Wuppertal Institut
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Defining Energy Efficiency

Wolfgang Irrek (Co-ordination) / Stefan Thomas
with support from: Susanne Böhler, Meike Spitzner

Introduction

The term "energy efficiency" is interpreted differently in national and international literature as well as in various scientific disciplines. The working definition, which will be presented here, reflects the preliminary findings of an internal, interdisciplinary discussion held at the Wuppertal Institute.

While effectiveness marks the degree of achievement of objectives of an activity, efficiency refers to the **ratio of benefits to expenses**. Energy efficiency, therefore, describes the ratio between the benefit gained and the energy used. In this context, different levels and perspectives can be distinguished concerning energy efficiency. They will be specified in the following:

- the consideration of energy efficiency in the macro-economic aggregated perspective of the market-driven economy,
- the perspective of the efficiency of energy conversion in the range of energy supply resp. energy provision, which is predominantly characterised by engineering science,
- the end-use energy efficiency perspective on the demand-side with an increase in energy end-use efficiency achieved by technical, organisational, institutional, structural or behavioural changes, and
- the energy end-use efficiency perspective of the caring economy that includes energy efforts of the human body during mainly unpaid household production.

Energy efficiency in the macro-economic perspective

According to the **macro-economic aggregated perspective** of the conventional market-driven economy, energy efficiency is either denoted as **energy intensity** or (reciprocal) as **energy productivity**. Thereby, energy input is related to **monetary output parameters.** For example, the energy intensity can be stated as primary energy consumption per unit of the gross domestic product (real GDP) or primary energy consumption per citizen. Furthermore, energy intensity can be on the sectoral level stated as primary energy consumption per unit gross value added differentiated by industry sectors. Energy productivity is usually stated as (real) GDP per **primary energy** input. Primary energies include renewables, oil, natural gas, coal, nuclear energy. Some also include the energy of the human body.

Moreover, energy intensity parameters can be measured on the aggregated level as ratios to certain **physical parameters**. Possible examples are, inter alia, the energy consumption per m^2 living space corrected by ambient temperature, the electric power consumption per refrigerator or the fuel consumption per 100 km driving performance. In the caring economy, it refers to the specific energy efforts of the supply of household production output (e.g. production of recreational or caring benefits, reachability benefits and freedom of movement benefits).

Statistical series including adequate index figures are to a great extend existing for the addressed indicators, however, they neither exist for all countries nor for specific indicators concerning energy efforts of supply. Moreover, while using these indicators one has to take into consideration that they are partly vague and imprecise and that they are subject to a range of structural influences (e.g. declining share of energy-intensive basic material production in the GDP). Furthermore, the validity of the GDP as an indicator for the prosperity of a society can be questioned. Another problem is that indicators showing the energy expenditure per citizen or household do not sufficiently differentiate between the energy consumption per citizen and the non-personal energy consumption of the household production in the sense of the caring economy.

Within the scope of the EU-project ODYSSEE (www.odyssee-indicators.org), aggregated energy intensity indicators of several EU member states are corrected by the use of various **correction factors**, e.g. taking account of climatic differences, purchasing power parities as well as industrial and economic structural differences. Further corrections are necessary in order to apply the indicators to measurement and verification in terms of the EU Directive on energy end-use efficiency and energy services. In this context and depending on the particular scope of application and the sector, the so-called “bottom-up” methods of measurement and verification of energy savings have to be weighed up against “top-down” indicators (for measurement and verification of energy savings cf. www.evaluate-energy-savings.eu).

The aggregated **ODEX** indicator, based on ODYSSEE indicators, measures the overall progress concerning the enhancement of energy efficiency. The basis for the indicator is formed by index figures of different fields. In Germany, for instance, the indicator is based upon 27 separate indicators (7 concerning transportation, 9 for end-use energy applications in private households, 11 with regard to industrial fields). Thereby, the **ODEX** indicator is calculated as triennial, moving average value (status information on ODEX: end of 2007).

Energy efficiency in the context of energy conversion

The **efficiency of energy conversion** in the range of energy supply resp. energy provision is **predominantly characterised by engineering science**. In this context, energy efficiency resp. efficiency of conversion can be defined by **efficiency factors** resp. **utilisation ratios** of the conversion (input / output of the conversion), as for instance the ratio of generated end-use energy in proportion to primary energy or to secondary energy used (e.g. efficiency factor of a power plant, a heating system, a cooking device or of a refinery).

End-use energies include those energies used by the end-consumer, such as electricity, heating oil, refined natural gas, long-distance heat, petrol and diesel. **Useful energies** comprise the forms of energy that are used during final application, e.g. radiated thermal heat in a room, process heat, light, compressed air, kinetic energy.

End-use energy efficiency

On the demand-side, the term energy efficiency resp. **energy end-use efficiency** refers to the proportion of the amount of energy used for the satisfaction of personal needs and energy use of non-personal demand. Thus, the term finally refers to the amount of energy or mobility service or the provided comfort . In most cases, the physical benefit achieved by an energy application is in the centre of attention concerning the measurement of end-use energy efficiency, e.g. heat of a living room, cooling of a refrigerator, energy content and heat of prepared food, the facilitation of daily shopping in order to prepare this food (e.g. either by moving from A to B by vehicle or e.g. by the infrastructure enabling shopping within walking distance), dried laundry, goods that are produced by an energy using machine or transmission of information in a company. The quality and the level of service demand / comfort wishes by the end-consumer is not questioned at this stage. Therefore, an increase in energy end-use efficiency means consuming less end-use energy for the same amount of mobility resp. energy application (service / comfort), and therefore, a reduction in energy intensity of the benefit resulting from using energy. This can be achieved by technical, organisational, institutional, structural or behavioural changes.

Energy end-use efficiency and useful energy efficiency in the perspective of caring economy

The analyses of caring economy approaches focus on the production by households, which is mostly un-paid (e.g., production of meals at home, production of caring for children, cleaning activities, etc.). Therefore, the analysis of the caring economy goes beyond the scope of the previously stated perspective. For example, it considers that using public transport instead of a private car usually demands more time (and thus more personal energy) to fulfill tasks like shopping, taking children to school, going to the doctor, etc. Therefore, the caring economy asks if energy savings also reduce the dependency on human activity (and thus personal energy input). An increase in useful energy in the perspective of the caring economy means satisfying needs and at the same time reducing personal and non-personal energy input.

Energy savings and its effects

An increase in energy efficiency can be realised by technical, organisational, institutional and structural changing **actions seeking to save energy**. Other possibilities are: arrangements enabling organisational changes in daily work, abolishment of social and further conflicting goals resulting from action with less energy efficiency and additional measures in order to reach a societal consensus of opinions. Examples of energy saving actions include:

- thermal insulation of buildings,
- efficient heating systems and industrial processes,
- energy saving cars and refrigerators,
- common kitchens and canteens,
- opening a window from time to time instead of a constantly opened window,
- optimisation of ventilating and air-conditioning systems (hours of operation depending on demand),
- creation of local supply superseding traffic needs.

In many cases the implementation of energy saving actions leads to energy savings featuring positive **ecological advantages** as well as to **cost savings**. Often, higher investment costs of efficient appliances and facilities are overcompensated by saved energy and maintenance costs resulting in savings of net costs. Additionally, two effects can emerge: On the one hand, further energy saving actions can be generated by energy saving actions by the involved persons (so called **multiplier effect**, e.g. if a neighbour copies the energy saving actions or purchases of efficient lighting systems by schools soon after one school has installed such a system). On the other hand, the purchase of an efficient refrigerator can for example lead to more energy consumption if the savings of net costs due to the purchase of a new and efficient refrigerator are used for consuming extra goods or services leading to additional energy consumptions. Another example would be an increase in room temperature after the insulation of the walls. However, these so called direct and indirect economic **rebound effects** are usually comparatively small, so that net savings remain. For instance, the Wuppertal Institute has developed a concept for an energy saving fund in Germany and the economic rebound effect was estimated by the use of an input-output-model and amounted to approx. 5% of the energy savings that have been induced by the fund.

Energy efficiency and conserving energy

The increase in energy end-use efficiency is one of the aspects of **energy conservation**. Additionally, energy conservation resp. the avoidance of energy consumption also contains a partial or entire abandonment or substitution of the use of energy consuming products and services. Thereby, fulfilling people's, households' and companies' needs with lower consumption of energy and therefore the limitation of growth regarding energy consuming products, infrastructures and services are in the centre of attention, e.g. going for a walk in the proximity instead of making a trip by car. In contrast to that, the avoidance of wasting energy by lowering a high room temperature to a comfortable temperature is a means to achieve energy efficiency.