A comprehensive indicator set for measuring multiple benefits of energy efficiency

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Abstract

In this paper we develop a quantitative indicator approach to measure multiple benefits of energy efficiency (MB-EE). The MB-EEs are classified into three groups: environmental, economic, and social –related benefits. The first group contains most relevant and direct aspects of energy efficiency such as energy savings and reduced GHG emissions. The second group includes macro-economic effects such as impacts on economic growth, for innovation and competitiveness as well as import dependency. The third group of impacts covers aspects such as health benefits, poverty alleviation and employment. Quantitative knowledge about these MB-EE is, however, scattered and not easily accessible for the actors in the policy field. We therefore develop a comprehensive quantitative indicator set consisting of 20 indicators covering the different aspects of MB-EE. We discuss the methodological approach, the underlying data sources and limitations. This indicator set is applied for 31 countries (EU28 plus Norway, Switzerland and Serbia) to provide a comprehensive tool of MB-EEs. It provides the basis for an in-depth comparison of developments and differences across Europe. The indicator set also supports the design of well-suited energy policies by taking into account, on an informed basis, more of the beneficial aspects of energy efficiency in future.

1 Introduction

Energy efficiency has been an issue since the first oil price shock in 1973, but lost its importance in periods of low energy prices. Its role has been reinvigorated in the last decade and today energy efficiency is seen as essential to all major objectives of climate and energy policies and is denoted as “first fuel” in the EU 2030 climate and energy policy framework [1] and by the International Energy Agency as well [2]. In that context, the Energy Efficiency First-Principle has been developed and energy efficiency is one of the five core dimensions of the Energy Union [3].

A part of energy efficiency options are not cost-effective when only energy savings are accounted as benefits, though most energy efficiency options are cost-effective. Co-benefits of energy efficiency like the reduction of emissions, health and economic benefits can be significantly higher than the cost of energy measures [4]. Throughout this paper, we refer to Multiple Benefits as both the direct benefits of energy efficiency such as energy savings as well as co-benefits such as economic or social impacts [5].

The environmental and health benefits of efficiently using on primary and final energy have repeatedly been studied [6–9]. Also, the economic impacts have been well studied over the last years. More recently, a rapidly increasing number of studies has been dealing with the social impacts of energy efficiency, i.e. effects on living conditions. To unify these different aspects and ensure a more holistic view on the benefits of energy efficiency in a single framework, Ryan and Campbell [10] presented the multiple benefits approach, which was further refined by the IEA [11]. Ürge-Vorsatz et al. [12] proposed several methods for the quantification of multiple benefits or ‘multiple impacts’ of energy efficiency in a green economy context developed as part of the COMBI project[1].

None of these approaches, however, came up yet with a quantitative approach, allowing to capture the Multiple Benefits by means of an indicator approach, using regularly updated time series. To close this gap, we develop in this paper an indicator framework allowing to quantify key aspects related to Multiple Benefits of energy efficiency. Such an approach can support a detailed comparison between countries across the EU and to help designing future effective energy policies for the future. The present paper builds on energy efficiency indicator analysis of the European countries based on decomposition analysis, which has been developed within the European Union Horizon 2020 project ODYSSEE-MURE[2],

In section 2 of this paper, we set out the general methodology for the indicator approach to Multiple Benefits of energy efficiency. In section 3 we discuss the different indicators, including their definition, their limitations and the data availability. It should be noted that the indicator set was defined with the objective of applying it to all European countries. Section 4 presents results for the indicator set. Given the limited space available in the paper, we discuss the results for the multiple benefits for a single country, Germany, having a good coverage for the indicators of Multiple Benefits. For all others results readers may visit the ODYSSEE-MURE web facility about

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1 http://combi-project.eu/

2 http://www.odyssee-mure.eu/

the multiple benefits available online[3]. In section 5 we discuss the indicator approach in a cross-cutting manner and conclude finally.

2 General Approach

For our approach for a comprehensive measurement of multiple benefits we designed a set of indicators, which should allow examining the most important aspects of energy efficiency in three different main categories, namely environmental, social and economic. These indicators are grouped into eight sub-categories, which cover a certain aspect of energy efficiency (see Table 1). The total set contains 20 indicators.

- *Environmental impacts* include the direct effects of energy efficiency on primary and final energy consumption and the mitigation of Greenhouse Gases (GHG) and other (local) emissions by reducing final energy consumption and thus lowering the primary energy consumption of the energy conversion sector for heat and electricity generation. Primary energy consumption and the related emissions are also directly impacted by the penetration of electricity and heat generation by renewable energy sources [13].
- *Social impacts* in our measurement framework are defined as direct effects on aspects such as alleviation of energy poverty, health and well-being (including improved living comfort) and disposable household income.
- *Economic impacts* comprise issues like enhanced economic growth (higher Gross Domestic Product GDP), increased employment, competitiveness and energy security, which are characterised as positive multiple benefits of energy efficiency.

These categories - especially economic and social - might overlap due to direct or more indirect linkages between their different aspects. However, some aspects like disposable household income, which clearly could also be labelled as economic have high immediate impacts on the well-being of those affected and are therefore categorised as social aspects. This categorisation is naturally not fully distinct due to the several interconnections between the aspects, but as we are only considering effects individually and do not aggregate different indicator or categories our categorisation should not raise issues due to overlaps and linkages, like double counting.

For our analysis, we consider the time period from 2000 to 2015 – if possible – as these years are strongly impacted by the Energy Efficiency Directive (EED) and the national programmes and measures the Directive triggered in the Member states of the EU.

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3 www.odyssee-mure.eu

Table 1: Set of indicators for the quantification of multiple benefits of energy efficiency

Category	Sub-category	Indicator
	Energy and Resource Management	
Environmental	Energy savings	Annual energy savings (top-down and bottom–up)
Environmental	Saving of fossil fuels	Annual fossil fuels saved due to energy efficiency
Environmental	Impacts on RES targets	Lowering of RES target due to energy efficiency
	Global and Local Pollutants	
Environmental	GHG savings	Annual CO_2 savings linked to energy savings
Environmental	Local air pollution	Avoided local pollutants from PM2.5, PM10 and NOx (incl. electricity and heat)
	Energy poverty	
Social	Alleviation of energy poverty	Impact of energy savings on energy cost shares in disposable incomes of low-income households
	Living comfort	
Social	Health and well-being	Externalities linked to health impacts
Social	Disposable household income	Changes in shares of energy costs in disposable income of households due to energy efficiency
	Innovation and Competitiveness	
Economic	Innovation impacts	Revealed Patent Advantage (RPA)
Economic	Competitiveness	Revealed Comparative Advantage (RCA)
Economic	Turnover of energy efficiency goods	Investments linked to energy savings in buildings
	Economy (Macro)	
Economic	Impact on GDP	Impact of energy savings on GDP growth
Economic	Employment effects	Additional full-time equivalents linked to energy savings
Economic	Impact on energy prices	Price elasticities
Economic	Public budgets	Additional income tax from employment based on energy savings
	Economy (Micro)	
Economic	Industrial productivity	Semi-quantitative classification of impacts
Economic	Asset value	Change in asset value of commercial buildings due to energy efficiency benefits
	Energy Security and Energy Delivery	
Economic	Energy security (A)	Import dependency
Economic	Energy security (B)	Impact on supplier diversity (Herfindahl-Hirschman-Index)
Economic	Impact on integration of renewables	Demand-response potentials by country

3 Methodology and Results

For a large number of our indicators the energy savings calculated from the ODYSSEE database which collects statistical energy efficiency indicators (top-down savings), or the MURE database which collects around 2400 energy efficiency measures in Europe and their impacts (bottom-up savings), are important starting points.

Figure 1 shows the relationships of indicators starting from final energy savings. Dashed arrows indicate that there is no direct relationship with the central indicator of final energy savings. This is the case for indicators for innovation and competitiveness.

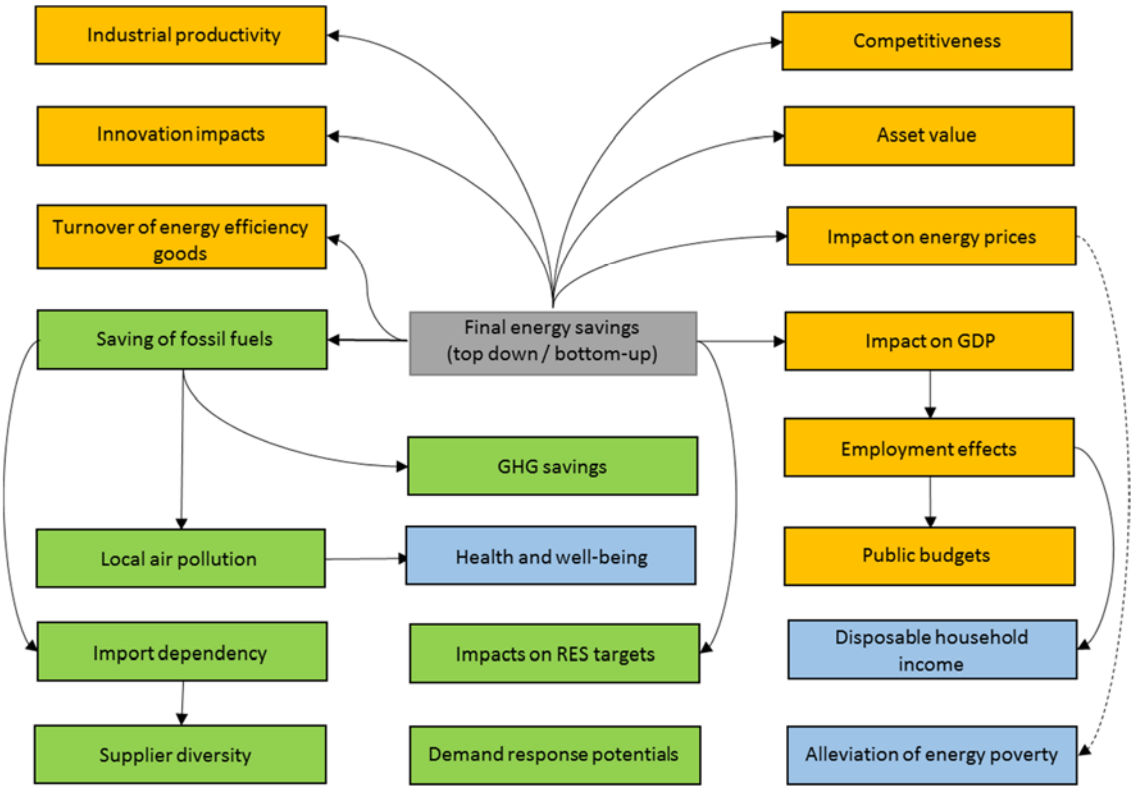

Figure 1: Overview of multiple benefits of energy efficiency and their interconnections (environmental: green, economic: orange, social: blue)

We describe the indicators developed according to their main group in the following.

3.1 Environmental Benefits of energy efficiency

The environmental effects of energy efficiency are mostly evident and well researched. In the context of climate change, these are one of the main reasons for the implementation of measures to increasing energy efficiency. Besides the energy savings, we consider several other effects in this category from emissions to impacts on target achievement.

3.1.1 Energy savings

The top-down savings from the ODYSSEE database are calculated based on the unit consumption, i.e. consumption specific to physical or monetary units, at the level of up to 30 sub-sectors or end-uses. Savings from international air transport and from Emission Trading (ETS) sectors in industry are included as well. In industry and freight transport, savings may be negative for some years due to a deterioration of energy efficiency; this is due to capacity effects in industry and freight transport in times of economic recession. They are derived from the ODEX, an indicator that measures as accurately as possible the progress in physical energy efficiency progress by sector. For each sector, this index is calculated as a weighted average of sub-sectoral indices of energy efficiency progress. Such sub-sectors are branches of the sectors industry (e.g. chemical and petro chemical, primary metals) or services (e.g. wholesale and retail trade or hospitality), end-uses for households (e.g. space heating) or modes for transport (e.g. road transport) [14].

The bottom-up savings provided by the MURE database originate from policy evaluation studies on a national level and National Energy Efficiency Plans (NEEAP) as well as so-called Article 7 notifications published by each Member state related to energy efficiency obligations, as specified by the Energy Efficiency Directive [15]. To calculate annual energy savings from the measures available in MURE, the available data by reference year are interpolated linearly per country and sector from 2000 onwards. The savings from cross-cutting measures are divided between sectors in proportion to the share of each sector in the country's total final energy consumption.

For the indicators in our framework we use, if suitable, both top-down and bottom-up energy savings, as they provide different but equally interesting perspectives. Top-down savings include also so-called autonomous energy savings and savings from energy efficiency policies undertaken before the period under consideration. These savings also bring about Multiple Benefits and should therefore be considered. Bottom-up savings arise from policy measures during the period considered. The main difference between energy savings from ODYSSEE and NEEAPs is that ODYSSEE in contrast to the NEEAPs also accounts for international air transport and from the ETS.

The energy savings are given in Megatons of oil equivalent (Mtoe).

3.1.2 Savings of fossil fuels

The reduction of the consumption of fossil fuels is a direct consequence of energy efficiency improvement and directly leads to CO_2 emission reductions. The indicator measures the impact of final energy savings on the reduction of the consumption of fossil fuels. The calculation of the savings of fossil fuels is directly linked to the input of (top-down or bottom-up) final energy savings For each sector, the total final savings are allocated by fuel (oil, coal and gas) according to the breakdown of fuel consumption in each sector (data from ODYSSEE). Fossil fuels savings are expressed as savings compared to 2000 and are calculated using the following formula:

$$ES_{fossil,j} = ES_{final} * FEC_{ij}$$

where ES represents the energy savings of the energy carrier j and FEC the final energy consumption of the sector I regarding the energy carrier j.

The savings of fossil fuels are given in Megatons of oil equivalent (Mtoe).

3.1.3 Avoided CO_2 emissions from energy savings

This indicator measures the impact of energy savings on the reduction of CO_2 emissions. CO_2 savings are calculated by multiplying the total energy savings by sector by the average emission factor of the sector (tCO_2/toe). This ratio is calculated by dividing the total CO_2 emissions of the sector (including the indirect CO_2 emissions from the power sector and heat production) by its final energy consumption, both data coming from the ODYSSEE database. CO_2 savings are also expressed in relation to 2000. These are calculated using the following formula:

$$EM_i = ES_{final,i} * FEC_{ij} * emf_j$$

where the *EMi* represent the emissions of sector *i*, which are calculated from the energy savings for sector *i* multiplied with the share of energy carrier *j* in sector *i* multiplied by the average emission factor *emf* for the energy carrier *j*. The emissions are given in Megatons of CO_2 [$MtCO_2$].

3.1.4 Local air pollution

Lelieveld et al. [16] estimates that outdoor air pollution, mostly by PM2.5[4], lead to 3.3 million premature deaths per year worldwide, predominantly in Asia. For Germany, a total of over 34,000 premature deaths were estimated for 2010 of which about 20% were related to energy conversion in power plants and the residential sector.

For our indicator approach, we use annual energy savings to calculate – based on a typical break-down by energy source – the local pollutants using end-use and fuel specific emission factors (see the formula below). The data are on one hand provided by the ODYSSEE-MURE project and on the other hand through national emission factors as for example provided by the European Environment Agency (EEA) [18]. This indicator measures the impact of energy savings on the reduction of local pollutants emissions. The pollutants considered are NO_x, SO_x, particulates (PM2.5 and PM10) and CO. The avoided emissions are calculated by multiplying the energy savings expressed in primary terms (using country specific factors to calculate the primary energy from final energy savings) by the average emission factor of the country, for each type of pollutant, per toe consumed. This ratio is calculated by dividing the total emissions of each local pollutant of the country ("national total emissions for the entire territory based on fuels sold", data from

4 Fine airborne particulate matter with a diameter < 2.5 μm, which is linked to respiratory diseases and cardiovascular diseases. (see [17]).

EEA's data viewer on air pollutants emissions) by the primary energy consumption from the ODYSSEE database. Energy savings in primary terms are calculated to be final energy savings (see Energy savings indicator) multiplied by the ratio between primary consumption and final consumption from ODYSSEE. The emission per pollutant and sector (E_{ij}) are calculated using the following formula:

$$E_{ij} = ES_{ij} * emf_j$$

Where ES_{ij} represents the energy saving per energy carrier *i* for the sector *j* and *emf* the emission factor specific for the energy carrier *I* (gas, oil, coal and electricity). The local emissions calculated are given in Gigagram [Gg].

3.1.5 Impact on RES targets

This indicator shows how energy savings contribute to reach more easily the RES target, i.e. the share of RES in (gross) final energy consumption, as set in Directive 2009/28. The RES share is calculated as the ratio between final consumption of RES and total gross final energy consumption. The actual values are published by Eurostat. The share of RES without energy savings is calculated by dividing the final consumption of RES (from Eurostat) by the total final consumption without energy savings (final consumption plus energy savings). The difference between the "actual RES share" (given by Eurostat) and the "RES share without energy savings" represents the effect of energy efficiency on the RES target.

3.2 Social Benefits of energy efficiency

Energy efficiency can have a range of social benefits to households. In our approach, the social effects of energy efficiency are mainly assigned to the household sector. Here we consider the effects of energy efficiency on disposable household income and, derived from this, the alleviation of energy poverty, as well as the positive effects on the health of residents.

3.2.1 Disposable household income

Disposable household incomes can be increased by energy efficiency in space heating, hot water generation or energy-using products like fridges or televisions, given that the overwhelming share of all implemented measures are cost-effective [19,20]. Initial investments in energy efficiency for renovation of buildings usually pay off in terms of heating cost reduction, which enables consumers to spend their money elsewhere in the long run. However, as the evaluation of the German KfW Energy-efficient Refurbishment Programme emphasizes, it must be noted that these investments are profitable after a period of several decades [21].

Taking energy-using products as an example, the net financial savings of fully implementing the Ecodesign Directive, which establishes minimum efficiency requirements for those products, are estimated at 332 EUR per household per year in Europe [22]. Nonetheless, in this regard rebound and spill over effects must be considered as well. These are a direct result of positive economic outcomes such as real income increase. In addition, potential energy savings might not be realised due to behavioural change, since it, for example, increases consumer access to energy-consuming appliances and to higher levels of comfort (e.g. due to higher indoor temperatures). Estimates on the reduction of energy savings through rebound effects range from 1% - 30% [23]. The scale varies by sector, location and time but it should still be taken into account by policy makers [24].

To calculate the effect of energy saving on the disposable incomes of households we use the following formula:

$$\Delta INC_E = [INC_E^0] - [INC_E^1] = INC_E^0 - [INC_E^0 + (ec * ES_{HH})]$$

where INC_E represents the share of energy costs in the disposable income of households with (1) and without energy savings, *ec* the cost per energy unit and ES_{HH} the energy savings per household.

This calculation result in the change of the share of energy costs in the disposable household income in percentage points [%p] for an average household of the respective country (see Figure 7 for Germany).

3.2.2 Alleviation of energy poverty

Tackling energy poverty is explicitly stated as a policy objective in the European Commission's Communication on the Energy Union Package [25]. In the European Union the problem of energy or fuel poverty is not limited to colder climates or particularly poor Member states as one might expect. It exists also in the south of the EU like in Spain, Portugal, Italy, Greece and Cyprus, as well as in relatively well-situated Member states like the UK and Ireland. [26] estimates that between 50 and 125 million people in the EU are currently suffering from energy poverty and are unable to afford proper indoor thermal comfort. At the same time energy efficient renovation of buildings in the EU holds a large potential for energy savings. BPIE [27] identified an overall energy efficiency potential in residential heating of 16 Mtoe to 45 Mtoe in the European Union. To unlock these potentials it is necessary to address all types of households in the residential sector. Considering that about 8 percent of the population in the European Union were in arrears on utility bills, and thus, can be considered to be energy poor this emphasizes the importance of targeting low-income and energy poor households in energy efficiency policy [28,29].

The definition of energy poverty differs from country to country and over time [30]. For example in the United Kingdom, a household is described as 'fuel poor' when more than 10 percent of its total income is spent for heating on an adequate level [31]. France has recently formulated a similar definition of 'energy precariousness' based on a household spending more than 10 percent of its income to meet its energy needs [32]. We represent this issue in our measurement framework with an indicator measuring the impact of energy measures on the share of energy costs in disposable household income, as this is one common basis of definition.

In order to determine the effect of energy efficiency on the financial situation of low-income households, we consider the effect of energy costs saved through energy efficiency on the disposable income of households in the first income quintile (i.e. below 11,700€ of household income for the EU28).

This approach might lead to an overestimation of the benefits of energy efficiency on low-income households, which are more prone to energy poverty, as they do not benefit as much from energy efficiency policies as higher income groups.

3.2.3 Health and well-being

Health benefits represent a more indirect effect of energy efficiency. On the one hand, these impacts on health are strongly related to (local) emissions from power plants, district heating and local residential heating systems as well as emissions from transport and industry. Electricity and heat generated by these facilities lead to increasing air pollution such as NOx, SO_2, small particulate matters (PM2.5) and CO_2. By reducing the energy consumption, a part of this air pollution can be avoided. Also, energy efficiency policies targeting industrial processes have a strong positive effect on health by reduction of emissions of PM2.5. Zhang et al. [4] discusses an example regarding the effects of energy efficiency measures on the emissions China's cement industry and the related premature deaths. For the Europe Union the EEA estimated 403,000 deaths related to PM2.5 and 72,000 deaths related to NOx in 2012 [33].

This indicator can be estimated based on an indicator regarding local air pollution in combination with premature mortality rates from studies such as [16]. The IEA [11] gives some examples for possible indicators used in measuring health and well-being impacts of energy efficiency. However, those are mainly based on (in situ) measurements, which should be performed before and after certain energy efficiency measures were carried out. Thus the data base for those indicators is every limited.

In our approach, we estimate health benefits in the form of avoided premature deaths related to NOx and PM2.5 based on the average trend between concentration and deaths per 1000 inhabitants derived from EEA data.

The health benefits in relation to final energy savings for each country are calculated based on the approach depicted in the following formula:

$$AD_i = EM_i * cf * \Delta conc_i * pop$$

Where the avoided deaths *AD* related to the pollutant *i* are calculated from the emission *EM* of the pollutant multiplied with the concentration factor *cf* and the corresponding change in concentration and population of country.

3.3 Economic Multiple Benefits

The economic effects linked to investments play a major role in the evaluation of energy efficiency policies, because these are usually designed and developed with cost-effectiveness in mind to keep their impact on public budgets and the burden for businesses as well as private households low. Considering economic effects other than costs makes investments in energy efficiency more attractive. Including these effects into the calculations of profitability can reduce payback times significantly.

3.3.1 Innovation impacts

Innovation is a driver for economic growth and is an enabler for the transition towards a competitive, secure and sustainable energy system. To show the impacts on innovation related to the diffusion of energy efficiency technologies in a country, patent indicators have been used in the past. Suitable indicators are in particular patent shares for a given energy efficiency technology as well as the relative patent share (RPA), normalised to the size of a country and calculated by dividing the patent share of the country for energy efficiency technology by the sum of the patent shares of the country in all fields [34]:

$$RPA_{ij} = 100 * \tanh \ln \left[\frac{(p_{ij}/\sum_i p_{ij})}{(\sum_j p_{ij}/\sum_{ij} p_{ij})} \right]$$

where p_{ij} represents the number of patents for a certain technology j from a country i. The value of RPA is positive if the patent share of a given technology is over-proportionally large. This implies that – compared to other technologies – there is more national innovation activity. When interpreting the results it should, however, be taken into account that it is more difficult for a technology to achieve a positive RPA value if a country is generally strong in patents.

Due to its methodological foundation, this indicator is not directly linked to energy savings.

3.3.2 Competitiveness

Developing a competitive industry for energy efficient technologies can be beneficial for the country's economy. Indicators such as world market shares, or specialisation indicators such as the Revealed Comparative Advantage (RCA), which is normalised to the size of a country, are commonly used in economics for calculating the relative competitive advantage or disadvantage of a certain country in a certain class of goods or services as evidenced by trade flows. The RCA is defined in a similar manner as RPA as:

$$RCA = 100 * \tanh \ln \left(\frac{X_i / IM_i}{X / IM} \right)$$

Where Xi and IMi describe the exports and imports of a branch i, while X and IM describe the total Exports and imports of a country. The formula gives normalized results for the RCA between -100 and +100.

If the RCA is greater than zero a comparative advantage is "revealed", otherwise it is considered to have a comparative disadvantage in the respective type of product or branch of industry.

As well as the innovation impacts, this indicator is not directly linked to energy savings.

3.3.3 Turnover of energy efficiency goods

This indicator represents on the turnover of energy efficiency goods in the residential sector. A high turnover with energy efficiency goods may contribute to the economic benefits of a country. Energy savings in the households can be achieved by different technical means, like insulation and efficient boilers or heat pumps and numerous further options which are characterized by their specific costs. To estimate the total turnover made with energy efficiency goods, the weighted average of these investments per unit of energy savings is multiplied by the total energy saved. We used a dataset based on case study[5] from the Netherlands [35] to carry out our calculations assuming a similar split of cost in all European countries:

$$TO = ES * SH_i * IN_{tech}$$

Where the turnover *TO* is calculated based on the energy savings *ES* and the share of space heating *SH* in final energy consumption of country *i* as well as the typical investments per energy saved. The turnover of energy efficiency goods are given in billion Euro [G€].

3.3.4 Employment effects

Employment effects have been a major benefit used in the past to justify energy efficiency programmes. The direct effects of energy efficiency on employment are based on two main drivers: investments in energy efficiency measures and related energy savings. While the former triggers a demand impulse in those industries producing relevant technology, the latter reduces the demand for energy products in the long-run. In an interrelated economy these impacts indirectly affect other sectors as well, for example energy producers and distributors. In order to comprehensively trace the economic impacts of certain demand changes to all sectors affected, an Input-Output analysis is applied. It allows for calculating how gross value added (GVA) in selected sectors is affected by demand changes [36]. The change in GVA is converted into employment effects by using sector specific productivity coefficients, which link GVA to fulltime equivalents (FTE) figures. In this analysis, data on energy savings from the ODYSSEE database are represented as demand changes in economic sectors, which currently make use of fuels and combustibles. The nature of the energy efficiency measure implemented determines in which sectors investments are included and for how long they remain in operation. Data on investments are provided by either policy evaluations from the MURE database or other specific studies. Results for this indicator are given as full-time equivalent.

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5 The study „Monitor Energiebesparing Gebouwde Omgeving" published yearly by the Ministry of Interior of the Netherlands collects these data for the Netherlands.

As various studies have shown, net employment gains are likely to occur due to a shift in spending on energy consumption towards investing in energy efficiency measures [37–39]. Provided that the energy efficiency measures are cost-effective they also increase the disposable incomes, which can further stimulate job creation in the long-run.

This approach is simplified compared to macro-economic analysis, which also looks at indirect effects arising, for example, from compensating impulses related to reduced expenses for the consumption of goods and services, meaning that the employment effects calculated here are gross effects, excluding other factors such as displacement effects and indirect second order effects through additional tax revenues, export/imports of EE related goods, etc.

3.3.5 Impact on GDP

The effects of energy efficiency measures on GDP are by determined analogy with the employment effects using an input-output analysis [40]. The input data to the analysis is the same as for the analysis of employment effects. The individual policies, whose effects on GDP are assessed, are the same as those considered for the employment effects. To calculate the GDP from the IO tables, the total GVA and taxes minus subsidies on products in final and intermediate consumption are summed up (income approach). The change in GDP is given as a percentage to the total GDP [%].

3.3.6 Public budgets

Public budgets are affected by energy efficiency in multiple ways. For this indicator we consider changes in public budgets due to additional income tax revenue triggered by new jobs generated by energy efficiency policies in the building sector. Thus, this indicator directly builds on data from the indicator “employment effects”. The additional tax revenue is calculated for a typical average job in the related sectors and subsectors using country specific income tax rates using the formula

$$\Delta IT_i = \Delta FTE * \overline{In} * Ir_i$$

where the additional income tax *IT* of the country *i* is calculated by multiplying the additional jobs in FTE with the average of income *In* of the branch considered and the income tax rate *Ir* of the country. This means, that we assume a uniform distribution of the employment effect over all occupational groups of the branches considered. The additional income tax is given in million Euro [M€].

3.3.7 Impacts on energy prices

Energy efficiency reduces the amount of energy that must be purchased or produced to meet customer’s needs. As most markets for energy products are characterized by an increasing supply curve, energy prices should decline, if demand for energy falls. For example, savings in electricity can reduce electricity prices, as fuel consumption for electricity generation, investment costs for power plants and power grid as well as greenhouse gas emissions decrease. There is widespread evidence both from empirical data and from modelling studies for a direct relationship between demand and price. However, besides the reduction of overall energy demand, energy prices are determined by several factors such as energy mix, quantities of domestic energy supply, substitutability and trading conditions. Energy efficiency measures may impact the consumption of one type of energy carrier more than the others, depending on the sector affected or on price differences across fuels. If significant at the global scale, energy savings are likely to induce downward pressure on prices of fossil energy fuels. Nevertheless, as energy fuels are globally traded commodities, it is unlikely that global energy prices will change to a large degree due to decreasing energy consumption of a single country [11,41]. Thus, to represent changes in energy prices due to changes in consumption we calculate price elasticities for the European Union as a whole for the world market prices of natural gas and crude oil applying the following formula:

$$\eta_{Q,P} = \frac{\frac{(Q_2 - Q_1)}{Q_1}}{\frac{(P_2 - P_1)}{P_1}}$$

Where Q_1 and Q_2 represent the Quantities of energy consumed in starting and end year considered and P_1 and P_2 the price of energy in both years.

3.3.8 Industrial productivity

Energy being an important production factor for industry, energy efficiency enhances productivity. Saving energy saves the corresponding costs of energy as well. In companies, this will have an effect on productivity expressed as added value per unit of energy used. Based on the savings calculated and a typical mix of energy carrier of the sectors the energy cost saved can be estimated and related to additional industrial value added.

The change in productivity is calculated as follows:

$$\Delta P = P^0 - P^1 = \frac{GVA^0}{FEC^0} - \frac{GVA^0 - (ES_i * p_i)}{FEC^1}$$

Where *P* represents the productivity with (P^0) and without (P^1). The product of the energy savings *ES* for the energy carrier *i* and the price for the energy carrier *i* (coal, gas, oil, electricity) gives the energy cost saved. These are subtracted from the GVA without energy savings to calculate the difference between the productivities. The change in productivity is given in million euro per peta joule [M€/PJ].

3.3.9 Asset value

Energy efficiency in buildings has an impact on the evaluated market values. According to a study of the US department of Energy (DOE), commercial buildings waste 30% of the energy paid for on average. This wasted energy was estimated at around 61 billion dollars for 2007. Based on a capitalization rate of 8%, a typical value used for building values, the lost asset value amounts to approximately $750 billion. Buildings with a certification of high energy efficiency generate a rent about 7 percent higher than otherwise identical buildings and realize an increase of selling prices by 16 percent.

For this indicator we consider commercial buildings as the market value of residential buildings is less dependent on energy efficiency than on location and other factors. To estimate the changes in asset value through increased energy efficiency we calculate the average savings in services related to the building itself, i.e. heating and cooling. Using average costs per energy for heating and cooling, we assess the additional average net income. Assuming a capitalization rate of 8% the change in asset value can be calculated for the service sector as a whole using the following formula:

$$\Delta AV = \frac{\sum_i ES_i * p_i}{cr}$$

Where ES_i represents the energy saving regarding energy carrier *i* (electricity and gas) with the price *p* and the capitalisation rate *cr* (in our case 0.08).

3.3.10 Import dependency

Many countries in the European Union are highly depended on a few suppliers of fossil fuels, like oil and natural gas. This dependency makes them vulnerable to supply disruptions, whether caused by political or commercial disputes, or infrastructure failure. Therefore, the European Commission released its Energy Security Strategy in 2014 [42], which calls for an increased energy efficiency (with a focus on industry and buildings) and which puts forward the 2030 energy and climate goals as a long-term measure to mitigate the energy import dependency of the EU. This indicator shows the impact of energy savings on the reduction of the energy import dependency, i.e. the extent to which a country relies upon imports to meet its energy needs. This dependency is measured through the energy dependency rate that is calculated as the ratio primary consumption minus primary production over primary consumption. This ratio is first calculated with the observed primary energy production and consumption ("actual dependency rate") and secondly in a fictive situation without the energy savings ("dependency rate without savings"). This second ratio is calculated by removing final energy savings in primary terms from the primary energy consumption.

The difference between the actual dependency rate and the dependency rate without savings represents the effect of energy savings on the import dependency of a country. Final energy savings in primary terms are calculated by multiplying the final energy savings (see Energy savings indicator) by the ratio between primary and final consumption.

$$\Delta ID = ID^0 - ID^1 = \left(\frac{net\ imports}{gross\ inland\ consumption + bunkers}\right) - \left(\frac{net\ imports}{gross\ inland\ consumption + bundkers + primary\ savings}\right)$$

The indicator is calculated as net imports divided by the sum of gross inland energy consumption plus bunkers, which represents the import dependency without energy savings (ID^0). The import dependency with energy savings (ID^1) is deducted from this with the savings through energy efficiency, which were converted into primary energy savings with an annual and country-dependent factor.

3.3.11 Supplier diversity

Supplier diversity is considered a corner-stone of a secure energy supply system and is therefore frequently used as a key indicator to assess energy security. It is beneficial for an energy system both through extending choice and increasing competition. The rationale behind the enhancement of supplier diversity through energy efficiency measures is that energy savings allow for reduction of the share of the dominant supplier. To measure the degree of supplier diversity of a country we use the Herfindahl-Hirschman-Index (HHI) [43]. HHI indicates the share of each supplier country and adds the squares of the shares. If there is only one supplier, the index is unity, i.e. representing a monopoly. If there are N suppliers with equal shares, the index is 1/N.

We assume that the energy savings (expressed in primary terms) reduce the primary energy imports from the main supplier (i.e. minimizing the share of the dominant supplier). The impact of energy efficiency in supplier diversity is measured with the difference between the observed HHI ("actual HHI") and a fictive HHI "without energy savings".

The calculation of the total HHI for each cases is done with following formula:

$$HHI = \sum_{i}^{4} \frac{\left(\sum_j (MS_{ji})^2\right) * I_i}{I_{tot}}$$

Where MS_{ij} represents the share of the supplying country *j* in the imports of energy carrier j (solid fuels, oil, gas, electricity) of the country considered weighted by the share of the respective energy carrier in total imports.

3.3.12 Integration of renewables

Renewable energies such as wind and solar depend on weather influences and therefore supplying fluctuating power to the grids. In order to keep the grid stable and to cover the required energy quantities, so-called demand response may be used. This describes the shift of energy services in order to counteract increased feed-ins or bottlenecks in production. This approach can thus contribute to increased efficiency in electricity generation in a country through better integration of renewables, as it increases their share in electricity generation.

This indicator shows the demand response potential per country in gigawatt [GW] and is not directly derived from energy savings.

4 Results

Here we now present the results for Germany based on our indicator set as for this country we reached a good coverage regarding all our indicators.

Figure 2 depicts the final energy savings linked to energy efficiency showing both top-down and bottom-up savings compared to the year 2000. These final energy savings amount to 48 Mtoe (TD) and about 37 Mtoe (BU) in 2015.

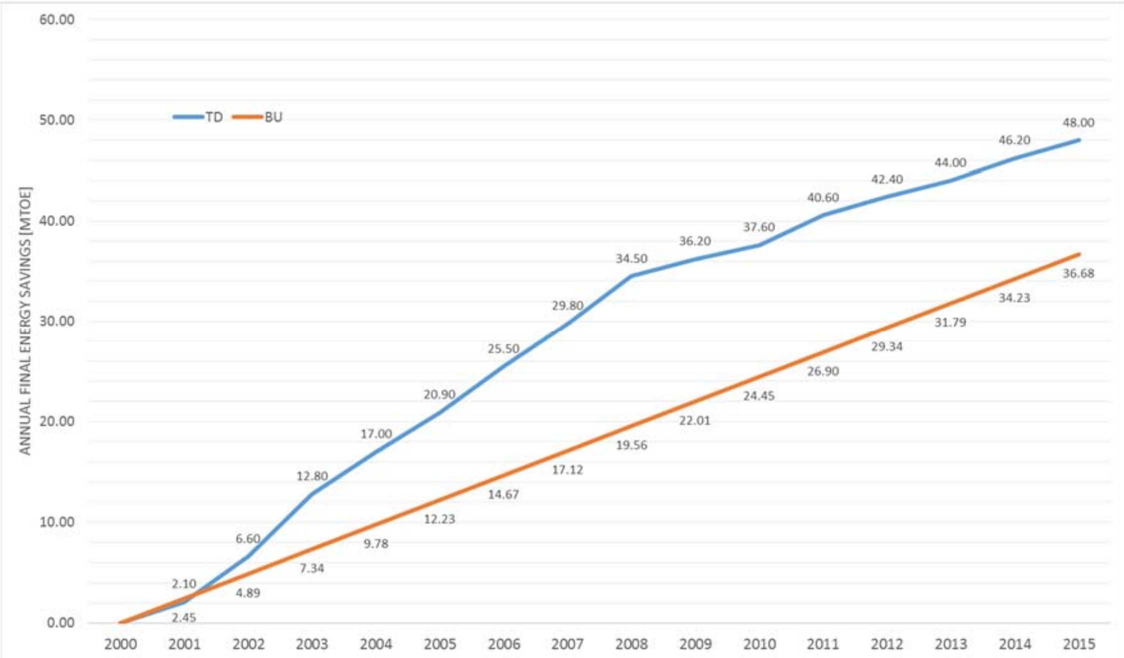

Figure 2: Final energy savings (top-down and bottom-up) compared to 2000 for Germany

The calculated avoided consumption of fossil fuels such as coal, oil and gas calculated on the basis of top-down savings amounts to about 1.6 Mtoe, 18.6 Mtoe and 13.3 Mtoe respectively for the year 2015 (Figure 3). Derived from bottom-up savings we calculated avoided fossil fuels consumptions of 1.5 Mtoe (Coal), 13.1 Mtoe (Oil) and 10.1 Mtoe (Gas).

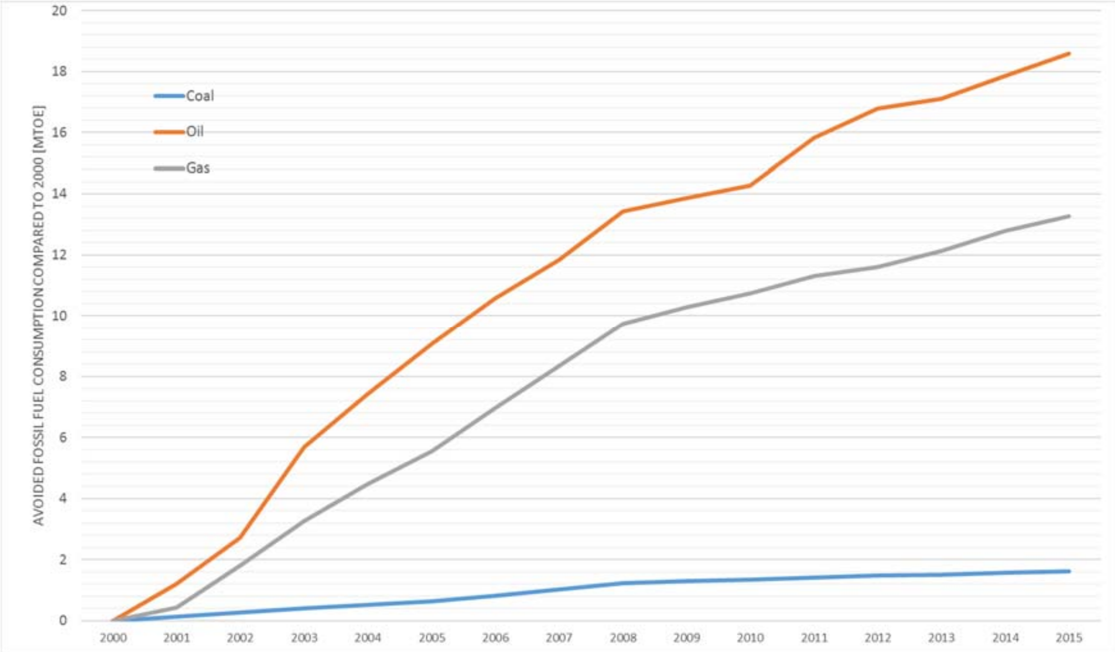

Figure 3: Fossil fuel consumption avoided by energy efficiency compared to 2000 for Germany

Linked to the savings of fossil fuels as well as the electricity saved, we calculated the avoided GHG emissions by sector. Figure 4 shows the avoided emissions in $MtCO_2$-eq. for Germany based on top-down savings for all four sectors considered.

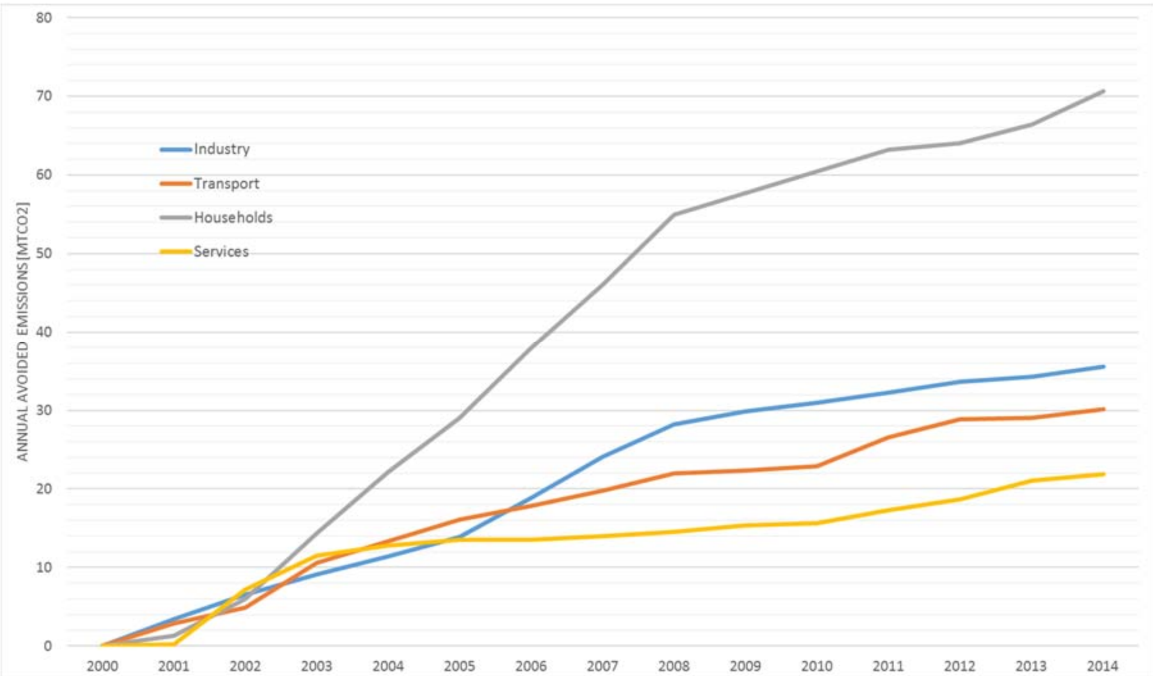

Figure 4: GHG emissions avoided by energy efficiency compared to 2000 for Germany

The main share of emission reduction in 2015 was realized in the sector households (71 $MtCO_2eq.$) followed by industry and transport (36 MtCO2eq and 30 MtCO2eq., respectively).

Besides the GHG emissions, we also calculated the local emissions of pollutants linked to energy consumption, such as CO, NOx, SOx and particular matter.

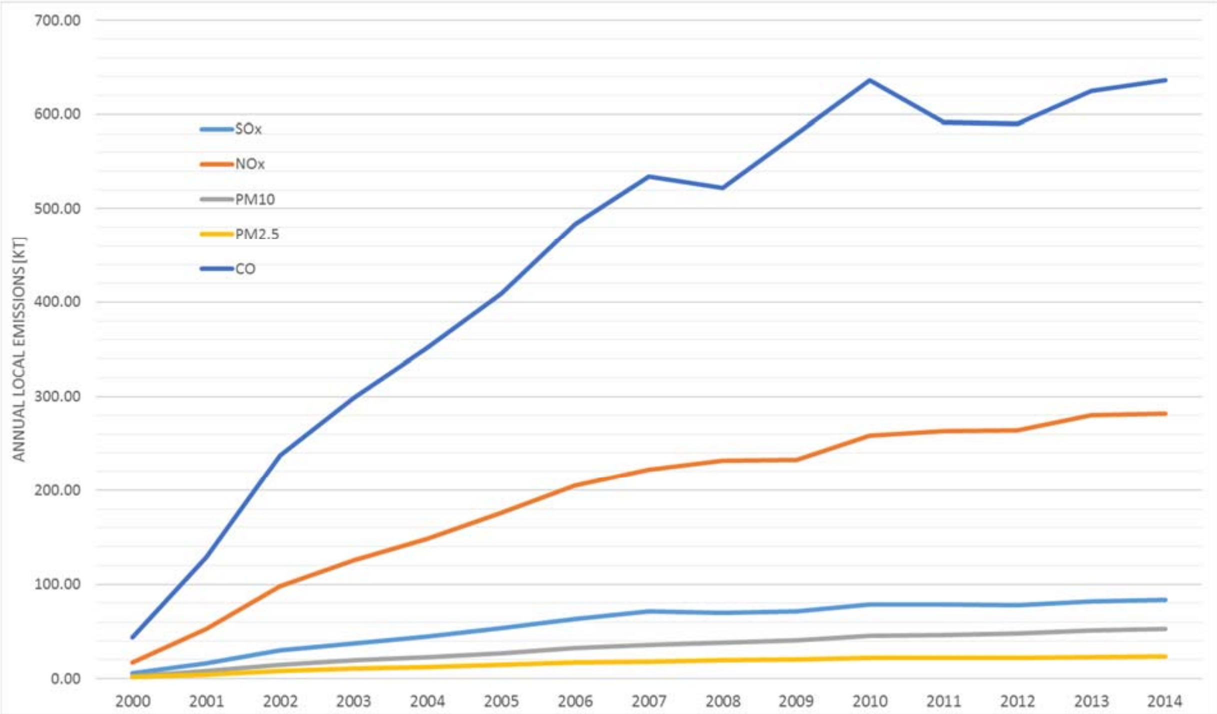

Figure 5: Total local emissions avoided by energy efficiency compared to 2000 for Germany (TD-savings)

In 2014 Germany's improvements in energy efficiency compared to the year 2000 resulted in the avoidance of 625 kt of CO as well as 280 kt of NOx, 82 kt of SOx and 51 and 23 kt of particulate matter (PM10 and PM2.5, respectively) (see Figure 5).

Apart from energy savings per se and emissions, energy efficiency also has an impact on the achievement of renewable targets. By reducing final energy consumption through energy efficiency, the targets set for renewables are easier to achieve.

For Germany, for example, this means that in 2015 a difference of 2.7 (TD) or 1.6 (BU) percentage points of the renewable energy target of 18% of gross final energy consumption was achieved through final energy savings (see Figure 6).

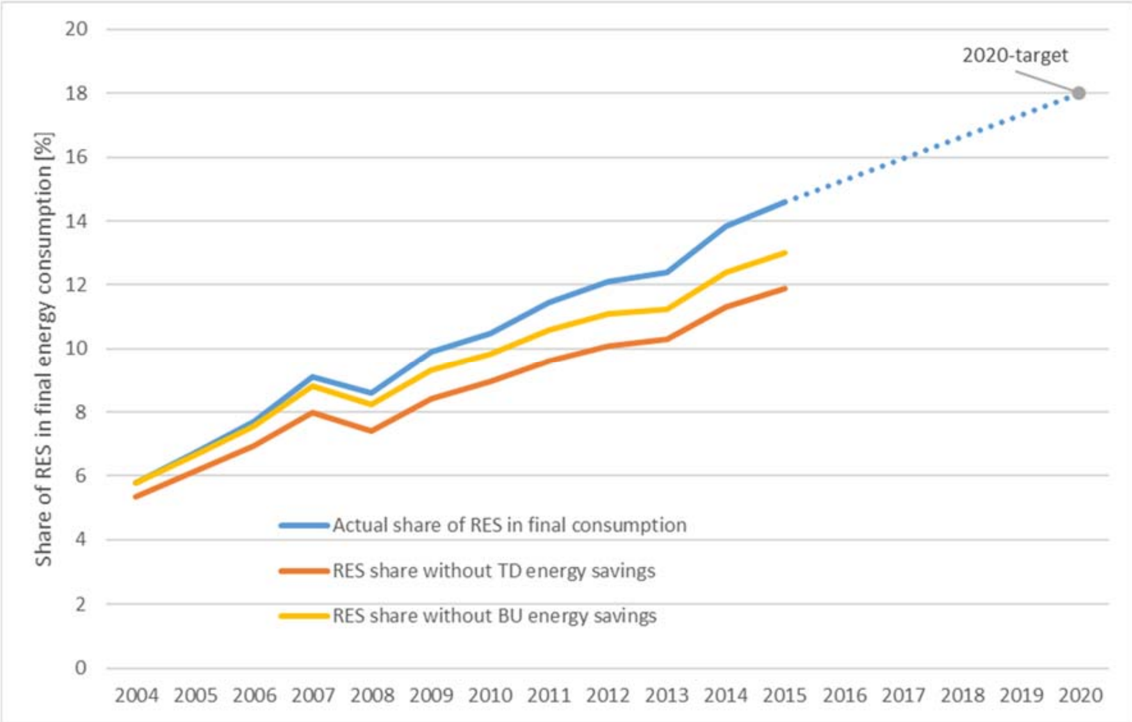

Figure 6: Change in RES share in gross final energy due to energy efficiency in Germany

With regard to the social effects of energy efficiency, we have studied the impact of energy savings on disposable household incomes in average and low-income households. We also estimate premature deaths from energy-related local emissions, which have been avoided by increasing energy efficiency.

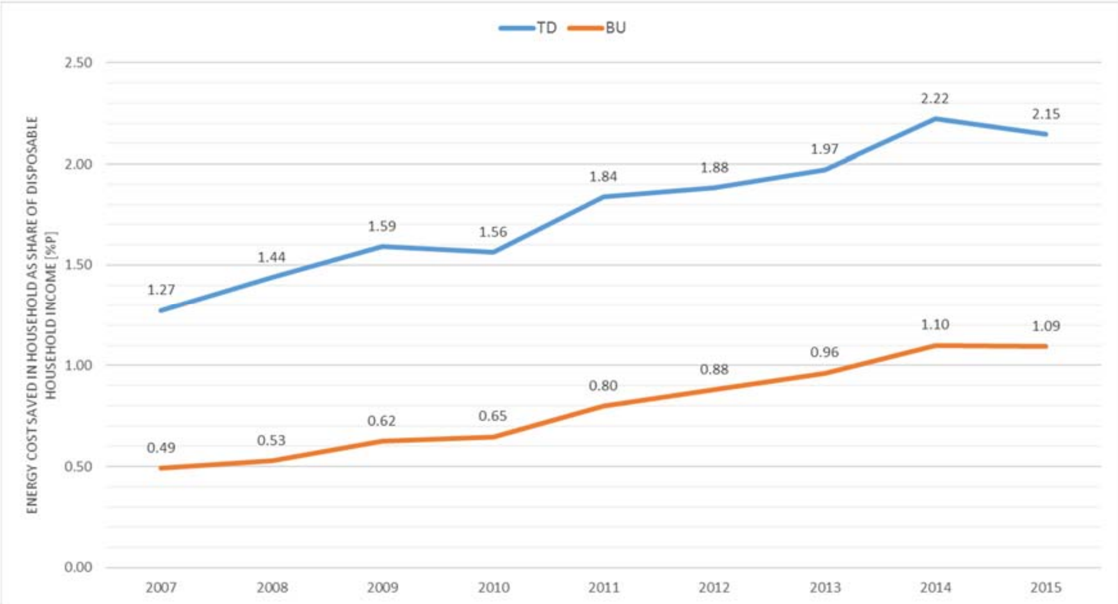

Figure 7: Change in share of energy cost in disposable household income related to energy efficiency (Germany, top-down and bottom-up savings)

For the average German household, energy efficiency resulted in about 2.2 (TD) and 1.1 (BU) percent lower expenditure on energy from disposable household income in 2015 (see Figure 7).

Low-income households benefit even more from energy efficiency. For these, savings of 2.5 (TD) or 1.3 (BU) percent of disposable household income resulted in 2015 (see Figure 8).

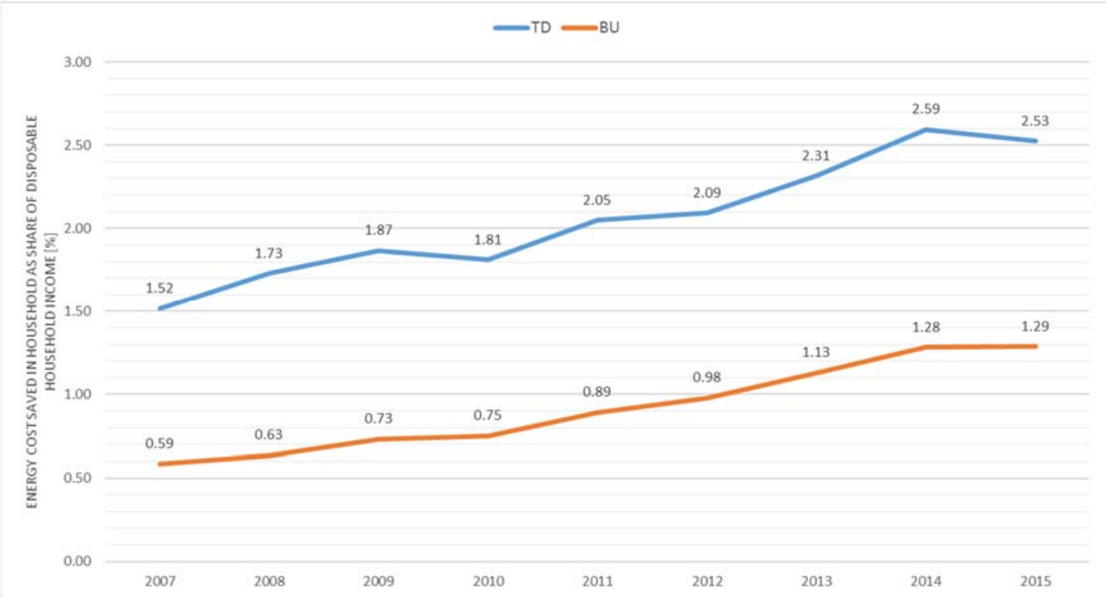

Figure 8: Change of disposable income for low-income households (1st quintile of income distribution)

Energy savings also help to avoid local emissions caused by power generation or heat generation, for example. These have a negative effect on life expectancy, which is mainly caused by pollutants such as NOx, SOx and particulate matter.

Through the avoidance of emissions of these pollutant linked to top-down energy savings about 31,000 premature deaths were prevented. Of these, around 18,000 were linked to avoided emissions of particulate matter (PM2.5) and 13,000 of NOx. Based on bottom-up savings, these were 12,800 (PM2.5) and 9,500 (NOx), respectively.

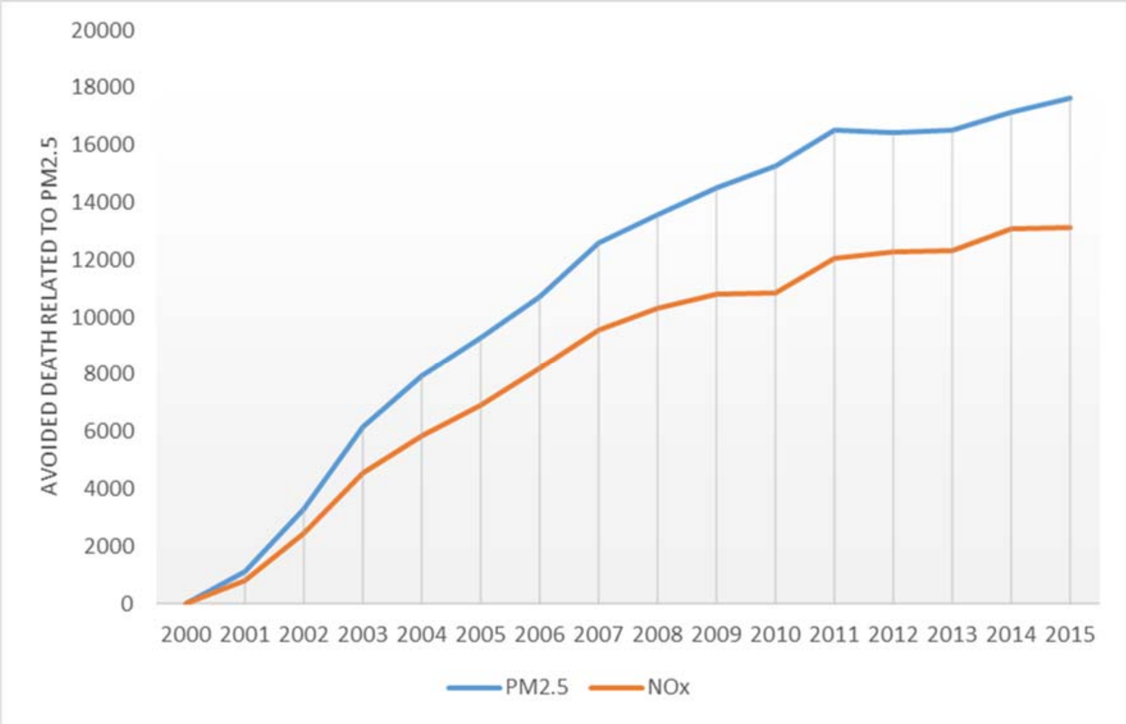

Figure 9: Avoided premature deaths though energy efficiency (TD) for Germany

For measuring the influences on innovation, we use the number of patents for relevant technology groups. In order to make these internationally comparable, we use the revealed patent advantage as an indicator. For the influences on innovation, we use the number of patents for relevant product groups. In order to make these internationally comparable, we use the revealed patent advantage as an indicator.

This indicator assumes values between -100 and 100 and shows the innovation performance of a country. Figure 10 shows a stable positive value for Germany which, compared to other countries, indicates a strong innovativeness for energy efficient technologies.

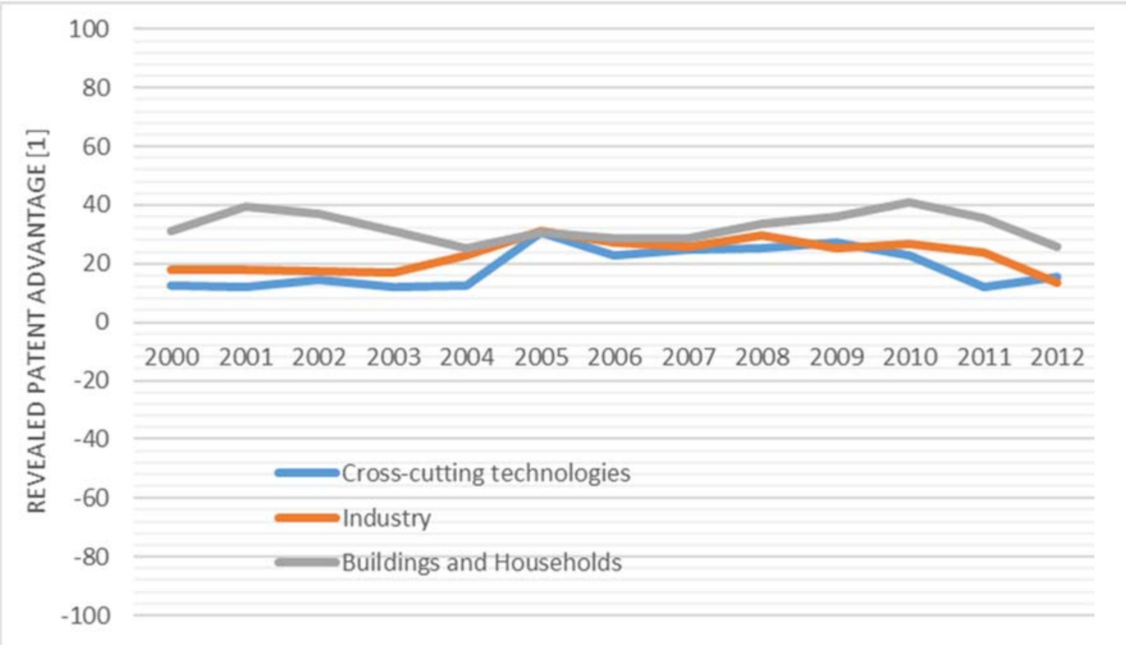

Figure 10: Development of the revealed patent advantage for energy efficient technologies for Germany (2000 to 2012)

Another more indirect indicator for the innovativeness of a country is the revealed comparative advantage (RCA), which indicates how strong the trade of a country is for a certain product group in comparison to other countries and total trade. Figure 11 shows the RCA for energy efficiency products for Germany between 2003 to 2013. Here, Germany shows a consistently strong position in the European context with a second place after Italy on a par with Finland.

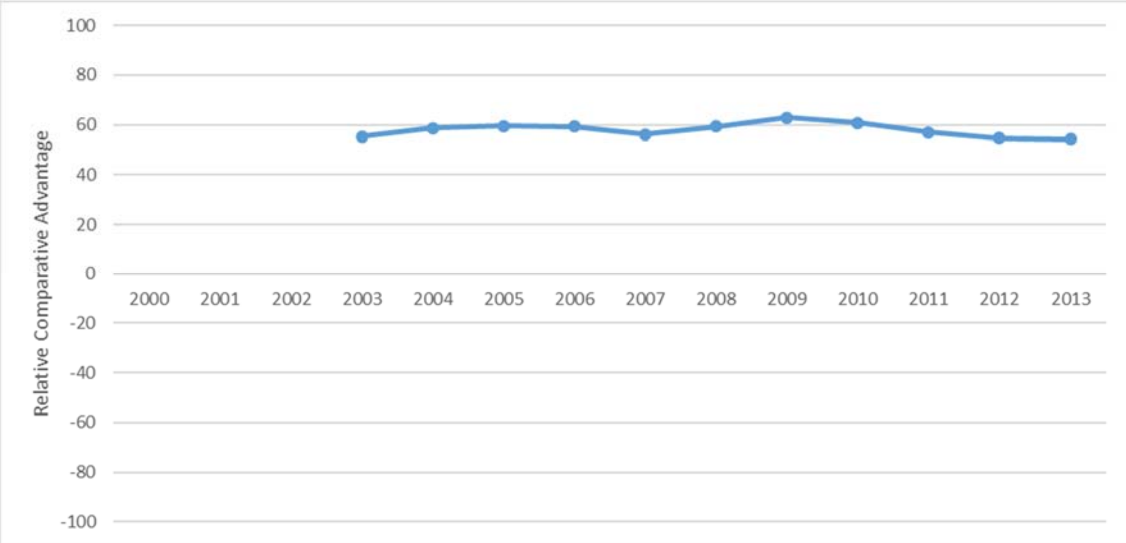

Figure 11: Relative Comparative Advantage for Germany

Other economic effects linked to energy efficiency in our analysis are those on employment, GDP and income tax revenue. Figure 12 shows the job effects we have calculated for energy efficiency in buildings for Germany. Based on top-down savings, this translates into around 570,000 full-time equivalents in the period 2010 to 2015. If only the bottom-up savings attributable to energy efficiency policies in the building sector are considered, there are about 535,000 full-time equivalents in the relevant industries.

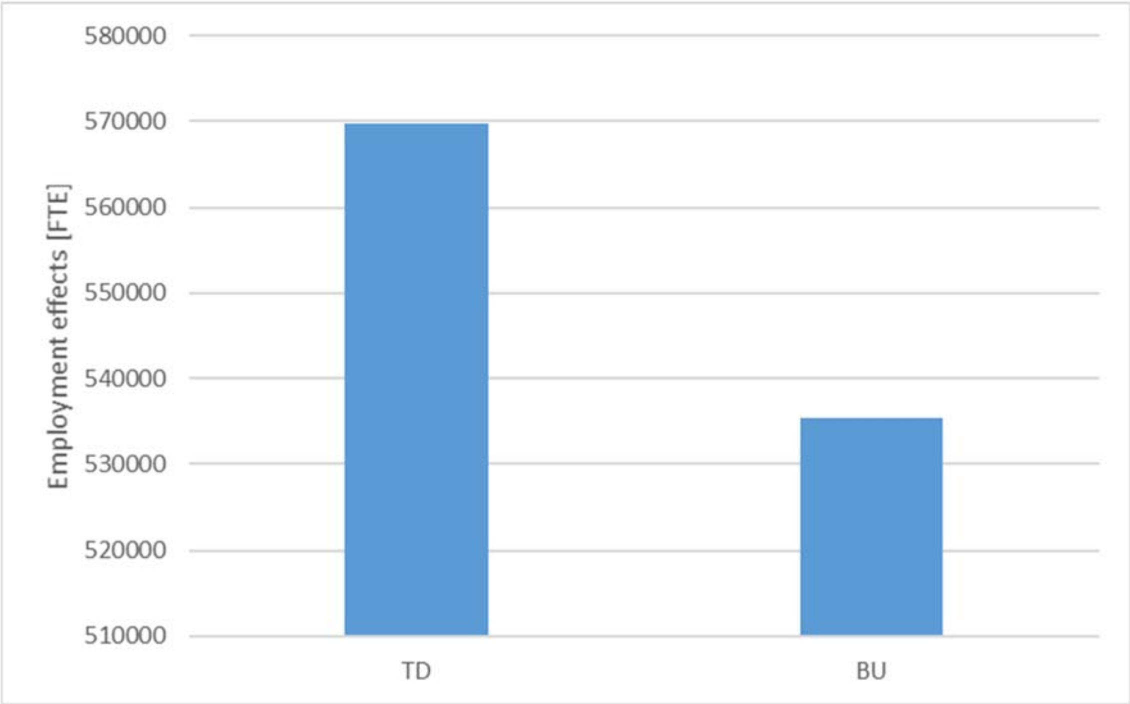

Figure 12: Employment effects for Germany for top-down and bottom-up savings (2010 - 2015)

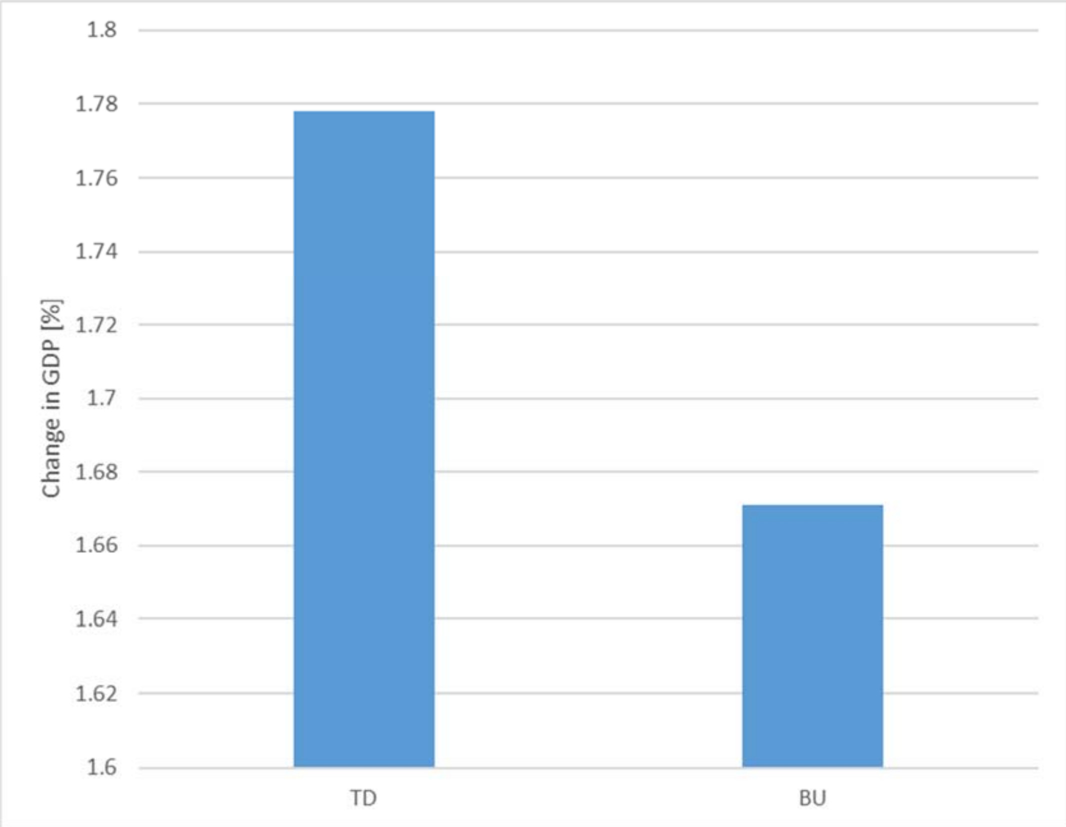

Figure 13: Change in GDP linked to energy efficiency for Germany (2010 - 2015)

Based on the calculations regarding the employment effect, which are derived from changes in GVA in industrial branches relevant for energy efficiency in the building sector, the effects on the GDP in general can be estimated. Figure 13 shows these changes linked to the energy savings (top-down and bottom-up) in the period 2010 to 2015 for Germany. This results in GDP growth of 1.8% (TD) or 1.7% (BU) due to energy efficiency in the building sector. The main share of these additional GVA was realized in the sectors "Constructions and construction works" and "Machinery and equipment".

Another economic indicator measures the impact of energy efficiency on the productivity of industry in form of reduced energy cost as part of GVA. Figure 14 shows this impact as a difference between the actual and counterfactual productivity related to the top down savings.

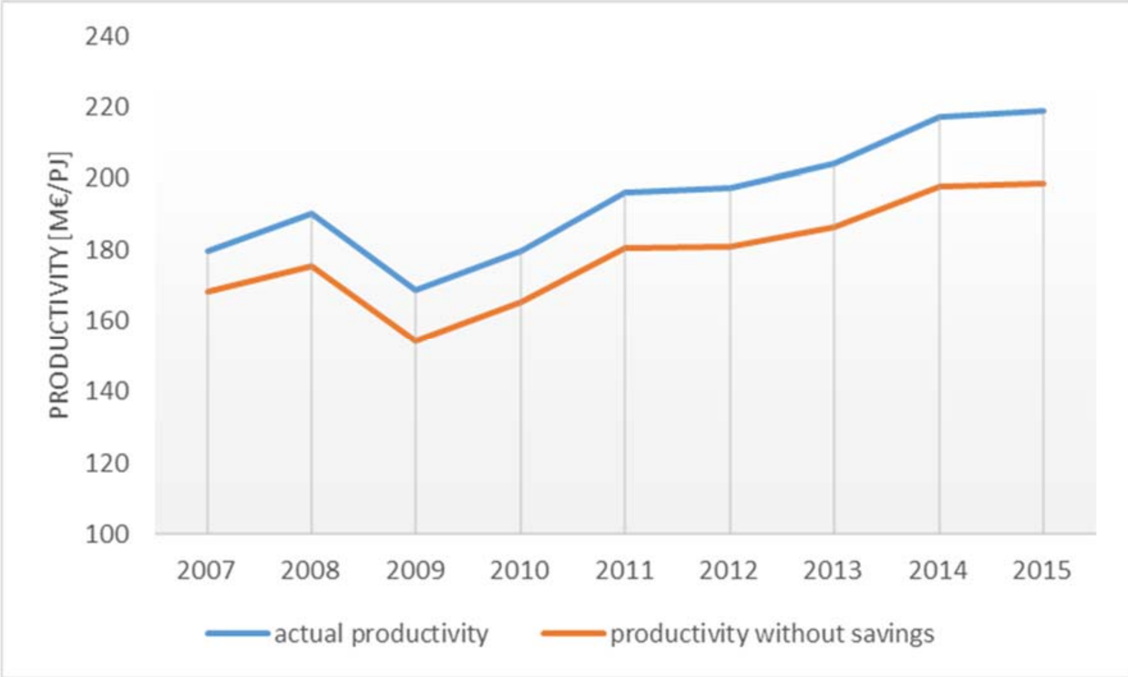

Figure 14: Changes in productivity due to energy efficiency (top-down savings) for Germany

The difference between the actual and counterfactual, i.e. without energy savings, is 6% (2007) to 9% (2015) for top-down savings and 5% (2007) to 10% (2015) for bottom-up savings.

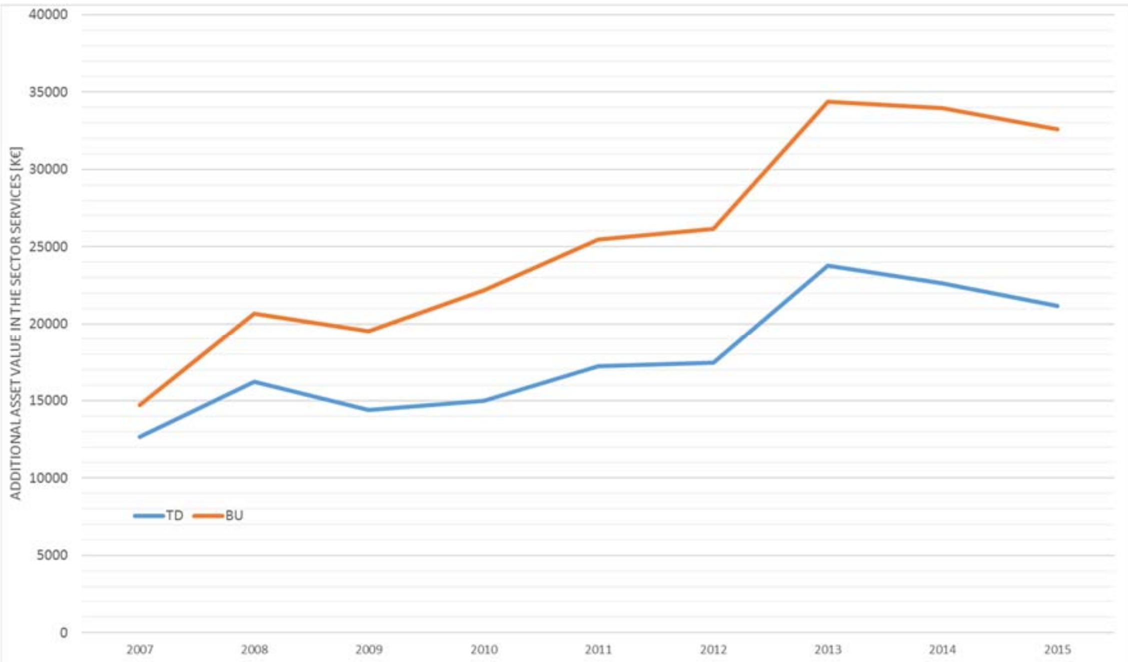

Figure 15: Additional asset value in the service sector due to energy efficiency compared to 2000 for Germany

As shown in Figure 15 the additional asset value for commercial buildings in the service sector of Germany increased steadily over time peaking in 2013 for both top-down and bottom-up savings as inputs. After 2013, a slight decrease occurs due to decrease of energy prices for commercial customers in Germany.

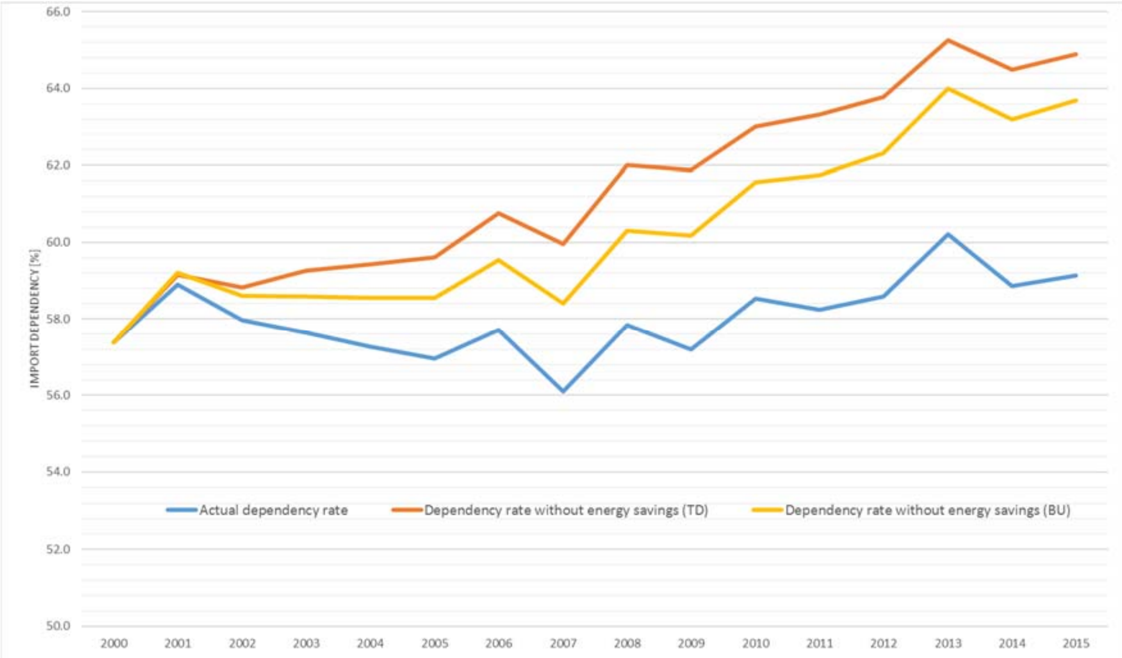

Figure 16: Differences in dependency rate due to energy efficiency (top-down and bottom-up savings) for Germany

Another indication for the dependency of a country is the diversity of energy suppliers, which can be measured by the HHI. Figure 17 shows the impact of energy efficiency on the supplier diversity regarding the energy imports of Germany between 2000 and 2015 for both bottom-up and top-down savings compared to the actual HHI, i.e. the HHI how it can actually be observed.

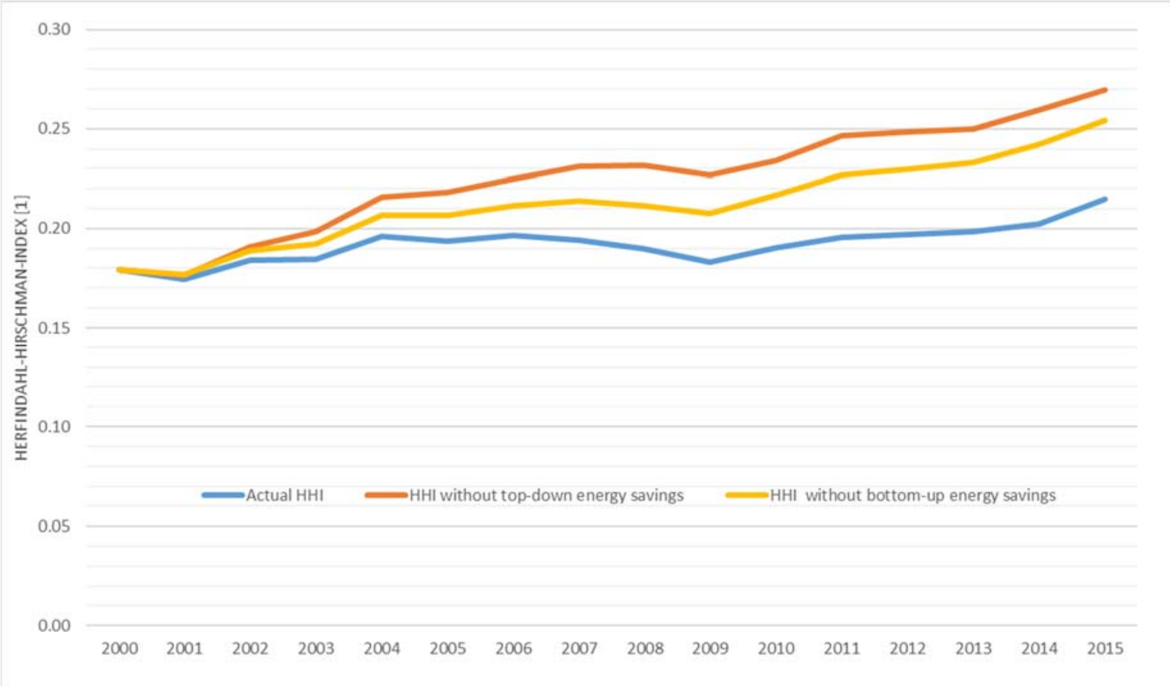

Figure 17: Difference in supplier diversity (HHI) due to energy efficiency (top-down savings) for Germany

Germany’s energy supply regarding imports became more concentrated in general between 2000 and 2015 without consideration of energy efficiency. However, this change would be much larger if there were no energy savings.

A country’s demand response potential are impacted by energy efficiency. As the potential decreases with an increasing energy efficiency and thus most often energy consumption in general. Figure 18 shows the demand response potential in 2012 of several European Member States.

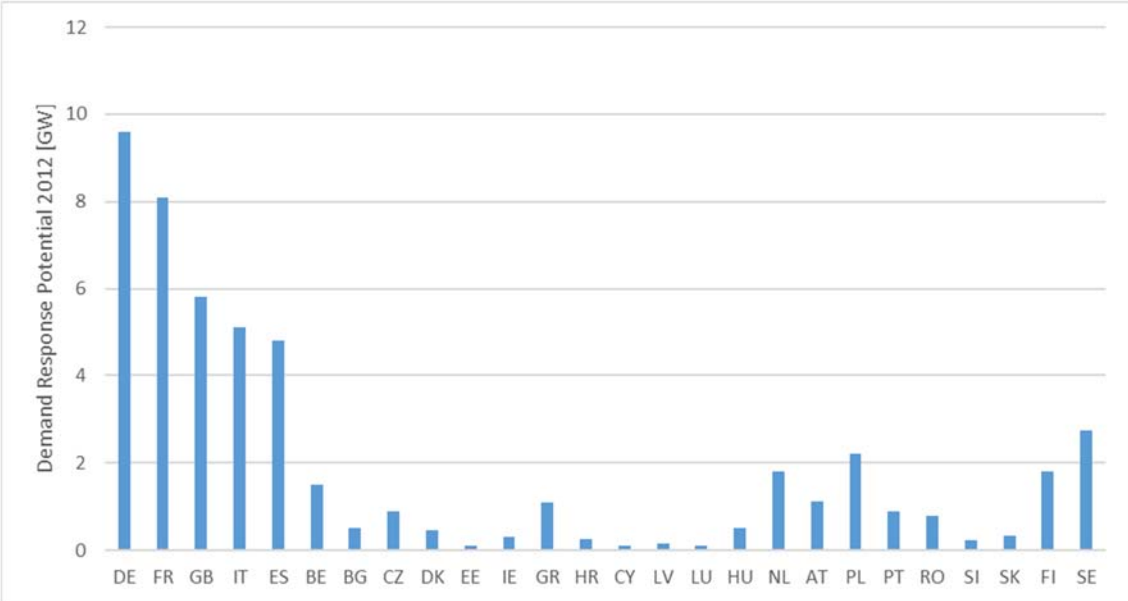

Figure 18: Demand response potentials in 2012

5 Discussion

In this paper, we present a set of indicators for measuring the multiple benefits of energy efficiency.

The indicators considered have a broad database, which has been compiled from several sources. These sources have different temporal and spatial coverage.

The resulting different quality levels can, however, be regarded as acceptable in view of the framework of our indicator approach, as we deliberately designed it without complex modelling and additional data collection (e.g. surveys) in order to be able to cover a spectrum of indicators as broad as possible.

Nevertheless, we want to present and discuss the limitations of the individual indicators and their input data. At the same time, we would like to take this opportunity to point out the potentials for future developments of our indicator set.

Table 2: Overview of the categorization of indicators depending on their methodological qualities and data bases

Indicator	Description	Category
Energy savings	Top-down and bottom-up savings from ODYSSEE or MURE database	A
Saving of fossil fuels	Typical split of final energy per sector	A
Impacts on RES targets	Lowering of the gap to targets defined based on energy consumption	A
GHG savings	Avoided GHG emissions	B
Local air pollution	Avoided pollutants (SOx, NOx, PM2.5, PM10 and CO)	B
Alleviation of energy poverty	Changes in the share of energy cost in household income for low income households	C
Health and well-being	Avoided deaths linked to local emissions	C
Disposable household income	Changes in the share of energy cost in household income	B
Innovation impacts	Revealed Patent Advantage (RPA)	A
Competitiveness	Revealed Comparative Advantage (RCA)	B
Turnover of energy efficiency goods		C
Impact on GDP	Change in Gross Value Added	B
Employment effects	Additional full time equivalents in relevant branches	B
Impact on energy prices	Elasticity of fossil fuels in European Context	B
Public budgets	Additional income tax revenue	B
Industrial productivity	Change in productivity through lower energy cost as part of GVA	C
Asset value	Additional asset value of commercial buildings	C
Energy security (A)	Supplier diversity(HHI)	A
Energy security (B)	Import dependency	A
Impact on integration of renewables		C

To assess the different quality levels we divided the indicators into several groups (category A to C). The first group (A) has a good temporal and spatial coverage as well as a solid methodological basis. This group includes *final energy savings*, *fossil fuels savings*, *impact on renewable targets* and *supplier diversity* and *import dependency.* These cover almost all Member States of the European Union as well as the complete period from 2000 to 2015. Furthermore, the methods these are based on are most straightforward with an excellent data basis directly from ODYSSEE or Eurostat. This should guarantee resilient results with a high validity and very low uncertainties. Innovation impacts are part of this group as well as they have a good data basis, coverage and method, even if they are not directly linked to energy efficiency.

The second group (B) of indicators consists of those with an limited spatial and temporal coverage, while still being based on good methodological foundation. To this group we count the indicators based on IO-analysis, such as *GDP effects*, *employment effects* and the *effect on public budgets*, as these only cover a few countries. Nonetheless, the methods used for these indicators are solid even when we only calculate gross effects in the limited frame of our indicator approach. To this group we also count the indicators measuring the impact of energy efficiency on the disposable household income and industrial productivity, as here data on income structure and energy process is only available starting from 2007 on. However, regarding the validity of this approach an evaluation using other existing studies on the impacts of energy efficiency policies by KfW [21,44] are available showing only minor differences to our result regarding the employment effects. This reinforces our assessment of the validity and quality of our methodology developed for this purpose. As potential improvements in the future, various adjustments can be considered for these indicators, which further develop them into net effects.

The next group consists of indicators, which might have a good temporal or spatial coverage, but suffer from the need for simplification because of the lack of suitable data, while the method still is valid. To this group we count the indicators calculating the local and GHG emissions as well health and well-being. These are based on only average emission factors for linking final energy savings to *GHG* or other *pollutants* (and further to *avoided premature deaths*). Also, the indicator turnover of energy efficiency goods, which is based on the data of a single study supplying data for a single European Country, can be counted to this group. The potential future improvements for these indicators are methodological refinements that take into account temporal and spatial changes in the systems under consideration and thus provide even more substantiated values. For these improvements, however, detailed data sets are usually lacking at the moment.

Due to this lack of detailed data these indicators have potential for errors in over- or underestimating the effects, but these can be assumed to be relatively minor as the average or single values used provide still an accurate basis for the calculations and the results should still have valid informative value.

Indicators, which have no direct linkage to energy savings, such as innovations impacts, competitiveness and the impact on the integration of renewables, however, have a more informative value and serve to round off the overall picture and should be included for a holistic evaluation. These indicators need further development in the future as better data might become available.

However, the indicator approach developed, may be gauged with more detailed improvements of methods and has the advantage that it is easily extended from year to year, making it attractive for policy makers to include the multiple benefits in their reporting. In addition, other energy researchers may have the opportunity of using the methods developed within our indicator approach for a quicker assessment of multiple benefits with easily applicable methods requiring only relatively easily available data.

6 Conclusions

Our analysis sheds light on the impact of energy efficiency from various angles and shows its quantification in detail. It shows how the effects beyond energy saving manifest themselves in the various aspects and underlines the importance of a holistic approach in order to assess the benefits of energy efficiency. This approach rather aims to give the big picture rather than an in-depth analysis of a single aspect.

The side effects that are most relevant in the perception of politicians and citizens are most likely to be strong economic and social effects. These are, for example, additional jobs, positive effects on public budgets, avoided premature deaths and the effect on the disposable income of the common citizen, which directly affect the lives of the latter.

Our indicators show that problems like energy poverty and public health can as well be targeted by energy efficiency policies, especially in buildings, while policy makers regularly use tools like income support, or fuel subsidies. Based on our quickly applicable methods in the design process of energy efficiency policies can be used to take various aspects into account at this stage and thus optimise positive effects in all relevant areas.

With regard to these aspects, the effects should not be underestimated and should be further emphasised as a rationale for the promotion of energy efficiency policies and their design.

To underline the importance of the Multiple Benefits we are highlighting in this paper, we want to put sizes of the effects in relation for Germany. As an example, our analysis regarding the employments effects of energy efficiency showed that from 2010 to 2015 new jobs in the amount of around 570,00 FTE solely related to energy efficiency of buildings were created. By way of comparison, the automotive industry, which is one of the most important economic sectors in Germany, employs around 790,000 people equalling to around 610,000 FTE.

7 Acknowledgements

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