation of energy efficiency indices;

— decomposition analysis of energy consumption variation.

This document is applicable to providing an aggregated statistical evaluation for a country, region or city. It does not apply to calculating changes in the energy consumption or in energy efficiency at the individual consumer's level (e.g. households, organizations, companies).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
activity factor
variation in the energy consumption levels of a sector or subsector due to the variation of the activity of the sector for a given period

Note 1 to entry: The quantification of this factor depends on the driver used to measure the activity.

3.2
apparent energy efficiency improvement
increase in *energy efficiency* (3.5) without correction or adjustment (i.e. gross value resulting from a calculation)

3.3
base year
reference year in the calculation

Note 1 to entry: It is usually the first year of calculation.

Note 2 to entry: The year can be calendar or fiscal. All data should have the same definition of year, whether calendar or fiscal.

3.4
behavioural factor
factor that shows the impact on the variation of energy consumption or on an energy indicator of changes in the behaviour of consumers

EXAMPLE Change in the level of thermal comfort with a higher or lower use of heating or air cooling equipment.

3.5
energy efficiency
ratio or other quantitative relationship between an output of performance, service, goods, commodities or energy and an input of energy

[SOURCE: ISO/IEC 13273-1:2015, 3.4.1, modified — The symbol has been deleted and "commodities" has been added.]

3.6
energy efficiency improvement
increase in *energy efficiency* (3.5) as a result of technological, behavioural and/or economic changes

[SOURCE: ISO/IEC 13273-1:2015, 3.4.3, modified — "technological, behavioural and/or economic changes" has replaced "technological, design, behavioural or economic changes".]

3.7
energy efficiency index
index measuring the increase in *energy efficiency* (3.5) compared to a *base year* (3.3)

EXAMPLE 100 for base year.

3.8
energy intensity
quotient describing the total energy consumption per unit of economic output

Note 1 to entry: The economic output should be measured at a constant price.

Note 2 to entry: The intensity can be interpreted as the amount of energy required to produce one unit of activity expressed in monetary terms (GDP or value added).

Note 3 to entry: The intensity can also be used at sector level (e.g. industry, residential, services). In that case, it is often referred to as "sectoral energy intensity".

Note 4 to entry: The term "energy intensity" is sometimes used with the same meaning as *specific energy consumption* (3.17), but this is not the case in this document.

[SOURCE: ISO/IEC 13273-1:2015, 3.1.14, modified — The example has been deleted and Notes 1, 2, 3 and 4 to entry have been added.]

3.9
energy savings
reduction of energy consumption compared to an energy baseline at same level of service

Note 1 to entry: Energy savings are positive when they reduce consumption. Due to some external factors that cannot be accounted for, consumption can increase instead of decrease: this phenomenon is referred to as "negative energy savings".

3.10
energy use
application of energy

EXAMPLE Ventilation; lighting; heating; cooling; transportation; data storage; production process.

Note 1 to entry: Energy use is sometimes referred to as "energy end-use".

[SOURCE: ISO 50001:2018, 3.5.4]

3.11
energy using system
physical items with defined system boundaries, using energy

EXAMPLE Plant, process, building, machines, equipment, product.

[SOURCE: ISO 50047:2016, 3.1, modified — The example has been replaced.]

3.12
explanatory factor
factor explaining the variation in an indicator or in the energy consumption

Note 1 to entry: It is different from the concept of "relevant variable" as defined in other standards as a "quantifiable factor that impacts energy performance and routinely changes" (e.g. ISO 50006:2014, 3.14). "Relevant variable" is more related to the performance of an *energy using system* (3.11), whereas "explanatory factor" relates to a sector and to both its consumption and performance. "Relevant variable" is more a micro concept, whereas "explanatory factor" is a macro concept.

3.13
final energy
energy as delivered to an *energy using system* (3.11)

Note 1 to entry: This concept is sometimes referred to as "delivered energy".

[SOURCE: ISO/IEC 13273-1:2015, 3.1.11, modified — Note 2 to entry has been deleted.]

3.14
fuel substitution factor
factor that shows the impact of fuel substitutions between types of energy with very different end-use efficiency on the variation of an energy indicator

3.15
indicator-based savings
energy savings (3.9) calculated by *indicator-based methods* (3.16)

[SOURCE: ISO 17742:2015, 2.28]

3.16
indicator-based method
determination of *energy savings* (3.9) from the variation of energy consumption indicators over a period

[SOURCE: ISO 17742:2015, 2.27, modified — The example has been deleted.]

3.17
specific energy consumption
quotient describing the total energy consumption per unit of output or service

EXAMPLE Gigajoule (GJ) per ton of steel, annual kilowatt-hour (kWh) per square meter (m^2), litres of fuel per 100 kilometre (km).

[SOURCE: ISO/IEC 13273-1:2015, 3.1.15]

3.18
structure effect
structural effect
measure of the variation in energy consumption or in *energy intensity* (3.8) due to a variation in economic structures

Note 1 to entry: Structure effects may refer more generally to any changes in the share of different activities (e.g. industrial branches in total value added of industry, transport modes in total traffic).

Note 2 to entry: “Hidden structure effect” refers to structure effects that exist but cannot be quantified due to a lack of data.

4 Factors to be calculated

4.1 General

4.1.1 Overview of methods included in the document

This clause is an introduction to Clauses 5, 6 and 7 on methods to assess energy intensity and energy efficiency trends and to analyse the energy consumption variation. It describes common issues, such as the different explanatory factors that need to be considered in these assessments (case of energy intensity and energy consumption) or excluded to measure energy efficiency improvements and the various ways to calculate them. This clause clarifies what kind of explanatory factors are covered in this document.

Explanatory factors of changes in energy intensity or in energy consumption and energy efficiency trends are calculated for a given period of time, normally one or more calendar years. The methods make use of statistical data and are normally applied to calculate explanatory factors, such as energy savings or energy efficiency improvements made during the past years. However, if a comparable set of data is available such as projections, e.g. from an energy scenario outlook, the methods can be applied for future years.

This document refers to the so-called “top-down” method of calculating energy savings as reported in ISO 17742 and ISO 17743, based on statistical energy efficiency indicators. The first and third methods analyse observed trends in energy intensity indicators (see Clause 5) and in energy consumption (see Clause 7) through the identification of some of the explanatory factors behind these trends. The second method (see Clause 6) proposes an energy efficiency index that is as far as possible corrected for factors that are not linked to energy efficiency.

4.1.2 Objectives of calculations

The main objective of this document is to help monitor energy efficiency targets, on energy intensity, on energy consumption or on energy efficiency improvements. More generally, this document can help to understand variations observed in energy intensity and energy consumption. It is critical for the analysis presented in this document to be useful that these objects of the analysis be carefully specified to align with the policy questions the analysis will inform. Mis-specifying the analytic objects can undermine the usefulness of the analytic framework presented in this document. For examples, see 4.2.4.

The target on energy intensity reduction used to be the most popular target linked to energy efficiency policy[9], as it is simple to define and to monitor. Separating structure effects can help in understanding the distance to the target and why targets are not reached. However, the scope of energy efficiency target is now broader and includes targets on energy savings, energy consumption and energy efficiency progress.

If targets on total primary or final energy consumption have been formulated, understanding the factors behind the observed variation in the energy consumption is useful each time there is a deviation as compared to the target.

EXAMPLE Annex XIV of Article 24 of the EU Energy Efficiency Directive requires that “in sectors where energy consumption remains stable or is growing, Member States shall analyse the reasons for it and attach their appraisal”.

The methodology proposed in this document can be used to fulfil such a reporting requirement. More generally, it allows evaluating the contribution of energy savings in the variation of energy consumption.

Policymakers often formulate targets for energy efficiency improvements but lack instruments to measure them. Energy efficiency indices help in formulating and monitoring such targets. In general, they provide a quantitative assessment of the magnitude of energy efficiency improvements.

4.1.3 Types of explanatory factors to be calculated

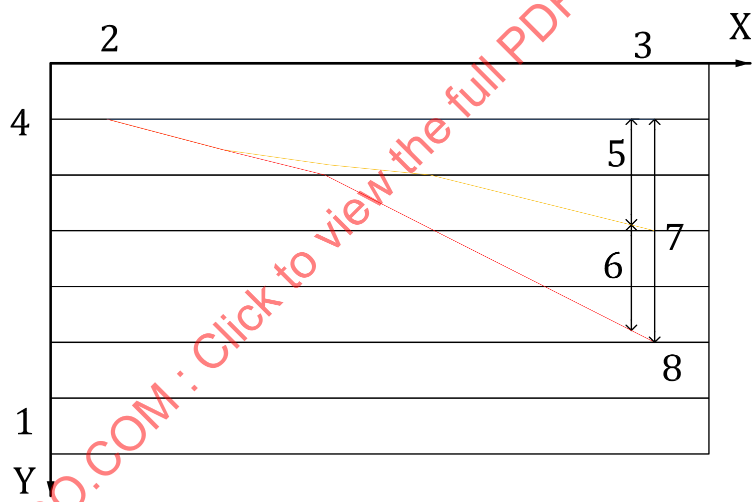
4.1.3.1 General

The three methods have in common to either quantify the effect of structure effects or to remove them as far as possible to assess energy efficiency trends.

4.1.3.2 Energy intensity

Energy intensity trends are influenced by changes in the structure of economic activities (e.g. increase in the share of the service sector in the GDP or of energy intensive branches in industry), as well as by other factors. These other factors include many influences, such as energy efficiency improvements, but also other effects (e.g. modal shift in transport, change in the mix of product/process in industry, changes in ownership of household equipment, climatic changes).

The relationship between energy intensity trends and structure effects is shown in Figure 2. Key 2 represents energy intensity in the base year. If everything is kept constant, the energy intensity will be constant up to the calculation year (Key 3). In reality, the energy intensity has decreased up to the calculation year (Key 8) because of two effects: changes in the structure of economic activities, called the "structure effect" (Key 5), and changes in the energy intensity of subsectors, mainly linked to energy efficiency improvements, called the "energy intensity effect" (Key 6).



Key

X year
Y energy intensity
1 unit of the energy intensity (e.g. MJ/$ at constant price)
2 base year
3 calculation year
4 energy intensity at base year
5 structure effect of the observed energy intensity
6 energy intensity effect
7 observed change in energy intensity
8 observed value of energy intensity at calculation year

Figure 2 — Trends in energy intensity and structure effect

4.1.3.3 Energy consumption variation

Variations in energy consumption result from the effects of three main factors: activity, structure effect and energy savings, and possibly of some less important factors.

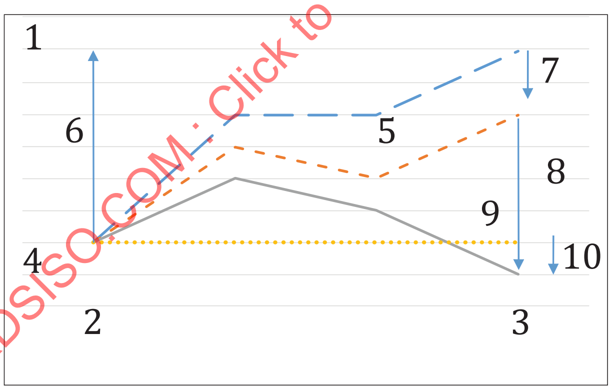
The activity factor corresponds to the impact of variations in socio-economic activities (e.g. number of households, production of industrial branches, equipment ownership, the traffic of goods and passengers) on the energy consumption variation.

The structure effect factor measures the impact of changes in the composition of economic activities at the macro level (i.e. in GDP structure), but also among various energy consuming activities (e.g. share of energy intensive industries, share of branches in the service sector, share of road transport in total freight transport, share of public transport in total passenger transport) on the energy consumption variation.

The energy savings factor measures the impact of decreases in specific consumption at end-use level on energy consumption.

The relationship between energy consumption trends and these three factors is shown in Figure 3. Key 4 represents energy consumption in the base year. If everything is kept constant, the energy consumption will be constant up to the year of calculation (Key 3). However, changes in activities will lead to a variation of energy consumption (uppermost line, Key 5). The increase in consumption for the calculation year from Key 4 to Key 5 is the activity factor (Key 6).

The structure effect is shown by Key 7. However, this structure effect can also raise energy consumption, e.g. through more intensive use of energy using devices (not shown here). Energy savings by definition lower energy consumption (Key 8). Together the three factors define the actual trend for energy consumption (Key 9). Figure 3 shows an increase in energy consumption compared to the base year (Key 10). The actual energy consumption can, however, also decrease, e.g. in the case of a small increase for activities, a mitigating structure effect and large energy savings (right side of Figure 3).



Key

1 energy consumption (unit)
2 base year
3 calculation year
4 energy consumption base year
5 energy trend due to socio-economic activities
6 activity factor
7 structure effect
8 total savings
9 actual energy consumption
10 observed change in energy consumption

Figure 3 — Trends for energy consumption and explanatory factors

4.1.3.4 Energy efficiency indices

Energy efficiency indices are indicators that measure energy efficiency trends. To be relevant, these indicators should be adjusted as much as possible for factors that are not linked to energy efficiency improvements, such as structure effects, but also other factors (e.g. change in equipment ownership, usage or type for households). This is done by calculating these indices at the most disaggregated level as possible to eliminate the most important structure effects.

4.2 Indicators, methods and applications

4.2.1 Indicators

The methods presented in this document rely on energy efficiency indicators that relate energy consumption to a driver, which is a quantity that is assumed to influence the energy consumption under consideration. The change in the indicator value is used to calculate the total energy savings or changes in energy efficiency (see Clause 5 and the examples in Annex B).

At an aggregated level, the indicator usually considered to assess energy efficiency is the energy intensity that relates the energy consumption (in GJ, toe, etc) to the GDP (in Euro, $, Yen, etc). The change in the total energy intensity (e.g. in GJ/monetary unit) does not provide a reliable estimate of energy efficiency improvements or energy savings, as it is influenced by developments at sector or subsector level that can deviate from the GDP trend. Therefore, indicators have to be applied at the level of subsectors or even energy uses, such as space heating in dwellings.

The indicators at the lower aggregation level relate energy consumption to an explanatory factor that is responsible for changes in this consumption. In indicator-based methods, energy savings or energy efficiency trends are calculated from changes in indicator values that are defined against the value in the base year (see ISO 17742).

EXAMPLE If in a country the average annual consumption of refrigerators owned by households has decreased from 500 kWh to 400 kWh between 2000 and 2015, i.e. by 20 % (400/500 – 1 × 100), it is considered that energy efficiency improved by 20 % for refrigerators in that country between 2000 and 2015. If the number of refrigerators is equal to 1,5 million in 2015, the amount of energy saved is equal to 1,5 × 10^6 × 100 kWh or 150 GWh.

This approach, with disaggregation of national energy consumption to a level where meaningful energy efficiency indicators can be defined, is called "top-down". Known applications are the indicators from the EU database Odyssee[7], the IEA indicators[8][18] or other projects and databases (e.g. WEC[9], BIEE for Latin American and Caribbean countries[10], Medener for Mediterranean countries[11] or APERC for APEC economies[18]).

As explained in ISO 17742, changes in indicator value can be due to policy measures, technological trends, high energy prices or other factors. Therefore, the calculated savings or energy efficiency improvements concern total savings or total energy efficiency improvements.

Energy efficiency indicators are generally based on statistical data measured at a disaggregated level, e.g. energy consumption and production in subsectors of industry, or total fuel use of cars and the distance driven by the cars.

4.2.2 Types of data used

The following types of data are used:

a) statistical data;

b) detailed data from surveys or modelling.

Statistical data include final energy consumption by sector as well as macro-economic or sectoral data, such as GDP, the number of households, employment in services, production by industrial sector (value added or physical production). Depending on the geographic entities (country, region or city) not all aggregated statistical data are available: they are generally available at country level but at regional and, above all, at city levels, macro-economic or sectoral data are not usually readily available.

Statistical data also include other less aggregated socio-economic data, such as number of dwellings per type or floor space in offices, and the results of large surveys, such as on kilometres driven by car, size of dwellings or ownership of appliances.

Detailed data from surveys or modelling are often needed for the calculation of additional energy efficiency indicators for specific end-use, for which regular statistical data are not available (e.g. space heating per m^2, litre /100 km for vehicles).

The activity data are first used to calculate the effect of changes in socio-economic activity, as one explanatory factor of the consumption variation, then to calculate the structure effects and, finally, to determine energy efficiency indicators, such as energy intensity (energy consumption per unit of GDP in GJ/Euro) or specific energy consumption (energy consumption per ton of steel, per household, per car, etc.). These indicators are used to decompose the energy consumption into various factors, in particular total savings, and to calculate the energy efficiency indices (see Clause 6).

4.2.3 Structure effects

The energy intensity is generally calculated at a high level of aggregation, generally a sector. Its variation is influenced by the effect of changes in the composition of the economic activity of the sector between the main subsectors, and by other factors, namely energy efficiency as well as all intra-structure effects (e.g. structure effects within each subsector). For example, in chemical industry, a shift between heavy and speciality chemicals is a typical intra-structure effect.

The calculation of energy efficiency indices or the decomposition of energy consumption variation is done at a disaggregated level, which will eliminate some of the structure effects. For example, household indicators can be calculated by end-use (e.g. space heating, hot water use, appliances), each of them with their own driver (e.g. number of dwellings, number of appliances) and are therefore less distorted by structure effects.

However, even at a high disaggregation level, the energy consumption trend can still incorporate the effect of other structure effects that influence the calculation of savings. For example, average energy consumption per dwelling can be influenced by changes in the type of dwellings or the occupancy rate, and by replacement of room heating by central heating. For energy-intensive industries, energy consumption per ton of output can be influenced by the capacity utilization rate. In transport, the consumption per car can be influenced by change in the size of cars, etc.

Therefore, indicators at a lower level of disaggregation can also be corrected for factors that hide energy savings or energy efficiency progress to improve the assessment. For example, energy use for space heating may be corrected for the shift from room heating to central heating, which will lead to extra energy consumption and, possibly, negative energy savings or lower apparent energy efficiency improvement.

Due to restricted data availability it is not always possible to quantify all structure effects. The structure effects that cannot be quantified are often called “hidden structure effects” (see ISO 17742).

4.2.4 Indicator choice for energy efficiency and energy savings calculation

The choice of indicators defines what is included in energy savings or energy efficiency. What is not included in energy savings or energy efficiency is then included in the other factors (activity or structure effects).

For example, for automotive energy efficiency, a choice can be made between three alternative indicators (see B.4.2 for more details):

— fuel consumption per person-km by car;

— fuel consumption per km driven by car;

— annual fuel consumption per car.

The average number of persons per car influences the value of the first indicator. The effect of policy measures aiming at increasing the load factor, such as car-pooling or modal split, is included in the energy savings or energy efficiency improvements, calculated with this first indicator. With the second indicator it is not included. With the third indicator, the savings or efficiency gains due to the reduction in car use (i.e. less km/year) become part of the energy savings or energy efficiency improvements instead of being reported in the activity factor.

To emphasize the importance of choosing appropriate indices, if instead the focus of analysis is on limiting car use (e.g. through a modal shift, encouraging the use of bicycles or public transport), a more appropriate indicator could be fuel use per person-km over all modes of transport (see C.3.2 on modal shift).

In the calculation of explanatory factors or energy efficiency indices, some alternative indicators are proposed to be used (see Annexes B and C). However, the user can adapt the method of calculation by deciding which type of indicator best fits his/her definition of energy savings and energy efficiency. Depending on these choices, corrections have to be made for factors that are considered structure effects in that specific case. If the focus is on the evaluation of the impact of policies, then the choice of indicators can be of importance.

In some cases, the choice of alternative indicators not only depends on the focus and the preferred scope for energy savings but also on data availability. For example, for countries without separate data on space heating, an alternative indicator could be used, e.g. consumption of all non-electric energy per dwelling. The use of alternative indicators is justified by the fact that it enables each country to use at least one indicator to assess the energy savings for a given end-use. There is a trade-off with the accurateness of the calculated savings. Annexes B and C discuss the various options possible for the selection of indicators.

4.2.5 Climatic corrections of energy consumption

For the interpretation of variation in the energy intensity, the calculation of an energy efficiency index or the decomposition of the energy consumption, the indicators used should be adjusted for variations of weather conditions that influence energy consumption. In other words, they should be calculated with climatic corrections (also called "climatic adjustment"). The correction should be done on the space heating and space cooling part of the consumption that is affected by these climatic variations. Climatic corrections are necessary for sectors that consume significant amount of energy for heating or cooling (e.g. mainly residential and service sectors) and for countries with strong weather variations from one year to the other. Once corrected, the energy consumption is measured at reference conditions (also called "at normal climate"). There are several approaches for climate corrections (see Annex D for the commonly used method).

For the decomposition of the variation in energy consumption, the calculation is usually made on the actual consumption. However, all the factors, in particular energy savings, should be calculated at reference conditions (i.e. at normal climate) and the influence of weather can be included as one explanatory factor.

5 Evaluation of structure effects in the variation of energy intensity

5.1 General

The value added of industry is one way to measure its activity: this value added is the sum of the value added of different industry subsectors (also called industrial branches). Each of the industry subsectors can be characterized by its energy intensity, i.e. the ratio energy consumption per unit of value added. Depending on the subsector, the energy intensity can vary significantly. For example, at EU level the subsector "primary metals" has an energy intensity 30 times higher than the subsector "equipment" (i.e. machinery, fabricated metals and transport equipment).

If the value added of machinery is growing faster than the average of industry while the value added of primary metals is growing slower, this will lead to an increase of the share of machinery and a decrease of the share of primary metals in the total value added of industry; this is what is commonly called a "structure effect". Because of the large differences in the energy intensity of these two branches, this structure effect will result in a reduction of the energy intensity of industry, all things being equal.

The method presented in this clause explains how to measure the impact of structural changes in the variation of the energy intensity of a given sector.

5.2 Calculation methods

5.2.1 Introduction to the calculation of structure effect

The energy intensity value of a sector (e.g. industry, services, all final consumers) relates the energy consumption of the sector to a monetary indicator of activity (e.g. value added for industry or services, GDP for final consumption), as shown in Formula (1):

$$e_t = \frac{E_t}{Y_t} \tag{1}$$

where

e is the energy intensity value of the sector;

E is the energy consumption of the sector;

Y is the monetary indicator of activity of the sector, measured at a constant price (e.g. value added);

t is the year of calculation.

The energy consumption can be expressed in various energy units, such as Joule, kWh, tonnes of oil equivalent (toe), or Btu. In line with ISO standardization, these figures should as far as possible be converted into Joule, the SI unit for energy consumption, or its multiple (MJ, GJ or PJ). Unit multiples should be chosen to reflect the accuracy of the calculation (e.g. 59,5 GJ/t rather than 59,500,000 kJ/t).

The monetary indicator should be measured at constant prices as defined in the macroeconomic statistics to represent changes in volume (i.e. by removing the effect of inflation), e.g. € 2 005, $ 2 005 or in national currency at constant prices.

The energy intensity, as defined in Formula (1), can also be written as shown in Formula (2) to show two components:

— the contribution of subsectors in the activity of the sector (structure component);

— the energy intensity of subsectors (energy intensity component).

$$e_t = \sum_i \frac{Y_{i,t}}{Y_t} \times \frac{E_{i,t}}{Y_{i,t}} \tag{2}$$

where

e is the energy intensity value of the sector (e.g. industry);

i is the subsector;

Y_i is the monetary indicator of activity of subsector i (e.g. value added);

Y is the monetary indicator of activity of the sector (e.g. value added of industry);

E_i is the energy consumption of subsector *i* (industrial branch, economic sector);

Y_i/Y is the ratio of the activity of subsector *i* in the activity of the sector = R_i (structure component);

E_i/Y_i is the energy intensity value of subsector $i = e_i$ (energy intensity component);

The most common method to measure the impact of structural changes in the variation of the energy intensity of a given sector is the Divisia method, which is described below and in 5.2.2[11].

Annex A (see A.1) presents another approach that is simpler to understand and to implement but for which the results are dependent on the choice of the base year. The Divisia method is recommended in this document, as it avoids this shortfall by using a moving reference year. The calculation shown in Annex A also indicates the definition of the activity indicators to be used for the different subsectors in the case of a calculation for the final energy intensity (e.g. industry, transport, households, services, agriculture) for the assessment of the structure effects for the final energy intensity.

Specific issues related to the calculation of structure effects are described in 5.3.

5.2.2 Decomposition of the energy intensity variation with the Divisia method

The Divisia method is a well-known method of decomposition, which was initially used for calculating price indices. Its scope has been adapted to the decomposition of energy intensity by decomposing its annual growth rate variation, $G_{\text{ar,tot}}$, into two components)[12]:

— a structure effect ($G_{\text{ar,str}}$) measuring the annual variation of the energy intensity of the sector due to changes in R_i (the ratio of the activity of each subsector *i* in the total activity of the sector), see Formula (3);

— an intensity effect ($G_{\text{ar,int}}$) measuring the annual variation of the energy intensity of the sector due to changes in the energy intensity of each subsector *i* (e_i), see Formula (4):

$$G_{\text{ar,str}} = \left[\sum_i w_{i,t} \ln\left(\frac{R_{i,t}}{R_{i,t-1}} \right) \right] \tag{3}$$

$$G_{\text{ar,int}} = \left[\sum_i w_{i,t} \ln\left(\frac{e_{i,t}}{e_{i,t-1}} \right) \right] \tag{4}$$

$$G_{\text{ar,tot}} = G_{\text{ar,str}} + G_{\text{ar,int}}$$

where

$G_{\text{ar,str}}$ is the annual growth rate structure effect;

$G_{\text{ar,int}}$ is the annual growth rate intensity effect;

$G_{\text{ar,tot}}$ is the annual growth rate variation;

$w_{i,t}$ is the weighting of subsector *i* at year *t*, measured as the share of subsector *i* in the energy consumption of the whole sector at year *t*; there are different alternatives to calculate w_i that are explained in 5.3.1;

$R_i = Y_i/Y$ is the ratio of the activity of subsector *i* activity in the activity of the sector;

$e_i = \frac{E_i}{Y_i}$ is the energy intensity value of subsector *i*.

To decompose the variation over a period from the base year 0 to the final year T, the annual growth rates in Formulae (3) and (4) have to be summed up over the period from 0 to T, as shown in Formulae (5) and (6):

$$G_{\text{ar,str }0,T} = \sum_{0}^{T} G_{\text{ar,str}} \tag{5}$$

$$G_{\text{ar,int }0,T} = \sum_{0}^{T} G_{\text{ar,int}} \tag{6}$$

where

$G_{\text{ar,str}}$ is the annual growth rate structure effect;

$G_{\text{ar,int}}$ is the annual growth rate intensity effect;

0 is the base year;

T is the final year.

Formulae (5) and (6) can be written in such a way that the decomposition is done on the index of variation and not on the annual growth rate, as shown in Formulae (7) and (8):

$$V_{\text{str}} = \exp\left[\sum_{0}^{T}\sum_{i} w_{i,t} \ln\left(\frac{R_{i,t}}{R_{i,t-1}}\right)\right] \tag{7}$$

$$V_{\text{int}} = \exp\left[\sum_{0}^{T}\sum_{i} w_{i,t} \ln\left(\frac{e_{i,t}}{e_{i,t-1}}\right)\right] \tag{8}$$

$$V_{\text{tot}} = V_{\text{str}} \times V_{\text{int}} / 100$$

where

V_{str} is the index of variation of the energy intensity of the sector due to changes in the ratio of the activity of subsector i in the activity of the sector (R_i);

V_{int} is the index of variation of the energy intensity of the sector due to changes in the energy intensity of subsector i, (e_i);

V_{tot} is the index of variation of the energy intensity of the sector between 0 and T;

0 is the base year;

T is the final year;

$w_{i,t}$, R_i, e_i are defined in Formulae (3) and (4).

5.3 Calculation issues related to structure effects

5.3.1 General

Three main issues related to the calculation of the structure effects are discussed below:

— the different options of calculation of the Divisia method (see 5.3.2);

— the level of disaggregation (see 5.3.3);

— the calculation over a period with a chained or unchained calculation (see 5.3.4).

5.3.2 Options of calculation of the Divisia decomposition

There are different versions of the Divisia method, depending on how to define the weighting of the different subsectors and whether the decomposition is done in an additive or multiplicative form. The two main methods of Divisia decomposition are:

— the arithmetic mean Divisia index (AMDI) method;

— the logarithmic mean Divisia index (LMDI) method, the most common of which is referred to as "LMDI1".

The AMDI is the simplest approach to implement as the weighting of subsector i at year t is the average weighting of year t and t–1 and is defined as indicated in Formula (9) (case of the multiplicative form):

$$w_{i,t} = \frac{\left(E_{i,t}/E_t + E_{i,t-1}/E_{t-1}\right)}{2} \quad (9)$$

where

$E_{i,t}$ is the energy consumption of subsector i at year t;

$E_{i,t-1}$ is the energy consumption of subsector i at year t–1;

E_t is the total energy consumption at year t (sum of subsectors i);

E is the energy consumption of the sector.

With LMDI1, the weighting w_i used in Formulae (2) and (3) is defined as indicated in Formula (10):

$$w_{i,t} = \frac{L\left(\frac{E_{i,t}}{Y_t}, \frac{E_{i,t-1}}{Y_{t-1}}\right)}{L\left(\frac{E_t}{Y_t}, \frac{E_{t-1}}{Y_{t-1}}\right)} \quad (10)$$

where

$E_{i,t}$ is the energy consumption of subsector i at year t;

$E_{i,t-1}$ is the energy consumption of subsector i at year t–1;

E_t is the total energy consumption at year t (sum of subsectors i);

Y_t is the monetary indicator of activity of the sector at year t;

Y_{t-1} is the monetary indicator of activity of the sector at year t–1;

$L(a,b) = \frac{a-b}{\ln(a)-\ln(b)}$ is the logarithmic mean proposed by Sato[17].

LMDI1 gives a perfect decomposition while with AMDI there is still a minor residual. In addition, LMDI1 handles values equal to zero in the data set. For that reason, LMDI1 is the preferred decomposition method.

These two methods can be applied in an additive or multiplicative form. In an additive form, the decomposition is done on the absolute value of the intensity, whereas in the multiplicative form the decomposition is done on the index of variation. For the decomposition of the energy intensity, the multiplicative approach is more common as the objective is to analyse a trend and not the change in the absolute value of the intensity. Annex A gives an example of a calculation with AMDI and LMDI1 with the multiplicative form.

5.3.3 Disaggregation level

Apart from the method of decomposition used, the results of the calculation also depend on the disaggregation level, especially for energy intensive subsectors. The issue is not necessarily to work at a very high level of disaggregation but to make sure that the most important branches in terms of energy consumption are well disaggregated (e.g. in the case of chemicals in industry).

Therefore, when presenting the results, it is important to specify, for industry, at which level of disaggregation the structure effect has been calculated (i.e. 10 or 20 branches) and, for the final energy intensity, if the structure effects include or do not include structural changes within industry.

5.3.4 Chained or unchained calculation

In the Divisia method, the calculation is done annually and the total decomposition for a period is obtained by summing up the yearly variations. This is called a “chained calculation”. Its main advantage is to provide the yearly decomposition over a period.

It is always possible to do the same calculation directly over the period by only taking into account the variation between the base year 0 and the final year *T*. This way of calculating is called the “unchained calculation”. The unchained calculation is less precise and has a higher residue, however, the differences between the chained and unchained calculation are usually not so significant and depend on the exact version of the Divisia method (no difference with LMDI).

The main disadvantage of the unchained calculation is that it does not provide for the intermediate calculation. On the other hand, if the necessary data are only available for two years, only a calculation over a period can be done. Therefore, the choice between the two calculations depends on the objective of the decomposition and on the data availability.

6 Calculation of energy efficiency indices

6.1 Objective and overview of calculation

Energy efficiency is usually calculated by subsector or energy use from the reduction in specific energy consumption (see 4.2.1). In the household sector, there are various energy uses, such as space heating, cooling, water heating and cooking, with different energy efficiency trends. The objective of developing an energy efficiency index (I_{EE}) at sector level is to summarize all these trends by end-use in a single energy efficiency index[15]. Energy efficiency indices can be defined at the level of all sectors (industry, transport, households, services and agriculture) and at the level of the whole economy (i.e. all final consumers). Beyond measuring the rate of energy efficiency improvements, this index can also be used to calculate energy savings which will be one of the components measured in the decomposition analysis of consumption variation.

For each sector, the index is calculated as a weighted average of sub-sectoral indices of energy efficiency progress. Subsectors are industrial or service sector branches, energy uses for households, or transport modes.

— The sub-sectoral indices are calculated from variations of specific energy consumption indicators, measured in physical units and selected so as to provide the best proxy of energy efficiency progress, from a policy evaluation viewpoint. The fact that indices are used enables different units to be combined for a given sector, e.g. for households: kWh/appliance, MJ/m^2, GJ/dwelling, or in transport: MJ/pkm, litres/100 km.

— The weighting used to get the composite index is the share of each subsector in the total energy consumption of the sector considered in the calculation.

An energy efficiency index equal to 90 means a 10 % energy efficiency gain from the base year.

Energy efficiency indices represent a better proxy for assessing energy efficiency trends at an aggregate level (e.g. overall economy, industry, transport, households, services and agriculture) than energy intensity, as they rely on physical indicators and exclude the main structure effects.

Energy efficiency indices for a sector or subsector can be useful. However, users should be aware that improvement in an index may not indicate an overall improvement. Users can check if the factors leading to the improvement in one sector's index do not have offsetting or other effects in other sectors.

6.2 General calculation

6.2.1 General

This clause describes the steps to calculate the energy efficiency index. Data collection and parameters are considered in Annex B.

The calculation steps are as follows:

— Step 1: selection of subsectors or energy uses to be included in the index (see 6.2.2);

— Step 2: choice of indicators (see 6.2.3);

— Step 3: calculation of indicator values (see 6.2.4);

— Step 4: calculation of indicator trends (see 6.2.5);

— Step 5: calculation of weighting factors (see 6.2.6);

— Step 6: calculation of energy efficiency indices by sector (see 6.2.7);

— Step 7: calculation of overall energy efficiency index (see 6.2.8).

Other issues related to the calculation of the energy efficiency indices are described in 6.3.

6.2.2 Step 1: Selection of subsectors or energy uses

For each sector (i.e. industry, transport, households, services, agriculture), a list of subsectors should be identified for which energy efficiency is to be calculated. Subsectors can be energy uses, such as space heating (in the case of households), modes of transport (in the case of transport), industrial branches (in the case of industry and services, and possibly agriculture). Annex B proposes a typical breakdown that can be considered in the different sectors.

6.2.3 Step 2: Choice of indicators

For each subsector or energy using system, energy efficiency improvement is measured from the reduction in specific consumption. Two types of indicators of specific consumption can be used (referred to as type A or B in ISO 17742) that are defined per year:

— specific energy consumption at subsector level relates energy consumption to physical quantities over a year, such as production, production index (or value added at constant price if production index is not available), traffic (e.g. GJ/tonne of steel for the iron and steel sector, or MJ/ton-km for the transport of goods): indicator type A;

— specific energy consumption for energy using systems relates the annual energy consumption for specific systems to the average number or size of systems over a year (e.g. GJ/dwelling, kWh/refrigerator or litre per car or GJ/m^2 of building floor space): indicator type B.

To calculate the indicators, the energy consumption per subsector or targeted end-use is related to a driver that depends on the type of indicator.

All the necessary definitions of each type of indicator are given in Annex B for the different sectors (industry, transport, households, services and agriculture).

6.2.4 Step 3: Calculation of indicator values

Indicators of specific energy consumption are calculated at the level of detailed subsector according to Formula (11), where the energy consumption is divided by the driver indicator of activity of the sector for the year t:

$$u_{i,t} = \frac{E_{i,t}}{A_{i,t}} \tag{11}$$

where

- u_i is the indicator value for subsector i;
- E_i is the energy consumption of subsector i; it should be weather adjusted (normalized) for indicators related to space heating and space cooling;
- A_i is the indicator of activity of subsector i;
- t is the year of calculation.

6.2.5 Step 4: Calculation of indicator trends as index

The indicators of specific energy consumption are expressed in different units so as to always select the best proxy of energy efficiency. As the energy efficiency progress can be measured in different physical units (e.g. kWh/appliance, toe/m^2), they need to be converted into an index to be aggregated, as shown in Formula (12). The base year is usually the first year for which the index is calculated (e.g. 2000).

$$I_{s,i,t} = \frac{u_{i,t}}{u_{i,0}} \times 100 \tag{12}$$

where

- $I_{s,i,t}$ is the index of indicator of subsector i at year t;
- $u_{i,t}$, $u_{i,0}$ is the indicator value of subsector i at year t or 0;
- t is the year of calculation;
- 0 is the base year.

6.2.6 Step 5: Calculation of weighting factors

The index for a sector (e.g. industry, transport, households) is calculated as a weighted average of the specific consumption index of each subsector or end-use, as calculated in the previous step with a weighting based on the relative consumption of each subsector shown in Formula (13):

$$w_{i,t} = \frac{E_{i,t}}{E_t} \tag{13}$$

where

i is the subsector;

$w_{i,t}$ is the weighting of subsector i at year t;

E_i is the energy consumption of subsector i (weather adjusted for heating or space cooling);

E is the energy consumption of the sector (weather adjusted for households and services);

t is the year of calculation.

EXAMPLE Considering two subsectors with a share of the consumption of 60 % and 40 %, respectively, in the base year and a change in the unit consumption from 100 to 85 for the first subsector and 100 to 97,5 for the second, the weighted average index is 0,6 × (85/100) + 0,4 × (97,5/100) = 90.

6.2.7 Step 6: Calculation of energy efficiency indices by sector

The energy efficiency index of a sector I_{EE} (i.e. industry, transport, households, services or agriculture) is calculated by weighting the indices of variation of each indicator by subsector. The mode of calculation of this weighted index has been carefully defined so as to enable a calculation of energy savings from the I_{EE} variation in a way that is totally equivalent to the calculation, based on the variation of specific consumption in top-down methods as described in ISO 17742.

The calculation is made by year instead of having a fixed base year, i.e. as a chained calculation. The formula used to define the variation of the weighted I_{EE} between t–1 and t is given in Formula (14):

$$\frac{I_{EE,t-1}}{I_{EE,t}} = \sum_i w_{i,t} \times \left(\frac{I_{s,i,t}}{I_{s,i,t-1}} \right) \quad (14)$$

where

I_{EE} is the energy efficiency index of the sector;

$I_{s,i}$ is the index of indicator of subsector i;

i is the subsector;

$w_{i,t}$ is the weighting of subsector i at year t (i.e. share of the subsector i in energy consumption of the sector);

t is the year of calculation;

t–1 is the year before the year of calculation.

The value of the energy efficiency index at year t is then derived from the value at the previous year by reversing the calculation, as shown in Formula (15):

$$\frac{I_{EE,t}}{I_{EE,t-1}} = \frac{1}{I_{EE,t-1} / I_{EE,t}} \quad (15)$$

The index can then be set at 100 for a reference year and successive values are then derived for each year t by the value of the energy efficiency index at year t–1 multiplied by $I_{EE,t} / I_{EE,t-1}$:

$$I_{EE,100_0} = 100$$

$$I_{EE,100_t} = I_{EE,100_{t-1}} \times \frac{I_{EE,t}}{I_{EE,t-1}}$$

where

$I_{EE,100}$ is the energy efficiency index expressed in base 100;

0 is the base year;

t is the year of calculation.

6.2.8 Step 7: Calculation of an overall energy efficiency index

The energy efficiency index for all final energy sectors is calculated as a weighted average of the energy efficiency indices of the five end-use sectors: industry, transport, households, services and agriculture, using Formula (15). The weighting is the proportion of the energy consumption of each of these sectors in the final energy consumption for energy uses.

6.3 Computational issues in the calculation of the energy efficiency indices

6.3.1 General

Two main computational issues are linked to the calculation of the energy efficiency indices:

— options for calculations;

— accounting for negative energy efficiency trends.

6.3.2 Options for calculation

6.3.2.1 Base year versus previous year

Two alternative reference years can be used to measure the energy efficiency progress at year t: a fixed base year or a moving reference year (year t–1).

The calculation used in Formula (15) is based on a moving base year, which means that energy efficiency gains are measured in relation to the previous year. Therefore, I_{EE} cumulates the incremental energy efficiency improvements from one year to the other.

In the fixed base year approach, all variations in unit consumption are measured in relation to a fixed base year. In other words, energy efficiency progress is measured compared to the situation of that base year (i.e. the energy performance of that year). The variation of the index is obtained by weighting the gains of each sector between the base year 0 and t. The drawback of the fixed base year approach is that the results are influenced by the situation in the reference year.

6.3.2.2 Smoothed indicator values

Annual indicator values sometimes show large fluctuations. Such fluctuations can be linked to various factors, e.g. imperfect climatic corrections (especially with warm winters), behavioural factors, the influence of business cycles and the imperfection of statistics (especially for the last year of calculation as data are often provisional and can be later revised).

Such fluctuations reflected in the energy efficiency indices are difficult to understand as energy efficiency progress should normally change smoothly (incremental technical change).

To reduce the fluctuations, it is recommended to calculate I_{EE} as a three-years-moving average. The value used for year t is the average of t–1, t and t+1. This method is traditionally used in statistics. When publishing results for the index, it should be clarified if the energy efficiency index is calculated as a moving average value.

NOTE 1 The method traditionally used in statistics to calculate the three-years-moving average is to take for year t the average of t–1, t and t+1. However, for the last year, the average can only be based on two years (t and t–1). Using years t–2, t–1 and t, as used officially in the Netherlands, would avoid this simplification for the last year, but it, however, always underestimates the gains achieved.

NOTE 2 Weighted values can be used to give greater emphasis on more recent data, e.g. using $[3It + 2I(t-1) + I(t-2)]/6$ for the index I over the most recent and two preceding time periods. This approach can be used, for example, when it is known that there is a rapid uptake of a new technology in recent years.

6.3.3 Indicators resulting in negative energy efficiency improvement

A decrease in the specific energy consumption indicators indicates that energy efficiency has been improving. However, in some cases, the observed indicator trend shows an increase, resulting in negative energy efficiency improvement.

This increase in the specific consumption can be due to an inefficient use of the equipment, as is often observed during economic recessions. This is particularly true in industry or transport of goods. For example, in industry in a period of recession, the energy consumption does not decrease proportionally to the activity as the efficiency of most the equipment drops, as they are not used to their full capacity, and, in addition, part of this consumption is independent of the production level. In that case, the technical energy efficiency does not decrease as such, as the equipment is still the same, but it is used less efficiently. It is therefore suggested to separate the technical energy efficiency improvement from the observed (or apparent) energy efficiency improvement. The apparent energy efficiency index can be replaced by a technical energy efficiency index, by considering that, if the specific consumption for a given subsector increases, its value will be kept constant in the calculation of the technical index.

The increase in specific consumption can also be due to an insufficient level of disaggregation, thereby mixing real savings with structure effects. If it is not possible to correct for these structure effects, it should be clearly stated that no energy efficiency progress has been calculated due to these hidden structure effects. This is often the case for electrical appliances in buildings.

When publishing the results of the index, it should be clarified if it measures the apparent or technical energy efficiency improvement and what energy uses could have been removed for the calculation because of hidden structural changes.

6.4 Reliability of energy efficiency indices

6.4.1 General

In order to calculate energy efficiency as the ratio between an input of energy and an output, both need to be clearly defined and be measurable. The quality of the calculated figures can be rated by determining the uncertainty margin for the resulting figures, as done in Reference [13]. In that study, a margin for the indicator value is calculated through a standard formula that combines the error margins in the energy and activity data, used to calculate the indicator value. The margin for the change in the indicator value is determined through another standard formula that converts the margins in two indicator values into a margin for the difference.

However, this analysis is rarely done due to the complexity of the procedure. Therefore, this document does not provide guidelines for a quantitative rating of the quality of the energy efficiency index.

A preferred practice would be to rate the quality of the energy efficiency index, based on its calculation method. According to Reference [16], the following factors define the quality of results:

— the status of data sources (see 6.4.2);

— the relevance of the selected indicators (see 6.4.3);

— the length of period for which energy efficiency is calculated (see 6.4.4).

Therefore, an assessment of the quality of the energy efficiency indices should incorporate a full description of data sources, each with a quality assessment, the rationale for the indicators used, and the length of the period.

It should be noted that as the energy efficiency index is calculated at the level of sectors from various indicators, the margin of error for the index is lower than that for the separate indicators: the positive and negative errors in the index calculation from individual indicators will compensate each other, provided that the indicator changes are independent of each other.

6.4.2 Status of data sources

The status of data sources can be divided into official statistical data, data based on comprehensive surveys, and data from small surveys and expert estimates. However, official data are not always more reliable than surveys conducted by other organizations. Important factors to be taken into account in evaluating the data quality are the following.

— How comprehensive are the data sets?

— If based on a statistical sample, is the sample representative of the whole country?

— What are the confidence levels for the statistics?

— How consistent is the collection or definition of statistical data over time? Have there been disruptions or changes in methods or definition?

— How consistent are the series values over time? Do they contain unexplained values?

All data should be retained for documentation purposes and the sources of all data documented in any reports.

6.4.3 Appropriateness of the indicator

The appropriateness of the indicator defines whether a change in indicator value represents energy efficiency.

NOTE The user has to consider carefully what indicators best characterize energy efficiency because the choice is often determined by the chosen definition of energy service level and/or by the choice of system boundaries.

Often the change is influenced by hidden structure effects (see 4.2.3). However, these structure effects may either be signals of energy efficiency or noise in the measurement, depending on the definition of efficiency. The higher these hidden structure effects (or the greater the extent of disagreement or uncertainty over whether the structure effects are signal or noise), the less accurate is the calculation of energy efficiency improvements. Therefore, the users of this method may perform an analysis of possible hidden structure effects for each indicator[14]. However, even if they can be identified in a qualitative way, the data needed to quantify them are often missing.

6.4.4 Length of period

The value of the energy efficiency index for one year is relatively unreliable because its change compared to the previous year is often in its range of uncertainty margin (e.g. around 0,5 % to 1 %). However, for a period of 10 years, the energy efficiency index value will be higher, while the uncertainty margin is still about the same, thus leading to a higher reliability.

7 Decomposition analysis of energy consumption variation

7.1 Objective and overview of calculation

The main objective of the decomposition analysis of the energy consumption is to show the various types of explanatory factors that explain the energy consumption variation over a given period.

In particular, it shows the relative contribution of the two main factors on the energy consumption changes: an activity factor and an energy savings factor. "Energy savings" refers to the consumption reduction coming from efficiency improvements at the level of the different subsectors and energy uses.

A third factor, a structure factor, will be considered in several sectors, but its definition will be sector specific. In industry and services, it corresponds to the changes in the contribution of each subsector in the total activity of the sector. In transport, it corresponds to modal shift. In the power sector, it corresponds to changes in the power mix.

Finally, for households, specific factors explaining the consumption variation can be measured, such as living standards and behavioural factors, or a fuel substitution factor.

The method can be applied at the level of the different end-use sectors (industry, transport, households, services and agriculture), at the level of the total final energy consumption, and finally at the level of the primary energy consumption. In each case, what will change are the different explanatory factors.

7.2 General calculation

7.2.1 General

This subclause describes the calculation steps of the decomposition. Data collection and parameters are considered in Annex C.

The calculation steps are as follows:

— Step 1: definition of explanatory factors (see 7.2.2);

— Step 2: calculation of the activity factor (see 7.2.3);

— Step 3: calculation of the energy savings factor (see 7.2.4);

— Step 4: calculation of structure effects (see 7.2.5);

— Step 5: calculation of other factors (see 7.2.6).

Other issues related to the calculation of the decomposition of energy consumption variations are described in 7.3.

7.2.2 Definition of explanatory factors

The main objective of the decomposition analysis of energy consumption variation is to show the relative contribution of different explanatory factors. All factors, as well as the energy consumption variation, are expressed in energy units (i.e. multiple of Joule, toe or kWh).

The first factor is the activity factor. It assesses the impact on the energy consumption variation of changes in the economic activity. For households, it measures the impact of demography, and in transport the effect of traffic variation. In periods of high economic growth (or of economic recession), this factor is usually the most important one to explain the growth (or decrease) in energy consumption.

The second factor is the energy savings factor coming from efficiency improvements at the level of the different subsectors and energy uses. The energy savings factor is negative as it contributes to a decrease in energy consumption.

The third factor to be considered is that, within each sector, the variation in activity is not the same for all subsectors, which leads to structural changes that can impact consumption. This third factor, called the "structure effect", will be especially important if the structure changes between subsectors with a very different specific consumption (e.g. between cars and public transport for passenger transport, between steel and equipment in industry). These structure effects can be calculated in industry, transport, services and in the power sector. For households, as explained above, there are also some structure changes, for which, however, the quantification needs data that are not commonly available.

NOTE 1 A change in the power mix between renewables, nuclear or thermal energy can also be considered as a structure effect. Indeed, according to the international accounting rules in the energy balance (e.g. IEA, UN), the primary energy consumption per kWh of electricity produced is quite different between renewables and nuclear (0,086 toe/1 000 kWh for renewables, 0,26 toe/1 000 kWh for nuclear, and between 0,15 and 0,25 toe/1 000 kWh for thermal).

Depending on the sector and/or level of disaggregation, other types of explanatory factors can be considered that are sector specific. Examples of other factors for households are: living standard factor, behavioural factors, fuel substitution factor or climate factor.

The living standard factor will reflect the fact that households have more equipment (e.g. refrigerators, air conditioners) or larger dwellings. The behavioural factor will reflect the impact on energy consumption of changes in the level of thermal comfort (higher or lower use of heating or air-cooling equipment). The fuel substitution factor shows the impact of fuel substitutions between types of energy with very different end-use efficiency. This factor is particularly important in developing countries with the substitution for cooking of traditional fuels (e.g. wood, wastes) with modern fuels [e.g. liquefied petroleum gas (LPG), kerosene, electricity]. Finally, the climate factor reflects the fact that the average temperature for heating or cooling was different between the two years of calculations. This last factor is also relevant in services.

NOTE 2 If the decomposition of energy consumption is done with the energy consumption data adjusted for climate difference, the climate factor does not exist.

7.2.3 Calculation of the activity factor

The activity factor captures the effect of changes in the activity of the sector. For each sector considered (e.g. industry, households, transport, services and agriculture), an indicator of activity should be selected reflecting the whole activity of the sector. It can be an indicator of economic activity (e.g. value added or index of production in industry and agriculture, value added or number of employees in services, traffic for passenger and goods in transport, power generation for the power sector) or an indicator of demographic activity (e.g. number of dwellings and/or appliances for households).

The activity factor of a sector F_a between t and t–1 is calculated by multiplying the variation of the driver quantity between t–1 and t by the indicator value for the sector of the previous year (t–1), as shown in Formula (16). The indicator value of the sector is defined as the ratio between the energy consumption of the sector and the activity indicator of the sector.

$$F_a = \left(A_t - A_{t-1}\right) \times u_{t-1} \tag{16}$$

where

F_a is the activity factor of a sector, in energy units (i.e. multiple of Joule, toe or kWh);

A is the indicator of activity of the sector;

t is the year of calculation;

t–1 is the year before the year of calculation;

u is the indicator value of the sector, see Formula (17):

$$u_t = \frac{E_t}{A_t} \qquad (17)$$

where E is the energy consumption of the sector.

NOTE 1 t–1 can be replaced by a base year 0 if the calculation is done between the base year and the year of calculation.

NOTE 2 An activity factor can also be calculated in the same way at the level of a subsector or energy use. The total activity factor can then be calculated as the sum of the activity factors by subsector or end-use. In that case, no structure effect can be calculated as it is included in the total activity factor. In addition, a different indicator of activity can be used for each subsector or end-use (e.g. physical production and value added in industry depending on the industrial branch).

Examples of calculation of activity factor by sector are given in Annex C.

7.2.4 Calculation of the energy savings factor

For the energy use sectors, the energy savings (S) factor is calculated as the sum of energy savings calculated at the level of detailed subsectors or energy uses, as shown in Formula (18):

$$S_j = \sum_i S_{ij} \qquad (18)$$

where

S_j is the energy savings of sector j, in energy units;

S_{ij} is the energy savings of subsector i within sector j.

The energy savings by subsector are obtained by multiplying the variation in specific energy consumption by an indicator of activity, as described in ISO 17742.

EXAMPLE Energy savings for refrigerators are equal to the variation in kWh per refrigerator multiplied by the number of refrigerators.

For the power sector, energy savings are derived from the improvement in the efficiency of thermal power generation.

NOTE 1 In the power sector, most of the savings come from a change in the power mix due to accounting rules used in the energy balance statistics. Therefore, it is more relevant to separate this power mix effect and not to include it with the energy savings coming from energy efficiency improvements in thermal generation.

NOTE 2 The energy saving factors by sector can also be calculated directly from the sector's energy efficiency index, as shown in Formula (19), taking into account that the energy efficiency index introduced in Clause 6 is also equal to the ratio between the energy consumption (E) at year t and a theoretical consumption that would have happened without energy savings (S).

$$S_j = E_j \times \left(\left(\frac{I_{\mathrm{EE},j,t-1}}{I_{\mathrm{EE},j,t}} \right) - 1 \right) \qquad (19)$$

where

S_j is the energy savings of sector j;

E_j is the energy consumption of sector j;

$I_{\mathrm{EE},j}$ is the energy efficiency index of sector j;

j is the sector name, i.e. industry, transport, households, services or agriculture.

The weighting method of the energy efficiency indices I_{EE} has been defined in such a way that the calculation of energy savings from I_{EE} is strictly equal to the sum of energy savings by energy use.

7.2.5 Calculation of structure effects

Structure effects can be calculated in the industry sector, in services and in transport. In industry and services, they correspond to the fact that all subsectors do not grow at the same rate as the average of the sector. In transport, structure effects correspond to changes in the share of transport mode in the total traffic of passenger and goods (i.e. modal shift).

The structure effect is calculated as the difference between the total activity factor minus the sum of activity factors by subsector, as shown in Formula (20):

$$F_{ST} = F_a - \sum \left(A_{i,t} - A_{i,t-1} \right) \times u_{i,t-1} \quad (20)$$

where

F_{st} is the structure effects, in energy units;

F_a is the activity factor;

A is the indicator of activity selected for the sector;

A_i is the indicator of activity of subsector i;

t is the year of calculation;

t–1 is the year before the year of calculation;

u_i is the indicator value of the sector, see Formula (21):

$$u_{i,t} = \frac{E_{i,t}}{A_{i,t}} \quad (21)$$

where $E_{i,t}$ is the energy consumption of subsector i at year t.

NOTE 1 The structure effect may not exist depending on the way the activity effect is calculated (see NOTE 2 in 7.2.3).

Examples of the calculation of structure effects by sector are given in Annex C.

7.2.6 Calculation of other factors

The calculation of the other factors, if any, depends on the sector and is explained further in Annex C. The number of these other factors depends on the data availability and the underlying definition of the previous factors (activity, savings and structure).

7.3 Other issues related to the decomposition of the energy consumption variation

7.3.1 General

For the calculation of the decomposition of the energy consumption variation, the following types of computation can be considered:

— calculation over a period;

— accounting for negative energy savings.

All issues related to the quality of the calculation are similar to those given for the energy efficiency indices in 6.4.

7.3.2 Calculation over a period

The calculations indicated in Formulae (17) and (21) are done between the years t–1 and t. The decomposition of the energy consumption between year t and a base year 0 can either be done directly, by replacing t–1 by 0 in the formulae, or as a chained calculation, by summing the variations year by year over the period. The results are the same.

7.3.3 Indicators resulting in negative energy efficiency improvement

As indicated for the energy efficiency indices, an increase in the specific energy consumption indicators in a given subsector or energy use will result in an increase of the energy consumption (i.e. negative energy savings). Such an increase is often observed during an economic recession in industry and freight transport, as explained in 6.3.3. In that case, there are two options to calculate the energy savings at the sector level:

— consider subsectors with real savings (i.e. negative value); or

— add subsectors with positive and negative savings.

The second approach will lower the value of energy savings. The first option corresponds to a definition of energy savings that is close to technical savings. In that case, a residual factor has to be added to account for these negative energy savings.

The increase in specific consumption can also be due to an insufficient level of disaggregation, thereby mixing real savings with structure effects. If it is not possible to correct for these structure effects, it should be clearly stated that no savings have been calculated due to structure effects. In that case, no savings will be presented, even if they become positive in a later period. This is often the case for electrical appliances in buildings.

Annex A
(informative)

Calculation of structure effects

A.1 Simple calculation of an energy intensity at constant structure

A.1.1 General

The simpler approach to assess the influence of structure effects on the energy intensity is to calculate an energy intensity at constant structure, i.e. a theoretical intensity that would result if all sectors were growing at the same rate as the activity of the whole sector (as measured, for example, by the total value added of industry for industry, or the GDP for the final intensity). Then, by comparing the variation of the energy intensity at constant structure with that of the observed intensity, the effect of structural changes can be calculated by difference. This method can be referred as the “Laspeyres Paasche method” as it combines values at base year and current year and is adapted from the calculation of the Laspeyres Paasche price calculation method. As explained in 5.2, although this method is simpler to implement, it provides less accurate results than the Divisia method.

In this method, there are two main steps of calculation:

— calculation of a theoretical value of the energy intensity at constant structure of a fixed base year;

— calculation of the structure effect.

The energy intensity at constant structure is calculated by assuming that the structure by subsector (R_j) remains unchanged from the base year and by considering the actual variation in energy intensity of subsectors (e_j), as shown in Formula (A.1):

$$e_{\mathrm{cst}}(t) = \sum_i Y_t \times \left(\frac{Y_{i,0}}{Y_0}\right) \times \left(\frac{E_{\mathrm{f},i,t}}{Y_{i,t}}\right) \quad \text{(A.1)}$$

where

e_{cst} is the theoretical intensity value of the sector at a constant structure;

0 is the base year;

t is the year of calculation;

Y_i is the monetary indicator of the activity of subsector i (e.g. value added of industrial branch i);

Y is the monetary indicator of the activity of the whole sector (e.g. value added of industry);

$E_{\mathrm{f},i}$ is the final energy consumption of subsector i.

Comparing the variation of the energy intensity at constant structure with that of the actual intensity measures, by difference, the structure effect.

The average annual variation of the intensity between year 0 and t due to structural changes is given in Formula (A.2):

$$G_{\text{ar,str}} = G_{\text{ar,tot},t,0} - G_{\text{ar,int},t,0} \tag{A.2}$$

where

$G_{\text{ar,str}}$ is the compound average annual intensity variation between 0 and t due to structural changes, in % per year;

$G_{\text{ar,tot}}$ is the compound average annual intensity variation between 0 and t, in % per year;

$G_{\text{ar,int}}$ is the compound average annual variation of the intensity at a constant structure between 0 and t, in % per year.

The compound annual growth rate should be calculated as shown in Formula (A.3):

$$G_{\text{ar,tot},t,0} = \left(\frac{e_t}{e_0}\right)^{\left(\frac{1}{t-0}\right)} - 1 \tag{A.3}$$

A.1.2 Simple calculation for industry

The energy intensity of industry relates the energy consumption of industry to the value added of industry measured at constant price, as shown by Formula (A.4). A similar energy intensity can be defined for the manufacturing industry only, with the manufacturing industry being defined as industry minus mining and construction. All the calculations in this subclause can be applied in the same way at the level of industry or manufacturing industry alone. For simplicity, this subclause refers to just “industry”.

$$e_{\text{ind},t} = \frac{E_{\text{ind},t}}{Y_{\text{ind},t}} \tag{A.4}$$

where

e_{ind} is the intensity value of industry;

E_{ind} is the energy consumption of industry;

Y_{ind} is the value added of industry;

t is the year of calculation.

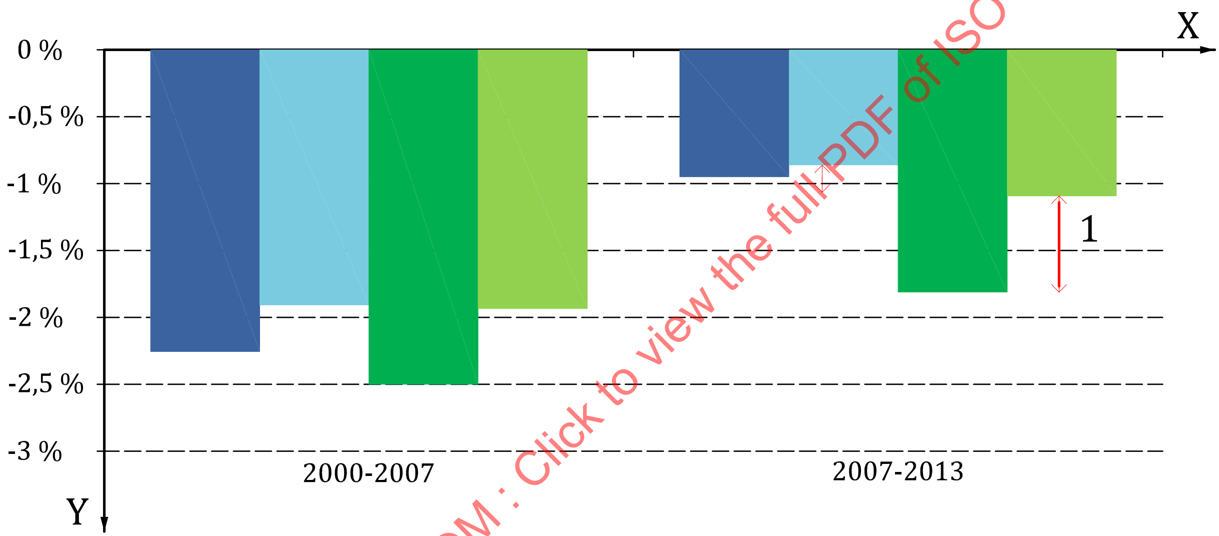
The energy intensity, as defined in Formula (A.4), can also be written as shown in Formula (A.5) to show the effect of structural changes and intensity changes:

$$e_{\text{ind},t} = \sum_i \left(\frac{Y_{\text{ind},i,t}}{Y_{\text{ind},t}}\right) \times \left(\frac{E_{\text{ind},i,t}}{Y_{\text{ind},i,t}}\right) \tag{A.5}$$

where

e_{ind}	is the intensity value of industry;
$E_{ind,i}$	is the energy consumption of industrial branch i;
$Y_{ind,i}$	is the value added of industrial branch i;
$E_{ind,,i}/Y_{ind,i}$	is the energy intensity of industrial branch i (energy intensity component);
$Y_{ind,i}/Y_{ind}$	is the share of industrial branch i in total value added (structural component).

Figure A.1 provides an example of intensity trends and structural changes in industry. It shows that, for the EU, the reduction of the energy intensity of industry since 2007 was at twice the rate of that of manufacturing (respectively, 0,9 %/year and 1,8 %/year). This trend is mainly explained by a structure effect: the strong recession in construction (−3,3 %/year between 2007 and 2013 for the value added) and the increasing share of manufacturing, the energy intensive part of industry in the total value added of industry (from 64 % in 2007 to 66 % in 2013). See Figure A.1.



Key

- industry
- manufacturing
- industry at constant structure
- manufacturing at constant structure

X time

Y %/year

1 structural changes

NOTE Source: Odyssee[20].

Figure A.1 — Energy efficiency trends and policies in industry, September 2015

NOTE The structure effect is the difference in the variations of the (observed) energy intensity and of the intensity at constant structure. The greater this effect, the wider the gap between these two intensities.

A.1.3 Simple calculation for final energy intensity

The final energy intensity relates the final energy consumption to the GDP expressed at constant prices, as shown by Formula (A.6). The final energy consumption should correspond to energy uses only and exclude non-energy uses. The calculation should preferably be done with a final consumption at normal climate, i.e. with climatic corrections, as explained in Annex D.

$$e_t = \frac{E_{f,t}}{Y_{GDP,t}} \tag{A.6}$$

where

e is the final energy intensity value;

E_f is the final energy consumption;

Y_{GDP} is the GDP;

t is the year of calculation.

The final energy intensity, as defined in Formula (A.6), can also be written as shown in Formula (A.7) to show the effect of structural changes and intensity changes with a constant structure:

$$e_t = \sum_i \left(\frac{Y_{i,t}}{Y_t} \right) \times \left(\frac{E_{f,i,t}}{Y_{i,t}} \right) \tag{A.7}$$

where

$E_{f,i}$ is the energy consumption of each of the five final energy consumption sectors (industry, transport, residential, services and agriculture);

Y_i represents the monetary activity of each of the five final energy consumption sectors, as follows:

- for industry, services and agriculture, which are the productive sectors that contribute to GDP, their activity Y_i is measured by their value added;
- for the residential sector, the activity can be measured by the household final consumption expenditure, also called "private consumption of households", which corresponds to the total expenditures of households in goods and services and is the main component of the GDP expenditure in a country;
- for transport, the activity is measured by GDP, as transport is generated by all economic sectors as well as by households;

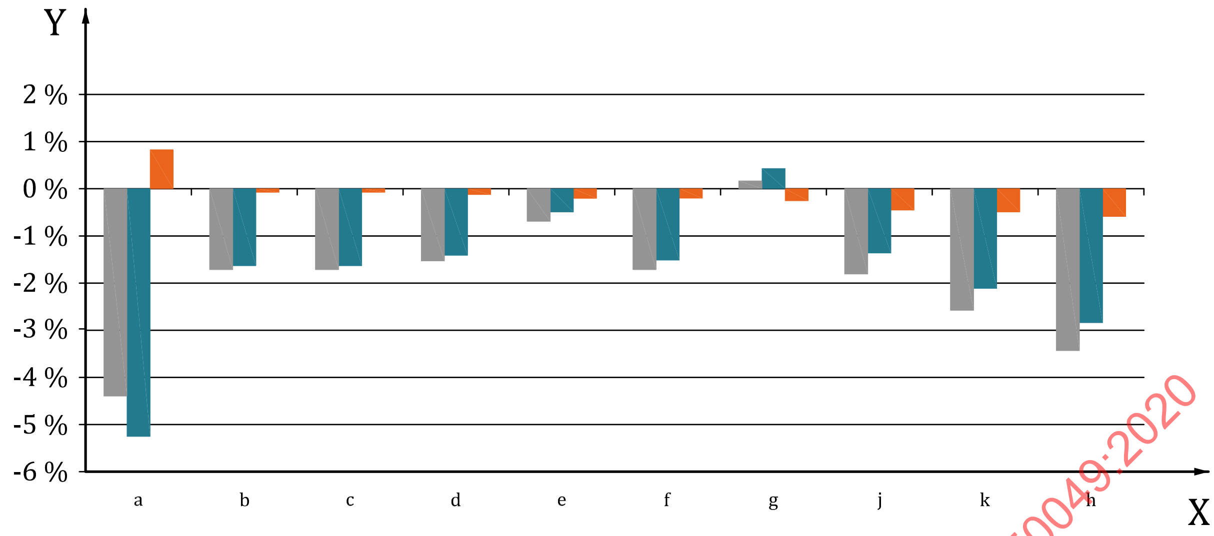
$E_{f,i}/Y_i$ is the energy intensity of each sector as defined above (energy intensity component);

Y_i/Y is the structural component, R_i; it is defined for each sector as indicated above.

If the purpose is to combine the effects of structural changes between main economic sectors and within industry as well, the intensity of industry in Formula (A.7) should be replaced by a theoretical intensity of industry calculated at constant structure (as calculated in A.1.2).

Figure A.2 provides an example of an application of the method of calculation of the final energy intensity at constant structure for different regions of the world. It shows that in three regions (Africa, India and China), the final intensity decreased faster than the intensity at constant structure. This means that part of the energy intensity decrease was due to an increasing share of services, the less energy intensive sector in the GDP. In CIS, however, structure effects contributed to increase the final energy intensity.

NOTE CIS is the Commonwealth of Independent States: Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine.



Key

■	actual	a	CIS
■	at constant structure	b	World
■	structural changes	c	North America
X	region	d	Asia OECD
Y	%/year	e	Latin America
		f	Europe
		g	Middle East
		j	Africa
		k	India
		h	China

NOTE Source: WEC[9].

Figure A.2 — Impact of structural changes in GDP on the final energy intensity trend (2000 to 2014)

A.2 Example of a calculation of Divisia decomposition

As explained in 5.3.1, there are two main versions of the Divisia method, depending on the weighting method of the different subsectors in the calculation of the structure and intensity effects [see 5.2.2 and Formulae (3) and (4)]:

— in the AMDI method, the weighting of subsector *i* at year *t* $w_{i,t}$ is the average weighting of year *t* and *t*–1:

$$w_{i,t} = \frac{\left(E_{i,t} / E_t + E_{i,t-1} / E_{t-1}\right)}{2}$$

— in the LMDI1 method, the weighting of subsector *i* at year *t* is calculated as:

$$w_{i,t} = \frac{L\left(\frac{E_{i,t}}{Y_t}, \frac{E_{i,t-1}}{Y_{t-1}}\right)}{L\left(\frac{E_t}{Y_t}, \frac{E_{t-1}}{Y_{t-1}}\right)}$$

where

$E_{i,t}$ is the energy consumption of subsector i at year t;

$E_{i,t-1}$ is the energy consumption of subsector i at year t −1;

E_t is the total energy consumption at year t (sum of subsectors i);

Y_t is the monetary indicator of activity of the whole sector at year t, e.g. value added.

Figure A.3 provides an example of the various steps of calculation with the AMDI Divisia method in a fictitious case with three subsectors.

Step 1: Collection of data and calculation of intensity and share of value added in total by subsector

Data	**2010**	**2011**	**2012**	**2013**
Consumption (PJ)				
Subsector A	550	530	490	440
Subsector B	270	280	260	260
Subsector C	520	570	570	550
Value added (M$2 000)				
Subsector A	18 360	17 880	17 150	15 700
Subsector B	12 050	13 210	14 500	14 230
Subsector C	44 390	50 600	51 190	49 890

Calculation for each subsector i:
– ratio between value added and total value added, R_i
– energy intensity, e_i

Structure R_i (%)	**2010**	**2011**	**2012**	**2013**
Subsector A	25 %	22 %	21 %	20 %
Subsector B	16 %	16 %	18 %	18 %
Subsector C	59 %	62 %	62 %	63 %

Intensity e_i (MJ/$2 000)	**2010**	**2011**	**2012**	**2013**
Subsector A	3	29,6	28,6	28
Subsector B	22,4	21,2	17,9	18,3
Subsector C	11,7	11,3	11,1	11

Step 2: Calculation of weighting factors by sector

Weighting factors:

$$w_{i,t} = \frac{E_{i,t}/E_t + E_{i,t-1}/E_{t-1}}{2}$$

Weighting factors	**2010**	**2011**	**2012**	**2013**
Subsector A		0,4	0,38	0,36
Subsector B		0,2	0,2	0,2
Subsector C		0,4	0,42	0,44

Step 3: Decomposition of energy intensity variation

$$\text{Structure effect} = w_{i,t} \times \ln\left(\frac{R_{i,t}}{R_{i,t-1}}\right)$$

Structure effect (%/year)	**2011**	**2012**	**2013**
Subsector A	−4,5 %	−2,1 %	−1,8 %
Subsector B	0,1 %	1,6 %	0,4 %
Subsector C	1,7 %	−0,1 %	0,5 %

$$\text{Intensity effect} = w_{i,t} \times \ln\left(\frac{e_{i,t}}{e_{i,t-1}}\right)$$

Intensity effect (%/year)	**2011**	**2012**	**2013**
Subsector A	−0,4 %	−1,4 %	−0,7 %
Subector B	−1,1 %	−3,3 %	0,4 %
Subsector C	−1,6 %	−0,5 %	−0,4 %

Expressed in %/year:

	2011	**2012**	**2013**
Structure effect (sum of subsectors)	−2,7 %	−0,6 %	−1 %
Intensity effect (sum of subsectors)	−3,1 %	−5,2 %	−0,8 %
Total variation	**−5,9 %**	**−5,9 %**	**−1,7 %**

Indices = exp(Total)

Expressed in indices:

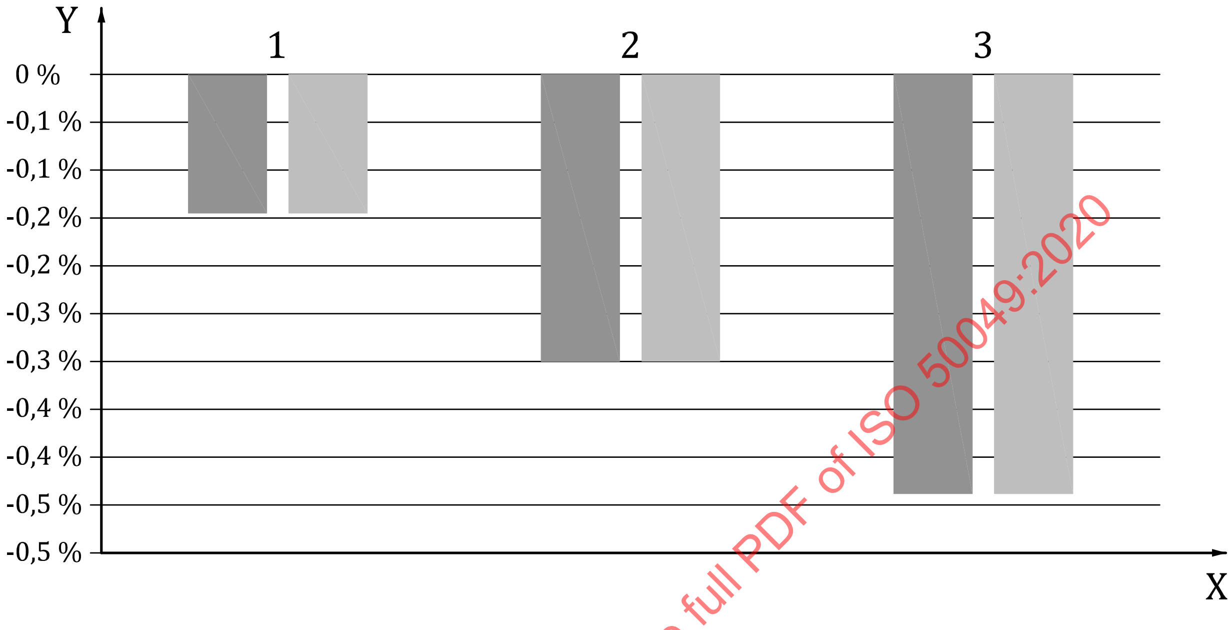
	2010	**2011**	**2012**	**2013**
Structure effect	1	0,97	0,99	0,99
Intensity effect	1	0,97	0,95	0,99
Total variation	**1**	**0,94**	**0,94**	**0,98**

Total variation = structure effect *x* intensity effect

Figure A.3 — Calculation of structure effect with the AMDI Divisia method

For the LMDI1 method, the steps of calculation are identical. The only change is that the formula of the weighting factors is different between the two methods.

The total variation of energy intensity is not strictly equal to the sum of effects because the AMDI method generates a residual, while, with LMDI1, the decomposition is made without residues. However, as shown in the example in Figure A.4, the residue is generally negligible and the two methods give almost the same results. Therefore, it is recommended to use the AMDI method, which is simpler to implement and to present.



Key

■	LMDI I	1	structure
■	AMDI	2	intensity
X	element	3	total
Y	%/year		

Figure A.4 — Decomposition of the energy intensity variation — Comparison between LMDI1 and AMDI

Annex B
(informative)

Examples of energy efficiency indicators

B.1 General

The calculation of the energy efficiency index (I_{EE}) makes use of energy efficiency indicators. In order to highlight the application possibilities of the general calculation method, an overview is provided of the recommended energy efficiency indicators to be used in the various sectors. These indicators originate from the Odyssee project on energy indicators for the calculation of the European energy efficiency index, called ODEX[7][15], and are also used by other organizations (e.g. IEA).

The sectors covered are industry (see B.2), transport (see B.3) and residential (households) (see B.4). Agriculture, forestry and fishery are not included as they generally constitute small sectors in terms of energy use. Energy transformation (central power and heat generation, refineries) is not covered here.

B.2 Industry

B.2.1 Selection of subsectors

In industry, the selection of subsectors (Step 1) consists of a selection of industrial branches for which both the energy consumption and an indicator of activity is available and defined in a consistent manner. The list of branches usually follows the International Standard of Industrial Classification (ISIC). In that case, the selection should be done so as to group them into around 10 to 15 branches, depending on the data available and their importance in the total industrial activity and energy consumption.

For some of the industrial branches, mostly in energy intensive subsectors, it is possible to characterize their level of activity with a physical output. The usual energy intensive branches considered are steel, cement, and pulp and paper, for which the respective outputs are the production of crude steel, cement and paper in tonnes. Other energy intensive branches that can be considered, provided data are available, are sugar, aluminium, copper, fertilisers, ethylene, glass, etc.

In other sectors, the output is very diverse and therefore the output is expressed as a production index, as this indicator of activity is based on physical production at a disaggregated level.

B.2.2 Indicators for energy-intensive industries

For these energy-intensive branches, the specific energy consumption is calculated as shown in Formula (B.1):

$$u_{\text{ind},x} = \frac{E_x}{O_x} \quad \text{(B.1)}$$

where

$u_{\text{ind},x}$ is the indicator value for specific energy consumption of energy-intensive product x;

E_x is the total energy consumption for product x;

O_x is the output for the energy-intensive product x.

The production is measured in physical units (e.g. Mt, kt).

NOTE 1 A correction can be included to consider the effect of variations in the utilization rate of production capacity by introducing a production performance factor. This coefficient will reflect the fact that, with a low capacity utilization rate, the fixed part of energy use counts more heavily and the equipment has a lower efficiency. This coefficient cannot be found in any statistics and is estimated. For that reason, it is not considered in the Odyssee efficiency index.

NOTE 2 A further breakdown by type of product or process can be considered (e.g. separation of steel produced from basic oxygen and electric arc furnaces, between clinker and cement for the cement industry). The decision for this additional disaggregation depends on the data availability.

B.2.3 Indicators for other industrial branches

For the other branches, the specific energy consumption is calculated as shown in Formula (B.2):

$$u_{\mathrm{ind},x} = \frac{E_{x,s}}{A_{\mathrm{ipi},x}} \tag{B.2}$$

where

$u_{\mathrm{ind},x}$ is the indicator value for specific energy consumption in industrial subsector x;

$E_{x,s}$ is the energy consumption of subsector x, minus the consumption of the energy intensive products that belong to the branch; e.g. for the branch called “non-metallic minerals” it is the consumption of the whole branch minus the consumption for cement production;

$A_{\mathrm{ipi},x}$ is the output for subsector x, measured with a production index.

B.2.4 Example of a calculation of an energy efficiency index

Figure B.1 provides an example of the four steps of calculation of the energy efficiency index in a fictitious case with three subsectors:

— Step 1: collection of data on energy consumption and activity data by subsector;

— Step 2: calculation of indicator values by subsector;

— Step 3: calculation of weighting factors by subsector;

— Step 4: calculation of the energy efficiency index for the sector as a whole.

1: Energy consumption and activity data by subsector

For subsector B, the most relevant activity data is the physical production. For the other subsectors, it is the production index.

Data	**2010**	**2011**	**2012**	**2013**
Consumption (PJ) – E_i				
Subsector A	550	530	490	440
Subsector B	270	280	260	260
Subsector C	520	570	570	550
Production index (2010 = 100) – A_i				
Subsector A	18 360	17 880	17 150	15 700
Subsector C	44 390	50 600	51 190	49 890
Production (kt) – A_i				
Subsector B	20 956	23 200	22 488	22 603

2: Calculation of indicator values by subsector

Specific consumption = $\frac{E_i}{Y_i}$

Specific consumption		**2010**	**2011**	**2012**	**2013**
Subsector A	GJ/100	5,5	5,44	5,25	5,15
Subsector B	GJ/t	12,9	12,1	11,6	11,5
Subsector C	GJ/100	5,2	5	4,94	4,89

Calculation of indicators trends in base 2010 = 100

Indicators index (I_s)	**2010**	**2011**	**2012**	**2013**
Subsector A	100	99	95	94
Subsector B	100	94	90	89
Subsector C	100	96	95	94

3: Calculation of weighting factors by subsector

Weighting factor:

$w_i = \frac{E_i}{E}$

Weighting factors	**2010**	**2011**	**2012**	**2013**
Subsector A	41 %	38 %	37 %	35 %
Subsector B	20 %	20 %	20 %	21 %
Subsector C	39 %	41 %	43 %	44 %

4: Calculation of the energy efficiency index for the sector as a whole

$$I_{IEE,t-1} / I_{IEE,t} = \sum_i (w_{i,t} \times (\frac{I_{s,i,t}}{I_{s,i,t-1}}))$$

$$I_{IEE,t} / I_{IEE,t-1} = 1 / (I_{IEE,t-1} / I_{IEE,t})$$

$$I_{IEE,100,t} = I_{IEE,100,t-1} \times I_{IEE,t} / I_{IEE,t-1}$$

	2010	**2011**	**2012**	**2013**
I_s of subsector A	100	99	95	94
I_s of subsector B	100	94	90	89
I_s of subsector C	100	96	95	94
$I_{IEE,t-1} / I_{IEE,t}$		1,03	1,03	1,01
$I_{IEE,t} / I_{IEE,t-1}$		0,97	0,97	0,99
$I_{IEE,100}$	**100**	**97**	**94**	**93**

In this example, the energy efficiency index of industry is equal to 93 in 2013 compared to 2010, this means that energy efficiency has improved by 7 % between 2010 and 2013.

Figure B.1 — Calculation of the energy efficiency index in a fictitious example with three subsectors

B.3 Transport

B.3.1 Selection of subsectors

In transport, the selection of subsectors (Step 1) consists of a selection of transport modes for which both the energy consumption and an indicator of activity are available. Transport can be split into the following main modes:

— road transport: cars, heavy trucks, light duty vehicles (vans, pickups), buses, and motorcycles;

— rail transport: goods, passengers;

— air transport: total or only domestic;

— domestic water transport (river, sea, waterways).

In transportation, the energy efficiency improvement can come from different factors:

a) improved efficiency of vehicles, including component and accessories;

b) optimal driving or operating patterns;

c) a shift between transport modes (e.g. from car to public transport, from trucks to rail);

d) less distance travelled with vehicles, due, for example, to greater use of public transport or bicycles for cars, or through logistical improvements for road freight vehicles;

e) increased rate of occupancy or load factor of transport modes and vehicles.

For the last three cases, the energy efficiency of the transport modes is not changing but there is a greater use of more efficient modes (for the third case) or a more efficient use of modes (for the fourth and fifth cases).

The definition of the energy efficiency index will therefore depend on the definition given to energy efficiency.

B.3.2 Indicators for cars

For cars, three main indicators can be used to characterize the energy efficiency:

— the specific energy consumption in litres/100 km (l/100 km), also expressed in km/l in most Latin American countries (in miles per gallon or mpg in the US) [see Formula (3)];

— the specific energy consumption in energy unit in GJ/km (or koe/km) [see Formula (4)];

— the specific consumption per passenger-km in MJ/pkm (or goe/pkm) [see Formula (5)].

The average fuel consumption per vehicle-km by car in physical units is shown in Formula (B.3):

$$u_{c,1} = \frac{E_c}{A_{vkm,c}} / 100 \qquad \text{(B.3)}$$

where

$u_{c,1}$ is the indicator value for fuel consumption per vehicle-km driven, in litre/100 km;

E_c is the total energy consumption of cars, in litres or m^3;

$A_{vkm,c}$ is the total number of vehicles-km by cars, in number of cars multiplied by the average distance travelled per year.

The average fuel consumption per km driven by car in energy units is shown in Formula (B.4):

$$u_{c,2} = \frac{E_c}{A_{vkm,c}} \tag{B.4}$$

where

$u_{c,2}$ is the indicator value for fuel consumption per vehicle-km, in MJ/km;

E_c is the total energy consumption of cars in energy units (e.g. Joule);

$A_{vkm,c}$ is the total number of vehicles-km by cars.

The average fuel consumption per person-km by car is shown in Formula (B.5):

$$u_{pkm} = \frac{E_c}{A_{pkm,c}} \tag{B.5}$$

where

u_{pkm} is the indicator value for fuel consumption per passenger-km in energy units, in MJ/pkm;

E_c is the total energy consumption of cars;

$A_{pkm,c}$ is the total traffic in passenger-km by cars.

The first indicator (litre/100 km) shows the combined effect of technological improvements, driving behaviour and fuel shift.

The second indicator (MJ/km) takes into account, in addition to the previous factors, the changes in the fuel mix (i.e. in the average calorific value of motor fuels, in Joule/litre). This fuel shift can come from a substitution between gasoline and diesel or from the penetration of biofuels. If the focus is on actual vehicle improvement, this fuel shift effect should be isolated. This is possible by defining separate indicators for the different fuels, e.g. for diesel, gasoline.

The third indicator (MJ/passenger-km) takes into account, in addition to the second indicator, the changes in the average occupancy rate of cars. If it increases due to carpooling, fewer cars are needed for transporting the same number of people, which translates into a reduction of that indicator, all other things being equal. The effect of changes in car occupancy can be calculated by comparing the trend of the two indicators proposed for cars.

As energy efficiency should preferably be measured in energy units. As policies on carpooling exist to improve the efficiency of cars, the use of the third indicator is recommended.

B.3.3 Indicators for buses and motorcycles

For buses and motorcycles, an average fuel consumption per vehicle is calculated, as shown in Formula (B.6):

$$u_v = \frac{E_v}{N_v} \tag{B.6}$$

where

u_v is the indicator value for fuel consumption per bus or motorcycle;

E_v is the total energy consumption of buses or motorcycles;

N_v is the total number of buses or motorcycles.

B.3.4 Indicators for passenger and freight rail transport and for air transport

For transport of freight and of persons by rail and air, the indicators relate the consumption to traffic. For passengers, the traffic is generally expressed in passenger-km travelled (in the case of rail and domestic air transport) or in terms of the number of persons transported (in the case of international air transport).

For transport of goods by trucks, trains or boats, the traffic is generally expressed in ton-km transported.

Official energy statistics provide the energy consumption of rail transport, as a whole, without a differentiation between passenger and goods. To separate this consumption between passengers and goods, one approximation can be to express the traffic of passengers and goods in the same unit, in gross ton-km hauled (gtkh), reflecting the total mass to be moved, including the mass of locomotives and carriages. For this purpose, a coefficient is used that expresses the average gross mass per passenger and per ton of goods. (A default value can be used as follows: 1,7 gtkm per passenger-km and 2,5 gtkm per ton-km for goods.) The total energy consumption of rail transport is then allocated between passenger and goods traffic according to the share of passenger and goods traffic, respectively, in the total traffic in gross ton-km hauled.

The specific consumption for air and rail passenger is defined as shown in Formula (B.7):

$$u_{\text{pkm}} = \frac{E_{\text{pkm}}}{A_{\text{pkm}}} \tag{B.7}$$

where

u_{pkm} is the indicator value in fuel consumption per person-km;

E_{pkm} is the total energy consumption of passenger mode;

A_{pkm} is the passenger traffic in passenger-km.

The specific consumption for transport of goods is shown in Formula (B.8):

$$u_{\text{tkm}} = \frac{E_{\text{tkm}}}{A_{\text{tkm}}} \tag{B.8}$$

where

u_{tkm} is the indicator value in fuel consumption per ton-km;

E_{tkm} is the total energy consumption of freight mode;

A_{tkm} is the traffic, in ton-km.

B.4 Residential (households)

B.4.1 Selection of subsectors

In the residential sector, the selection of subsectors (Step 1) consists of a selection of energy uses and/or appliances types. The main energy uses and the largest electrical appliances to be considered are:

- space heating;
- water heating;
- cooking;
- cooling (air conditioning);
- large electrical appliances:
  - refrigerators;
  - independent freezers;
  - washing machines;
  - dishwashers;
  - clothes dryers;
  - TV;
- others.

The selection of energy uses will depend on the data availability, especially for the electricity consumption by type of appliances. The category "others" should include all energy uses and appliances that cannot be separated because of a lack of data.

NOTE Sampling or surveys can be used to get data by end-use as long as the data produced are statistically representative of the country (or region).

B.4.2 Indicators for space heating

This indicator represents the average energy consumption for space heating per m² of floor area of occupied dwellings, as shown in Formula (B.9):

$$u_{sh} = \frac{E_{sh,nc}}{\left(N_{odw} \times M_{dw}\right)} \tag{B.9}$$

where

u_{sh} is the indicator value of energy consumption for space heating;

$E_{sh,nc}$ is the weather adjusted final energy consumption for space heating;

N_{odw} is the number of occupied dwellings;

M_{dw} is the mean floor space per dwelling, in m^2.

Energy consumption for space heating comprises fossil fuels, such as natural gas, heating oil, coal, lignite or peat. It also includes wood, electricity and delivered heat from a district heating system or solar water heater.

Energy consumption should be adjusted for weather variations from one year to the other, using degree days (see 4.2.5 and the details of calculation in Annex D).

Energy consumption is dependent on the occupancy of dwellings as, for example, summer homes and houses waiting for a new buyer or renter will show quite different energy use patterns. Therefore, only dwellings occupied throughout the year should be considered: the so-called “permanently occupied dwellings”. Their number may be counted at the middle of the year (or as the average between the beginning and end of the year).

The average floor space per dwelling comprises all living space and usually excludes cellars and attics, which normally are not heated.

Depending on data availability and influence on the indicator value, a correction can be made for the type of heating (central heating, room heating), e.g. in the case of ODEX[14]. Indeed, room heating consumes less energy than central heating as all the rooms are not heated (only some rooms are heated with stoves). To enable a correction for central heating, a distinction should be made between centrally heated dwellings and dwellings with room heating in the formula of the calculation of the total heated area.

B.4.3 Indicators for water heating

The indicator considered is the specific energy consumption for water heating per person in a household, as shown in Formula (B.10):

$$u_{wh} = \frac{E_{wh}}{\left(N_{hh} \times P_{hh}\right)} \quad \text{(B.10)}$$

where

- u_{wh} is the indicator value of energy consumption for water heating;
- E_{wh} is the final energy consumption for water heating;
- N_{hh} is the number of households;
- P_{hh} is the average number of persons per household.

The number of households multiplied by the average number of persons per household is generally slightly lower than the total population because a small fraction of the population lives in institutional habitats (e.g. prisons, homes for old people).

Energy consumption, delivered to households, can be influenced by renewables-behind-the-meter, depending on the definition or coverage of energy consumption. For example, hot water from solar water heaters will reduce the amount of fuels or electricity purchased (i.e. the delivered energy). If the final energy consumption for water heating includes the solar energy used, the switch from fuel or electricity to solar will only have a minor impact on the consumption and thus on energy efficiency. If the consumption is based on the delivered energy, then energy efficiency improvements will be greater.

B.4.4 Indicators for cooking

The indicator considered is the specific energy consumption for cooking per dwelling, as shown in Formula (B.11):

$$u_{ck} = \frac{E_{ck}}{N_{hh}} \quad \text{(B.11)}$$

where

- u_{ck} is the indicator value of energy consumption for cooking;
- E_{ck} is the energy consumption for cooking;
- N_{hh} is the number of households.

In developing countries, the substitution from wood to LPG, natural gas or even electricity significantly reduces the specific energy consumption for cooking due to the large differences in energy efficiency (around a factor of 10). If this substitution is considered as an energy efficiency improvement, it will be accounted for in the energy efficiency index. If the user wants to separate the fuel substitution effect and exclude it from the index, then Formula (B.11) should be calculated with a specific consumption in useful energy.

The indicator considered is the specific energy consumption for cooking per dwelling in a household, as shown in Formula (B.12):

$$u_{ck,u} = \frac{E_{ck,u}}{N_{hh}} \tag{B.12}$$

where

$u_{ck,u}$ is the indicator value of useful energy consumption for cooking;

$E_{ck,u}$ is the useful energy consumption for cooking;

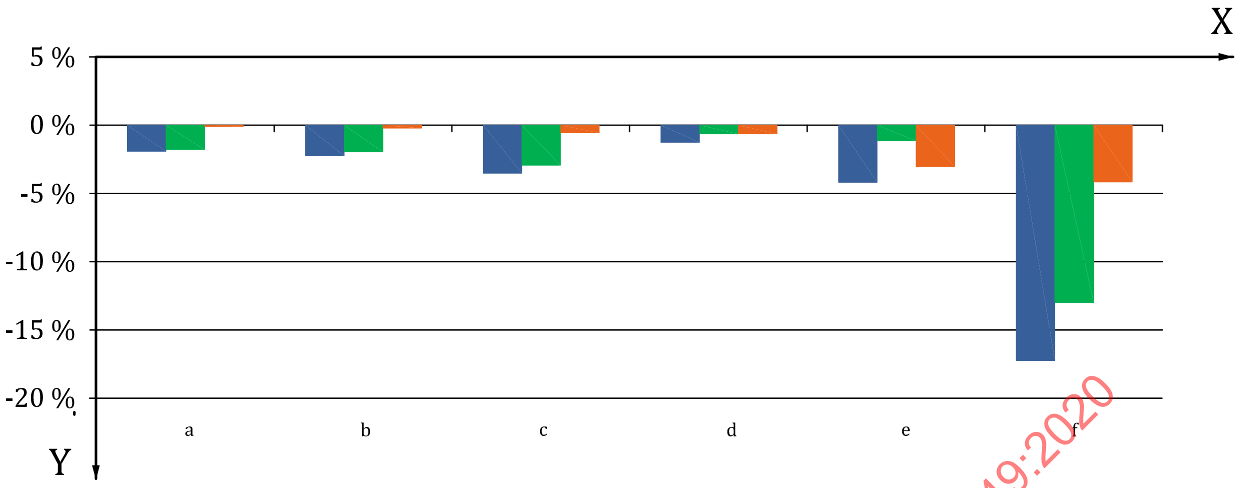
N_{hh} is the number of households.

The consumption in useful energy is calculated by multiplying the energy consumption of each fuel by its average energy efficiency (e.g. for cooking 45 % for LPG and gas, 80 % for electricity, 10 % for charcoal and 5 % for wood).

NOTE Useful energy is different from the thermodynamic concept of available energy or exergy.

The variation of the specific consumption in useful energy provides the trend in energy efficiency. The fuel substitution effect is calculated as the difference between the annual change in the specific consumption in final energy and useful energy.

Figure B.2 provides an example of a sample of Latin American countries showing that the effect of a substitution from biomass to modern fuels was the greatest in El Salvador and Paraguay. Substitutions from biomass to LPG in El Salvador and to electricity in Paraguay contributed to decrease the specific consumption by more than 3 %/year.



Key

- ■ specific consumption (final energy)
- ■ substitution effect
- ■ energy efficiency effect (useful energy)
- X country
- Y %/year (2000 to 2012)

- a Brazil
- b Dominican Rep
- c Nicaragua
- d Uruguay
- e El Salvador
- f Paraguay

NOTE Source: BIEE[10].

Figure B.2 — Fuel substitution effect for household cooking in selected countries of Latin America

B.4.5 Indicators for air cooling and large appliances

For large electrical appliances, including refrigerators, independent freezers, washing machines, clothes dryers, dish washers, televisions and air conditioning, an indicator of specific electricity consumption per appliance is used, shown in Formula (B.13):

$$u_{\mathrm{la},x} = \frac{E_{\mathrm{la},x}}{N_{\mathrm{la},x}} \tag{B.13}$$

where

- $u_{\mathrm{la},x}$ is the indicator value for electricity consumption of large appliance x;
- $E_{\mathrm{la},x}$ is the total electricity consumption for large appliance x;
- $N_{\mathrm{la},x}$ is the number for large appliance x owned by households.

NOTE The specific consumption can be corrected for the size of appliances x (e.g. in litre of storing capacity for refrigerators or freezers) or the intensity of use (e.g. kg of clothes washed and dried per cycle and number of cycles), so as to get a better indicator of efficiency from a technical point of view. But due to a lack of data, this is not very common. In that case, Formula (B.13) becomes Formula (B.14):

$$u_{\mathrm{la},x} = \frac{E_{\mathrm{la},x}}{\left(N_{\mathrm{la},x} \times P_{\mathrm{la},x}\right)} \tag{B.14}$$

where $P_{\mathrm{la},x}$ is the size or intensity of use of appliance x.

B.4.6 Indicators for lighting

For lighting, the indicator considered is specific electricity consumption for lighting per household, as shown in Formula (B.15):

$$u_{\text{lt}} = \frac{E_{\text{lt}}}{N_{\text{hh}}} \qquad \text{(B.15)}$$

where

u_{lt} is the indicator value of electricity consumption for lighting;

E_{lt} is the electricity consumption for lighting;

N_{hh} is the number of households.

Annex C
(informative)

Examples of explanatory factors

C.1 General

The calculation of the activity factor makes use of activity indicators and indicators of specific energy consumption. In order to highlight the application possibilities of the general calculation method provided in the core of this document (Clause 7), this annex provides an overview of the most common indicators used to calculate the various explanatory factors: activity indicators to calculate the activity and structure effects. The indicators of specific consumption used to calculate energy savings are the same as the ones used to calculate the energy efficiency index, see Annex B.

The sectors covered are industry, transport, households and services. Agriculture, forestry and fishery are not included as they generally constitute small sectors in terms of energy use. Central power generation is also included but not the detail of the other energy transformations (e.g. refineries, district heating).

Four types of explanatory factors are considered to explain the energy consumption variation of a given sector:

— the activity factor, which assesses the impact on the energy consumption variation of changes in the sector's economic activity;

— the structure effect factor, which considers that, in a sector, the variation in activity is not the same for all subsectors, leading to structural changes that can impact the sector's consumption;

— the energy savings factor coming from efficiency improvements at the level of the different subsectors and energy uses; this factor is negative as it contributes to a decrease in energy consumption;

— other factors.

This annex explains the calculation of two first factors for each sector. The calculation of the energy savings factor is not considered here because its calculation is described in ISO 17742 and it can also be derived from the sector's energy efficiency index, as explained in 7.2.4.

Depending on the sector and/or level of disaggregation, other types of explanatory factors can be considered that are sector specific. Examples of other factors are described in C.4.

The decomposition method described in this document uses the Paasches-Laspeyres method. It leads to results that are very similar to a decomposition using an LMDI Divisia decomposition[19].

C.2 Activity factor

C.2.1 Industry

In industry, the activity factor is generally calculated from the value added of the sector, as shown in Formula (C.1):

$$F_{a,ind,t,t-1} = \left(Y_{ind,t} - Y_{ind,t-1}\right) \times e_{ind,t-1} \tag{C.1}$$

where

$F_{a,ind,t,t-1}$	is the activity factor for industry between t–1 and t;
Y_{ind}	is the total value added of industry;
t	is the year of calculation;
t–1	is the year before the year of calculation;
e_{ind}	is the total energy intensity of industry, calculated as the energy consumption of industry divided by the total value added of industry, see Formula (C.2):

$$e_{ind,t} = \frac{E_{ind,t}}{Y_{ind,t}} \tag{C.2}$$

where E_{ind} is the total energy consumption of industry.

C.2.2 Transport

In transport, the activity factor, as for all the other factors, is usually calculated for passenger transport and transport of goods separately, and is then added together to get the total for transport. For passengers, it is measured from the change in passenger traffic, including air, and for goods, from the variation of the traffic of goods.

For passenger transport, the activity factor is calculated as shown in Formula (C.3):

$$F_{a,pkm,t,t-1} = \left(A_{pkm,t} - A_{pkm,t-1}\right) \times u_{pkm,t-1} \tag{C.3}$$

where

$F_{a,pkm,t,t-1}$	is the activity factor for passenger traffic between t–1 and t;
A_{pkm}	is the indicator of total passenger traffic for all modes in passenger-km (pkm);
t	is the year of calculation;
t–1	is the year before the year of calculation;
u_{pkm}	is the energy consumption of passenger transport per passenger-km, see Formula (C.4):

$$u_{pkm,t} = \frac{E_{pkm,t}}{A_{pkm,t}} \tag{C.4}$$

where E_{pkm} is the total energy consumption for passenger transport.

