Understanding variation in energy consumption

Methodology

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1. Introduction

This report presents a methodology of decomposition of the variation of the primary and final energy consumption by sector into different explanatory factors, among which energy savings based on top-down indicators.

The main objective of this decomposition analysis is to show the drivers that explain the energy consumption variation over a given period, and in particular what has been the role of energy savings coming from efficiency improvements at the level of the different sub- sectors and end-uses.

The methodology has been developed by Enerdata.

Energy savings

In ODYSSEE, energy savings are derived from ODEX, an indicator that measures the energy efficiency progress by main sector (industry, transport, households, tertiary and agriculture) 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 or service sector branches or end-uses for households or transport modes.

The sub-sectoral indices are calculated from variations of unit 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, toe/dwelling…

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

Energy savings by sector in absolute values (ktoe, GWh) are directly calculated from the ODEX. Indeed, ODEX can also be defined as the ratio between the energy consumption at year t (E) and a fictive consumption that would have happened without energy savings (ES).

Therefore, energy savings are equal to

$$\mathbf{ES}= \boldsymbol{C_t} * \left(\left(\frac{\boldsymbol{ODEX\ t}}{\boldsymbol{ODEX\ t-1}}\right) - \mathbf{1}\right)$$

With C : Energy consumption
ODEX : Energy Efficiency Index
t: year

The weighting method has been defined in such a way that the calculation of energy savings is strictly equal to the sum of energy savings by end-use[1], with energy savings obtained by multiplying the variation in unit energy consumption by an indicator of activity. For instance, energy savings for refrigerators are equal to the variation in kWh per refrigerator multiplied by the number of refrigerators.

The direct calculation provides the value of what is called the “gross” ODEX. This gross ODEX is then converted in a “technical” ODEX, that is considered to be closer to the actual progress in the technical efficiency of appliances, vehicles, buildings or technologies.

The technical ODEX is obtained by correcting the gross ODEX of the negative efficiency trends due to inefficient operation of facilities or behaviors, in particular in a period of recession or low economic

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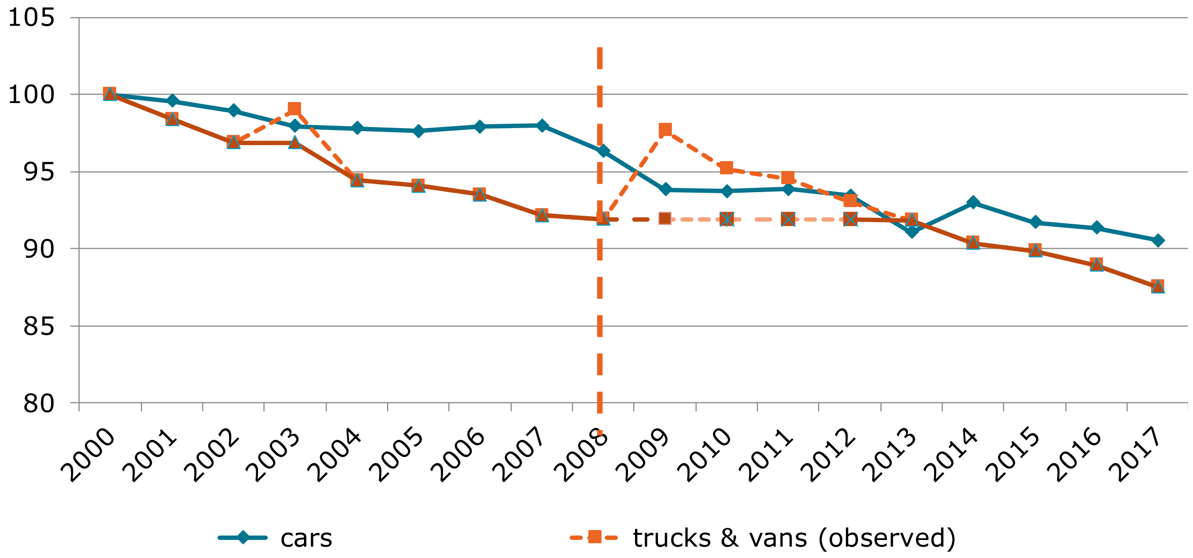
growth: an increase in the indices by sub-sector is not associated to a decrease in efficiency, but as no energy efficiency progress, from a technical point of view.

Figure 1 illustrates these concepts of gross and technical ODEX in the example of transport. For trucks, the specific consumption increases in 2008 and decreases slowly afterwards, but still remaining above its 2008 value until 2013. This trend does not mean that the trucks were less efficient from a technical point of view but that they were used less efficiently, because of the economic recession (empty running, low-rate utilization of their capacity). A calculation of the gross ODEX would take into account this trend and would imply negative energy efficiency trends for trucks, i.e. a decrease in the efficiency of trucks. The technical ODEX freezes the level of efficiency reached in 2008 until 2013 (lower orange dashed line).

The energy savings calculated with the gross ODEX, the "gross energy savings", decrease over 2008-2013. With the technical ODEX the "technical" energy savings of trucks are considered to be equal to zero.

Figure 1: Trends in energy efficiency indicators: example of cars and trucks



In the tool the two definition of energy savings are used: **gross** and **technical,** derived respectively from the "gross" and "technical" ODEX.

By default, **technical savings** are displayed but an option allows the user to show instead the gross energy savings.

2. Decomposition of the energy consumption in industry

The variation of the final energy consumption in industry can be explained by 4 effects:

1. **Activity effect**, measured by the change in industrial activity (measured with the production index);
2. **Structural changes**, measured by the change in the structure of the industrial by branch (based on production index);
3. **Energy savings**, measured by the ODEX, i.e. calculated from changes in specific energy consumption at branch level[2].
4. **Other effects**: mainly "negative" savings due to inefficient operations in industry.

The sum of "energy savings" and "other effects" show the impact of changes in specific energy consumption at branch level.

The **activity effect** captures the changes in the production. It is calculated by multiplying the energy consumption related to production index (previous year, t-1) by the variation of the production between t and t-1.

Activity effect: $EQ_{t/t_{-1}} = IPI_{t/t_{-1}} * (\frac{C_{t-1}}{IPI_{t-1}})$

EQ: activity effect
IPI : production index of industry
C : Energy consumption of industry

The **structural effect** is equal to the variation in energy consumption that would have taken place if the unit consumption of each branch had stayed "constant" (compared to the previous year t-1) minus the activity effect. The first component (named quantity effect) is calculated as the sum of the variation of the production index (between t and t-1) multiplying by the energy consumption per production index of the previous year (of the previous year t-1) for each branch.

Structural effect: $SE_{t/t_{-1}} = \sum_{i=0}^{n} (\Delta IPI_{t/t_{-1}} * \left(\frac{C_{t-1}}{IPI_{t-1}}\right))$ - $EQ_{t/t_{-1}}$

IPI : production index of industry
C : Energy consumption of industry

Energy savings[3] are based on ODEX.

Energy Savings: $ESI = C_t * (\left(\frac{ODEX\ t}{ODEX\ t-1}\right) - 1)$ with C_t: Energy consumption

For industry, ODEX is carried out at the level of 12 branches (10 manufacturing branches, mining and construction if available):

- 4 main branches: chemicals, food, textile & leather and equipment goods (machinery and transport equipment);
- 3 energy intensive branches: steel, cement and pulp & paper

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[2] Specific consumption relating the energy consumption to a physical production (case of steel, cement and paper) and to industrial production index for the other branches.

[3] Energy savings calculated with ODEX similar to the method proposed to ESD; however, in ESD methodology, in principle, only the part of the consumption, and thus of savings, not covered by the Emission Trading Scheme is considered. In ODEX, all savings are considered.

- 3 residual branches: other primary metals (i.e. primary metals minus steel), other non-metallic minerals (i.e. non-metallic mineral minus cement) and other industries.
- Mining industry
- 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.

The change in the value of products is measured by the ratio of the value added by production index or physical production of the current year t divided by this ratio for the previous year t-1.

The last effect (other) represents “negative” savings due to inefficient operations in industry. This deterioration of energy efficiency is mainly taking place during a recession when factories do not operate at full capacity.

3. Decomposition of the energy consumption in transport[4]

The variation of the final energy consumption of transport is decomposed into four main factors:

1. **Activity effect**, based on the change in domestic passenger traffic as well as for traffic of goods;
2. **Modal shift effect** measuring the impact of changes in the distribution of each mode in total traffic of passengers and goods.
3. **Energy savings**, measuring the impact of the variation of the energy consumption per passenger kilometre or tonne-km for each mode of transport[5];
4. **Other effects**, i.e. behavioral effects and "negative savings" in freight transport due to low capacity utilization.

The activity effect is calculated for the different modes of transport separately and summed up. For passengers, it is calculated by multiplying the variation of the traffic measured in passenger kilometre for each mode (cars, bus, rail, tram, metro and national air transport), by the specific energy consumption per passenger-km at base year. For goods, it is calculated by multiplying the traffic in tonne-km of each mode (road, rail, inland waterways) by the specific energy consumption per tonne-km at base year.

Activity effect (passenger): $EQT_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{n}(\Delta pkm_{n,t/t_{-1}} * CU_{n,t-1})$

Activity effect (good): $EQT_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{m}(\Delta tkm_{m,t/t_{-1}} * CUn_{,t-1})$

EQT: activity effect
CU : energy consumption per passenger or good kilometre by mode
n=cars, bus, rail and national air transport for passengers
m= trucks and light vehicles, rail and inland waterways for goods
pkm : number of passenger kilometre by mode
tkm : number of ton kilometre for goods by mode

The savings effect is measured by multiplying the variation of the specific energy consumption per passenger-km or tonne-kilometre of each mode of transport by the number of passenger/goods kilometre.[6]

Savings (passenger): $EST_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{n}(\Delta CU_{n,t/t_{-1}} * pkm_{n,t})$
Savings (goods): $EST_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{m}(\Delta \mathrm{CU}_{\mathrm{m},t/t_{-1}} * tkm_{m,t})$

EST: savings effect
CU : energy consumption per passenger or good kilometre for all transport mode
n=cars, bus, rail and national ait transport for passengers
m= trucks and light vehicles, rail and inland waterways for goods,
pkm : number of passenger kilometre by mode
tkm : number of ton kilometre for goods by mode

At an aggregate level (for passengers or for goods), an additional effect can be calculated, a modal shift effect, corresponding to difference between the sum of savings of each mode for passenger and goods respectively and the aggregate savings calculated directly for passenger or goods as a whole.

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[4] International air transport excluded.

[5] Same definition as proposed to calculate energy savings for ESD.

[6] This calculation is conformed to the methodology proposed by the Commission to calculate energy savings for the monitoring of the ESD in the top-down approach.

Indeed, modal shift illustrates a change in the distribution of each mode in terms of traffic (for example a decreasing share of public transport in passenger traffic contributed to increase the consumption).

Modal shift: $MST_{t/t_{-1}} = EST - (\Delta \mathrm{CU}_{t/t_{-1}} * pkm_t)$ for passenger as a whole

Modal shift: $MST_{t/t_{-1}} = EST - (\Delta CU_{t/t_{-1}} * tkm_t)$ for goods as a whole

For cars, the variation of the energy consumption is influenced by:

- Change in traffic in passenger-km and distance travelled (“activity effect”)
- A “technical efficiency effect”, reflecting the change in the efficiency of cars measured in goe/pkm;
- Other effects, which include a substitution effect and the effect of changes in the average rate of car occupancy (person/car). The substitution effect reflects the impact of changes in fuel mix: from gasoline to diesel and from oil products to biofuel, both leading to an increase of the average heat content (in toe/litre).

4. Decomposition of the energy consumption for households

The variation of the final energy consumption of households can be explained by:

- **Climatic difference** between year t and t_0 ("climatic effect");
- **Change in number of occupied dwelling** ("more dwellings");
- **"More appliances per dwelling"** (electrical appliances, central heating);
- **Change in floor area** of dwelling for space heating ("larger homes");
- **Energy savings**, as measured from ODEX;
- **Other effects** (mainly change in heating behaviors);

The **climatic effect** is calculated by difference between the variation between t and t0 of the actual energy consumption and the variation between t and t0 of the energy consumption with climatic corrections.

Climatic effect: $(C_t - C_{t0}) - (C_{cc,t} - C_{cc,t0})$

C: energy consumption
C_{cc}: energy consumption with climatic corrections

The **demographic effect** due to the increasing number of dwellings is calculated as the variation in the number of dwellings multiplied by the energy consumption per dwelling (with climatic corrections):

Demographic effect: $DEH_{t/t_{-1}} = \Delta nbrlpr_{t/t_{-1}} * CU_{\mathrm{t-1}}$

nbrlpr : number of permantly occupied dwellings
CU : Energy consumption per dwelling with climatic corrections

Two lifestyle effects may also influence the energy consumption of households: the increase in the household equipment ownership (electrical appliances and central heating) and in the size of dwellings (i.e. larger homes).

The increasing number of equipment per households is due on one hand to the increasing number of electrical appliances (ICT, small electrical appliances, air conditioning in Southern countries), larger homes which requires more energy and central heating which requires around 25% more energy compared to single room heating[7].

The increasing number of electrical appliances is approximated with the electricity consumption of large appliance (refrigerators, freezers, TV, washing machine, dish washers) per dwelling in relation with the overall index for electrical appliances (based on the evolution of the electricity consumption per appliances weighted by their energy share). For small appliances and lighting, we take into consideration the energy consumption per dwelling.

The "central heating' effect is calculated as a ratio between the unit consumption per m2 (with climatic corrections) and the unit consumption per equivalent dwelling[8] (with climatic corrections).

Energy savings are based on ODEX, expressed in Mtoe.

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[7] The penetration of central heating was mainly significant in the southern European countries and in Ireland. Central heating (around 85% of EU dwellings in 2009), which includes district heating, block heating, individual boiler heating and electric heating, implies that all the rooms are well heated, as opposed to room heating, where generally a stove provides heat to the main room only.

[8] The unit consumption per equivalent dwelling considers the number of dwellings with central heating (a correction factor of 0.75 is applied to take into account that a dwelling with room heating consumes 25% less than a dwelling with central heating)

Energy Savings: $ESI = C_t * (\left(\frac{ODEX\ t}{ODEX\ t-1}\right) - 1)$

For ODEX, the following indicators are considered to measure efficiency progress:

- Heating: unit consumption per m2 at normal climate (koe/m2)[9]
- Water heating: unit consumption per dwelling with water heating
- Cooking: unit consumption per dwelling
- Large electrical appliances: specific electricity consumption, in kWh/year/appliance

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5. Decomposition of the energy consumption in services

The variation of the final energy consumption in services can be explained by:

- **Activity effect**, measuring the effect of a change in the value added of tertiary
- **Climatic difference**
- **Structural changes**, measured by the change in the structure of the value added by branch
- **Productivity effect**, measured by the change in the ratio of the value added per employment
- **Energy savings**, due to a decrease in the energy consumed per employee by branch
- **Other effects**

The **activity effect** in services is measured by the variation of the value added multiplied by the energy intensity by branch.

Activity effect: $EQT_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{n} \quad \Delta VA_{\ i,t/t_{-1}} * I_{\ \mathrm{i},t_{-1}}$

EQT: activity effect
VA: value added by branch i
I : Energy intensity by branch i
i: hotel-restaurant, health, education, public, private offices, wholesale and retail trade

The **climatic effect** is calculated by difference between the variation between t and t0 of the actual energy consumption and the variation between t and t0 of the energy consumption with climatic corrections.

Climatic effect: $(C_t - C_{t0}) - (C_{cc,t} - C_{cc,t0})$

C: energy consumption
C_{cc}: energy consumption with climatic corrections

The **energy savings** are calculated by multiplying the number of employees by the variation of unit consumption per employee by branch.

Energy savings: $ESH_{t/t_{-1}} = \sum_{\mathrm{i}=0}^{n} \quad \Delta CU_{\ i,t/t_{-1}} * \mathrm{EMP}_{\mathrm{i,t}}$

ESH: energy savings
EMP: number of employees
CU_i : Energy consumption per employee in branch i
i: electric, non-electric or by branch (hotel-restaurant, health, education, public, private offices, wholesale and retail trade)

If the unit consumption per employee by branch increases, the index is kept constant to get the technical energy savings.

The **productivity effect** is calculated by difference between the energy consumption variations, the activity effect and energy savings effect.

The calculation can be done at an aggregate level if detailed data by branch are not available; in this case we consider the evolution of the unit consumption of the tertiary sector, by separating fuel consumption ("non electric") and electricity[10].

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[10] This calculation corresponds to the use of the so called "minimum indicators" according to ESD.

6. Decomposition of the energy consumption in agriculture

The variation of the final energy consumption in agriculture can be explained by:

- An **activity effect** (measured by the variation of the value added)
- **Other effects**

The activity effect is calculated by multiplying the energy intensity of the base year by the variation of the value added between t and t_0.

Activity effect: $EQ_{t/t_{-1}} = \frac{\Delta VA_{t/t_{-1}}}{VA_{t_{-1}}} * C_{t_{-1}}$

VA : value added of agriculture
C_0 : Energy consumption

The **other effect**s represent the effect of the variation in the energy intensity of agriculture: this includes the influence of weather, that can explain significant fluctuations in the energy intensity, changes in the structure of activities and finally energy efficiency. The separation of all these effects is not easy at such a level of aggregation and not necessary given the low share of agriculture in the energy consumption.

7. Decomposition of the final energy consumption[11]

The decomposition of the final energy consumption variation is calculated by combining the sectoral decomposition, i.e. by adding the contribution of the different drivers by end-use sector (industry, transport, households, services and agriculture) in broad categories, as follows:

- Activity: change in the economic activity (value added in industry and agriculture, number of employees in services), in the number of dwellings and appliances, as well as in the size of dwellings for households and in the traffic for passenger and goods in transport
- Structural effects: due to a change in the structure of the value added in industry among the various branches, or due to modal shift in transport
- Energy savings (as measured from ODEX)
- Climatic effect in households and services
- Other effects: behaviors for households, value of product in industry, labor productivity in services and “negative” savings due to inefficient operations in industry and transport.

8. Decomposition of total energy supply and primary energy consumption

Total energy supply represents the quantity of primary energy available for a country to satisfy the national energy demand (including non-energy uses). It includes the energy production and the energy imports but excludes energy exports and international air and marine bunkers.

According to the EED, the primary energy consumption corresponds to the gross available energy (i.e. all energy available for a country for all its energy demand, including international air bunkers). It excludes ambient heat, international maritime bunkers and non-energy uses. It is referred to in the decomposition tool as “**primary energy consumption (EU definition)”**

The variation of the **total energy supply** is explained by:

- the variation of the final energy consumption for energy uses (excluding international air transport);
- the variation of the net consumption of the power sector in three effects (changes in electricity consumption, changes in thermal power efficiency and changes in power mix);
- the variation in the consumption for the other energy transformations
- the variation of the consumption for non-energy uses.

The variation of the **primary energy consumption (EU definition)** is explained by:

- the variation of the final energy consumption for energy uses (including international air transport),
- the variation of the net consumption of the power sector in three effects (changes in electricity consumption, changes in thermal power efficiency and changes in the power mix between thermal, renewables and nuclear).
- the variation of the consumption for the other energy transformations

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[11] Non energy uses excluded.

9. Decomposition of the power sector

Four main effects explain the variation of the net consumption for power generation:

- The variation in the electricity consumption, i.e. the variation of total final consumption and of the market share of electricity that, all things being equal, contribute to increase the losses in power generation;
- Changes in net imports of electricity ("electricity imports"), that has a negative effect on the net consumption for power generation if net imports increase, as less power is generated, implying lower losses (and positive if they decrease);
- Changes in the power mix between renewables (solar, wind, hydro), nuclear and thermal); as renewables are considered with an efficiency of 100% in energy statistics, compared to 33% for nuclear and 35-45% for thermal power, an increased penetration of renewables will, all things being equal, reduce the net consumption of the power sector.
- Variation in the average efficiency of thermal power generation.

Table 1 displays the actual variation in these different factors at EU level for two periods:

- 2010-2020, characterized by a decrease in the share of nuclear and thermal and a strong increase in the share of renewables (+14 points) and a slight increase in the average efficiency of thermal power (+1.9 pts), two factors that contributed to reduce the net consumption of the power sector.
- 2020-21 characterized by a decrease in the share of renewables (-1.1 pts)

Table 1: Variation of the driving factors of the consumption of the power sector at EU level

	Unit	2010	2020	2021
Power mix				
Share of nuclear	%	28,6	24,5	25,1
Share of hydro, solar & wind	%	18,9	32,9	31,8
Share of thermal	%	52,1	42,2	42,7
Average efficiency of thermal generation				
	%	38,0	39,9	39,6

The effect of changes in net imports of electricity ("electricity imports") is calculated using the ratio electricity production /final electricity consumption. An increase in net imports corresponds to a decrease in this ratio, and vice versa. This effect is calculated from the variation of this ratio between t-1 and t (in %) applied to the net consumption at year t-1. For instance, if the ratio electricity production over final electricity consumption decreases from 1.45 to 1.4, because of an increase in net power imports, which means a reduction by 4%, this means that all things being equal, the increase in net power imports would reduce the net consumption of the power sector by 4%.

The last two effects are calculated as the difference between the actual consumption of the power sector in year t and a fictive consumption:

  - At year $_{t-1}$ power mix and power efficiency of year t: power mix effect
  - At year $_{t-1}$ efficiency and power mix of year t: efficiency effect

The variation in the average efficiency of thermal power generation can be due to two factors:

- Change in the fuel mix, in the share of oil, gas and coal in thermal power generation: a higher share of gas would reduce the net consumption of the power sector, whereas a higher share of coal would have the reverse effect, i.e., increase this consumption.
- Change in the efficiency for each type of fuel (change in the efficiency of gas power plants or coal power plants); for instance, the efficiency of gas power may increase if the share of efficient technology increase (e.g. higher share of gas combined cycles in gas-fired power generation) ; it may decrease on the other hand if the load factor of gas power generation decrease, which is happening with the rapid diffusion of renewables.

Table 2 displays the actual variation in these different factors at EU level for two periods:

  - 2010-2020, characterized by a strong increase in the share of natural gas in the thermal power mix (+10 points) and a strong decrease of the share of coal (-15) and an increase in the efficiency of both gas and coal power generation, factors that contributed to reduce the net consumption of the power sector.
  - 2020-21 characterized by a decrease in the share of gas (-3.3 pts) (and an increase for coal) (-1.1 pts), as well as a slight improvement on the efficiency of coal power.

Table 2: Variation of the driving factors of the average efficiency of thermal power at EU level

Thermal mix				
Share of natural gas in thermal power	%	37,8	47,7	44,4
Share of coal in thermal power	%	48,4	32,5	36,4
Share of biomass in in thermal power	%	8,3	15,6	15,3
Efficiency of thermal generation by fuel				
Efficiency of coal thermal power plants	%	36,0	35,7	36,4
Efficiency of gas power plants	%	45,3	49,8	49,5