Measuring energy efficiency progress in the EU: the energy efficiency index ODEX

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Abstract
In the framework of the SAVE-ADEME project ODYSSEE, gathering 15 national energy efficiency agencies, a methodology has been developed over the past ten years to monitor energy efficiency at national and sectoral levels. From the 200 energy efficiency and CO_2 indicators available in this database, we have recently developed an **"aggregated bottom-up energy efficiency index**, called **"ODEX"**. It has been conceived in order to meet the political need for monitoring energy efficiency and to have an easily understandable, workable and comparable indicator depicting the energy efficiency progress in EU Member States.

This index is obtained by aggregating the unit consumption changes observed for a given period at detailed end-use levels. Using relevant physical parameters, the ODEX-indicator provides a good "proxy" of the energy efficiency progress from a policy evaluation viewpoint. ODEX is an alternative to monetary energy intensities, which include many factors that are not directly linked to energy efficiency. Results at the EU-15 level and by country at national and sectoral level are presented for the period 1990-2002. Comparison with energy intensities and further methodological improvement are discussed as well as the possible use of ODEX for monitoring the 1% energy efficiency target of the "Energy Service Directive".

Introduction
Policy-making in the energy and environment fields often relies on quantitative objectives. In the future there will be even more requirements on quantitative monitoring and evaluating the impact of energy policies and measures. The reason for this development is that there are firm targets for the reduction of energy consumption and greenhouse gases, in particular since Kyoto. Obligation to report on the progress of actions carried out is mentioned in:

- the European Union Energy Efficiency Action Plan and the SAVE programme which have the global objective to reduce energy intensity annually by one additional percentage point
- the EU Directives on electric appliances and Energy Star for IT-appliances, as well as the Directive on the Energy Performance of Buildings, the CHP Directive or the (proposed) Energy Service Directive
- the EU Renewable Electricity Directive and the White Paper on Renewable Energy Sources
- National Communications to the United Nations Framework Convention on Climate Change UNFCCC
- National and EU Monitoring Reports under the EU Monitoring Directive 99/296/EC, which requires Member States to report regularly on emissions and reduction policies (hence on energy efficiency measures) to the European Commission
- the European Climate Change Programme ECCP, proposing detailed policies and measures to cope with the EU Kyoto target of –8%

- Reporting of Member States on climate change measures under the EU burden sharing and for national targets.

In order to respond to the growing need for monitoring quantitatively the progress of energy efficiency in the European Union, the ODYSSEE database was developed during the nineties. This database contains, for the EU-15 countries and Norway, information on energy consumption and related activities for the various end-uses, at a detailed level of description. (For further information see www.ODYSSEE-indicators.org).

FROM DETAILED ENERGY EFFICIENCY INDICATORS...

In ODYSSEE, various indicators, referred to as **"unit consumption"**, are calculated to depict the changes in energy efficiency by sector at a detailed level: end-uses, such as heating, electrical appliances, transport mode and types of vehicles, industrial sub-sectors). They are expressed in different units, depending on the sub-sector or end-use, so as to provide the best proxy of energy efficiency, taking into account the data available. In the transport sector, for instance, efficiency indicators combine litre/100km, toe/vehicle, koe/ton-km or toe/passenger-km. For households the indicators are expressed in toe per dwelling or per m^2 for heating, in toe per dwelling or per capita for water heating and kWh per dwelling or per appliance for electrical appliances. In industry, energy efficiency is described in terms of toe/ton of production or in toe per value added. Finally, in the service sector, energy efficiency indicators are expressed in toe or kWh per employee or per m^2. All these indicators will be referred to as **"unit consumption".**

...TO AN AGGREGATED BOTTOM-UP INDICATOR

The described bottom-up approach is useful in order to get a detailed diagnosis by sub-sector or end-use and to be able to evaluate the impact of individual policy measures on energy efficiency improvement. However, especially at the policy level there is a demand to provide an overall perspective of energy efficiency trends. This demand is most often met by very aggregated indicators such as energy intensities (i.e. energy consumption per unit of Gross Domestic Product (GDP) at the overall level of the economy, or energy per unit of value added for the industrial sector), or energy consumption per dwelling for the residential etc. Such types of indicators have a number of advantages:

- only very few indicators are needed, hence comparatively few data need to be collected
- they are available for a large number of countries and comparison is therefore easy
- they do not create confusion for non-experts, as they are simple to calculate, opposed to the combination of various indicators at the detailed level described above.

However, these aggregate indicators have the great disadvantage that they combine a variety of different aspects, which can either enhance or hamper energy efficiency progress such as structural changes in the industrial sectors, increasing comfort levels in the residential sector, increasing use of information/communication technologies in the tertiary sector etc. Hence there is a need to retain the exactitude of the detailed indicators while looking for the simplicity of the previously used aggregated indicators of energy intensity. In other words, the detailed indicators need to be complemented with an aggregated (or synthetic) indicator by sector that combines the energy efficiency trends in all detailed indicators by end-use or sub-sector. Such an indicator will be called "aggregated bottom-up energy efficiency index" or in short **energy efficiency index**. By aggregation across the main sectors (industry, households, transport and services), an energy efficiency index is also calculated for all final consumers. This overall energy efficiency index is called ODEX in ODYSSEE, as it plays for the expression of energy efficiency progress the same role as the main stock exchange indices for the economy

The ODEX-indicator represents a better proxy for assessing energy efficiency trends at an aggregate level (e.g. overall economy, industry) than the traditional energy intensities cited above, as they are cleaned from structural changes and from other factors not related to energy efficiency (more appliances, more cars…).

This paper presents the methodology used to calculate the energy efficiency index. It is also illustrated how such indices can be used to measure the energy efficiency progress achieved. This is done through calculation of the ODEX for different end-use sectors at EU-15 level.

The energy efficiency index: definition

To aggregate the unit consumption trends of all sub-sectors or end-uses of a given sector into a simple energy efficiency index, two complementary methods can be used.

First of all, the energy efficiency index can be defined as a ratio between the actual energy consumption of the sector in year t and the sum of fictive energy consumption of each underlying sub-sector/end-use that would have been observed in year t had the unit consumption of the sub sector been that of a reference year. For instance, if the actual consumption of the sector is 90 Mtoe and if the unchanged unit consumption in all sub-sectors/end-uses should lead to a sector's consumption of 100 Mtoe, the index is equal to 90/100 = 0.9 or 90, if expressed as an index. Such an index of 90 means a 10% energy efficiency gain.

The ODEX can also be calculated as a weighted average of the unit consumption index of each sub-sector or end-use, with a weight based on the relative consumption of each sub-sector in the base year. For instance, considering two sub-sectors 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 sub-sector and 100 to 97.5 for the second, the weighed average index is 0.6*(85/100)+0.4*(97.5/100) = 90. By choosing the way to calculate this weighted index properly, the two methods give exactly the same results (*see Appendix 1*) However, the second calculation method is intuitively easier to understand than the first.

Energy efficiency progress in EU countries

MANUFACTURING INDUSTRY

An energy efficiency gain of 1.1% per year on average was achieved in manufacturing between 1990 and 2002, with an acceleration since 1996 to 1.8% per year. Industry is 13% more efficient than in 1990 with chemicals, metals and non-metallic minerals contributing the most (see Figure 1).

For each branch, the indices are based on unit consumption expressed in terms of energy used per unit of physical output (tons produced for steel, cement, glass and paper and production index for the other branches[1]) (see Box 1). Indices capture 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, due to the fact that this sector is not sufficiently disaggregated. On average, over the time period 1990 to 2002, the aggregated bottom-up index decreased by 1.1% annually, with most individual branches in the range from 0.5 to 1.8% per year, except for the chemicals with 2.9% per year.

HOUSEHOLD SECTOR

In the household sector, energy efficiency improved by 10% in the EU 15 (about 1% per year) in the period 1990-2002, as shown by the sector energy efficiency index that reached a value of 90 in 2002. Since 1999 no more progress was achieved, although the efficiency for large electrical appliances improved significantly (Figure 2). This index aggregates the trends in the different end-uses on the basis of their weight in the total consumption. For space heating, en-

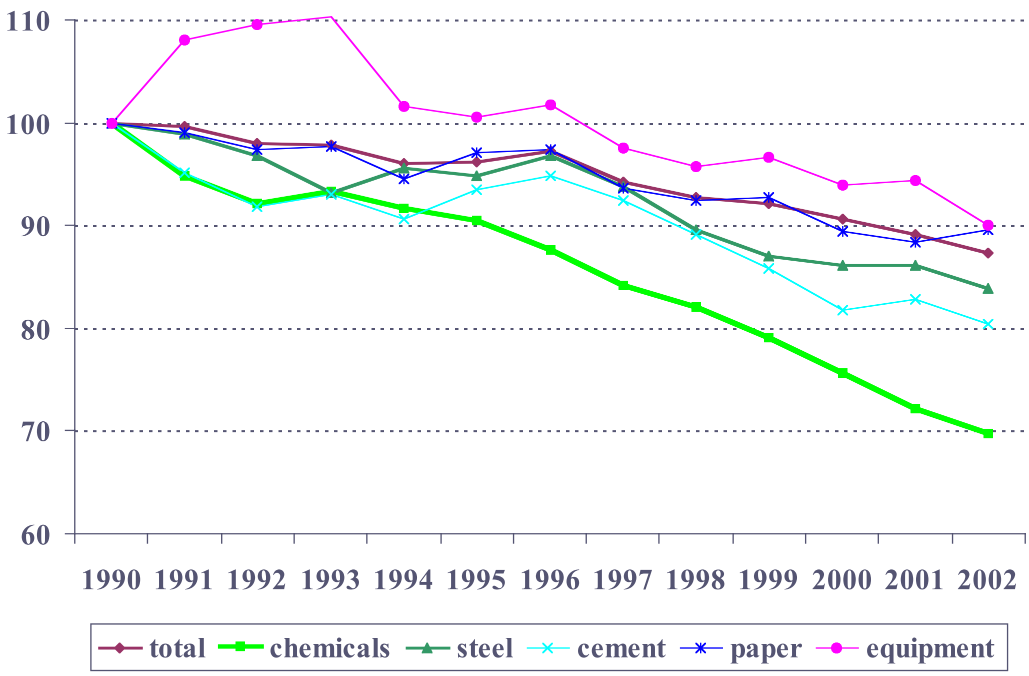

Figure 1. *Energy efficiency trends in industry in the EU-15.*
For the sake of clarity only selected branches are shown in the graph: the total indicator is based on 10 branches

Box 1. Energy efficiency index for industry.

For industry, the evaluation is carried out at the level of 10 branches:

4 main branches: chemicals, food, textile & leather and equipment goods;

3 energy intensive branches: steel, cement and pulp & paper

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 pulp, paper and printing (i.e. mainly printing).

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

* In principle it would also be possible to use value added for the second group. However, the production index is considered closer to the physical production.

1. The production index is a measure of the physical output of a branch

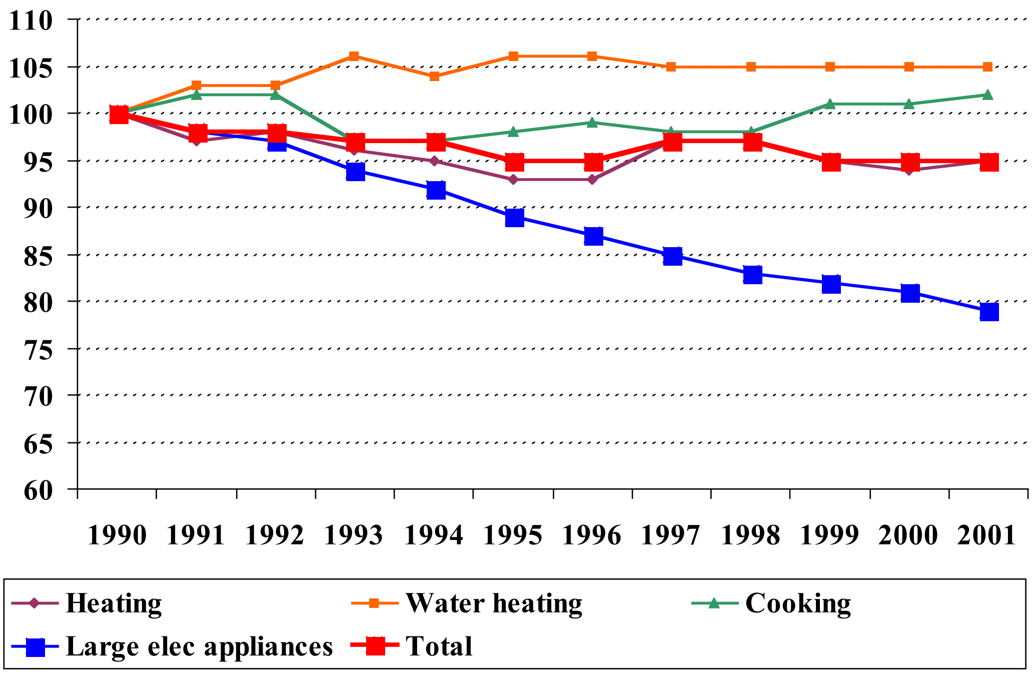

Figure 2. *Energy efficiency index for the household sector.*

Box 2. Energy efficiency index for households.

For households, the evaluation is carried out at the level of 3 end-uses (heating, water heating, cooking) and 5 large appliances (refrigerators, freezers, washing machines, dishwashers and TVs).

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

Heating: unit consumption per m^2 at normal climate (toe/m^2)*

Water heating: unit consumption per dwelling with water heating

Cooking: unit consumption per dwelling

Large electrical appliances: specific electricity consumption per appliance (kWh/year)

* Normal climate means that the heating consumption is corrected to a fictive value corresponding to a normal winter ("climatic corrections").

ergy efficiency trends are calculated from the change in unit consumption per m^2 at normal climate, and for large electrical appliances from the change in specific electricity consumption, in kWh/year/appliance (Box 2). For water heating and cooking, energy efficiency trends are captured by the change in unit consumption per dwelling.

As mentioned earlier, large appliances experienced the greatest energy efficiency improvement, namely 21% since 1990 (index of 79), or slightly above 2% per year (Figure 2). Probably the EU labelling policies initiated in the period since 1992 for the different electrical appliances played an important role, although it must be emphasized that the trend was rather similar in the first and the second half of the nineties.

For space heating, the improvement was rapid until 1995 but a reverse trend is observed since then with a decrease in the efficiency. As technical savings have not actually stopped, with all the extra policy measures in the late nineties and the continuous addition of new dwellings that are much more efficient, this phenomenon is due to behavioural factors that have not been taken into account, such as the higher thermostat settings (see Boonkamp, 1997). Altogether, the energy efficiency progress in the household sector can be estimated at 10%.

All the energy efficiency progress is offset by lifestyle changes

If we compare the trends in the average energy consumption per household with the energy efficiency index, an increasing gap between these two indicators emerges (see Figure 3). In 2002 the unit consumption is at almost the same level as in 1990, whereas the energy efficiency index is 10% below its former value. This means that lifestyle improvements have offset all the energy efficiency improvements achieved.

To measure the impact of lifestyle factors on the average consumption per dwelling, three main influences have been quantified:

- increase in the average size of dwelling;
- the diffusion of electrical appliances and central heating, i.e. the influence of increased appliance ownership;

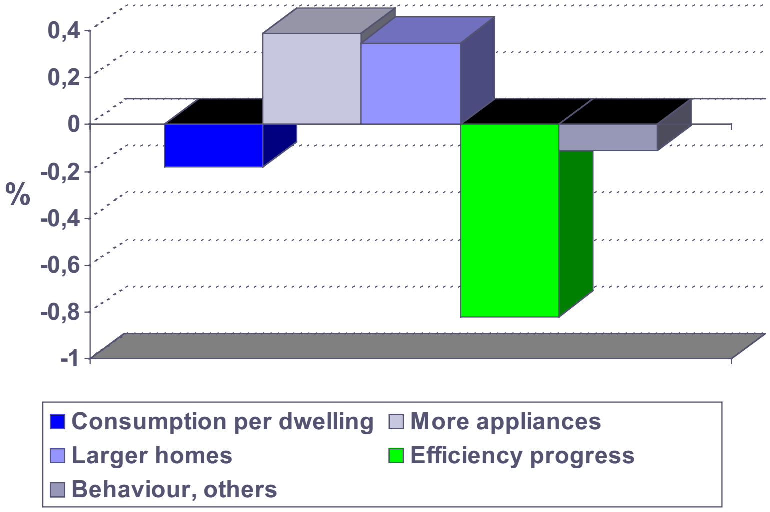

Figure 3:. *Drivers of the energy consumption per household in the EU 15 (1990-2002).*

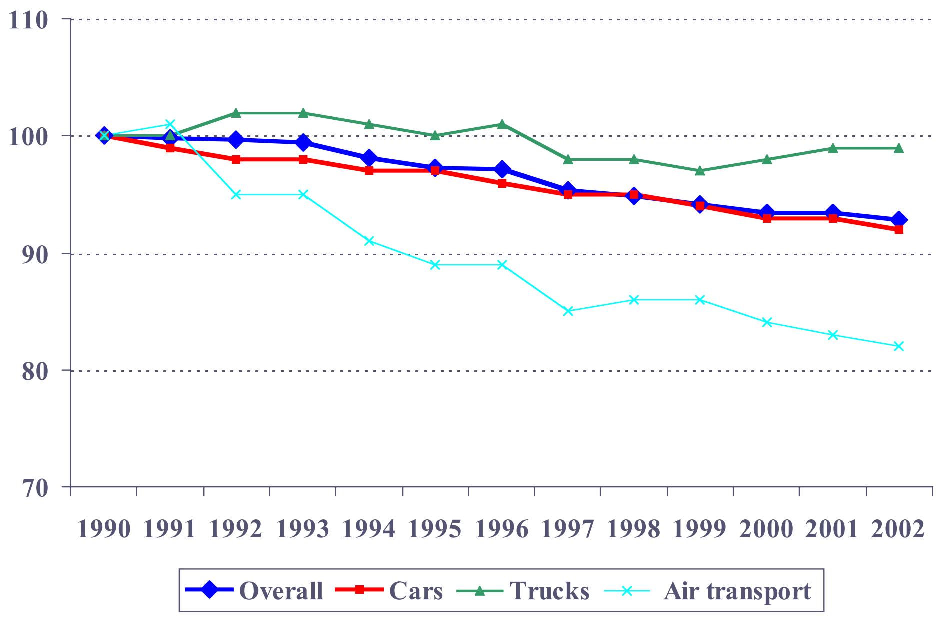

Figure 4. *Energy efficiency index for transport by mode and road vehicle.**

*Only the most important modes of transport in terms of energy consumption are shown in the graph; the index is based on 8 modes.

- behaviour related to increased comfort (mainly an increasing use of hot water).

The results indicate that larger homes and an increasing number of appliances both have contributed to raising the consumption per household by about 5% (Figure 3). These two factors completely offset the progress made in energy efficiency.

TRANSPORT

The transport sector includes road, water, air and rail transport. Energy efficiency in transport improved by 7% between 1990 and 2002 as shown by the aggregated index (index of 93) (Figure 4). This overall energy efficiency index aggregates the trends for each transport mode in a single indicator for the whole sector. For cars, the energy efficiency is measured by the specific consumption, expressed in liter/100 km. 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 other modes of transport various indicators of unit consumption are used, taking for each mode the most relevant indicator given the statistics available: toe/passenger-km for air transport, goe/pass-km for passenger rail, goe/t-km for transport of goods by rail and water, toe per vehicle for motorcycles and buses (see Box 3). Cars, as well as air transport, experienced greater energy efficiency progress than the average of the sector (8 and 18% respectively).

OVERALL ASSESSMENT FOR FINAL CONSUMERS.

The various sectoral bottom-up indicators described so far for manufacturing industry, households and transport can be

Box 3. Energy efficiency index for 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. For each mode, the energy efficiency indicators considered are the following:

cars: specific consumption in litres/km

trucks & light vehicles: unit consumption per ton-km

air transport: unit consumption per passenger

rail, water: unit consumption/pkm or tkm **motorcycles, buses**: toe/vehicle

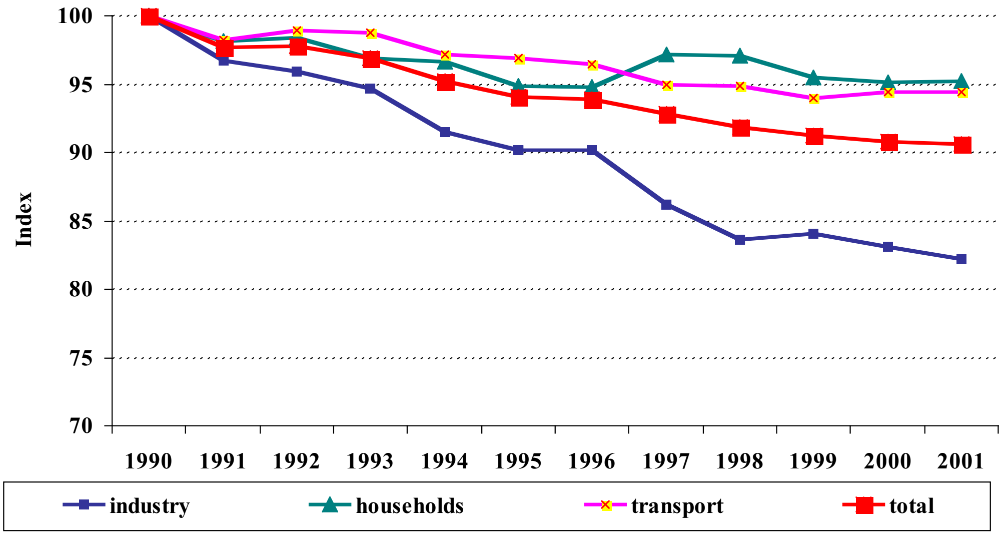

Figure 5. *Energy efficiency progress in the EU-15.**
*1990-2001; at normal climate

combined in a single bottom-up energy efficiency index for the overall economy, called ODEX[2].

Energy efficiency policies and measures implemented since 1990 in the EU-15 have, in combination with autonomous energy efficiency progress, contributed to improve, the energy efficiency of the EU-15 between 1990 and 2002 by almost 10%, or 1% per year (Figure 5): Without these energy efficiency gains, the final energy consumption of the EU-15 would have been 10% higher in 2002. This represents energy savings of 100 Mtoe for the EU-15. Most of the improvement comes from industry.

There is a discrepancy in the trends of the bottom-up energy efficiency index and that of the energy intensity from year tot year However, the trend in the index is more steady (see Figure 6). This discrepancy in fact measures the influence of the structural changes in the economy and the improvements in living standards (as increased indoor temperature and more household appliances for example). The bottom-up energy-efficiency index presents a progress compared to the energy intensity as it takes into account most of the lifestyle and structural factors[3].

Conclusions

There is a strong political need and demand for monitoring energy efficiency trends, mainly through the use of indicators. Practitioners of energy efficiency indicators are often confronted with the problem how to "communicate" on these indicators. On the one hand, they would like to provide relevant information for evaluating all the dimensions of energy efficiency, and therefore develop detailed indicators to get the most precise assessment of a complex reality. On the other hand, decisions makers like to have a limited number of simple, understandable and "saleable" indicators. Within the framework of the ADEME-SAVE project ODYSSEE, we have developed a methodology which aims at filling this gap between the two justified levels of understanding. We have thus created an index called "ODEX". ODEX is a new type of aggregated energy efficiency indicator, conceived such as the "Down Jones stock exchange index". We consider ODEX as a very relevant alternative to the famous but too simplistic energy intensity ratio. Including many structural changes, the energy intensity is only a

2. The service sector is not considered as physical indicators (per m2) are not available for most countries. The overall index is actually based on 26 indicators (10 for industry, 8 for households and 8 for transport)
3. It must, however, also be said that even the efficiency index indicator still contains such factors. The energy intensity includes the service sector, whereas ODEX only includes the three sectors industry, transport and households.

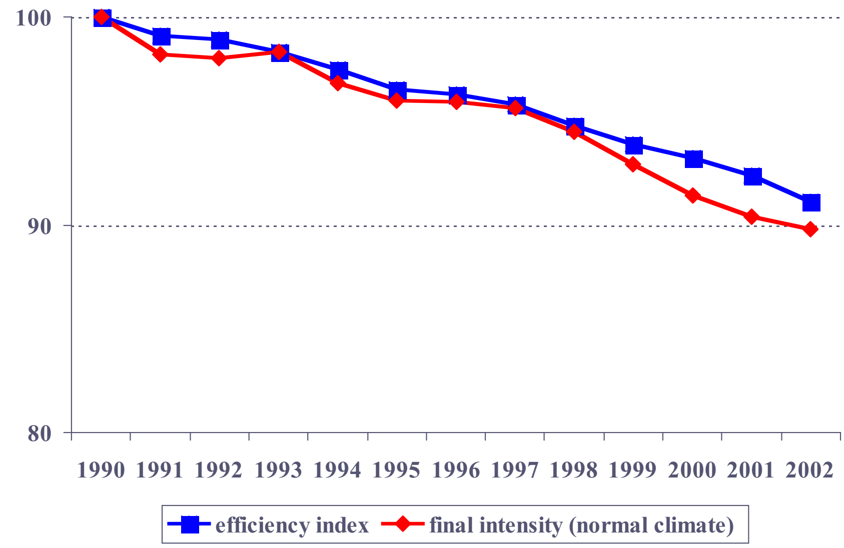

Figure 6. *Energy efficiency index and energy intensity in the EU-15.*

"proxy" of real energy efficiency and mainly assesses the energy productivity of a country.

As it has been demonstrated in this paper, the ODEX has several merits. It is relatively easy to understand by non-specialists. Our first experience on disseminating this methodology is very encouraging from this point of view[4]. ODEX also eliminates structural effects and lifestyle effects as far as possible, although it still contains some influence of these factors because of data constraints. In that sense it can be concluded that this indicator is closer to an engineering based evaluation of energy efficiency. ODEX can be updated easily within a 2 years time lag with the existing data available in most of EU-15 countries.

Results obtained with the ODEX show an overall progress of energy efficiency of around 1% per year over the last decade (including both policy induced efficiency and autonomous technical progress). However, results at country level reveal discrepancies in the pace of improvement of the energy efficiency index. The largest contribution of this 1% improvement is provided for by the industry sector (1.1% per year). However, our current assessment does not properly take into account all the structural shifts in the chemical branches. The improvement in the transport sector amounts to 0.5% per year between 1990 and 2002. This could be due to the technological progress encompassed in the new vehicles, following the ACEA voluntary agreement. The performance in the household sector is very disappointing, particularly for space heating in existing dwellings, probably because of behavioural factors (higher heating temperature). For electrical appliances substantial savings of 2% per year have been realised, probably supported by the EU directives on labelling and minimum standards.

Further improvements of the ODEX methodology are necessary from a theoretical point of view, taking into account the data limitations. The type of activity chosen at the bottom level should be further discussed. Disaggregation of certain sub sectors, e.g. iron/steel, aluminium, other electric appliances, etc should be better incorporated in our assessment. We plan to investigate further methodological aspects through sensitivity analyses. How does the activity indicator chosen influence the overall result, e.g. the use of value added instead of production index in industry? How does the level of disaggregation of the end-uses influence the overall results?

Other attempts will concern extending the geographical coverage of this ODEX methodology to the EU-25. We are also considering developing an ODEX CO_2, certainly extremely useful to depict the "demonstrable progress" of the climate change policies.

We believe that the ODEX methodology could be a very valuable tool to complement other P&Ms evaluation methodologies for the monitoring and verification process of the "Energy Service Directive[5]. As an aggregated bottom-up indicator, on one hand, ODEX serves the need of the European Commission for an aggregated indicator to monitor the energy efficiency target fulfilment. On the other hand, it also matches the need for a good proxy of a pure bottom-up evaluation that some member states are still reluctant to adopt due to the comparatively complex calculation procedure. The consensus reached among European experts, however, gives a certain legitimacy to this methodology, and the adoption by certain Member States of a similar methodology is very encouraging. It gives us a certain responsibility to spread this methodology, notably through a stronger dissemination for a better political acceptance.

4. The European Commission and a number of energy efficiency agencies are making use of the ODEX.
5. ODEX could be used to compare efficiency targets with realisations, but not to judge the effect of policy itself as it is not known which part comes from policy measures and which part from autonomous technological development or energy prices.

Appendix: Method of calculation of the energy efficiency index

Two alternative methods can be considered to calculate the ODEX that gives the same result. The first one aggregates the energy efficiency progress achieved in all sub-sectors on the basis of the amount of energy saved (e.g. Mtoe): it is based on the "unit consumption effect". The second method weighs the individual index of each sub-sector on the basis of its share in the energy consumption of the sector.

AGGREGATION METHOD BASED ON THE UNIT CONSUMPTION EFFECT

The **unit consumption effect** measures the influence on the consumption of the unit consumption variations between year t and either the previous year (t-1) or a base year, depending on whether the energy efficiency progress s is assessed compared to a reference year (e.g. 1990) or on a yearly basis. For instance, a unit consumption effect of –1 000 ktoe in 2000 means that, with the energy technologies and practices of 1990, the consumption would have been 1 000 ktoe higher in 2000.

For a given sub-sector or end-use i, the unit consumption effect at year t is calculated by multiplying the activity level of year t by the unit consumption variation between year t and the reference year. The unit consumption effects (all in the same unit Mtoe) are then aggregated over all sub-sectors and end-uses to provide an aggregate unit consumption effect at the sector level. In industry, for instance, the overall unit consumption effect will be obtained by the aggregation of unit consumption effects by branch. The ODEX is then calculated for each year as the ratio between the actual energy consumption E_t and fictive energy consumption without the unit consumption effect (i.e. without energy savings). An index of 85 in 2000 means an energy efficiency improvement of 15% compared to energy technologies and practices of 1990. Box 4 illustrates this calculation in the case of one industrial sub-sector, the cement industry.

The unit consumption effect (EFCU) measures the impact of the variation of the unit energy consumption per tonne of cement It is calculated by multiplying the cement production by the variation of unit consumption (UC) between year t= 2000 and the base year 1990 ($UC_t - UC_0$). $EFCU_t = A_t * (UC_t - UC_0) = (0.076-0.07)*30$. Thus, the variation of the unit consumption led to a reduction of the consumption of 0.18 Mtoe in relation to 1990. The energy efficiency index of the cement industry in 1999 is then 92, which means that energy efficiency improved by 8%:

$$I_t = \frac{Et}{Et - EFCUt} * 100 \text{ or } 2.1/(2.1+0.18) = 92$$

Equation 1

WEIGHTED INDEX

In this approach, the ODEX is calculated as a weighted average of unit consumption indices by sub-sector. Its interpretation is easier as the value obtained is directly linked to the observation of the energy efficiency change within each sub-sector. F Altdorfer from ECONOTEC has shown how

Box 4. Unit consumption effect: case of cement.

		t_0 = 1990	t = 2000
Production (A)	Mt	25	30
Unit consumption (UC)	Toe/t	0.076	0.070
Consumption (E)	Mtoe	1.9	2.1
Variation of consumption	Mtoe		+0.20
Unit consumption effect (EFCU)	Mtoe		-0.18
Efficiency index (I)	100		92

Box 5. Weighted index: case of transport.

	Unit	1990	1991	1992	1993
Consumption					
Cars	Mtoe	135	136	140	142
Air	Mtoe	28	29	30	32
Unit consumption					
Cars	l/100km	8.7	8.5	8.4	8.3
Air	koe/pass	80	79	74	73
Unit consumption					
index	1	100	97.7	96.6	95.4
Cars	1	100	98.8	92.5	91.3
Air					
Consumption share					
Cars	1	0.828	0.824	0.824	0.816
Air	1	0.172	0.176	0.176	0.184
Efficiency Index					
Weighted average	I_0/I_t*		1.0216	1.0217	1.0124
	I_t/I_0		0.9788	0.9787	0.9878
Index (1990=100)		100	97.9	95.8	94.6

* $I_0/I_t = (\Sigma EC_{it}*(UC0_i / UC_{it})$ with : energy share EC_i ; unit consumption index UC_i (0 refers to 1990 and t to current year).

to make exactly the weighting so as to ensure the same results between the two methods[6]. The principle is to calculate the variation of the weighted index of the unit consumption between t-1 and t, as follows:

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

Equation 2

with UC $_i$: unit consumption index of sub-sector I and EC $_i$: share of sub-sector I in total consumption. Then the index is calculated taking 1990 as reference. Box 5 illustrates the calculation in a simple example of two transport modes.

References

ADEME-SAVE-EnR (2004): "Cross countries comparison on energy efficiency indicators (4 volumes), Paris

ADEME-SAVE (2004): "Energy efficiency indicators in Central and Eastern Europe , Final report, Paris (Volumes 1 and 2)

ADEME-SAVE (2000): "Monitoring tools for energy efficiency in Europe", Paris

Bosseboeuf D., Lapillonne B., Eichhammer W.(1999): "Energy efficiency indicators: the European experience, 167 p., ADEME .Paris

APERC (2001): "Energy efficiency indicators: a study of energy efficiency indicators in APEC economies", p. 161, Tokyo

APERC (2000): "Energy efficiency indicators for industry in the APEC Region", p. 153, Tokyo

EUROSTAT (2003): "Energy efficiency indicators", Luxemburg

IEA (2004):"30 years of energy use in IEA countries", p 211, IEA, Paris

WEC, ADEME (2004): "Energy efficiency: a worldwide review", 229 p., WEC, London

6. For more details, see Energy efficiency index in ODYSSEE; the bottom-up energy efficiency index, ENERDATA, September 2002.