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ODYSSEE-MURE

Definition of energy efficiency index ODEX in ODYSSEE data base

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Content

1. Introduction: why an energy efficiency index?

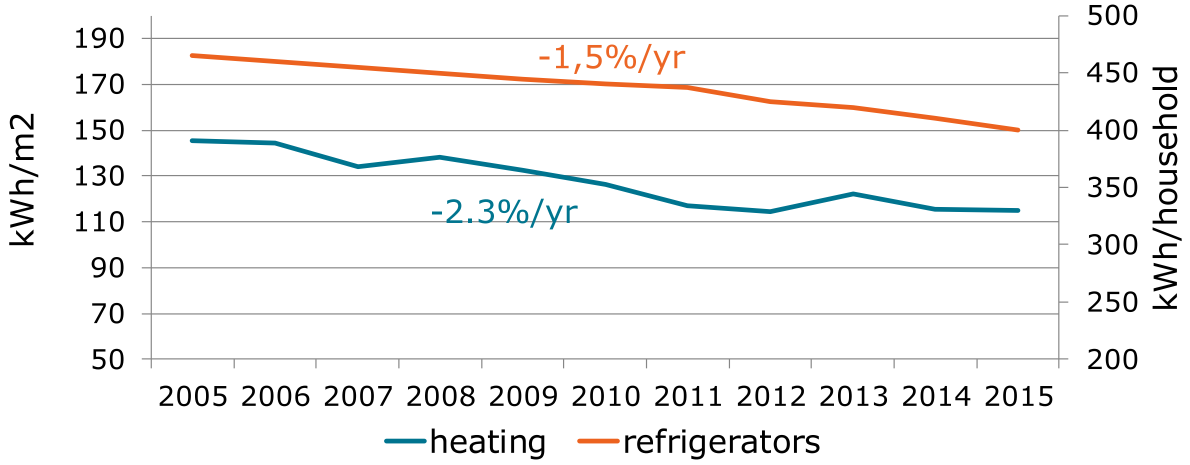
The ODYSSEE data base provides a variety of indicators of specific consumption, measured in physical units, at a detailed level:

- By sub sector in industry (e.g. toe/ton for steel, cement) and services (e.g. kWh/employee, /per m2/per bed…),
- By end-use/appliances for households (e.g. toe/m2 for heating, kWh/household for electrical appliances and AC…)
- By transport mode/ vehicle type in transport (e.g. km/l or pkm for cars, toe/tkm for freight …)

These detailed indicators can be used to assess energy efficiency progress at the level of sub sectors, end-uses and mode of transport.

For households, we may obtain for instance different energy efficiency trends: 1.5%/year for refrigerators and 2.3%/year for heating (Figure 1). The question is what is the overall energy efficiency progress for households? This is the objective of the energy efficiency index, called **"ODEX"**.

Figure 1: Energy efficiency trends by end-use for households



2. Definition of ODEX

2.1. General principle of calculation

ODEX measures the energy efficiency progress by main sector (industry, transport, households, services) and for the whole economy (all final consumers).

For each sector, the index is calculated as a weighted average of sub-sectoral indices of energy efficiency progress; sub-sectors being industrial branches, service sector branches, end-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 to combine different units for a given sector, for instance for households' kWh/appliance, koe/m2, tep/dwelling…

- The weight used to get the weighted aggregate is the share of each sub- sector in the total energy consumption of the sector.

Box 1: Principle of calculation of ODEX

ODEX is calculated as follows:

- First, by expressing trends in specific energy consumption by end-use or sub-sector, as an index of variation.
- Then by calculating a weighted average index for the sector on the basis of the share of each end-use/sub-sector in the sector's energy consumption.

Example with two sub-sectors:

- Change in the specific consumption from 100 to 85 for the first sub-sector and 100 to 97.5 for the second
- Share of consumption of 60% and 40% respectively

The weighted average index is: 0.6*(85/100)+0.4* (97.5/100) = 90

A value of ODEX equal to 90 means a 10% energy efficiency gain.

Table 1 gives a fictive example of calculation for households with only 2 end-uses in which energy efficiency gains are measured in relation to the previous year. The energy efficiency index is set at 100 for the base year (e.g. 2015) and successive values are derived by multiplying the value at t-1 by IE_t / IE_{t-1}. The index at year t thus cumulates the incremental energy efficiency progress since the base year. In this example, ODEX equals 88.6 in 2018, which means that energy efficiency improved by 11.4% between 2015 and 2018[1].

Table 1: Principle of calculation of energy efficiency index over a period (fictive example)

Specific energy consumption	**2015**	**2016**	**2017**	**2018**
Heating (toe/household) (index)	0.85 (100)	0.83 (98)	0.82 (96)	0.82 (96)
Lighting (kWh/household) (index)	300 (100)	290 (97)	260 (87)	250 (83)
Energy consumption				
Heating (Mtoe) (%)	20 (50)	20 (48)	20 (44)	22 (46)
Lighting (Mtoe) (%)	20 (50)	22 (52)	25 (56)	26 (54)
Energy efficiency index				
Heating	100	98	96	96
Lighting	100	97	87	83
Total	100	97,4	90,9	88,6

[1] *11.4%= (1-(88.6/100)*100)*

ODEX indicators represent a better proxy for assessing energy efficiency trends by sector (e.g. industry, households, transport, services) and for all final consumers than the traditional energy intensities relating the energy consumption to a monetary value (eg GDP, VA, private consumption), as they are cleaned from structural changes and from other factors not related to energy efficiency (more appliances, more cars…).

2.2. ODEX and energy savings

2.2.1. Energy savings

Top-down energy savings are derived from the multiplication of the variation of a unit energy consumption by an indicator of activity over a reference period.

For instance, the energy savings of a given appliance (e.g. refrigerators) are derived from the variation in the average specific energy consumption per appliance (in kWh/year) multiplied by the stock of refrigerators[2]; for example, a reduction of the specific consumption of refrigerators from 400 to 300 kWh in a country with one 1 million of refrigerators will result in total electricity savings equal to 100 GWh (Figure 1).

Another example can be given for cement. In that case, energy savings measure the impact of the reduction in the specific energy consumption per tonne of cement. They are calculated over a period by multiplying the cement production by the variation of the specific consumption (SEC) between a base year (e.g. 2010) and year t (e.g 2018): P_t * (SEC $_0$- SEC $_t$) . In the example of Table 2, energy savings are thus equal to (0.076-0.07)*30= 0.18 Mtoe. The rate of energy savings is equal to around 8% in other words energy efficiency improvements, which reduce the specific energy consumption, led to

Table 2: Energy savings: case of cement

		t_0 = 2010	t = 2018
Production (P)	Mt	25	30
Consumption (E)	Mtoe	1.9	2.1
Unit consumption (SEC)	toe/t	0.076	0.070
Energy savings	Mtoe		0.18
Energy saving rate	%		~8%[3]

2.2.2. Choice of the weighting system

The weighting system used to calculate ODEX has been defined in such a way that energy savings are the same if calculated as the sum of energy savings of each underlying sub-sector /end-use or directly from ODEX.

[2] For market diffusion indicators, the energy savings are derived from the increase in the market share; for instance, energy savings from solar water heaters will be calculated from the diffusion of solar water heaters (in terms of installed stock in m^2) multiplied by a coefficient expressed in terms of kWh/m^2.

[3] i.e: (0.18/(2.1+0.18))*100

ODEX is the ratio between the actual energy consumption (E) of the sector in year t and actual energy consumption (E) without energy efficiency improvement (i.e. without energy savings (ES):

$$ODEX = (E/(E+ES)) * 100$$

Energy saving (ES), as derived from the previous formula is equal to:

$$ES = E*((100/ODEX)-1)$$

For instance, if the actual consumption of the sector is 50 Mtoe and if the ODEX is equal to 90, the energy savings are equal to 50*((100/90)-1)= 5.56 Mtoe

2.2.3. Weighting system in ODEX

The variation of the weighted index of the unit consumption I between t-1 and t is defined as follows:

$$I_{t-1}/I_{t} = \sum_i EC_{i,t} * (UC_{i,t}/IUC_{i,t-1})$$

with UC $_i$: unit consumption index of sub-sector i and EC_i: share of sub-sector i in total consumption.

The value at year t can be derived from the value at the previous year by reversing the calculation: $I_t/I_{t-1} = 1/(I_{t-1}/I_t)$,

ODEX is set at 100 for a reference year and successive values are then derived for each year t by the value of ODEX at year t-1 multiplied by I_t/I_{t-1}.

Annex 1 gives more details on the weighting system used that enables a convergence between the calculation of energy savings of a sector from ODEX or from the sum of savings by end-sue/sub-sector.

2.3. Base year for the ODEX calculation: 2000 versus t-1

Two alternative reference years can be used: a fixed base year or a sliding reference year (year t-1).

In the fixed base year approach, all variations in unit consumption are measured in relation to a fixed base year (e.g. 2000); in other words, energy efficiency progress is measured compared to the situation of 2000 (i.e. the energy performance of 2000). The variation of the ODEX is obtained by weighting the gains of each sector between t and 2000. The drawback of this approach is that the results are strongly influenced by the situation at the reference year.

The calculation used in ODYSSEE is based on a sliding base year, which means that energy efficiency gains are measured in relation to the previous year. ODEX cumulates the incremental energy savings from one year to the other.

2.4. Calculation of ODEX as 3 years moving average

The trends observed for some sectors or end-uses, especially for space heating are very irregular, which results in strong fluctuations in the ODEX, that are difficult to understand as energy efficiency progress should normally change smoothly (incremental technical change). Such fluctuations can be linked to various factors: imperfect climatic corrections, especially with warm winters, behavioural factors, influence of business cycles, imperfection of statistics, especially for the last year.

To reduce the fluctuations, ODEX is calculated as 3 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[4].

2.5. How to manage negative energy efficiency improvement

A decrease in the specific energy consumption indicators indicates that energy efficiency has been improving. However, in some cases the indicator may increase, resulting in negative energy efficiency improvements.

This increase in the specific consumption may be due to an inefficient use of the equipment, as it is often observed during economic recession; this is particular true in industry or transport of goods. For instance in industry, in a period of recession, the energy consumption does not decrease proportionally to the activity as the efficiency of most equipment drops, as they are not used at their rated 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. This is the same for road transport of goods by truck as shown in Figure 2.

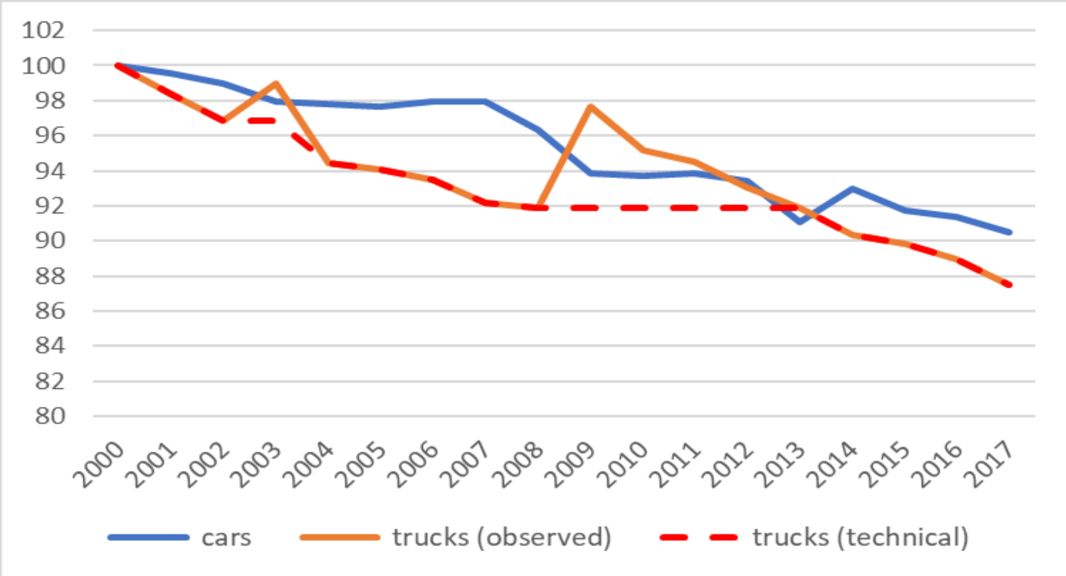
An increase in specific consumption can also be due to the fact that the indicator used is not detailed enough and is not cleaned from other factors that are not related to energy efficiency (phenomenon often called “hidden structural changes”). For instance, the specific consumption of refrigerators may increase because the size of refrigerators is growing.

In ODYSSEE, we separate the technical efficiency from the apparent energy efficiency. The apparent energy efficiency is measured by the gross ODEX, i.e. by the direct application of the formulas.

We also measure a “technical energy efficiency” by replacing the gross ODEX by a “**technical energy efficiency index”,** by considering that if the specific consumption for a given sub sector increases its value will be kept constant in the calculation of the technical index**.** This is illustrated in Figure 2 for trucks.

[4] For the last year, the average is based on 2 years only as well as for the second year. A second method could have been to take for year t the average of t-2, t-1, and t. This method, which is used officially in the Netherlands, however, always underestimates the gains achieved.

Figure 2: Technical versus gross energy efficiency index: case of road freight transport



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

2.6. Case of sub-sectors not accounted for in ODEX

Some sub-sectors are not accounted for in ODEX, such as small electrical appliances for households. The reason is that energy efficiency progress is difficult to capture with the existing indicators (e.g. electricity consumption per dwelling for small appliances), that is usually increasing because of more appliances. The implicit assumption in the mode of calculation of the ODEX is that all these sub-sectors have the same energy efficiency gains as the sector average.

3. Industry

For manufacturing industry, the evaluation is carried out at the level of 12 branches:

- 7 main branches: chemicals, food (beverage and tobacco), textile (and leather), wood, machinery (and metal products), transport vehicles and other manufacturing.
- 3 energy intensive branches: steel, cement and pulp & paper.
- 2 residual branches: other primary metals (i.e. primary metals minus steel) and other non-metallic minerals (i.e. non-metallic mineral minus cement).

For industry, two other branches are added: mining and construction.

The unit consumption is expressed in terms of energy used per ton produced for energy intensive products (steel, cement and paper) and in terms of energy used related to the production index for the other branches.

Unit energy consumption captures the energy efficiency development better than traditional energy intensities (per unit of value added). For some branches the trends shown include also some non-technical changes, especially in the chemical industry the shift to light chemicals, since this sector is not sufficiently disaggregated.

4. Transport

For the transport sector, the evaluation is carried out at the level of 8 modes or vehicle types: cars, trucks, light vehicles, motorcycles, buses, domestic air transport, rail, and water transport.

The overall energy efficiency index aggregates the trends for each transport mode in a single indicator for the whole sector.

For the transport of goods (trucks and light vehicles), the unit consumption per ton-km is used, as the main activity is to move goods. For the transport of passengers (cars, buses, train) the unit consumption per passenger-km is used.

For motorcycles and light duty vehicles the indicator used is the unit consumption (toe) per vehicle.

5. Households

For households, the evaluation is carried out at the level of 11 end-uses or large appliances: heating, water heating, cooking, cooling, lighting, refrigerators, freezers, washing machines, dishwashers, dryer, and TVs.

For each end-use, the following indicators are considered to measure efficiency progress:

- Heating: unit consumption per m2 at normal climate (toe/m2), with a separation between new and existing dwellings.
- Water heating: unit consumption per dwelling with water heating
- Cooking: unit consumption per dwelling.
- Large electrical appliances, cooling and lighting: specific electricity consumption, in kWh/year/appliance.

6. Services

For services, the evaluation is carried out separately for thermal uses fuel and captive electricity uses at the level of 6 branches if data by branch are available[5] : offices (public and private), health (and social work), wholesale (and retail trade), hotels and restaurants, education, and others. Thermal uses are approximated by the consumption of fuels and heat

[5] Case of 12 countries and the EU: Croatia, Denmark, France, Germany, Italy, the Netherlands, Norway, Romania (>2010), Portugal (only electricity and since 2008), Spain, Sweden, UK (since 2005).

(i.e. all energies outside electricity). For countries with a large share of electricity used for space heating (mainly France, Sweden and Norway), the consumption of electricity for space heating is included in the thermal uses

The overall energy efficiency index aggregates the trends by branch.

For electrical uses, the indicator used is the unit consumption (toe) per employee.

For thermal uses, the indicator is the unit consumption (toe) per m² (buildings surface area) when floor area data is available[6], otherwise it is the same as for electrical uses: toe per employee.

If data detailed by branch is not available, the evaluation is carried out using the aggregated indexes of fuel (as a proxy for thermal uses" and electricity for the whole service sector. Similarly to the more detailed approach, if the overall floor area is available, it will be used to calculate the indicator of unit consumption for fuels[7] ; if it is not available , employment is used.

[6] Case of Germany, Spain, France, the Netherlands, Sweden, UK and Norway.
[7] Countries where the overall floor area is available: Finland, Greece.

Annex 1[8]

Methodology of calculation the energy efficiency index: equivalence between an average index and the method of effects

Assume an energy efficiency index is available for each of a number of energy consuming sectors[9]. At the most detailed sector disaggregation level, this index would be a specific energy consumption (e.g. an number of TJ/t of flat glass), a ‘unit consumption’ (energy consumption/activity variable) or an index proportional to one of those.

This note suggests a way of constructing an *aggregate energy efficiency index*, i.e. an energy efficiency index for the aggregation of these sectors. It is a *bottom-up* index, because constructed from specific energy consumptions or unit consumptions at the most detailed sector disaggregation level allowed by the available data.

This aggregate index is defined as follows. If I_t is its value for year t, then the ratio I_t/I_{t-1} is defined as the energy consumption of year t divided by the energy consumption that would have taken place in year t had the unit consumptions been those of year t-1.

Hence the formula:

$$\frac{I_t}{I_{t-1}} = \frac{\sum_i EC_{i,t}}{\sum_i A_{i,t} \,.\, UC_{i,t-1}} \qquad (1)$$

where :

- i : sector
- $A_{i,t}$: activity variable of sector i in year t
- $UC_{i,t}$: unit consumption of sector i in year t

This formula can be generalized by noting that for sector i it becomes :

$$\frac{I_t}{I_{t-1}} = \frac{UC_t}{UC_{t-1}} \qquad (2)$$

For the individual sector, the energy efficiency index can be considered as an index of unit energy consumption.

Equation (2) can be written as follows:

$$UC_{t-1} = \frac{I_{t-1}}{I_t} \,.\, UC_t \qquad (3)$$

Replacing UC_{t-1} by its value in (1) leads to:

[8] Prepared by F Altdorfer from ECONOTEC

[9] ‘Sector’ is taken here in a general sense, representing an energy consumption category, like ‘cement production’, ‘space heating in new appartments’, ‘road transportation of goods’…

$$\frac{I_t}{I_{t-1}} = \frac{\sum_i EC_{i,t}}{\sum_i A_{i,t} \, . \, UC_t \, . \frac{I_{t-1}}{I_t}}$$

or:

$$\frac{I_t}{I_{t-1}} = \frac{\sum_i EC_{i,t}}{\sum_i EC_{i,t} \, . \frac{I_{i,t-1}}{I_{i,t}}}$$

Inverted, this gives:

$$\frac{I_{t-1}}{I_t} = \frac{\sum_i EC_{i,t} \, . \frac{I_{i,t-1}}{I_{i,t}}}{\sum_i EC_{i,t}}$$

or:

$$\boxed{\frac{I_{t-1}}{I_t} = \sum_i ec_{i,t} \, . \frac{I_{i,t-1}}{I_{i,t}}}$$

where $ec_{i,t}$ is the share of sector i in the total energy consumption of year t.

This last formula shows that I_{t-1}/I_t is the average value of the sectoral ratio $I_{i,t-1}/I_{i,t}$ weighted by the share of each sector in the total energy consumption.

Comments

- This relationship has interesting mathematical properties, which allow in particular to calculate the aggregate energy efficiency index in several steps, each with a different level of aggregation. It is possible for example to calculate first separate indexes for industry, transport, residential and tertiary, and afterwards, based on these indexes, a general index for all these sectors together.

- The aggregate index does not require an activity variable for the aggregate sector (which is an advantage, as such an activity level is often not available).

- The unit consumptions used at the most disaggregated levels can be expressed in different units (GJ/t, l/100 km…).

- A complete index can be constructed year by year, by assigning an arbitrary value to any particular year. Say $I_0 = 100$. Then:

$$I_1 = 100 \, . \left(\frac{I_1}{I_0}\right)$$

$$I_2 = I_1 \, . \left(\frac{I_2}{I_1}\right)$$

…

- The above definition is based on two subsequent years. But the formula remains valid if any two different years are considered, for example a base year 0 and a current year t. However, the index calculated directly between year 0 and year t, say J, would not be the same as the one obtained year by year:

$$\frac{J_t}{J_0} \neq \frac{I_t}{I_0} = \frac{I_t}{I_{t-1}} \cdot \frac{I_{t-1}}{I_{t-2}} \cdot \quad \ldots \quad \cdot \frac{I_1}{I_0}$$

- The value of an energy efficiency index will depend on the degree of sector disaggregation. Efficiency indexes based on unit consumptions calculated at levels that are too aggregated will be influenced by structural effects, which should generally be avoided. The greater the disaggregation, the more structural effects will be removed from the indicator and the closer this indicator will get to the ‘real’ energy efficiency.

However, some structural effects might be considered as energy savings, for example the shift from one process to another. If the cement sector is considered as a single sector, the shift from the wet process to the dry process will be considered as an efficiency improvement in the above formula. If the dry and the wet processes are considered as two different sectors, it will not.