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Dimensions of energy efficiency in a political context

Barbara Schlomann · Clemens Rohde · Patrick Plötz

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Abstract Energy efficiency is widely accepted as a simple and cost-effective way to reduce energy consumption and greenhouse gas emissions. It is accordingly a corner stone of European energy and climate policies. However, in formulation of explicit political energy efficiency goals as well as in monitoring these targets, discussions arise both concerning the concrete definition and the measurement. Accordingly, there is a lack of clarification and in-depth discussions of several fundamental aspects or dimensions of measuring energy efficiency, in particular in a political context. Here, we discuss and analyse two aspects of energy efficiency and ways to measure it, namely the formulation of a baseline and the accounting methods, in order to clarify ongoing discussions. We find that both top-down and bottom-up methods contain a series of "adjustment settings" which can strongly influence the degree of energy efficiency target achievement. Additionally, several baselines can be meaningfully defined and used in a political context. We find a factor of 10 or more between different meaningful definitions of energy efficiency easily achievable. Our results indicate that rigorous definitions should be used for formulating and monitoring energy efficiency targets in a political context if exactly the same understanding of target is to be achieved.

B. Schlomann (✉) · C. Rohde · P. Plötz
Fraunhofer Institute for Systems and Innovation Research,
Breslauer Strasse 48, 76139 Karlsruhe, Germany
e-mail: barbara.schlomann@isi.fraunhofer.de
URL: http://isi.fraunhofer.de/isi-de/

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Introduction

Today, it is widely acknowledged that energy efficiency plays a decisive role within a global strategy to limit the long-term increase of global temperature to 2 °C above pre-industrial levels. According to IEA (2012, p. 253), energy efficiency, i.e. the better use of energy for the production and consumption of goods and services, accounts for 72 % of the CO_2 emission savings in 2020 in a scenario targeted to achieve the 2 °C goal. Though the importance of energy efficiency compared to the other CO_2 reduction strategies considered in the IEA scenario (renewable energies, carbon capture and storage, nuclear energy) falls to almost 44 % until 2035, energy efficiency will remain the most important strategy for achieving global climate targets for decades.

Against the backdrop of a growing number of energy efficiency targets, it has also become more important to regularly monitor the progress made towards these targets. Therefore, quantification becomes more and more important for policy design and evaluation also with regard to energy efficiency. At the EU level, for example, the Directive 2006/32/EC on energy end-use efficiency and energy services (ESD) demanded for a regular reporting on the progress achieved towards national energy efficiency targets by three national energy efficiency action plans (NEEAPs). The Energy Efficiency Directive from October 2012 (2012/27/EU) also provides for annual as well as more comprehensive reporting obligations at 3-year intervals in Article 24. A regular monitoring process is also increasingly being included at the level of individual policy instruments as for energy efficiency obligation schemes. These market-oriented systems to promote energy efficiency, which several European countries have already introduced (see, e.g. Bertoldi and Rezessy 2008, Bertoldi et al. 2010, Bertoldi 2012, Giraudet et al. 2012, Lees 2012 or Staniaszek and Lees 2012) are recommended for all Member States in Article 7 of Directive 2012/27/EU.

Furthermore, there are a lot of open questions with regard to the definition and the monitoring of energy efficiency, though a similar discussion was already led in the wake of Directive 2006/32/EC. This is astonishing for two reasons. Firstly, the general acceptance of energy efficiency as a useful strategy to reduce GHG and CO_2 emissions seems to be more pronounced than for any other strategy (IEA 2012, European Commission 2011). Secondly, there is a long history of profound research on the issue of the definition and measurement of energy efficiency already starting almost 40 years ago after the first oil crisis in 1973. This research mainly aimed at better understanding the link between energy use and economic growth based on indicators relating energy consumption to some kind of economic activity.[1] Since that time, we know that increasing growth is not inevitably linked with an increase in energy consumption due to the resource energy efficiency (also see Schipper et al. 1992).

The actual discussion, however, mainly focus on the setting of energy efficiency targets and its regular monitoring, which causes new challenges and the need for additional measurement methods. The deeper analysis of measurement issues during the implementation process of Directive 2006/32/EC brought some progress with regard to methodological problems and data constraints related to the measuring of energy efficiency (see, e.g. Bowie and Malvic 2005, Boonekamp 2006, Eichhammer et al. 2008, Thomas et al. 2012). The main focus of these studies was on the development of a suitable framework for the measurement and verification of energy savings at the level of a country.[2] The authors addressed the key measurement problems and the tried to harmonise the so-called “top-down” and “bottom-up” measurement methods which were recommended in Directive 2006/32/EC for the Member States’ reporting of target achievement[3] .

In spite of the analytical progress which was already achieved, it seems that a similar discussion started again in the frame of Directive 2012/27/EU. Consequently, the topic of energy efficiency measurement aroused growing interest again. The revival of the discussion shows that clear definitions and common rules for the measuring of energy efficiency are still missing and that some methodological problems are still unsolved (see, e.g. Bach 2012, Pérez-Lombard et al. 2013, Bertoldi and Cahill 2013).

In this paper, we take up two basic aspects of this discussion where we still see a considerable lack of clarification in spite of the previous research in this field. These are firstly the formulation of a baseline and secondly the accounting methods which are used for the measurement of energy efficiency. We will show that without a clear definition of these central elements the formulating and monitoring of energy efficiency targets in a political context is more or less useless.

The paper is structured as follows: the “Overview of the dimensions of energy efficiency” section introduces basic definitions of energy efficiency and discusses the issues “baseline” and “accounting method” from a

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[1] The discussion started during the second half of the 1970s in the USA (see e.g. Schipper and Lichtenberg 1976, Darmstadter et al. 1977, Berndt 1978 and Schipper 1979). During the 1980s and 1990s, energy efficiency indicator projects started both at the country level (see e.g. EIA 1995 for the USA, Farla et al. 1998 and Farla and Blok 2000 for the Netherlands, Natural Resources 2004) and for the IEA (2004) and the European Union (Morovic et al. 1989, Bosseboeuf et al. 1999). For a critical view of these approaches see Horowitz (2008).

[2] Since the late 1970s, monitoring of energy savings has also been part of Demand Side Management (DSM) that aimed at changing both the level and timing of electricity demand. Especially in the USA, extensive programs have been running and various measurement methods have been developed (Loughran and Kulick 2004, Koomey et al. 2010, Violette et al. 2012). But these methods only aimed at a given energy efficiency program and not at the whole energy savings achieved in a country. This is the main difference to the present discussion in Europe which is in the focus of this paper.

[3] In this context, “top down” means a measurement at an aggregated level of the economy using statistical data whereas “bottom up” means an adding up of efficiency gains from individual energy efficiency improvement measures.

theoretical point of view. In the sections "The reference evolution and baseline dimension" and "The accounting method dimension", we discuss these two fundamental aspects in connection with the setting and monitoring of energy efficiency targets in detail. In the final section, we summarize the main points of discussion and give an outlook of the future of energy efficiency measurement with regard to baselines and accounting methods.

Overview of the dimensions of energy efficiency

Definitions of energy efficiency

A typical definition of energy efficiency is the following:

Energy efficiency: useful output divided by energy input (Rosenfeld et al. 2004).

In this manner, energy efficiency is typically defined from a physical consumption of energy as input, which might be electricity, heat, or any other physical form of energy, which is compared to a certain use-value such as output, service, good, or energy. Thus, it is important to note, that all in-depth discussions of energy efficiency and energy efficiency goals start from a specific value of energy consumption in physical units.[4] Both ratios, output per energy input and energy input per output, can serve as energy efficiency indicators. A simple example is provided by "miles per gallon" and "litres per kilometre", both indicating fuel efficiency in of vehicles. Similar ratios are likewise used as measures of energy efficiency in other fields.

For the ratio "energy required per output" the term "specific energy consumption" as well as "specific energy use" or "unit energy consumption" is used (Blok, 2007, p. 171). In some publications, these ratios are also called "intensity indicators"(Pérez-Lombard et al. 2013, p. 242), whereas in others the term "energy intensity" is limited to those cases where the output is measured in monetary units (Enerdata 2008, IEA 2014a, p. 17). This short discussion shows that no general agreement on the definition of these terms exists. In the present paper, we will use the term "energy efficiency" for discussing both ratios, i.e. output per energy input and its inverse..

Specific disciplines have, of course, more specialised definitions of energy efficiency.[5]

Using these and related definitions of energy efficiency, the "useful output" and precise definition of "energy input" can differ significantly depending on the application or context and different names for the specific ratios are also in use, such as "energy performance" or "energy usage". Accordingly, many notions of efficiency and usefulness are met. In engineering, considering for example the efficiency of electric motors, energy conversion efficiency is quite common: efficiency=mechanical energy out/electric energy in (Emadi 2005). Similar to thermo-dynamics, the efficiency of a machine or process is a ratio of two energies and thus a dimensionless quantity.

Furthermore, it is important to note that energy efficiency has to be distinguished from "energy savings". Energy savings could, e.g., be defined to include reduced consumption due to behavioural changes, but the dividing line between energy saving and energy efficiency is of course ambiguous. A comprehensive discussion of the distinction between the two is beyond the scope of the present paper.[6] For the following, we define energy efficiency as "the ratio between a useful output and energy input" closely connected to energy efficiency discussions in a political context. Energy savings, on the other hand, will be used as "a reduction in the use of energy" (Pérez-Lombard et al. 2013, p 252). This means that energy efficiency indicates a relative improvement in the use of energy, whereas energy savings mean an absolute amount of "not used" energy (Pérez-Lombard et al. 2013, p 240).[7] The main focus of this paper will be on energy efficiency as defined above.

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[4] The alternative approach to measure energy consumption in monetary units, i.e. to assess the energy quantities by energy prices, which was especially followed until the mid 1980s (see e.g. Turvey and Nobay 1965 (pp. 787), Schmitt and Görgen 1981 pp 275, Sweeney 1984 p. 34, Nguyen 1984 p. 103), did not gain general acceptance.

[5] For example, the thermo-dynamical definition of the (energy) efficiency of any heat engine is the ratio of mechanical work that engine performs to the needed input of heat the engine requires (Schwabl 2006, p. 143). A comprehensive overview and discussion of the different concepts of energy efficiency from a thermodynamic and economic perspective also gives Patterson (1996). Similarly, the energy conversion efficiency of machines is given by the ratio between energy input and useful energy output. Clearly, all these formulations define energy efficiency as the ratio between an input and a useful output.

[6] See, for example, Lebot et al. (2004), Moezzi (1998), Pérez-Lombard et al. (2013) and Boonekamp (2006).

[7] This definition is also in line with Directive 2012/27/EU where "energy efficiency" is defined as the ratio of output of performance, service, goods or energy, to input of energy and energy savings (Art. 2(4)) and "energy savings" as an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of an energy efficiency improvement measure. (Art. 2(5)).

The various dimensions of energy efficiency

Despite the various possible and useful definitions of energy efficiency, the focus of the present paper is on problems that arise when *comparing* energy consumptions or usage or intensity. The notion of “comparing” immediately raises several questions that evoke different aspects or dimensions of energy efficiency: “Compare what?”, “Compare with respect to what?”, e.g. time, efficiency measure, usage patterns, and many questions alike. Taking together the various definitions of energy efficiency and problems in comparing energy efficiencies, we are led to discuss several aspects or *dimensions* of energy efficiency:

- The *reference evolution* or *baseline* of to which the time evolution of an energy efficiency measure is to be compared
- The *output* and input analysed which are the use-values to be achieved with different physical energy inputs.
- The moment or period of *time* for which a level of energy efficiency is to be reached or the between two measures of energy efficiency shall be compared
- The specific *accounting method* for energy efficiency. Here, not the use-value is meant, but different technical variants possibly leading to very different results (more in the following section)
- *Other* dimensions not discussed in detail here can also play a role.

We refer to these aspects as “dimensions of energy efficiency” in order to emphasise that their clarification or specification in dealing with energy efficiency in a political context is not a minor topic—as “aspect” or might suggest—but instead vital for fixing the actual meaning of or target for energy efficiency. These different dimensions will be discussed in more detail in the present and the following section.

Output and input dimension

As discussed above, different quantities for “useful output” or “useful energy” are applied in measures or indicators of energy efficiency. This can be confusing or misleading, but different applications or settings clearly have different goals and it is only natural to apply different indicators. Common denominators for an energy efficiency indicator are the gross domestic product (GDP—the corresponding indicator is usually called energy intensity), mass, mechanical energy (e.g. for electric motors), capita and many others alike.

To give an example, the energy input can be given as primary energy consumption or final energy consumption. This has important consequences: since renewable energies are usually integrated into total primary energy consumption with an energy conversion efficiency of 100 %, the change from fossil fuels or nuclear energy in electricity generation to renewable energies can lead to a significant reduction in primary energy consumption. By this “computational effect” an economy can become “more energy efficient” without reducing its final energy consumption at all.[8]

A further problem with energy input and system output lies in the notion of “system”. The system boundaries or precise definition of system can be rather involved and can complicate specific definitions of energy efficiency. For example, the energy efficiency a household heating system will depend on the efficiency of the boiler and on the level of thermal insulation (Sorrell and Dimitopoulos 2008, p. 638).

Time-dimension

Time is an obvious dimension for comparisons. It is customary to study the time evolution of energy efficiency indicators in order to identify trends or a general direction of change. However, a comparison in time is only useful under the common “ceteris paribus”, i.e. except for time and the parameters directly entering the energy efficiency indicators, all other parameters and circumstances should not change. To accomplish this exactly is virtually impossible. Thus, many additional normalisation procedures are required and performed when comparing in time. We will discuss different methodologies in the following chapter.

Reference evolution and baseline selection

In a political context, the change in energy efficiency of a system is often compared to the potential evolution of energy efficiency in the same system under different

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[8] Also see the discussions on energy efficiency versus renewable energy sources in Pérez-Lombard et al. (2013) and on the relationship between energy efficiency and renewable energy targets in Harmsen et al. 2014 or Schlomann and Eichhammer 2014.

conditions, e.g. without energy efficiency policies in place (sometimes denoted as "business-as-usual scenario"). This comparison to a reference evolution and different choices of references will be further discussed below.

Accounting and calculation method

A monitoring process for energy efficiency in a political context is usually implemented in practice via a set of indicators which are calculated using a defined accounting method based on a specific database. Depending on the monitoring objective, the demands made of such indicators can vary considerably according to whether this involves

- An ex post or ex ante evaluation of targets and of the policies implemented to achieve these targets
- A top-down calculation based on aggregated statistical data or a bottom-up calculation summarizing the impacts of individual energy efficiency improvement measures.

Many of the reporting obligations and monitoring processes mentioned above actually include more than one objective at the same time, i.e. they may include an evaluation of what has been achieved so far as well as an estimation of future developments or the derivation of aggregated top-down indicators and the concrete assessment of individual energy efficiency improvement measures. Directive 2006/32/EC, e.g. explicitly demanded for "a harmonised calculation model which uses a combination of top-down and bottom-up calculation methods" (Annex IV, point 1.1) for the measurement and verification of target achievement. The methodological problems connected with such an approach will be further elaborated below. We will then show that all indicators usually applied to measure energy efficiency have associated problems which can strongly influence the result of the monitoring process.

The reference evolution and baseline dimension

Motivation: comparison in time

A comparison in time is most common to estimate energy efficiency changes. However, one has to account for the variations in many parameters that change over time. This includes normalisation with respect to weather fluctuations (cold winters certainly require more heating then warm winters, thus energy consumption indicators for heating need to take these "external" conditions into account), economic fluctuations (the recent economic crisis led to a reduced demand for products and reduced production of goods resulting in a reduced energy consumption in industry, whereas the specific consumption per output increased in many countries; see Enerdata 2012) and other system specific changes.

The changes and shifts within industry and between different industrial branches, the so-called structural changes, also lead to a shift in energy consumption and thus to a change in energy efficiency. Furthermore, the energy consumption of producing specific products changes not only due to more energy efficient production procedures but also due to changes in product itself, e.g. its quality and composition. For example, glass bottles are being produced with thinner walls than 20 years ago and even the simple product "glass bottle" cannot directly be compared. Likewise, there are endless methodological and technical issues involved in accounting for such "unwanted" external factors distorting the real change in energy efficiency, which are widely discussed from the early 1970s (see, e.g. Berndt 1978, Diekmann et al. 1999, Farla et al. 1998, Farla and Blok 2000, Ang 2004, Pérez-Lombard et al. 2013).[9] How far a correction of energy efficiency indicators for these external factors is common in practice will be discussed in the next chapter.

Definition of reference evolution

Not only are energy efficiency indicators of a single system compared at different instances of time, but also two possible versions, one of these is fictitious, of one system at the same point in time. That is, one assumes that a certain time evolution had taken place, and compares the actual time evolution to this hypothetical one. The hypothetical evolution of the system under consideration is called reference evolution. Please note that this definition of reference evolution contains a comparison to a fixed point in time as well, as this point in time can be simply extended in time as constant. Other reference

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[9] Similar problems as for the time-dimension occur for cross-country or regional comparisons of energy efficiency (see, e.g. Zhang and Ang 2001).

evolutions could be a "baseline scenario" or "business-as-usual". This idea is schematically depicted in Fig. 1.

The use of reference evolutions can easily be identified by the formulation of conditional statements, i.e., if-clauses. These are counterfactual statements when comparing past evolution, e.g., "If we had not used that energy efficient fridge, our electricity bill would be higher." But reference evolutions are also used for extrapolations into the future, such as "With continued economic growth and no increase in energy efficiency, the energy use in Europe will be *xyz* in 2020." In political contexts, the future reference evolutions can be particularly important when formulating energy efficiency goals. For example, the achieved savings compared to a reference evolution do strongly depend on the assumptions for the reference evolution.

Choosing a baseline

Depending on the field of study or the specific use-value for which a reference evolution is discussed, many ways of formulating reference evolutions are possible. Let us discuss one example in more detail. In many fields, more and more efficient products are produced and offered to costumers, but only slowly enter the markets and corresponding stocks of appliances or machines. This diffusion of energy efficient products, its barriers and economical aspects are a field of its own (see Fleiter and Plötz (2013) for an introduction). Within this context, different speeds of diffusion of the energy efficient products could be distinguished and could serve as reference evolutions, such as frozen efficiency, autonomous diffusion, near-economic diffusion, economic diffusion, technical diffusion. To each of these possible future evolutions belongs an energy saving potential. These possible evolutions and potentials are schematically depicted in Fig. 2.

Fig. 1 Schematic view of reference evolution for comparing energy efficiencies

The "frozen efficiency" evolution is the possible future evolution in which the technologies or products in stock or in the market maintain their current degree of energy efficiency. A second reference evolution with a future increase of energy efficiency of the technology or product under consideration is coined "autonomous diffusion" referring to the speed of diffusion without any external stimulus or incentives. In this case, more efficient technologies automatically diffuse into stocks because older technologies are being replaced with newer, more efficient ones. Within diffusion of energy efficient technologies, the economical aspects and possible financial savings for users are an important group and different "economic diffusions" are being discussed in the literature (see, e.g. Jaffe and Stavins 1994). Here, we chose to display "economic diffusion" denoting the case of each consumer optimizing his total costs of ownership and buying more efficient technology in order to save running costs. However, not all consumers actually perform such an analysis and in practice one would observe a diffusion that is slightly slower diffusion which might be termed, somewhat vaguely, "near-economic diffusion".[10] If all consumers acquired the most efficient technology available irrespective of their cost, one could speak of "technical diffusion". Whatever the speed of diffusion of efficient technologies into the stocks or markets might be, they cannot become more efficient than some technology-specific limit. However, this depends on the technological scope under consideration. For example, in efficiency of propulsion technologies of passenger cars, electric propulsion can reach much higher efficiency (in terms of MJ per kilometre) than internal combustion engines, such that the theoretical limit would depend on whether only combustion engines are being considered or more general propulsion technologies.

Overall, the different speeds of diffusion of energy efficient technologies provide a good example for different reference evolutions for comparing energy efficiency of a system.

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[10] The economic optimum itself is not uniquely defined but requires further discussion (which is not the scope if the present paper). Different near-economic diffusions could, e.g., be defined with different internal discount rates

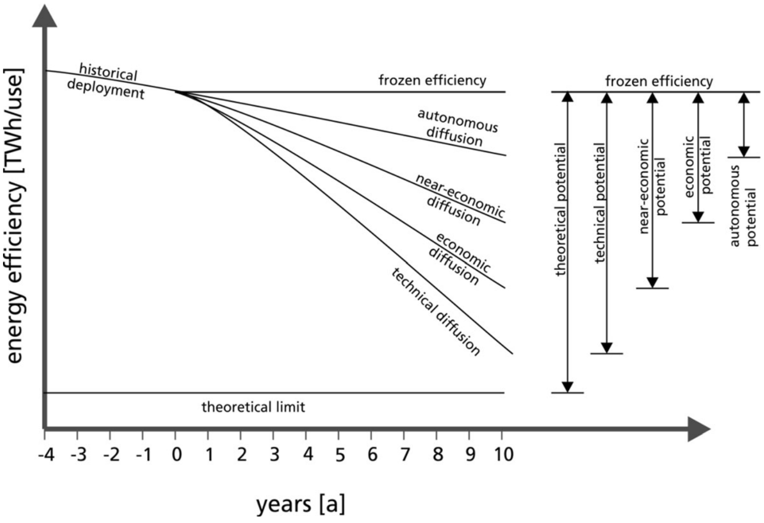

Fig. 2 Schematic view of different possible reference evolutions

Other factors, which are not directly related to energy efficiency, are the autonomous energy technology improvements or direct rebound effects, i.e. a negligent handling of energy following energy efficiency improvements (Lebot et al. 2004; Sorrell et al. 2009).

In summary, many different measures and indicators of energy efficiency exist and various aspects play an important role in determination of an actual energy efficiency and energy savings. The following section will analyse one aspect, actual measures for quantification, in more detail.

The accounting method dimension

Overview of applied methods to measure energy efficiency

As already described above, a monitoring process for energy efficiency in a political context is usually implemented in practice via a set of indicators which are calculated using a defined accounting method and is based on a specific database. A good example for such a monitoring process is Directive 2006/32/EC, which demanded for “a harmonised calculation model which uses a combination of top-down and bottom-up calculation methods” (Annex IV) for the reporting of the energy efficiency progress in the Member States. In the following, a top-down method means that the energy consumption is considered at a highly aggregated level of a country or an economic sector. As a rule, the consumption is related to a reference quantity such as the number of households or an activity quantity such as the economic performance of the area under consideration. Bottom-up methods, on the other hand, start from calculating individual energy savings for one final consumer or one piece of equipment and add these up (Thomas et al. 2012).[11] Directive 2006/32/EC was the starting point for an extensive discussion of measurement issues associated with energy efficiency in Europe.[12] The broad range of possible top-down and bottom-up methods and data sources for measuring energy efficiency and the resulting indicators, which was worked out during the implementation process of Directive 2006/32/EC, is indicated in Table 1.

Some of these methods are also part of the European standard “Energy efficiency savings calculation, top-down and bottom-up methods” (EN 16212), which became valid on 1 October 2012. Directive 2012/27/EU (Annex V, part 1) also recommends the bottom-up

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[11] In Annex IV, point 1.1. of Directive 2006/32/EC, these methods were defined in a similar way: “Top-down calculation method means that the amount of energy savings is calculated using the national or larger-scale aggregated sectoral levels of energy savings as the starting point”. And “bottom-up calculation method means that energy savings obtained through the implementation of a specific energy efficiency improvement measure are measured in kilowatt-hours (kWh), in Joules (J) or in kilogram oil equivalent (kgoe) and added to energy savings results from other specific energy efficiency improvement measures”.

[12] Important methodological issues were especially tackled within the project “Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services” (EMEEES) (see Eichhammer et al. 2008; Wuppertal Institute 2009; Thomas et al. 2012).

Table 1 Spectrum of methods measuring energy efficiency

Method type	Calculation method/ indicator	Origin of the database
Top-down	Aggregated energy consumption	Aggregated information from statistics (energy balances)
Top-down	Simple ratios relating energy consumption and an activity	Aggregated information from statistics (energy balances, national accounts etc.)
Top-down	Normalised and/or corrected indicator	Detailed information from statistics
Top-down	Methods for re-aggregation of indicators (e.g. chain index)	Detailed information from statistics
Top-down	Econometric methods (e.g. regression analysis)	Long-term time series from statistics (e.g. national accounts, energy price statistics)
Top-down/ bottom-up	Market diffusion indicator	Market statistics (share of specific equipment or practice in the market)
Top-down/ bottom-up	Stock modelling of products/equipment	Market statistics/partly market surveys
Bottom-up	Deemed estimates	Use of standard or default values
Bottom-up	Engineering estimates	Use of technical relations
Bottom-up	Aggregated measurement	Billing analysis
Bottom-up	Individual measurement	Direct measurement

Source: own compilation based on Eichhammer et al. 2008, Seefeldt et al. 2010

methods described in Table 1 for reporting obligations under Article 7 and 20 of the Directive.

Regardless of the broader use of these methods in official European standards and Directives, all accounting methods mentioned in Table 1 contain a series of "adjustment settings" which can strongly influence the degree of energy efficiency target achievement. These methodological problems and its implications for the monitoring of energy efficiency targets are discussed in the following paragraphs.

The problem of normalisation and correction

One major practical problem of an accurate measurement of energy efficiency are the *normalisations* and *corrections* for external influences which are not primarily attributable to changes in energy efficiency in a technical sense or to specific energy efficiency policy measures. Though there is a long-lasting theoretical discussion on this issue, as it was shown in the previous section, the use of correction factors when measuring energy efficiency over time is not as widespread as imagined against this backdrop. Whereas a normalisation for weather fluctuations is relatively undisputed, even corrections for structural effects are not natural despite the long history of methodological discussions. The same applies to the impact of short-term economic fluctuations, autonomous technical changes or rebound effects, where mainly the unavailability of suitable data often prevents from taking into account these external factors. This is summarized in Table 2 for the most relevant normalisation and correction factors. A distinction is made between the relevance of these factors for top-down and/or bottom-up accounting methods.

Normalisation factors are in principle similar for top-down and bottom-up indicators, whereas correction factors are different. The main difference between bottom-up and top-down evaluation methods with regard to corrections is that the first are applied to all participants of an energy efficiency policy measure, or a particular sample of the participants, while in the case of a top-down evaluation, the scheme also includes non-participants in the policy measure ("autonomous progress") who have to be corrected for as well if "additional" energy savings are desired which are induced by a policy measure (Eichhammer et al. 2008).

In how far normalisations and corrections are taken into account, can have a considerable influence on the amount of energy savings. This is both true for top-down and bottom-up indicators, though the impact will be more pronounced in the case of top-down due to fact that also non-participants in the policy measure are included, as stated above. Depending on the external influence, the impact on energy savings can be in both directions. Two of the most critical factors in case of top-down measurement, i.e. the impact of the autonomous technological progress and the impact of earlier policies, however, increase the amount of energy savings and thereby reduce the efforts necessary to gain additional energy savings.

The problem of data availability

As shown in the previous section, missing data is one major problem for a widespread use of methods for correction (Table 2). But the problem of data availability

Table 2 Normalisation and correction for external influences in the case of top-down and bottom-up indicators

External influence	Methods for correction	Problems
Normalisation—case of top-down and bottom-up indicators		
Temperature variations	Yearly deviation from average temperature	Climate-independent part of energy consumption uncertain
Stock variations	Yearly stock of storable energy sources	Limited data availability
Occupancy levels, opening hours etc.	Normalisation factors	Partly lack of suitable data to derive the normalisation factors
Correction—case of top-down indicators		
Quantity influences: influence of economic or other drivers on energy consumption (e.g. value added in industry, no. of population or households)	Use of energy intensities/specific consumption values	Choice of suitable driver for respective sector/end-use/object
Structural effects (e.g. sector or product structure in the industrial and tertiary sectors)	Disaggregation of energy consumption, factor decomposition methods	Limited data availability at disaggregated levels; suitable decomposition method
Business cycle: influence of short-term changes in capacity utilization	Econometric approach	
Autonomous technological progress: energy efficiency improvement independent from policies	Econometric approach; derivation of a baseline without autonomous development	Limited availability of long-term time series and esp. of longer time periods without policy influence
Impact of energy prices (not policy-induced)	Econometric approach; use of price elasticities	Limited availability of long-term time series
Economic rebound effect: additional quantity effects, mainly depending on income (e.g. larger living area or appliances, higher room temperature)	Correction factor	Suitable data for the derivation of correction factor are missing
Early Action: influence of policies from earlier periods	Baseline without impact of earlier policies	Restricted information on impact of earlier policies
Correction – case of bottom-up indicators		
Double-counting: due to interaction of policies	Correction factor	Suitable database for the derivation of plausible correction factors (e.g. by surveys or ex post evaluations of policies) is often missing.
Non-compliance: stipulations are not fulfilled (esp. in case of regulatory instruments)	Correction factor	
Multiplier effect: enhances the initial impact of a energy saving measure	Correction factor	
Free-rider effect: energy saving would have occurred without saving policy	Correction factor	
Direct rebound effect: behavioural changes due to saving measure (e.g. increased lighting or room temperature)	Correction factor	

Source: Own compilation based on Eichhammer et al. 2008, Thomas et al. 2012

also occurs with regard to the different methods measuring energy efficiency (Table 1). This both applies for top-down and bottom-up methods, though the kind of necessary data is different.

For statistic-based top-down indicators, especially detailed, complete, timely and reliable statistics are essential to monitor the energy situation at a country level as well as at an international level (see, e.g. IEA 2005, 2014b). The data gaps generally grow with a higher degree of disaggregation. As the ODYSSEE database on energy efficiency indicators[13] shows, there are data gaps in many EU countries especially at the level of final end-uses (as, e.g. energy consumption for heating and cooling), on energy consumption for building types and for the tertiary sector. The latter is especially characterized by a very heterogeneous structure of energy consumption. Another problem of top-down indicators, which makes a regular and current monitoring difficult, is the often long delay involved in supplying the statistical data for a specific year. Depending on the data, the time delay can amount up to 2 years or even more. In order to bridge the data gap until the current year, there are first attempts to develop short-term indicators based on energy intensities as a proxy for energy savings (Boonekamp 2012).

For model-based top-down indicators, the problems here primarily concern the methodology. Stock models, which are mainly used for forecasts, frequently only contain historical data for a reference year, or are only brought in line with the statistics for isolated years and then extrapolated. Moreover, the models illustrating energy consumption structures in great detail also frequently make extensive use of estimates which, in turn, have been obtained with different methods (e.g. surveys, measurement, expert interviews, literature searches).

All the bottom-up methods of determining savings shown in Table 2 contain only two basic elements to start with (European Commission 2010): an activity variable (usually number of cases or objects) and a uniform saving per case (usually the consumption before carrying out an energy saving measure minus the consumption after the measure). This means that data at the level of individual measures are necessary which can, however, be gathered at different levels of accuracy depending on the method used: by direct or indirect measurement of individual actions or by the use of more aggregate average data standard values based on theoretical considerations or estimates (see Table 1). Conducting direct measurements on the respective object or case represents the "ideal" bottom-up method; this is, however, also by far the most complex and costly and will therefore only be applied in a few cases. The data collection cost in the other bottom-up methods is successively reduced by using already existing measurement data, especially from energy consumption invoices as well as by relying on technical impact assessments and the use of standardized key figures. But the cost reduction is gained at the expense of the accuracy of the energy saving assessment. Here, it is essential that the technically identified impact correlations are properly illustrated. This may involve a certain effort when generating deemed estimates, but this only has to be done once, unlike the approaches based on continuous measurements and seems justified from the viewpoint of the accuracy of the evaluation. Using already existing data collected at case level in another context (e.g. building energy performance certificates, production statistics, energy management systems in companies) can also help to reduce the cost of data collection at a relatively high level of data accuracy.

To sum up, a sufficient amount of data availability is a prerequisite for all monitoring approaches and must be taken into account for each decision on a specific monitoring process in good time.

Importance of the accounting method

The method of accounting of efficiency measures over time is another important characteristic especially of bottom-up methods. When efficiency measures are evaluated, the generated savings have to be accounted in some way to reflect the temporal development of the measures impact. Accounting energy savings has always a temporal dimension as it is the integral of power savings over time. The second dimension of accounting is whether a single measure is accounted or a variety of different measures is cumulatively accounted.

Depending on the approach, the calculated efficiency gains can differ significantly. To illustrate these differences, an illustrative example is chosen to enhance the transparency of the considerations. As an example, the replacement of a refrigerator based on fictitious figures is chosen. Several assumptions are made to define this example: The baseline definition is not considered in this illustration to enhance transparency by leaving out another variable. Instead, the energy use of the refrigerator is used. The same kind of efficiency measure, the purchase of a refrigerator, is conducted each year over 10 years (indicated by a red dot in Fig. 3). This results in a total installation of 10 refrigerators. After 10 years lifetime, each refrigerator has reached its end-of-life and will be disposed of (indicated by a blue dot in Fig. 3).

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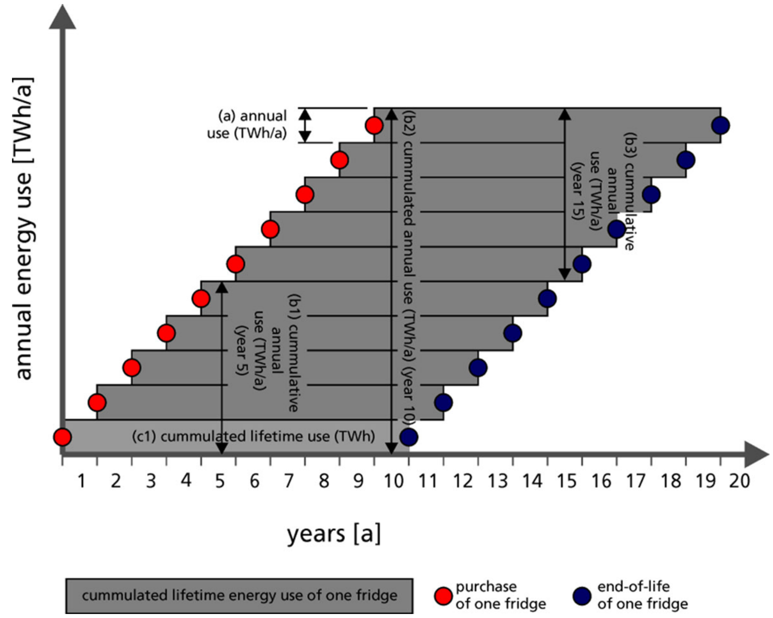
[13] www.odyssee-mure.eu

Fig. 3 Possible accounting methods for energy use



Let us assume the annual energy use of each refrigerator amounts to 1 kWh (per unit). The energy use over its lifetime (cumulated lifetime energy use) is 10 kWh (per unit).

The total energy use of all ten refrigerators over their lifetimes amounts to 100 kWh (per 10 units). In the 10th year, the cumulated annual energy use of all ten refrigerators equals 10 kWh (per 10 units).

These different methods are illustrated in Fig. 3. Each refrigerator is represented by a bar, showing its cumulated lifetime energy use. Within the graph, the different annual energy uses are indicated by arrows, the cumulated lifetime energy uses are represented by the area filled by the bars.

In addition, the three sample calculations are given in Table 3. As a result, the energy uses assigned to the refrigerators vary considerably with the calculation methods though all of them are correct and accountable savings.

The already existing EEO schemes in Denmark, Italy, France and UK show that the reflections above are not only theoretically, but that these accounting methods are actually in use, resulting in very different accounted energy savings for the same efficiency measure. As the example above does not only apply to energy use, but as a consequence also for energy savings (and thus for efficiency improvements), it may be used to illustrate this issue.

The following considerations are based on the accounting methodologies of the different countries, but do not reproduce them in any detail. For example, UK does not account energy savings in their EEO, but the reduction of CO_2 emissions. All other factors not directly linked to the accounting methodology as described above are neglected.

The four countries' accounting methodologies can be summarized as follows:

Table 3 Exemplary energy use for different accounting methods

Accounting method	Unit	Accounted efficiency gains
(a) Annual use	kWh/a	1
(b1) Cumulated annual use (year 5)	kWh/a	5
(b2) Cumulated annual savings (year 10)	kWh/a	10
(b3) Cumulated annual savings (year 15)	kWh/a	5
(c1) Cumulated lifetime savings (measures of year 1)	kWh/a	10
(c2) Cumulated lifetime savings (measures of year 1–10)	kWh/a	100

Table 4 Role of the lifetime of an energy saving measure in different EEOs

Country	Accounted savings in the different EEOs assuming the same size of real savings	Volume of induced saving measures assuming a numerically identical accounting of energy savings (here: 10 kWh/a)
Denmark	1 kWh/a (only energy saving in the 1st year)	100 refrigerators (since each year only the energy savings of the "new" refrigerators of the respective year are accounted for)
Italy	1 kWh/a in the 1st year up to a maximum of 5 kWh/a in the 5th year	20 refrigerators (since the energy savings from the first year are also accounted for in the following years; after 5 years, the savings from the refrigerators bought in the first year cannot be credited, so that another 10 refrigerators have to be supported)
France	8 kWh cumac^1/a[a]	12.5 refrigerators (since each year the savings during the lifetime of 1.25 refrigerators are accounted for; cumulative and discounted)
UK	10 kWh/a (energy savings over the whole lifetime)	10 refrigerators (since each year the total lifetime savings of 1 refrigerator are accounted for)
Description of the energy saving measure: Replacement of a refrigerator (lifetime: 10 years) each year over 10 years with annual savings of the new refrigerator of 1 kWh.		

Source: Schlomann et al. 2012, 2013

[a] Cumac ("cumulé actualisé"): specific energy unit in the French EEO expressing the energy savings during the whole lifetime of an energy saving measure

- Denmark accounts the first year savings of the implemented measure.
- UK accounts the cumulated lifetime savings (using an average lifetime).
- France accounts discounted cumulated lifetime savings (using an average lifetime).
- Italy accounts cumulated savings over the accounting period.

Taking up the same fictitious figures as above, Denmark has therefore decided to account for an annual saving of only 1 kWh from the first year of the measure, whereas the UK scheme accounts for 10 kWh for the exact same efficiency measure, since the cumulated lifetime savings of the refrigerator are accounted for in the first year (see Table 4). They represent the extreme approaches, the Italian and French mechanisms account for 5 and 8 kWh, respectively. The differences between the least and the largest imputed savings in this example comprise a range with factor ten. In practice, with longer lifetimes of saving measures, this range can even become a lot larger. The other way round, the different accounting modes lead to completely different amounts of induced saving measures, assuming a numerically identical accounting of energy savings. The idea behind this consideration is to show that numerically identical targets may lead to quite different savings, when different accounting methodologies are used. This is shown in the last column of Table 5. The required extent of saving measures would amount to 100 refrigerators in Denmark and only 10 in UK in order to obtain the same accounted savings. France and Italy are somewhere in between with 12.5 and 20 units. However, the realized savings in Denmark would be, in fact, 10 times higher than the ones in the UK.

This implies that for a similar energy saving target and a free choice of accounting method, different savings can be reached that vary by factor 10 and more. This means that the same target can be very ambitious or not at all ambitious, only depending on the accounting mode chosen. These examples show the need for a precise definition of the accounting methodology, which is lacking sometimes when targets are set or measures are evaluated.

Importance of the baseline

As pointed out in the previous section, the choice of baseline is yet another issue which can further spread the

Table 5 Exemplary accounted savings for different baseline methodologies for energy savings

Accounting methodology	A+ refrigerator in year 1	A+ refrigerator in year 11	A+++ refrigerator in year 1	A+++ refrigerator in year 11
Baseline: Stock in base year				
(a1) annual saving (year 1–10)	2 kWh/a	2 kWh/a	4 kWh/a	4 kWh/a
(b1) cumulative lifetime savings (year 10)	20 kWh	20 kWh	40 kWh	40 kWh
Baseline: Minimum standards in base year				
(a2) annual saving (year 1–10)	1 kWh/a	1 kWh/a	3 kWh/a	3 kWh/a
(b2) cumulative lifetime savings (year 10)	10 kWh	10 kWh	30 kWh	30 kWh
Baseline: Actual minimum standards				
(a3) annual saving (year 1–5)	1 kWh/a	0 kWh/a	3 kWh/a	1 kWh/a
(a3) annual saving (year 6–10)	0 kWh/a	0 kWh/a	2 kWh/a	0 kWh/a
(b3) cumulative lifetime savings (year 10)	5 kWh	0 kWh	25 kWh	5 kWh

Source: own calculations

different amount of energy savings which are achieved by a certain saving measure. As it was elaborated in the previous chapter, the role of the reference evolution is of particular importance when measuring energy savings.

Most simple, the status-quo ante can be used as the baseline for the achieved energy savings. To reflect legal or technological boundary conditions, normally only energy savings that exceed a standard defined by the baseline should be legitimated for the generation of savings. Nevertheless, there is a broad variety of baseline definitions in relation to which the energy savings can be calculated.[14] Again, an example with a refrigerator is chosen in order to illustrate the crucial issue of the selection of the baseline. Figures 4 and 5 show the cumulated lifetime savings as well as the annual savings of a single product. Three exemplary baselines are shown in the example:

- The stock in the base year
- The minimum standards in the base year
- The actual minimum standards for each year

Not shown are baselines like the actual stock in each year, the market average etc., but the highlighted problems will also apply to them.

Four scenarios are shown in Figs. 4 and 5:

- The purchase of an A+ refrigerator in year 1 (the base year)
- The purchase of an A+ refrigerator in year 11
- The purchase of an A+++ refrigerator in year 1 (the base year)
- The purchase of an A+++ refrigerator in year 11

For these four scenarios, several kinds of savings (and therefore efficiency gains) can be derived from the graphs, when combining different baselines and accounting methods. They are all summarized in Table 5. As in the example before, the efficiency measure is the same for each of the two column sets. Thus, the realized savings are of course the same, too. Nevertheless, the accounted values differ from 5 to 40 kWh/a for the "A+++" example considering the cumulative lifetime savings. All figures are "right", nevertheless without the detailed information about the baseline, the figures (but not the savings) may differ by a magnitude.

Looking at these substantial differences in the calculation of energy savings, the clear definition of the baseline

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[14] The principles for baseline setting are discussed generally in Vine (2008) or Staniaszek and Lees (2012). Concrete examples for the setting of the baseline for specific products or energy uses were developed in several case studies which were carried out within the EMEEES project (Wuppertal Institute 2009, Thomas et al. 2012) and partly used in the recommendations for the measurement and verification of energy savings in the framework of the ESD (European Commission 2010).

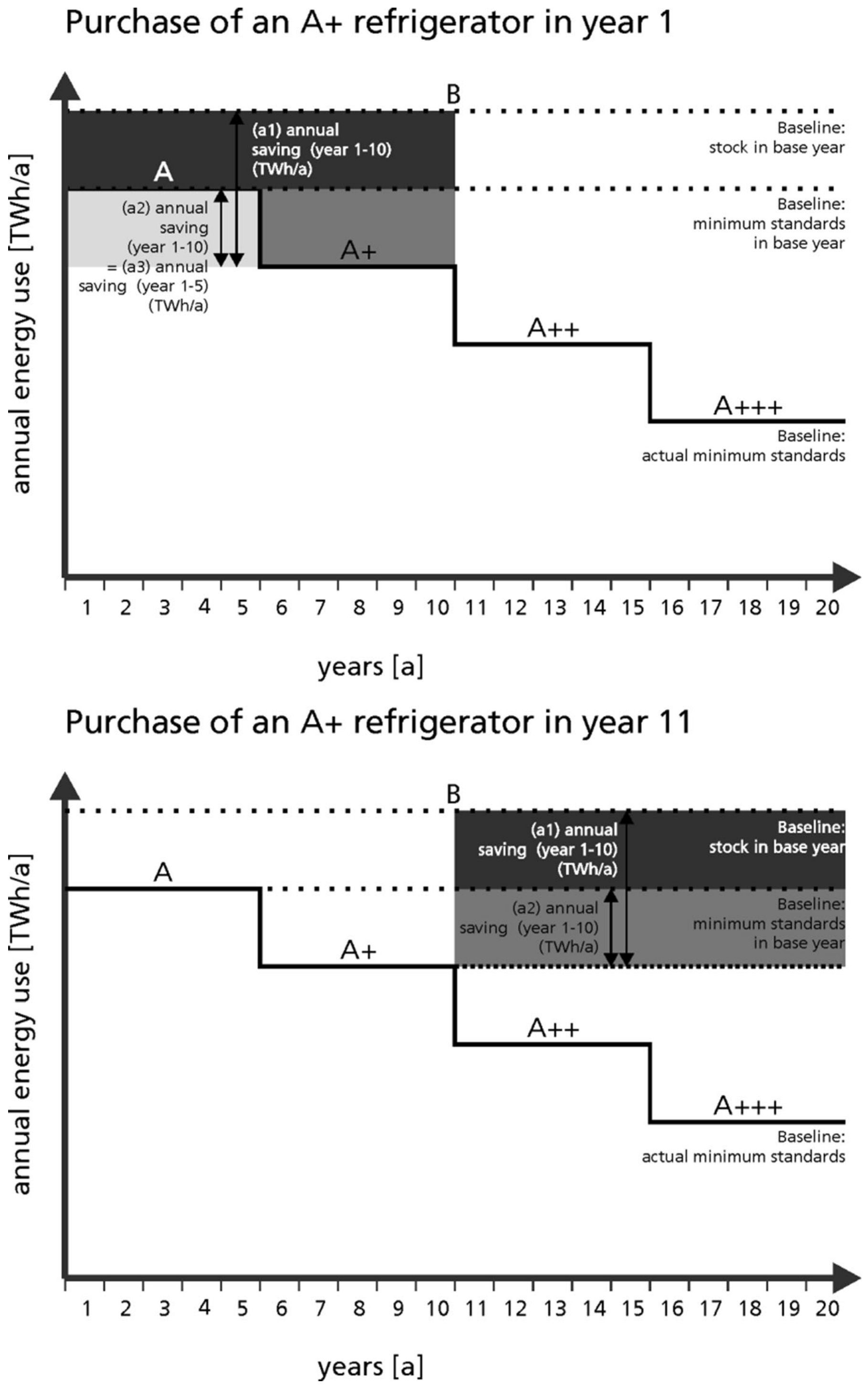
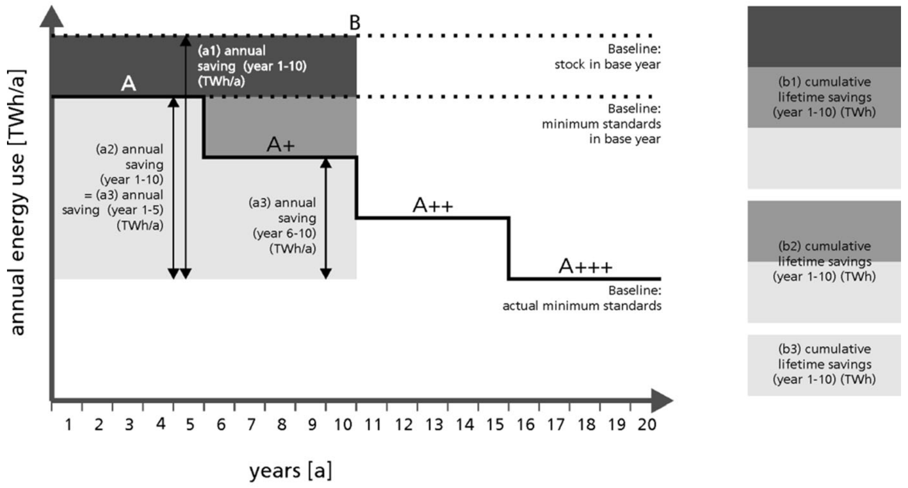


Fig. 4 Baseline definitions for energy savings (example: purchase of an "A+" refrigerator)

is, besides the accounting method, one of the most important issues in the framework of the measurement and verification of energy savings as the basis for the calculation of efficiency gains.

Purchase of an A+++ refrigerator in year 1



Purchase of an A+++ refrigerator in year 11

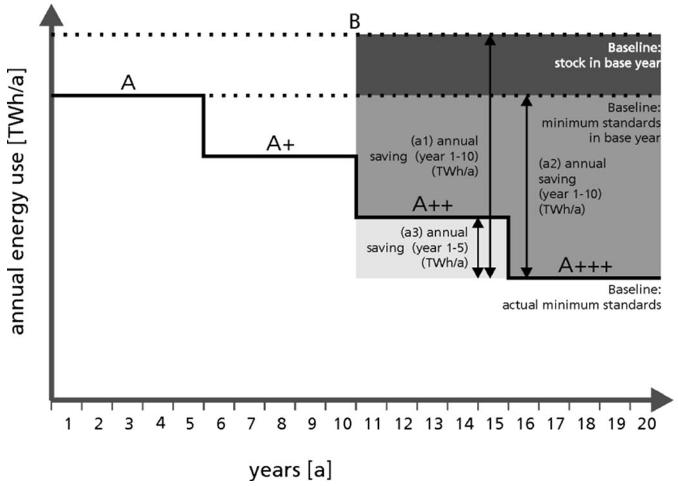


Fig. 5 Baseline definitions for energy savings (example: purchase of a “A+++” refrigerator)

Role of the lifetime

The accounting of the lifetime of an efficiency measure is another feature which can considerably influence the amount of energy savings undertaken in order to achieve a specific energy saving target. As shown above, the consideration of lifetime in the different existing EEO schemes is quite different and ranges from no consideration of the lifetime at all to a full consideration of an (estimated) lifetime.

In the following, the role of different lifetime accounting methodologies will be illustrated by an example from the new EED.

Annex Va (3e) of the EED states that “calculation of energy savings shall take into account the lifetime of savings. This may be done by counting the savings each individual action will achieve between its implementation date and 31 December 2020.” If read literally, savings from a measure with a lifetime >7 years in the year 2014 may be accounted seven times, for all annual savings could contribute to a lifetime cumulated saving. If this lifetime cumulated saving is compared to the annual savings target of Article 7 EED, some strange implications may occur: the accountable lifetime savings decrease in time; this means that measures implemented in 2014 may be credited with a lifetime of 7 years, measures from 2020 only with a single year. This may make sense if only the achievement of the 2020 savings target is the purpose of Article 7. With regard to future saving from the year 2021 onwards,

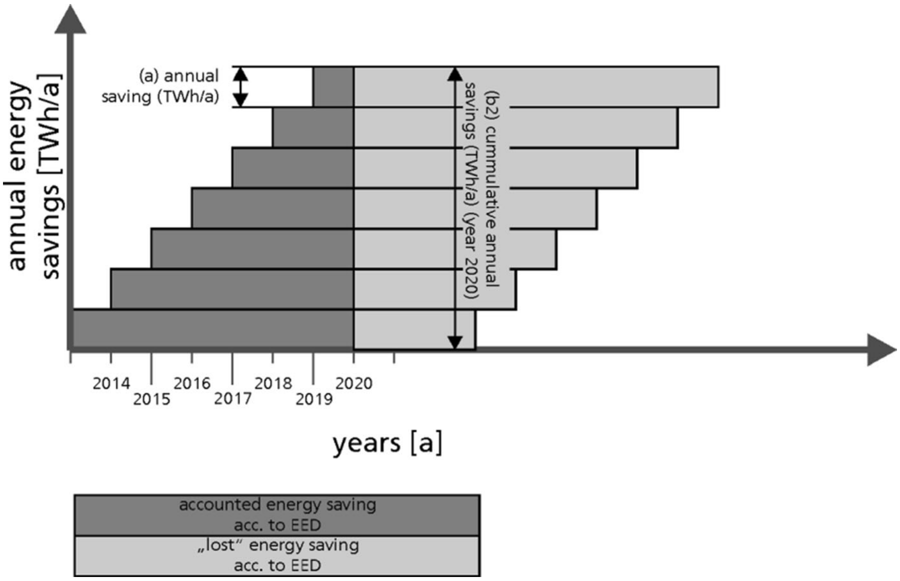


Fig. 6 Accounting methodology of energy savings in the new EED source: Own calculations based on European Commission 2013a

such a design of lifetime accounting seems a bit short-sighted.

In an interpretative note on Article 7 of the EED (European Commission 2013a), the methodology considers a cumulative target increasing over time. So, for the first year 2014, the saving target is equal to the annual saving target of 1.5 %, in the second year 2015 3 % and so on. The following graph (Fig. 6) shows this issue more clearly, assuming measures with an equal technical lifetime are implemented over the years to fulfil the requirements of the EED.

Table 6 Accounting methodology of energy savings in the new EED

	Accountable years acc. to Annex V (3e)	Annual target acc. to Article 7	
(=effective annual target)	Cumulative savings target		
2014	7	1.5 %	1.5 %
2015	6	1.5 %	3.0 %
2016	5	1.5 %	4.5 %
2017	4	1.5 %	6.0 %
2018	3	1.5 %	7.5 %
2019	2	1.5 %	9.0 %
2020	1	1.5 %	10.5 %

Source: own calculations based on European Commission 2013a

It is quite obvious, that measures taken in 2014 account more than the ones taken in 2020, as a result of the chosen accounting of the lifetime (see Table 6). In fact, if a country is bound to miss its saving target in 2020, the target could be reached by implementing a short-living (fiscal) measure, leading to the required savings, as the lifetime is of no relevance in this year. Whether it is in the intention of the directive to incentivize measures with lower lifetime in later years may be doubted.

Without the consideration of the interpretative note, the directive allows even other interpretations of the target. Another accounting mechanism leading to the

Table 7 Alternative accounting mechanism for the EED target

	Max. accountable years acc. to Annex V (3e)	Annual target acc. to Article 7 (=effective annual target) (%)	Life time adjusted savings target (%)
2014	7	1.5	10.5
2015	6	1.5	9.0
2016	5	1.5	7.5
2017	4	1.5	6.0
2018	3	1.5	4.5
2019	2	1.5	3.0
2020	1	1.5	1.5

Source: own calculations

same result is shown in the following (see Table 7). The actual numerical value of the target for 2014 could reflect the lifetime issue and should be set to 10.5 %, which would lead to an effective annual target in accordance with the EED target. The accounting would then reflect the lifetime in such a way, that all the "lifetime" (always keeping in mind that the "lifetime" is limited to 7 years) savings are accounted in the year of measure implementation as it is, e.g. done in the British obligation scheme CERT (see Table 4). Such a lifetime-adjusted target would reflect the lifetime, but on the other hand, the sheer numbers would lead to a much more complicated communication, for we would face a numerically declining target over the years. Nevertheless, such a target setting (which leads to equal savings that the proposed one) makes the effect of declining importance of lifetime quite obvious, whereas the proposed mechanism suggests an increasing effort.

Summary and outlook

In this paper, we discussed different ways to define and measure energy efficiency in order to clarify ongoing discussions concerning the formulation of explicit political energy efficiency goals as well as its monitoring. We showed that there are many definitions and measuring approaches, each in its own right and usefulness. We found that the accounting methods usually used for the measuring of energy efficiency in a political context contain a series of "adjustment settings" which can strongly influence the degree of energy efficiency target achievement. Additionally, several baselines can be meaningfully defined and used in a political context. We find a factor of 10 or more between different meaningful definitions of baselines and accounting methods easily achievable.

Our results indicate that rigorous definitions should be used for formulating and monitoring energy efficiency targets in a political context if exactly the same understanding of target is to be achieved. That is, without a precise and rigorous definition of the relevant dimensions of energy efficiency such as baseline and accounting method, the setting and monitoring of energy efficiency targets in a political context is not meaningful at all.

So far, these clarifications are still outstanding with regard to energy efficiency measurement in the political context. The CEN standard "Energy efficiency savings calculation, top-down and bottom-up methods" (EN 16212) could offer the chance to rely on an agreed methodological basis at least. But this kind of standard only offers a defined framework within which the monitoring demands have to be determined for each process again. Guidelines, as they have only recently been prepared for the interpretation of Directive 2012/27/EU by the European Commission (2013b) itself, the Coalition for Energy Savings (Scheuer 2013) and by eceee (2013) can bring some clarification, too. Nevertheless, all these documents are not binding and may not hinder to make use of existing loopholes due to unclear definitions and measurement approaches.

What is necessary is a common and widely accepted understanding of some basic rules which should at least cover central issues as the choice of the baseline and the accounting method which is crucial to evaluate impacts. This also requires to be as precise as possible about the energy efficiency measure under consideration. Comparability of the approaches is necessary in order to ensure similar efforts or at least to make different efforts transparent. Otherwise, a target which seems to be ambitious at first sight can turn out to be a paper tiger which will not contribute to the priority targets in the field of energy and climate policy. Without rigourous definitions at least on baselines and accounting methods, similar discussions as described here are to be expected in the near future with regard to the design of targets within a 2030 framework for climate and energy policies.

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