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Monitoring of the “Energiewende” – Energy Efficiency Indicators for Germany

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Abstract

The increasing number of energy and climate targets both at national and international level induces a rising demand for regular monitoring. In this paper, we analyse the possibilities and limits of using energy efficiency indicators as a tool for monitoring these targets. We refer to the energy efficiency targets of the German "Energiewende" and calculate and discuss several energy efficiency indicators for Germany both at the level of the overall economy and the main energy consumption sectors. We make use of the energy efficiency indicator toolbox that we have developed within the ODYSSEE database in recent years and find that there is still a considerable gap to close to achieve the overall energy efficiency targets in Germany by 2020. We also show that progress in energy efficiency slowed down between 2008 and 2012, i.e. compared to the base year of most of the German energy efficiency targets and find that energy efficiency progress in the industrial sector during the last decade has been especially slow. We conclude that improvements in energy efficiency have to speed up considerably in order to achieve the targets for 2020. Although the use of energy efficiency indicators is limited by data constraints and some methodological problems, these indicators give a deep insight into the factors determining energy consumption and can therefore complement the official monitoring process of the German "Energiewende" which only relies on highly aggregated indicators for energy efficiency.

Keywords: energy efficiency targets, target monitoring, energy efficiency indicators, decomposition analysis, German "Energiewende"

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1 Introduction

Targets for the reduction of energy consumption or greenhouse gas emissions play an increasing role in the field of energy and climate policy. Against the backdrop of a growing number of targets and the introduction of new policy instruments to meet them at national and international levels, it has become more important to regularly monitor the progress made towards these targets in order to make sure they are reached.

The European Union (EU) launched a system of climate and energy targets for 2020 (EC, 2008) aimed at a reduction in GHG emissions by 20% compared to 1990, an increase of the share of renewables in the total EU gross final energy consumption to 20% and a reduction of primary energy consumption by 20% against a reference development. A new framework for energy and climate targets up to 2030 is now being developed (EC, 2013). With its Low Carbon Roadmap from 2011 (EC, 2011), which demands reduction of GHG emissions to 80-95% below 1990 levels by 2050, the EU has also set, for the first time, a long-term decarbonisation target. At national level, an increasing number of European and other countries have introduced targets or target systems with regard to energy and climate issues (for an overview see Wade et al., 2011; Enerdata, 2011a). In Germany, the Federal government adopted an Energy Concept (German Government 2010) which laid down the main strategic targets of Germany's energy and climate policy for the medium-term up until 2020 and the long-term up until 2050. These targets remained in place when the Federal government, as a response to the nuclear disaster in Fukushima, took decisions to fundamentally transform the German energy system in summer 2011: the so-called “Energiewende” (BMWi, 2011 and BMU, 2011).

Our paper focuses on targets addressing energy efficiency given its relative importance for decarbonising the economy. According to the IEA (2012, p. 253), energy efficiency accounts for more than 70% of the CO_2 emission savings in 2020 in a policy scenario targeted to limit the long-term increase of global temperature to 2°C above pre-industrial levels. Energy efficiency is accordingly a corner stone of European energy and climate policies. In Germany, a significant improvement in energy efficiency is, besides an accelerated switch to renewable energies, a key pillar of the “Energiewende” (see Section 2).

In this paper, we analyse the possible role and limits of energy efficiency indicators as an instrument for the regular monitoring of energy consumption and energy efficiency targets, and refer to the targets incorporated in the German “Energiewende”. With these targets, Germany has become one of the most ambitious countries in terms of energy transition. So monitoring the transition is not only relevant for Germany, but also for countries that take her lead. The “Energiewende” has now been running for a few years, so with the statistical data it provides, the time is right to do an evaluation. In this paper we analyse the progress on the demand side, i.e. for the energy efficiency-related targets of the “Energiewende”[1], making use of the energy efficiency indicator toolbox that we have developed within the ODYSSEE database in recent years[2]. We believe that the current “Energiewende” targets are good, but do not provide explanations of the underlying processes (i.e. especially activity, structure, behaviour and efficiency). Therefore, we calculate and discuss several energy efficiency indicators for Germany both at the macro-economic and sectoral level, which enable us to reveal some central developments behind the progress to the targets.

We present and discuss a possible tool for the regular monitoring of energy efficiency targets. Methodologically, our tool is based on index decomposition analysis which has been used for analysing energy-related trends since the 1970s[3]. An aggregated component, for example the energy consumption or the energy intensity of a country or a sector, is broken down into several determining factors to analyse their influence on the aggregate. This aims to analyse the extent to which improvements in energy efficiency have been responsible for the observed changes in energy consumption in a country. This is done by ana-

1 Compared to energy efficiency, the targets addressing renewable energy sources (RES), which are the second pillar of the German “Energiewende” (see Chapter 2), are much easier to define and monitor, since there are less defining options (see e.g. Harmsen et al., 2014 or Schlomann and Eichhammer, 2014) and less problems interpreting a certain development.

2 The ODYSSEE database was developed within the ODYSSEE-MURE project which has been financed by the European SAVE and IEE programs since 1993. Within the project, a huge statistical database on energy consumption in the EU Member States and Norway was built-up and is regularly updated. Based on these data, a comprehensive set of energy efficiency indicators was developed which are calculated both at the level of the whole economy and at the sectoral level. For more information see http://www.odyssee-mure.eu/ and Section 3.1.

3 The use of index decomposition analysis in order to describe and analyse trends in energy consumption started in the 2nd half of the 1970s in the U.S. (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 EIA, 1995 for the U.S. Farla et al., 1998 and Farla and Blok, 2000a for the Netherlands, Diekmann et al., 1999 for Germany, Natural Resources Canada, 2004 for Canada) and for the IEA (2004) and the European Union (Morovic et al., 1989; Bosseboeuf et al., 1999).

lytically separating the impact of energy efficiency improvement from other factors that influence the demand for energy (e.g. economic growth, structural changes within an economy or a sector, or fluctuations in weather).There are several competing methods for index decomposition (for an overview see Ang, 1995, 2004). Generally, however, such analysis and the resulting calculation of so-called "energy efficiency indicators" is widely accepted as an important tool for policy making in the field of energy efficiency (IEA, 2014a).

The paper is organised as follows. Section 2 provides background on the German "Energiewende" outlining its suitability as a case study. In Section 3 we describe the methodological approach and the statistical data which we use for our analysis. In the following Section 4, we show the development of energy efficiency indicators in Germany for the period 2000 to 2012 and reflect the results in the energy efficiency-related targets of the German "Energiewende". In Section 5, we interpret our results and discuss the strengths and limits of energy efficiency indicators as monitoring instruments. In the final Section 6, we summarise the main results and draw some conclusions.

2 Background to the German "Energiewende"

In Germany, the Federal government adopted an Energy Concept (German Government 2010) which laid down the main strategic targets of Germany's energy and climate policy in the medium-term up to 2020 and in the long-term up to 2050 (see Table 1). These targets also remained in place when the Federal government, as a response to the nuclear disaster in Fukushima, took decisions to fundamentally transform the German energy system in summer 2011 creating the so-called "Energiewende" (BMWi, 2011 and BMU, 2011). The main pillars of the "Energiewende" are (i) the gradual phase-out of nuclear power by 2022, (ii) a significant improvement in energy efficiency to reduce the demand for energy and (iii) an accelerated switch to renewable energies for the remaining energy demand.

Table 1: Quantitative targets of the German Energiewende

Sector	Target	Target value 2020	Target value 2050
Total Emissions	Greenhouse gas (GHG) emissions	-40% (comp. to 1990)	-80 to -95% (comp. to 1990)
Energy Consumption / Energy Efficiency (EE)	Primary energy consumption	-20% (comp. to 2008)	-50% (comp. to 2008)
	Final energy productivity (i.e. GDP related to total final energy consumption)	2.1% per year	
	Gross electricity consumption	-10% (comp. to 2008)	-25% (comp. to 2008)
	Share of CHP in total electricity production	25%	-
Building stock	Heating requirement	-20% (base year not specified)	
	Primary energy demand		-80%
	Building renovation rate	Doubling to around 2% per year	
Transport	Final energy consumption in transport	-10 % (comp. to 2005)	-40% (comp. to 2005)
	Number of electric cars	1 million	6 million (in 2030)
Renewable Energy Sources (RES)	Share of RES in gross final energy consumption	18%	60%
	Share of RES in gross electricity consumption	35%	80%

Source: German Government, 2010

The progress made towards the overall targets and the current status of implementation is evaluated in annual monitoring reports. After three years, a progress report has to be provided which also includes some information on the actual impact of policy instruments and programmes. The corresponding monitoring process “Energy of the future” was approved by the Federal government in October 2011 (German government, 2011).The first two annual reports for the reporting years 2011 and 2012 have already been submitted (BMWi and BMU, 2012; BMWi, 2014). The governmental reports are accompanied by an expert's opinion from an independent commission which was appointed by the Government (Löschel et al., 2012, 2014). The focus of the annual reporting is on the verification of the progress towards the quantitative targets of the Energiewende. A set of 49 monitoring indicators was defined for the first monitoring report (BMWi and BMU, 2012) and further developed in the second report (BMWi, 2014). In contrast to our paper, which only refers to the energy efficiency-related targets, these indicators cover all relevant areas of the “Energiewende”, i.e. energy supply, energy efficiency, renewable energies, power plants, grid infrastructure, buildings, transport and mobility, greenhouse gas emissions, energy costs and macro-economic impacts. With regard to energy efficiency, however, the indicators in the official monitoring process are less detailed than those we discuss in this paper (see Section 3.3), but remain at a highly aggregated level of energy statistics.

Most of the targets of the Energiewende refer to an absolute reduction in primary and final energy consumption and a respective improvement in energy efficiency (see Table 1). The sectoral targets for the building stock and the transport sector also primarily relate to energy efficiency. This means that the improvement in energy efficiency - besides the increased use of renewable energies – is a key pillar of the “Energiewende”.

In this paper, we purely focus on the energy efficiency element of the “Energiewende”. We take into account the development of both energy consumption and energy efficiency at the level of the whole economy and at the sectoral level. Although there are no explicit energy efficiency (EE) targets for the industrial and tertiary[4] sectors, these sectors will also be taken into account, because an energy efficiency improvement in these sectors is a prerequisite for the achievement of the overall EE targets. For our analysis, we not only rely on the aggregated energy consumption data and simple ratios as they are used in the official monitoring process, but also on energy efficiency indicators which are

4 In the German energy balances, this sector comprises public and private services, trade, commerce, agriculture, construction industry and some small industrial companies below 20 employees.

calculated based on index decomposition methods. These indicators give more insight into the factors determining energy consumption and can therefore complement the official monitoring process of the German “Energiewende”.

3 Methodology and Statistical Database

3.1 The ODYSSEE approach of monitoring energy efficiency targets

The ODYSSEE database on the one hand contains detailed data on energy consumption and its drivers in the main energy consumption sectors and, on the other hand, energy efficiency-related indicators. The following types of indicators are considered in ODYSSEE to describe and characterise energy efficiency trends and thereby monitor energy efficiency targets (for a detailed description of the methodology see Appendix A and Enerdata, 2008, 2010, 2011b; Lapillonne and Pollier, 2011):

1. Different types of ratios relating energy consumption to an activity driving energy consumption of the overall economy or sector:
   - Economic ratios, relating energy consumption to an activity measured in monetary units; these indicators are called "energy intensities" in ODYSSEE.
   - Technical-economic ratios, relating energy consumption to an indicator of activity measured in physical terms; these ratios are called "unit consumption" and are usually calculated at the level of sub-sectors. Examples include energy consumption per passenger or tonne-kilometre in passenger and freight transport or related to physical production in manufacturing industry. Examples in the residential sector are the energy consumption per electrical appliance type or per dwelling or square metre.
   - Adjusted ratios, from which external factors, which are not primarily attributable to changes in energy efficiency, have been removed (e.g. weather conditions or economic structure). These ratios are also used to make cross-country comparisons unaffected by such distortion.
   - Ratios at constant structure of the economy, which are derived from the ratios described above keeping the structure within one sector or the economy constant (over one reference year). These ratios are calculated by the Divisia method, which is a frequently used method of factor decomposition, separating the impact of structural changes from changes in sectoral energy intensities. It is especially applied to an analysis of the industrial sector (see Ang, 1995 and 2004).
2. Re-aggregated indicators at total economy or sectoral level, which are calculated by aggregating the individual indicators described above. The re-aggregated indicators are calculated in two forms:

- As an energy efficiency index, called “ODEX”, measuring the energy efficiency progress at the level of the main final energy consumption sector (industry, transport, households[5]) and for the whole economy. Broadly speaking, this index is obtained by aggregating the unit consumption changes at detailed levels (i.e. by sub-sector or end-use): the ODEX of a given sector is calculated from the variation of unit consumption indices by sub-sector (end-use or equipment) weighted by the share of each sub-sector in the total consumption of the sector. Measuring the variation in terms of indices enables the use of different units for the detailed indicators (e.g. kWh/appliance, MJ/m^2). A decrease in the ODEX implies an improvement in energy efficiency.
- As energy savings, expressing the variations of the ODEX in terms of amount of energy saved compared to a situation without energy efficiency progress; in the case of a worsening of energy efficiency, these savings can also be negative.

3. A decomposed indicator, which breaks down the variation in energy consumption over a given period into various components (e.g. economic growth, lifestyles, and energy savings) to analyse their influence on the aggregate.[6] This indicator is calculated at the following levels:
   - the main energy consumption sectors (industry, households, transport, tertiary, agriculture)
   - total final energy consumption
   - the power sector
   - total primary energy consumption.

3.2 Statistical database for the German energy efficiency indicators

Detailed, complete, timely and reliable energy statistics are essential to monitor the development of energy efficiency at a country level (see IEA, 2005 and 2014b). They are used to calculate statistically-based energy efficiency indicators in the ODYSSEE database. The data demands generally increase with the level of disaggregation. This is especially true for the calculation of unit con-

5 For the tertiary sector, the ODEX is not calculated in ODYSSEE due to data gaps in many European countries.

6 For a user-friendly calculation of the decomposed indicator, a new “decomposition facility” was developed which enables the user to make their own calculations by selecting a country, a sector, an energy unit and a time period for the analysis. See http://www.indicators.odyssee-mure.eu/decomposition.html

sumption indicators at the sub-sectoral level and for the re-aggregated and decomposed indicators (see Section 3.1), which need highly detailed statistics. For the calculation of most of the indicators described above, ODYSSEE relies on data from national sources. Data for the power sector from Eurostat (2014) are only used for the decomposition of primary energy consumption, since the transformation sector is not covered by the ODYSSEE database.

In Germany, the statistics on energy consumption and on the main activities driving energy demand is relatively good compared to some other European countries and at the international level, where data gaps still exist (IEA, 2014b). The most important source of statistical energy consumption data in Germany is that of the Working Group on Energy Balances[7]. They provide the national energy balances (AGEB, 2013) and – in collaboration with three research institutions – the yearly end-use balances for Germany (AGEB, 2014). Most of the macro-economic data in the ODYSSEE database, at both the total economy and sectoral levels (GDP, added value of industry and industrial branches, added value of the commercial/public sector, private consumption, number of employees) are directly taken from the National Accounts (Federal Statistical Office, 2014). The Federal Statistical Office also provides the statistics on energy consumption in industry in accordance with the European classification (NACE Rev. 2) of industrial branches at a detailed 4-digit level (Federal Statistical Office, 2014). Detailed data on energy consumption in the residential and tertiary sectors, which go beyond energy balances, are collected through regular surveys which are carried out every two years (RWI and forsa, 2013; Fraunhofer ISI et al., 2014; Schlomann et al., 2014). The survey data are extrapolated for Germany as a whole and interpolations and extrapolations are made for years not covered by the original surveys. The most important data source for the transport sector is an annual publication ("Verkehr in Zahlen"), which is produced by the DIW Berlin on behalf of the Federal Ministry of Transport (DIW and BMVBS, 2014): it includes detailed data on the stock of vehicles, kilometres travelled, passenger and freight traffic and energy consumption by transport mode, and passenger and freight transport.

A detailed overview of the data sources for Germany in the ODYSSEE database, including a classification of the sources, is given in Annex 2. These data

7 The Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen) in Germany is a merger of some industrial associations and research institutes in the field of energy which both provides the national energy balances and the energy balances by end-uses on an annual basis (see http://www.ag-energiebilanzen.de/EN/downloads/downloads.html).

sources are also the main data bases for the official monitoring of the energy efficiency elements of the Energiewende (BMWi and BMU, 2012; BMWi, 2014) and for the German reporting of the energy efficiency progress in the National Energy Efficiency Action Plans (NEEAPs) under the former EU Directive on energy efficiency and energy services (ESD) (BMWi, 2011). Despite the relatively satisfactory data situation in Germany, there are still some data gaps which affect both the calculation of energy efficiency indicators in the ODYSSEE database and the official reporting obligations mentioned above. The Expert Commission accompanying the official monitoring of the "Energiewende" targets refers particularly to data gaps in the building and tertiary sector and recommends an improvement of the statistical database in these fields (Löschel et al., 2014, p. 4) The reporting of top-down energy savings under the ESD was mainly limited by missing statistical data on energy consumption for electrical appliances and cooling in the residential sector (BMWi, 2011).

In the ODYSSEE database (and in the German NEEAP) these data gaps were partly filled by the use of data from stock models (see Annex 2), allowing all types of indicators as described in Section 3.1 to be calculated for the country. Most German indicators go back to 1991 (the year of the German reunification) or at least to 1995 or 2000. The last year which is statistically available is 2012.

3.3 Choice of energy efficiency indicators for the monitoring of the German "Energiewende"

The choice of energy efficiency indicators, as presented in this paper, is oriented towards the targets of the "Energiewende" which are related to energy efficiency (see Table 2). First of all we consider indicators which directly refer to the EE targets as they are formulated in the energy concept. However we also consider EE indicators from which external factors not attributable to energy efficiency are completely removed (see Section 3.1). These are not only suitable to describe the progress achieved towards the targets, but also help analyse and explain the developments which are behind the observed trends. They include ratios for the overall economy and the main energy consumption sectors (private households, transport, industry, and tertiary) and re-aggregated ODEX and decomposed indicators.

We calculate these indicators on an annual basis over two time periods:

- 2000-2012 in order to give a detailed picture of the development of primary and final energy consumption in Germany over the last decade, and

- 2008-2012 (transport: 2005-2012) to show the development between the base year for the targets of the “Energiewende” and the latest year which is statistically available.

The ODYSSEE database offers the choice of several energy units for the calculation of energy efficiency indicators. In our analysis we will use the unit “Joule” (J).

Table 2: Choice of energy efficiency indicators for the monitoring of the "Energiewende"

Sector	EE-related targets of the "Energiewende"	EE indicators which directly refer to the EE target	Additional EE indicators to explain the development towards the targets
Overall Economy	Primary energy consumption	Total primary energy consumption -actual -temperature-corrected	Primary energy intensity -actual -temperature--corrected Decomposition of primary energy consumption
	Final energy productivity (defined as GDP / final energy consumption)	Final energy intensity, i.e. the reciprocal of the productivity -actual -temperature corrected	Final energy consumption (total and by sector) Global ODEX Decomposition of final energy consumption
	Gross electricity consumption	Total electricity consumption	Electricity intensity
Households	Heating requirement Primary energy demand Building renovation rate	Final energy consumption for space heating -actual -temperature-corrected	Unit consumption per dwelling (temperature-corrected) Unit consumption for electricity per dwelling Unit consumption for space heating per dwelling (temperature-corrected) Unit consumption for space heating per m2 (temperature-corrected) ODEX Households Decomposition of residential energy consumption
Transport	Final energy consumption in transport	Final energy consumption of the transport sector	Final energy consumption by transport mode Unit consumption of passenger and freight traffic Kilometres for passenger and freight traffic ODEX Transport Decomposition of transport energy consumption
Industry	No specific target	-	Final energy intensity of manufacturing -actual -at constant structure Unit consumption of energy-intensive products (steel, cement, paper) ODEX Industry Decomposition of industrial energy consumption
Tertiary / Services	No specific target	-	Energy intensity of services (temperature-corrected) Unit consumption per employee (temperature-corrected) Decomposition of service energy consumption

4 Results

In the following paragraphs, the energy efficiency indicators described in Table 2 are calculated for Germany and analysed with regard to the targets of the “Energiewende”. All indicators have been calculated based on the tools provided by the ODYSSEE database.[8]

4.1 Indicators for the overall economy

Total energy consumption

The overall energy efficiency targets of the German “Energiewende” refer to primary energy and gross electricity consumption. In addition, Germany has a productivity target which is based on final energy (see Table 1)[9]. Between 2000 and 2012, primary energy consumption (not temperature-corrected) fell from 14,401 PJ to 13,757 PJ, i.e. by 4.5%. Between 2008 and 2012, i.e. compared to the reference year of the target, the decrease amounted to 4.3%, i.e. was in the same order of magnitude (Figure 1). This is, however, only a little more than one fifth of the decrease which is required to achieve the 20% reduction target in 2020. The decrease in final energy consumption was considerably smaller, amounting to 2.6% over the whole period. Between 2008 and 2012 it was only 1.1%.

The impact of weather fluctuations on energy consumption is shown by the different development of the actual and the temperature-corrected consumption. Beginning with 2000, all years except 2010 were warmer than the long-term average (in terms of degree days). As a result, the temperature-corrected final energy consumption is higher than the actual consumption except in the cold year 2010. Although the difference is relatively small in most of the years, the temperature-corrected consumption shows the more meaningful trend. Both over the whole period 2000-2012 and from 2008 the consumption decrease based on temperature-corrected data was more pronounced: between 2000 and 2012, primary energy consumption fell by 5.9% (2008-2012: -4.8%), and

8 http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

9 These targets are set without a reference whether or not the values are to be adjusted to normal climate. The official monitoring report (BMWi, 2014) shows both an actual and a temperature-corrected development. The distance to the target, however, is only measured with regard to the actual development, i.e. without temperature correction. In this paper, we will calculate both actual and temperature-corrected indicators, in order to analyse the impact of weather fluctuations on energy consumption.

final energy consumption by 4.8% and 2.1% respectively. Although it seems that the primary energy reduction target is closer when considering temperature-corrected data, a strengthening of the falling trend is necessary to achieve the 20% reduction in the eight remaining years.

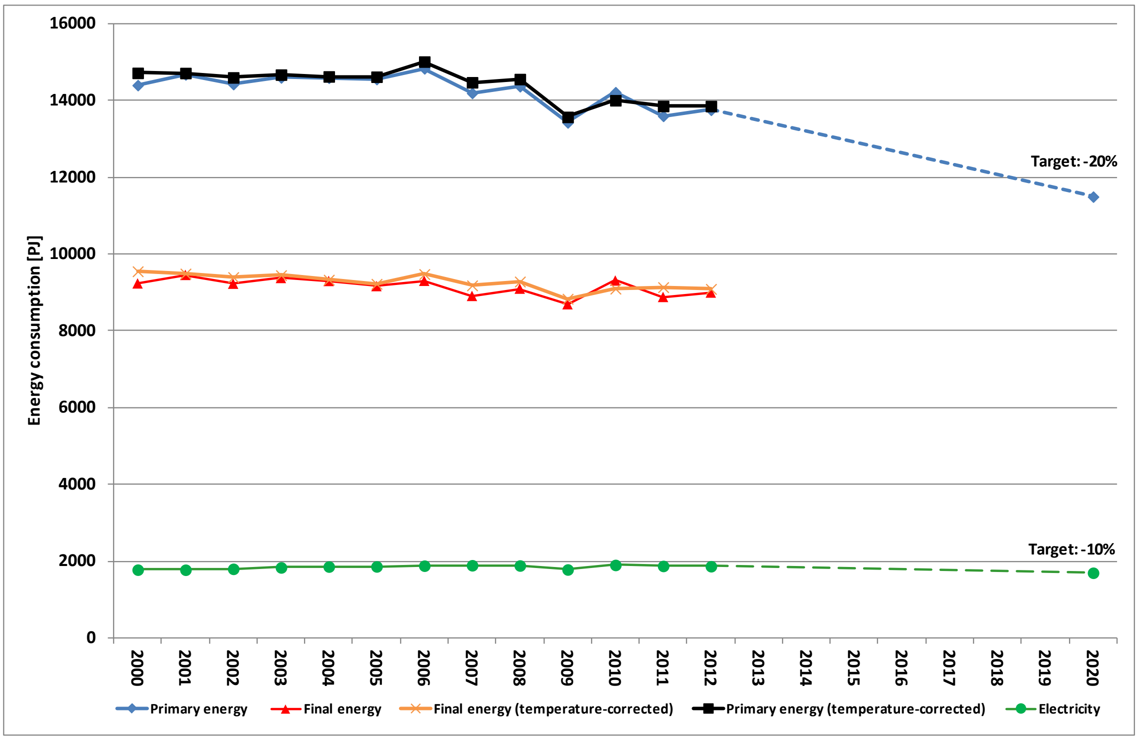

Figure 1: Development of primary and final energy consumption 2000-2012

With regard to the composition of final energy consumption by sector, the main sectors, i.e. households, transport and industry, contribute relatively equally with a share of slightly below 30% of total final energy consumption in Germany (Figure 2). There have been no fundamental changes since 2000;the share of industry only slightly increased, by 2 to 3 percentage points, during the last decade which was mainly due to the relatively high industrial growth since 2005 (apart from the recession year 2009).

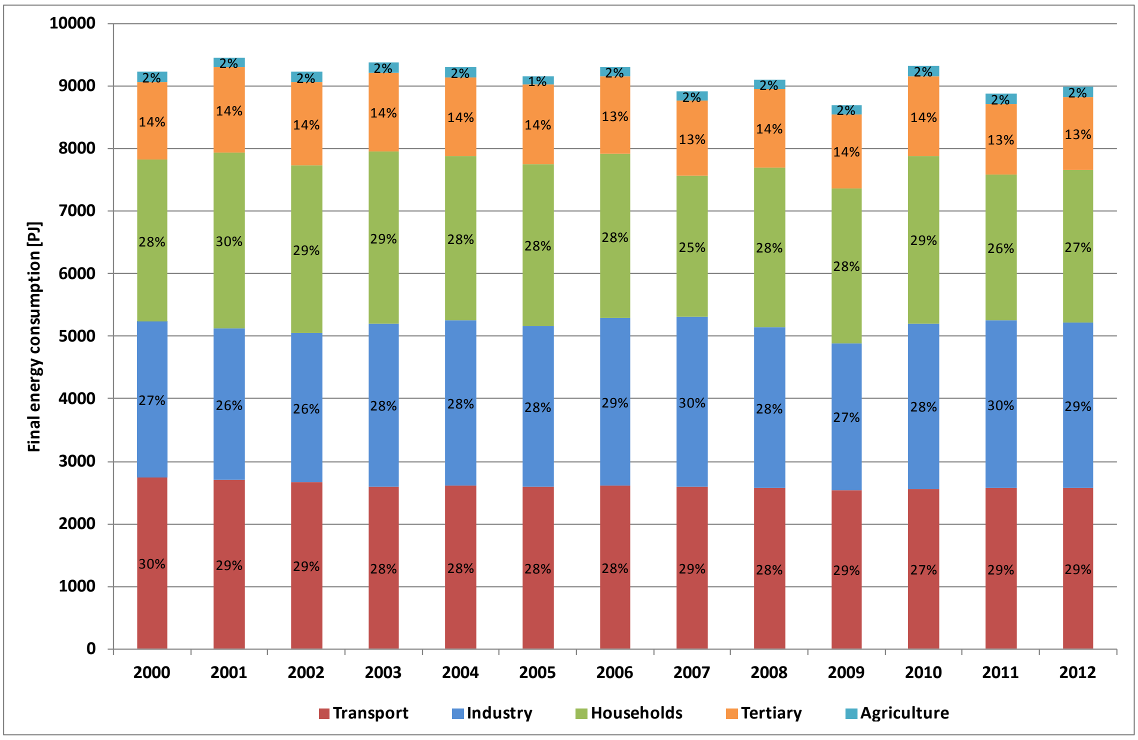

Figure 2: Final energy consumption by sector 2000-2012

Energy intensity

There are two general indicators which are often used to characterise the overall energy efficiency of a country from an economic viewpoint: the primary energy intensity and the final energy intensity, i. e. the ratio between primary or final energy consumption and gross domestic product (GDP). The reverse of this ratio, which is called “energy productivity”, is one of the targets of the German “Energiewende” (Table 1). The effects of economic growth, as measured by GDP, are removed from this indicator as are weather fluctuations; the temperature-corrected intensities are the more meaningful ratios.

Since 2000, actual primary energy intensity in Germany fell by 1.5% per year on average (by 1.6% with temperature correction). The decrease in final energy intensity, as required by the “Energiewende” target, was less pronounced in this period with an annual improvement amounting to 1.3% or 1.5% based on temperature-corrected data (Table 3). When only looking at the development from 2008, the starting year of the target, the decrease in final energy intensity was even less pronounced than over the whole period; it fell by only 0.9% per year or 1.2% with temperature correction. The period 2008-2012 was characterised by strong fluctuations in the economic development due to the financial and economic crisis in 2008/2009 and the subsequent revival of the economy which also had an impact on energy intensity. In 2009, the main year of the economic crisis, final energy intensity even began to increase, i.e. showing a worsening of energy productivity, which was mainly caused by developments in the industrial sector (see Section 4.4). As a result, an even stronger annual improvement of around 2.6% (see Löschel et al., 2014, p. Z-9) is required to achieve the German 2020 target in the remaining years. Primary energy intensity showed a more favourable development during these years; the decrease from 2008 was even stronger than over the whole period (Table 3). This was, however, only due to changes in the power sector (especially the rising share of renewable energies), which will be further analysed below.

Table 3: Development of primary and final energy intensity in the periods 2000-2012 and 2008-2012

Indicator	**Period**		**Target**
[change in % per year]	**2000 - 2012**	**2008 - 2012**	**2008 - 2020**
Primary energy intensity	-1.5%	-1.7%	
Primary energy intensity (temperature-corrected)	-1.6%	-1.9%	
Final energy intensity	-1.3%	-0.9%	Final energy productivity: +2.1% per year (eqv. to an intensity drop by --2.1%)
Final energy intensity (temperature-corrected)	-1.5%	-1.2%	
Final electricity intensity	-0.7%	-0.9%	

ODEX indicator

Although the overall energy intensities described above already take into account the impact of short-term weather fluctuations and changes in activities, the meaningfulness of aggregate energy intensities in capturing energy efficiency is limited by many structural effects within or across the different energy consumption sectors (e.g. sector or product structure in the industrial and tertiary sectors) and several comfort effects (e.g. larger living area per household, higher room temperature, larger appliances). In addition, energy intensities which are based on monetary activities at a highly aggregated level (i.e. total GDP or added value of a sector) only give a limited understanding of the pure energy efficiency developments. In order to improve the meaningfulness of such ratios, the use of activities measured in physical units (e.g. production in tons in manufacturing or per kilometre driven in transport) is widely recommended (see e.g. Farla et al., 1998; Farla and Blok, 2000a, b; Neelis et al., 2007). In our paper, we will take into account these effects at the sectoral level by using indicators which are calculated based on activities measured in physical terms. This will be described in the following sections.

In addition, ODYSSEE provides a re-aggregated energy efficiency indicator (the so-called ODEX) at the level of final energy consumption, which takes into account both short-term fluctuations as well as some structural effects (especially changes in the shares of sectors or industrial branches in total economic output) and behavioural changes (such as higher room temperature or user habits).. Since the ODEX is originally calculated at the sectoral level and largely based on ratios using physical instead of monetary activities (for the calculation of the ODEX see Appendix A), it is a more suitable indicator to evaluate pure energy efficiency trends than energy intensities.

The development of the ODEX indicator in Germany in the period 2000-2012 is shown in Figure 3. In the year 2012, the global ODEX in Germany was 88 which represents a 12% improvement of the overall energy efficiency since the base year 2000, or 1% per year on average. This is around one third lower than the decrease in the (temperature corrected) final energy intensity during that period (see Table 3). That indicates the development of total final energy intensity was still influenced by some external factors not primarily attributable to energy efficiency which are removed from the ODEX. From 2008, the global ODEX in Germany stagnated and only improved again from 2011. In the period 2008 to 2012, the energy efficiency improvement at the level of the whole economy was cut by half to an average of around 0.5% per year. The stagnation of the global ODEX between 2008 and 2010 was caused by the reversal in development of energy efficiency in industry. During these years the industrial ODEX showed an increase, i.e. a worsening of energy efficiency, by around 1.4% per year, whereas the transport and household ODEX further improved, though at a slightly slower rate. This trend in industry is due to the fact that during an industrial recession the energy consumed per unit of production tends to increase. This reflects the fact that process energy does not decrease in proportion to activity (as the efficiency of equipment drops when not used at full capacity) and other energy uses (e.g. heating and lighting of the premises) remain roughly constant.

A more detailed analysis of the development of the ODEX at the level of final energy consumption sectors will be given in the following sections.

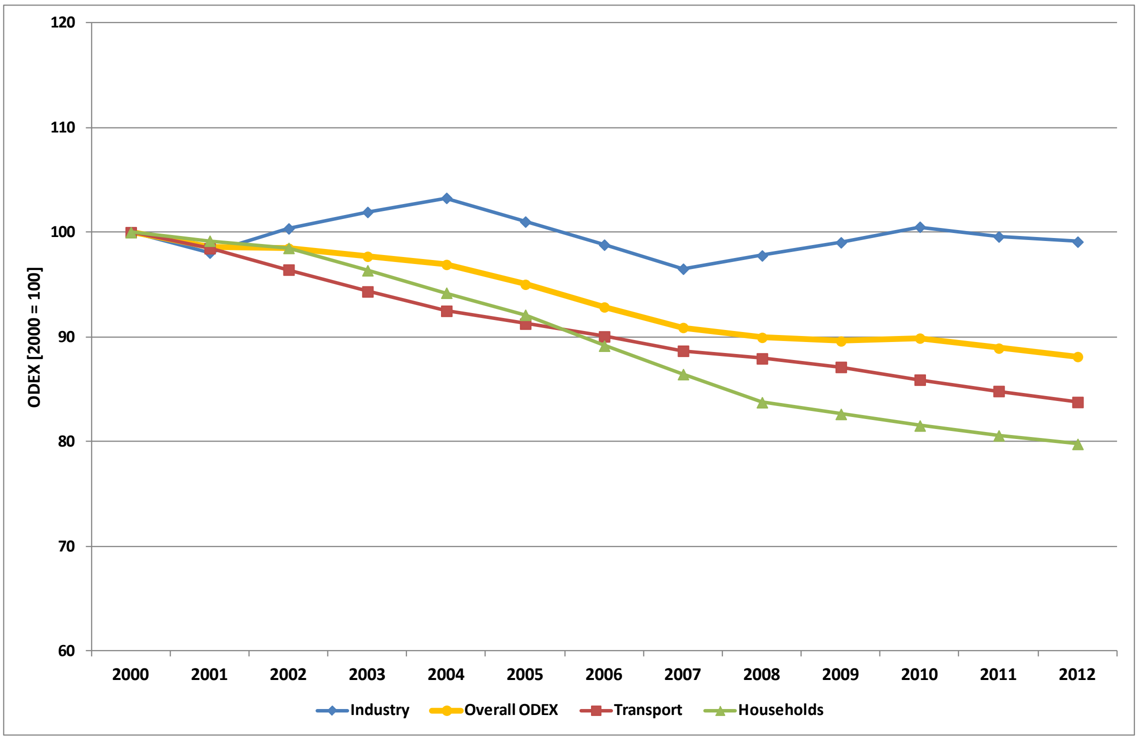

Figure 3: Development of the energy efficiency index ODEX in Germany for the overall economy and by sector for the period 2000-2012

Decomposition of final energy consumption

As described above, the ODEX measures the impact of energy efficiency gains (or losses) at the level of the overall economy. Other factors influencing final energy consumption which are not primarily attributable to energy efficiency are removed. In order to show the impact of these external factors on the variation of the total final energy consumption and to relate it to energy efficiency trends as measured by the ODEX, a new indicator was separated out from the ODYSSEE databases. It breaks down the variation of total final energy consumption over a given period into various components to analyse their influence on the aggregate (for a detailed description of this indicator see Appendix A).

The variation of final energy consumption is split into the following explanatory factors, which are calculated at the level of the energy consumption sector and totalled to provide a result for the overall economy:

- an activity effect due to an increase in an activity measured in economic or – as far as possible - physical units
- structural effects due to several changes in the structure of the economy

- a demographic effect due to changes in the number of inhabitants or households
- a so-called "lifestyle effect" due to an increase in comfort and in the number of appliances in a private household as a result of a growing income
- an energy efficiency effect as measured with the ODEX
- weather fluctuations which are taken into account for the household and tertiary sector
- other effects which are defined differently in the sectors and totalled; they mainly include behavioural changes and comfort effects in the household sector, changes in the value of products in industry, changes in labour productivity in the tertiary sector and the impact of statistical differences especially in the transport sector (see also Appendix A).

Figure 4 shows the decomposition of total final energy consumption in Germany for the periods 2000-2012 and 2008-2012.

During the period 2000-2012, total final energy consumption in Germany decreased by almost 240 PJ. The activity, demographic and lifestyle effects as well as the weather fluctuations contributed to a total increase in final energy consumption by around 1,570 PJ. These were, however, compensated for by the energy savings achieved through a considerable improvement in energy efficiency as measured by the ODEX and, to a lesser extent, some structural changes and other effects which also caused decreasing energy consumption over the period 2000-2012. The main drivers of the energy consumption variations were the growth of economic activity on the one hand and the reversal effect of the energy efficiency improvements in all final energy consumption sectors which were calculated from the ODEX and resulted in annual energy savings of around 120 PJ between 2000 and 2012 (see Figure 4).

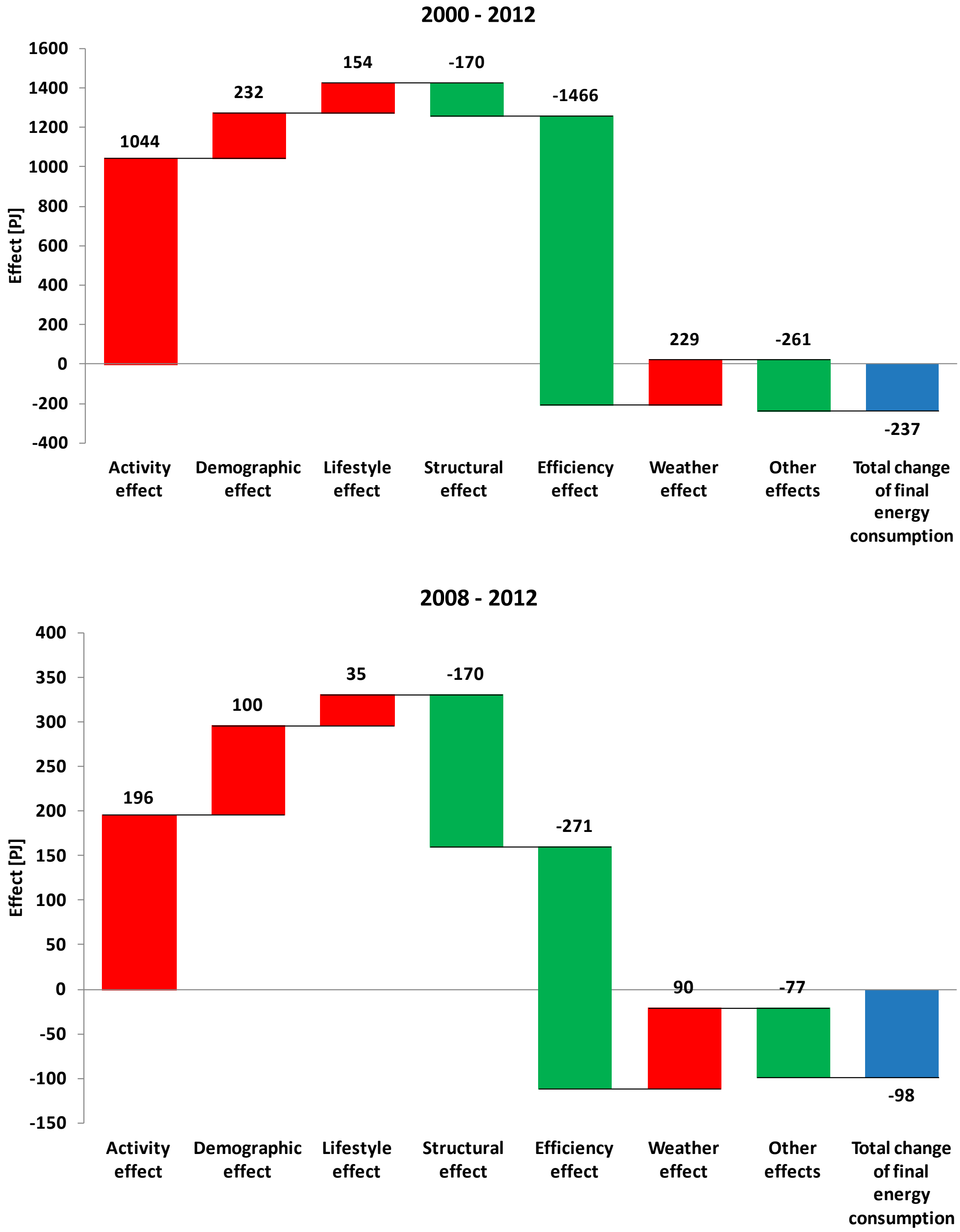

Figure 4: Decomposition of final energy consumption for the periods 2000-2012 and 2008-2012

When looking solely at the period 2008-2012, i.e. starting with the base year of the "Energiewende" target, the general direction of the effects is the same as for the whole period under review. However, the impact of the two main drivers of activity (increasing effect) and energy efficiency (decreasing effect) was almost halved each year. On the other hand, structural effects, i.e. structural changes within the economy towards less energy-intensive sectors, were strongly negative leading to an even larger reduction of final energy consumption between 2008 and 2012 than over the whole period (around 25 PJ per year compared to almost 20 PJ).

As already stated above, the variation in total final energy consumption in a given time period was at first calculated at the sectoral level and then summed up for the total economy. Therefore, in the following Sections 4.2 to 4.4 we will analyse the developments in the different sectors level more deeply.

Decomposition of primary energy consumption

The variation of primary energy consumption analysed here is the sum of the variation of final energy consumption, the variation of the net consumption of the power sector, and the variation in the consumption of other transformations (incl. non-energy uses). The variation of the net consumption of the power sector is further decomposed into three underlying effects, which contribute to the total change (see also Appendix A):

- the effect of “electricity penetration” measuring the impact of increased electricity consumption in terms of additional losses in power generation,
- the impact of changes in the “efficiency of thermal power plants” and
- the impact of changes in the ”power mix“, i.e. the shares of renewable energies, nuclear energy and thermal power plants in total power production.

In the following, we base our analysis on temperature-corrected data. As Figure 5 shows, the (temperature-corrected) primary energy consumption of Germany decreased by 864 PJ (or almost 6%) in the time period from 2000 to 2012 and by 703 PJ (4.8%) from 2008 to 2012. Changes in the power mix had the greatest effect on this development in both periods (primarily the switching to renewable energy sources). It accounted for a reduction of 507 PJ from the year 2000 and 269 PJ from 2008. Changes in demand reduced primary energy consumption by 238 PJ in the period 2000-2012 and by around 100 PJ from 2008-2012. Compared to these effects, the contribution from changes in the efficiency of the thermal power plant and other transformational changes to the total reduction in primary energy consumption was relatively small. The increase in electricity penetration slowed this development down by 225 PJ in the period 2000 – 2012. However, in the period 2008-2012 a slightly reducing effect of 52 PJ was observed. Overall the analysis of primary energy consumption shows that most of Germany's efforts to reduce its primary energy consumption, by pushing the development of renewable energies, pay off. These efforts were slowed down however, by contradicting effects like the growing consumption of electricity.

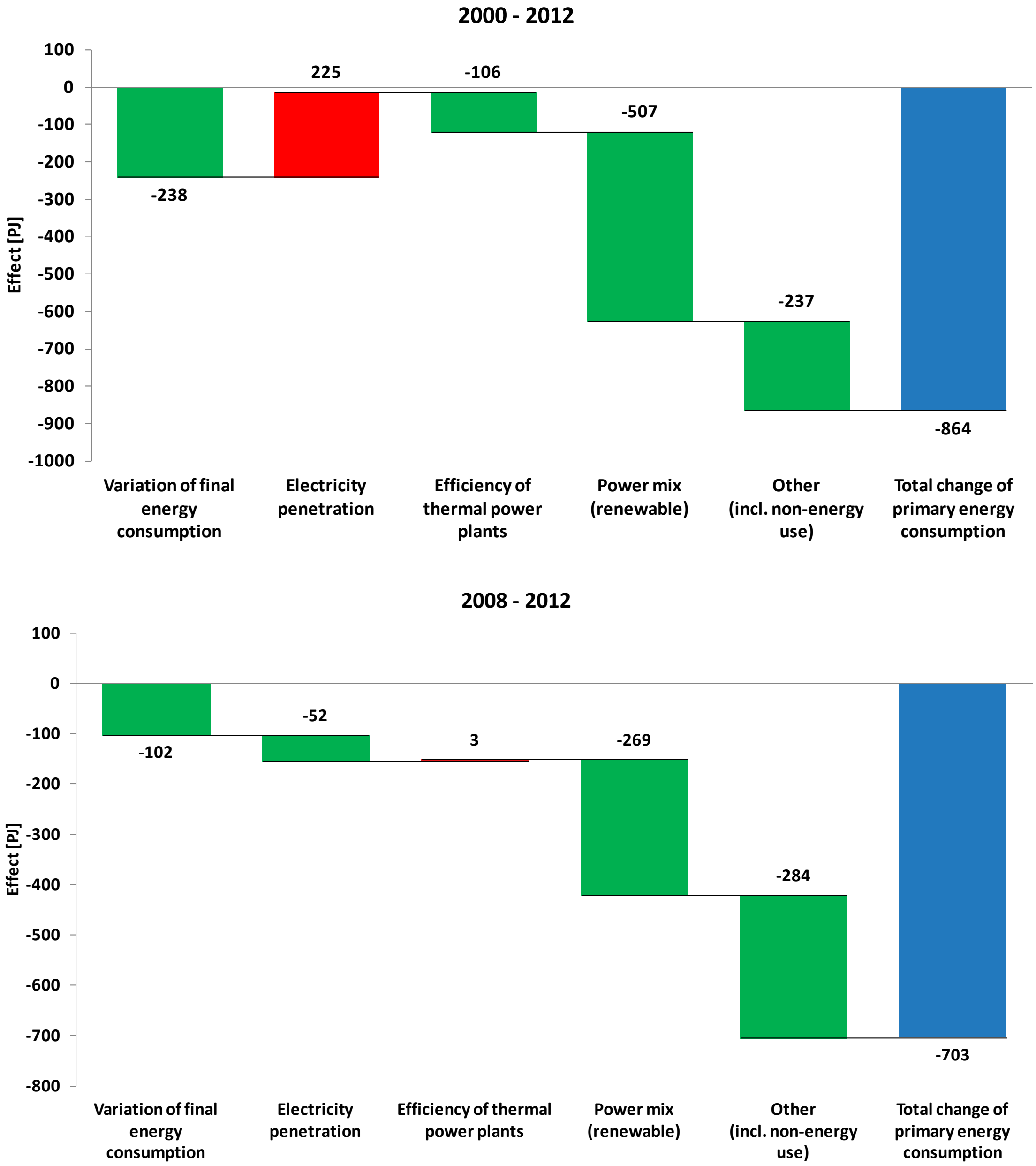

Figure 5: Decomposition of primary energy consumption for the periods 2000-2012 and 2008-2012

4.2 Indicators for the household sector

In the German energy concept, the household sector is addressed through targets for buildings (Table 1). Although the building targets comprise both residential and non-residential buildings, the current monitoring of the "Energiewende" primarily focuses on energy consumption for space heating in private households (BMWi, 2014). The ODYSSEE database also follows this sectoral approach, not least because of the gaps in statistical data for non-residential buildings.

Total consumption for space heating

Energy consumption for space heating in residential buildings generally decreased in the last decade. In a few years however, it was interrupted by consumption increases (Figure 6). This was partly due to weather fluctuations, which are an important influencing factor for this part of energy consumption, but even the temperature-corrected curve, which is steadier than the uncorrected curve, shows some jumps especially in the mid 2000s[10]. Over the whole period 2000-2012, the temperature-corrected energy consumption for space heating in residential buildings decreased by around 450 PJ or 20%. This is in line with the target for the building stock, which also predicts a reduction in heating requirements up to 2020. There is also a relatively continuous decline since 2008, the base year of the overall energy consumption targets. Therefore, we can conclude that if the general trend of the period 2000-2012 (based on temperature-corrected consumption values) can be maintained Germany is likely to achieve its 2020 target for the building sector.

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10 A sharp decline, in particular in the consumption of mineral oil and to some extent also in the consumption of gas, has been noted in the national energy balances (AGEB, 2013) for the year 2007. This is partly explained by variations in stocks. But a recording error may be suspected, too, since survey data do not confirm this sharp decrease.

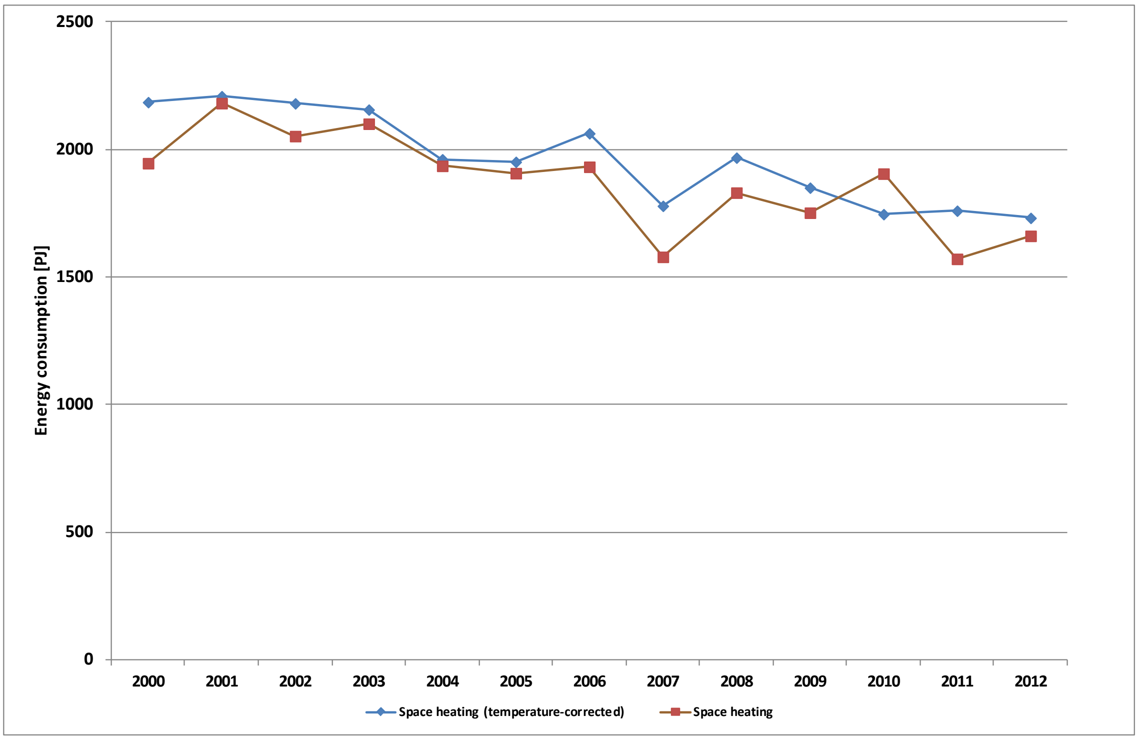


Figure 6: Total consumption for space heating in residential buildings 2000-2012

Unit consumption

We calculate unit consumption both for total energy and electricity consumption of private households and for space heating alone. Energy consumption is related to physical factors (number of dwellings or square metre) and the total energy consumption and space heating figures are temperature-corrected, to remove the effect of weather fluctuations. Total unit consumption generally follows the development of unit consumption of space heating (Figure 7), which represents about 70% of total household energy consumption in Germany[11]. Although total unit consumption and unit consumption for space heating declined over the period, electricity consumption per dwelling remained quite static. After an increase to the mid 2000s, this ratio decreased by around 1% per year from 2005.

11 In the ODYSSEE database, the following end uses are distinguished in the household sector (respective share in total household energy consumption in Germany in 2012): space heating (68%), water heating (15%), cooking (4%), electrical appliances (11%), lighting (2%).

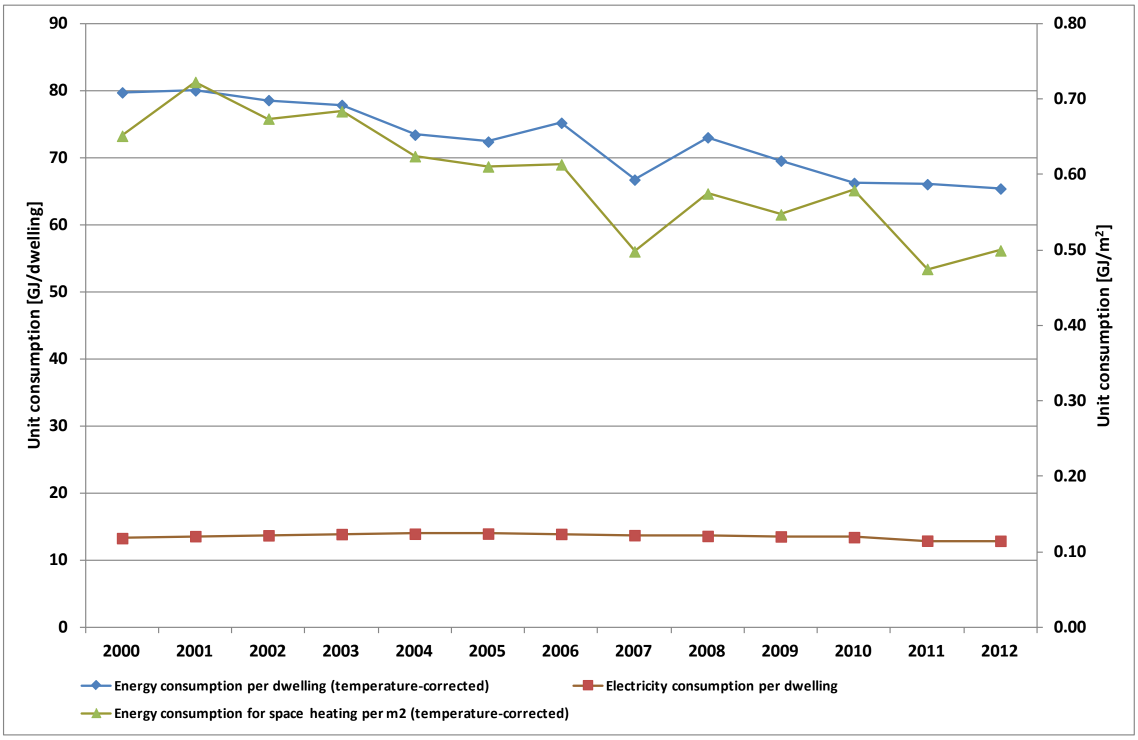


Figure 7: Unit consumption for space heating in households 2000-2012

Although the impact of the activity drivers (i.e. number of dwellings or square metre) and weather fluctuations are removed from the unit consumption indicator of private households in ODYSSEE, it is still influenced by several factors, which partly compensate for each other: fuel substitution, higher energy efficiencies due to thermal regulations, changes in dwelling size or heating system (trend to central heating), changes in the share of single and multi-family dwellings and last but not least behavioural factors (e. g. a trend to higher indoor temperature or a more intensive use of electrical appliances and lamps).

ODEX indicator

The calculation of the household ODEX is also affected by the behavioural factors listed above, which play an important role in the household sector and often counteract the energy efficiency gains as measured by the ODEX. In order to remove these influences , the calculation of the household ODEX was revised to calculate a "technical ODEX", which separates technical and behavioural trends (see Enerdata, 2010 and Appendix A).

For the household sector, the ODEX is calculated at the level of eight end-uses or appliances: heating, water heating, cooking and five large appliances (refrigerators, freezers, washing machines, dishwashers, TVs). Between 2000 and

2012, the technical ODEX in the household sector as a whole decreased by 20%, which represents an average energy efficiency improvement of 1.7% per year (Figure 8). As in the case of unit consumption, the development of the total household ODEX is strongly influenced by space heating, which is responsible for around 70% of total energy consumption (AGEB, 2014). With around 23% or 1.9% per year, the energy efficiency improvement for heating was even more pronounced than that for the total. However, in the period 2008-2012, it slowed down to 1.2% per year on average. The efficiency improvements of the five large appliances also contributed considerably to the total energy efficiency gains in the household sector, whereas the improvement for water heating and cooking was less pronounced.

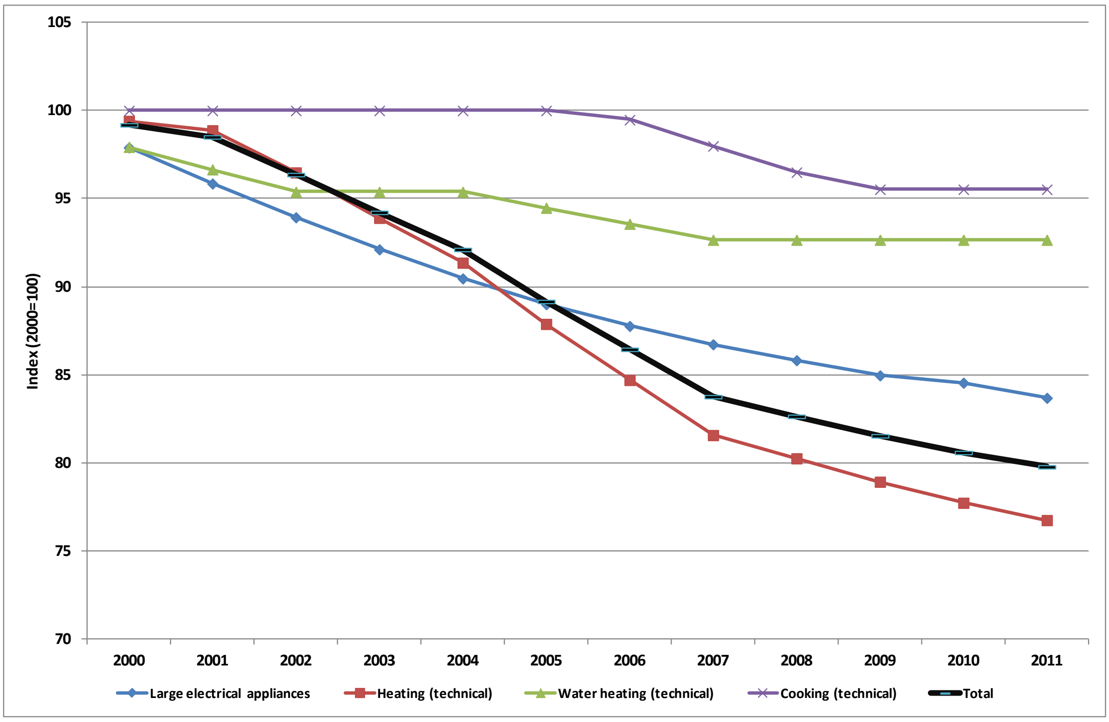
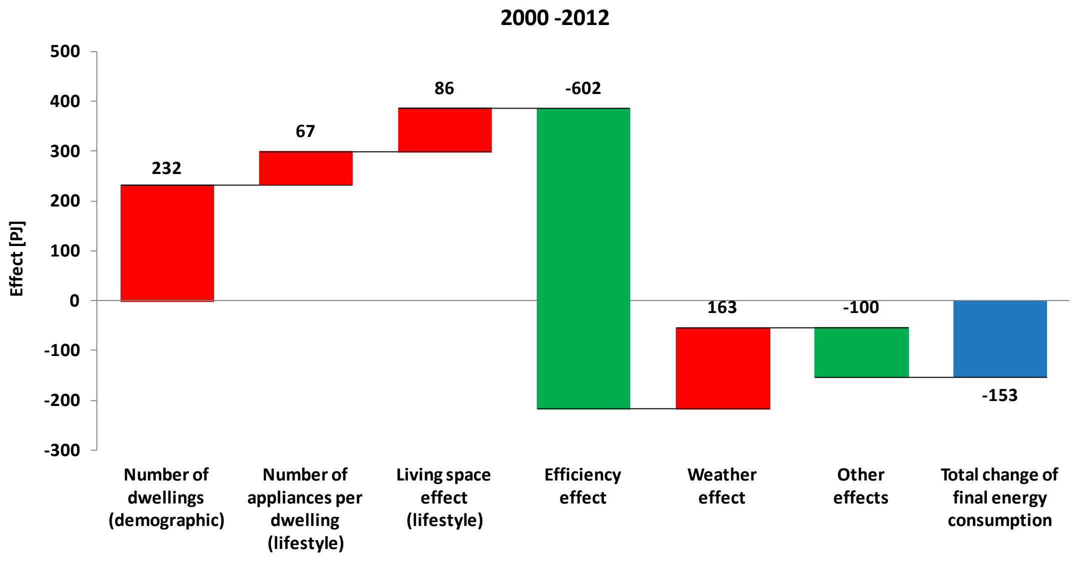


Figure 8: Development of the energy efficiency index ODEX in the household sector for the period 2000-2012

Decomposition of household energy consumption

Between 2000 and 2012, total energy consumption in the household sector decreased by around 150 PJ or 13 PJ per year. This decrease was mainly due to the energy efficiency improvement observed during this period (Figure 9). The increasing number of dwellings (demographic effect) and living space (lifestyle effect) and the weather fluctuations caused energy consumption to increase which was not, however, fully compensated for by the impact of energy efficiency. It was "other effects" which contributed to a reduction of energy consumption in Germany in both periods and became even more important in the period 2008-2012. These "other effects" were primarily behavioural changes (e.g. changing indoor temperature or changed intensity of use of electrical appliances or lamps), which were separated from the energy efficiency improvement measured by the ODEX. In this period, they contributed, along with the energy efficiency improvements, to the total decrease in household final energy consumption of around 130 PJ or 32 PJ per year.[12]

12 Why the "other effects" are so pronounced in the period 2008-2012 cannot be fully explained by the decomposition method applied here. The effect is calculated as a residual (see Appendix A) and can therefore also include the impact of changes in the underlying statistical database (see Section 3.2 and Appendix B).



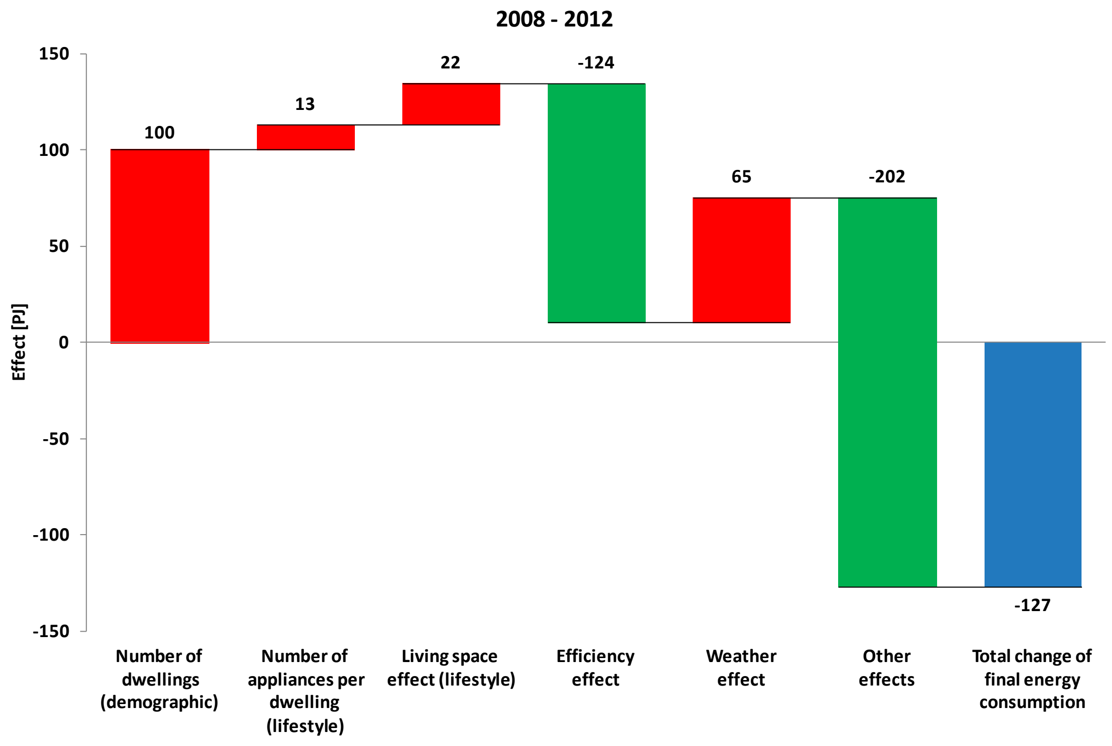


Figure 9: Decomposition of final energy consumption in the household sector for the periods 2000-2012 and 2008-2012

4.3 Indicators for the transport sector

Total energy consumption

Between 2000 and 2012, total energy consumption in the transport sector decreased by around 6.5% from 2,751 to 2,571 PJ. Compared to 2005, the base year for the German energy consumption reduction target of 10%, consumption was almost at the same level as in 2012 (Figure 10). This means that there is still a considerable gap to close to meet the 2020 reduction target of 10% compared to 2005.

In contrast to road and rail transport, energy consumption for air transport (international and domestic) strongly increased especially between 2004 and 2008 (Figure 10). This can particularly be explained by the relatively strong growth of GDP by 2.2% per year during that period and also by the increasing market entry of low-cost carriers. In the following years, a consumption decrease could be observed during the economic recession, but consumption started to grow again in 2011. The share of air transport in total transport energy consumption increased from 11% in 2000 to 14.4% in 2012.

Nevertheless, with a share of more than 80%, road transport still dominates energy consumption of this sector in Germany. Therefore, the main focus of our analysis is on this mode of travel. Road energy consumption widely follows the total trend, it only lies slightly below (Figure 10). Around 70% of energy consumption on roads is by cars and 30% by trucks and light duty vehicles.

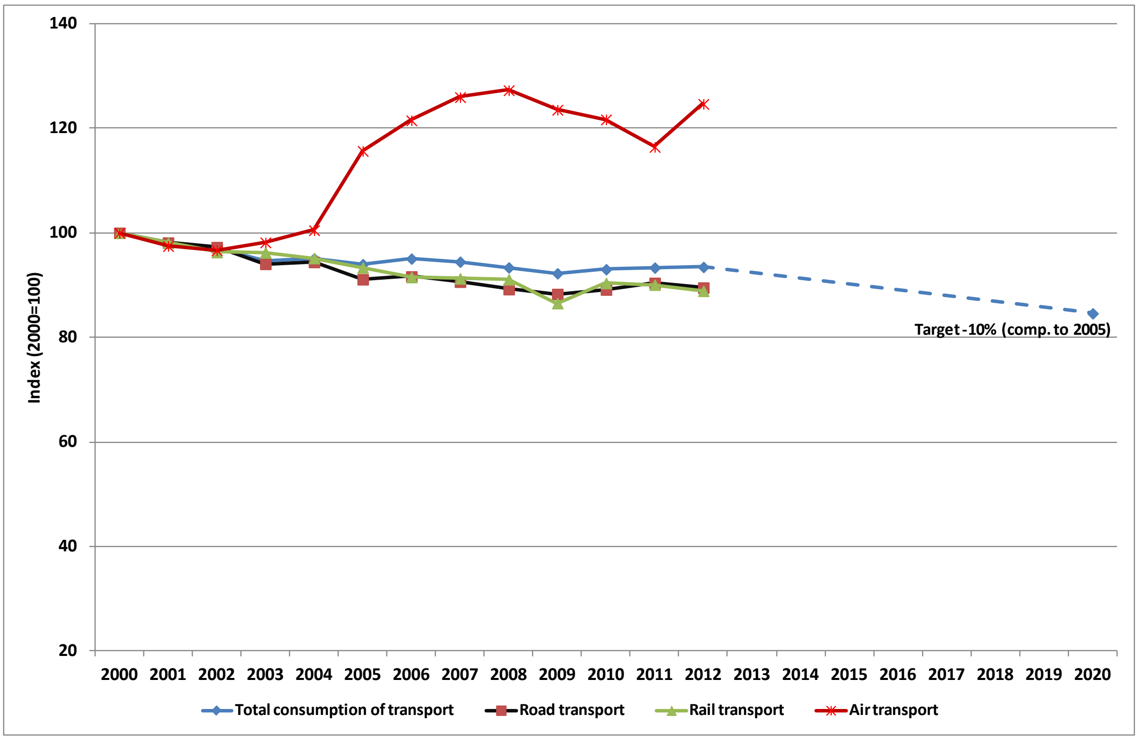


Figure 10: Final energy consumption of transport by modes 2000-2012

Unit consumption and traffic kilometres

The development of total energy consumption of road transport in the period 2000-2012 was influenced by two opposite trends: the rising number of passenger-kilometres for cars and ton-kilometres for trucks, and the decreasing unit consumption of these vehicle types (Figure 11). For freight transport, this trend was only interrupted in the recession year 2009. In this year there was a decline in the freight kilometres and an increase in unit consumption, both caused by the economic recession.

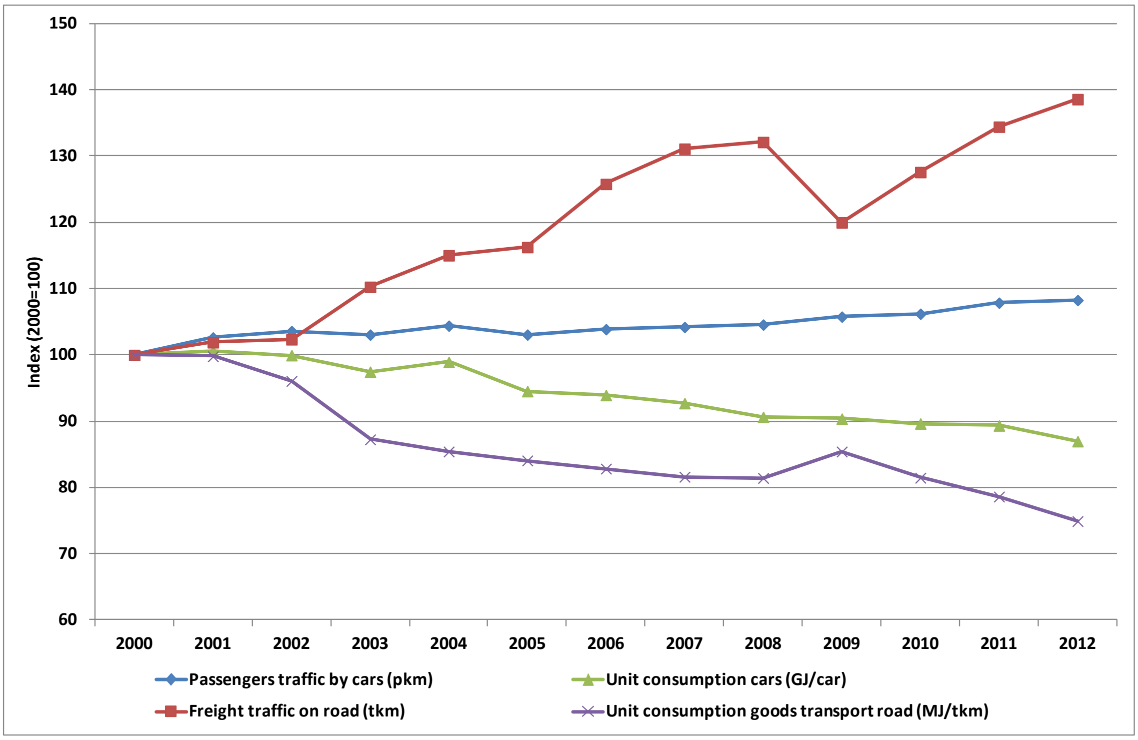


Figure 11: Unit consumption and traffic kilometres of passenger and freight transport 2000-2012

ODEX indicator

The energy efficiency progress in the transport sector is measured by the aggregated energy efficiency index (ODEX), which is calculated at the level of seven transport modes or vehicle types: cars, trucks/light duty vehicles, motorcycles, buses, rail, water and domestic air transport (Figure 12). The calculation is based on the unit consumption indices for these modes.

In 2012, the energy efficiency index of transport improved by 25% compared to 2000. Efficiency improvements in the car stock as a consequence of the penetration of new, more efficient cars (measured by a specific consumption in l/km) including a continuous trend to diesel cars, contributed steadily to this development. Since 2009, however, the energy efficiency improvement for cars has slowed down considerably. The energy efficiency index for trucks and light duty vehicles also contributed to energy efficiency gains in transport, especially over the period 2001-2006. Between 2007 and 2009, the ODEX for trucks increased, which represents a worsening of energy efficiency during the economic crisis. The contribution of the other transport modes (air, train, buses, motor cycles) is less important due to their relatively small shares in consumption. Air transport showed a considerable increase in the ODEX, i.e. a worsening of energy efficiency since 2006.

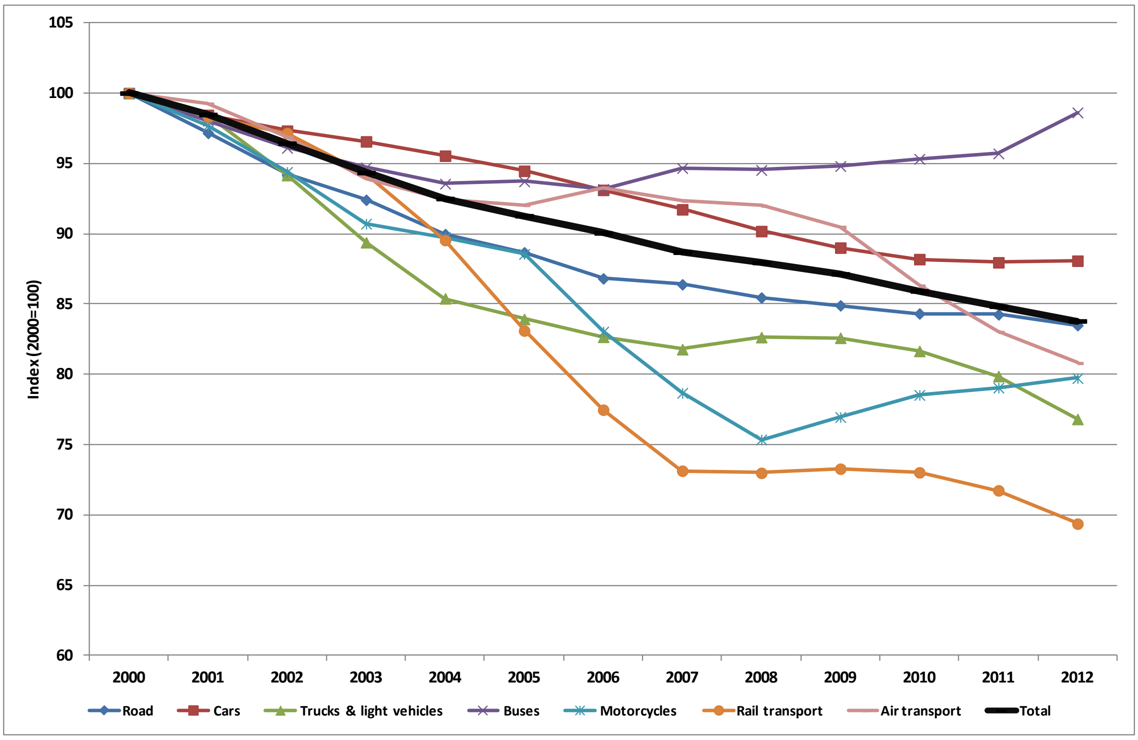


Figure 12: Development of the energy efficiency index ODEX in the transport sector for the period 2000 and 2012

Decomposition of transport energy consumption

The decomposition of transport energy consumption is mainly aimed at road transport, which is still by far the dominant transport mode in Germany. Therefore, the analysis is here done without air transport. As already stated above, the variation of transport energy consumption is dominated by an increasing traffic of passenger and goods (activity effect) which contributed to an increase in energy consumption by around 300 PJ in the period 2000-2012 (Figure 13). This effect was compensated for by an energy efficiency improvement, resulting in a total decrease of transport energy consumption by around 250 PJ or 21 PJ per year. Modal shift, i.e. changes in the distribution of each mode in total passenger and goods traffic, had a comparatively small impact on transport energy consumption between 2000 and 2012 and slightly increased consumption. In the period 2005-2012, the direction of the impacts was the same as in the whole period under review. The energy efficiency improvement has, however, slowed down from around 66 PJ to 37 PJ per year on average since 2005. As a result, total energy consumption only decreased slightly during that period (-41 PJ)

This again suggests that there is still a considerable gap to close to meet the 2020 transport target (see Table 1). Since the development of transport energy consumption is strongly dominated by the activity and energy efficiency effects, the main targets for closing the gap are a reduction in the traffic and/or an improvement of energy efficiency.

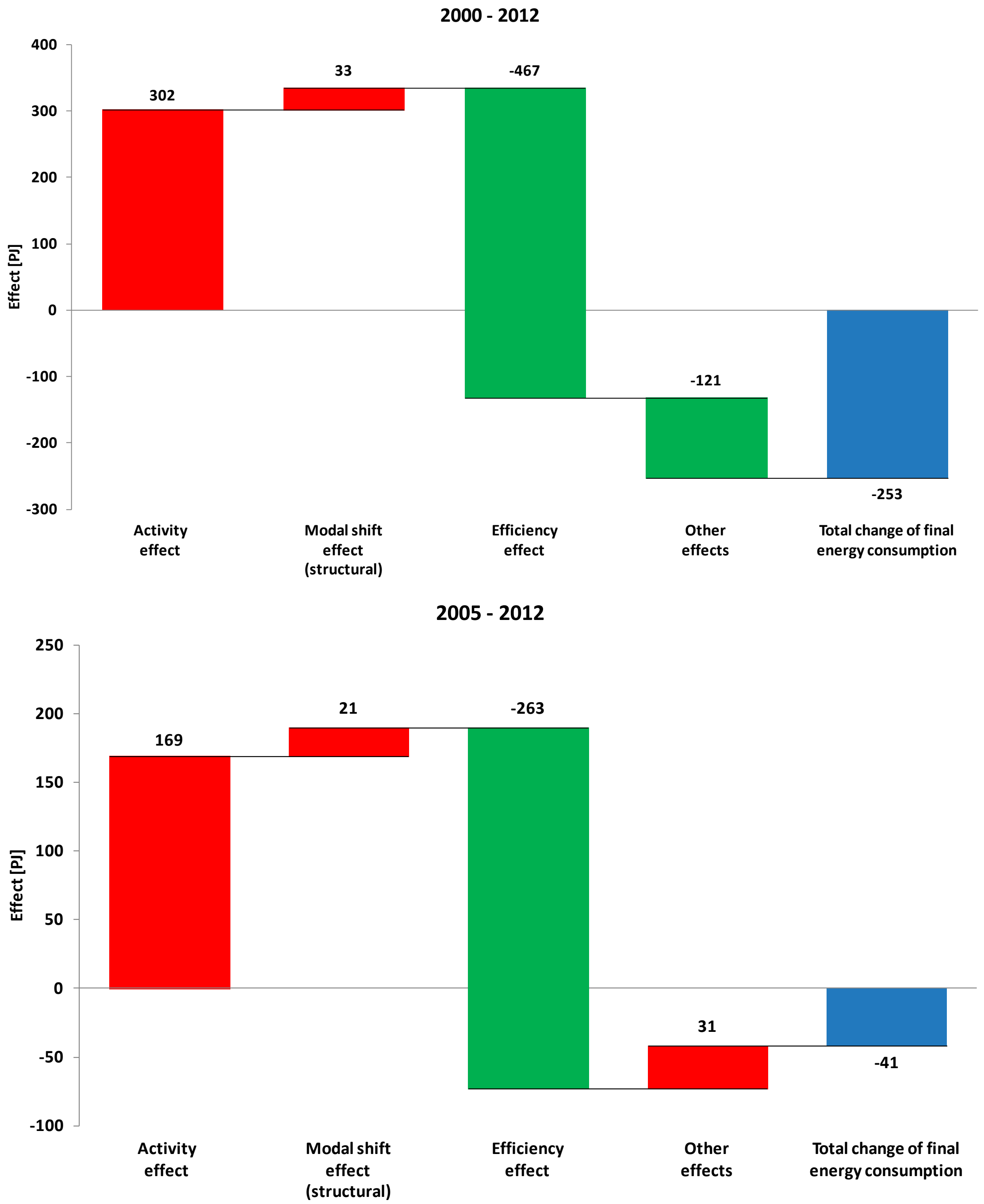


Figure 13: Decomposition of final energy consumption in transport (without air transport) for the periods 2000-2012 and 2008-2012

4.4 Indicators for industry and manufacturing

Although there is no specific energy efficiency target for the industrial sector in Germany, this sector contributes to the overall targets in total final energy consumption with a current share of around 30% (Figure 2). Therefore, we will also need to take a more detailed look at the development of energy consumption and energy efficiency in industry. Our analysis will mainly focus on manufacturing industry, which contributes around 97 % of total energy consumption of industry[13] in Germany.

Energy intensity and unit consumption

Energy intensity is an aggregate indicator which is often used to describe the develop-ment of energy efficiency in industry. Between 2000 and 2012, energy intensity of manufacturing decreased by 0.8 % per year on average. When taking only the period 2008-2012 into account, the decrease slowed down to 0.1% per year. This means that the contribution of industry to the final energy productivity target of the “Energiewende” was below the average of the overall economy in both periods (see Table 3).

As already stated above, the development of energy intensity does not only reflect energy efficiency improvements; structural changes within manufacturing (i.e. changing shares of the more or less energy-intensive branches in total industrial output), may also have an important influence. This is shown by the energy intensity calculated within a constant structure of manufacturing. The intensity at constant structure better reflects the predominantly technically induced efficiency changes in manufacturing since the impact of structural changes are removed, using a Divisia index (see Appendix A). In the period 2000-2008, i.e. before the economic recession, the decrease of the actual energy intensity of manufacturing by around 1.6% per year has almost equally been influenced by energy efficiency improvements and structural changes towards less energy-intensive branches (Figure 8-14). In the following period from 2008-2012, this trend changed completely. Whereas the intensity-reducing impact of structural changes more than doubled compared to the period before, there was no energy efficiency progress at all, but energy intensity at constant

13 Industry is defined in ODYSSEE as manufacturing industry, mining, water processing and construction. The branches are defined in accordance with the statistical classification of economic activities in the European Community (NACE, Rev. 2, 2008) http://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC

structure increased by 1.7% per year. As already stated above (see Section 4.1), this increasing trend of energy intensity was mainly caused by the economic recession. It reflects the fact that process energy does not decrease in proportion to activity (as the efficiency of equipment drops when not used at full capacity) and other energy uses (e.g. heating and lighting of the premises) remain roughly constant.

As a result, however, there was no energy efficiency progress in manufacturing over the whole period 2000-2012, but a slight increase in the intensity at constant structure by 0.1% per year (Figure 8-14). This means that the observed decrease in the actual energy intensity by 1.1% per year was primarily caused by structural changes within manufacturing towards less energy-intensive branches and not by energy efficiency gains.

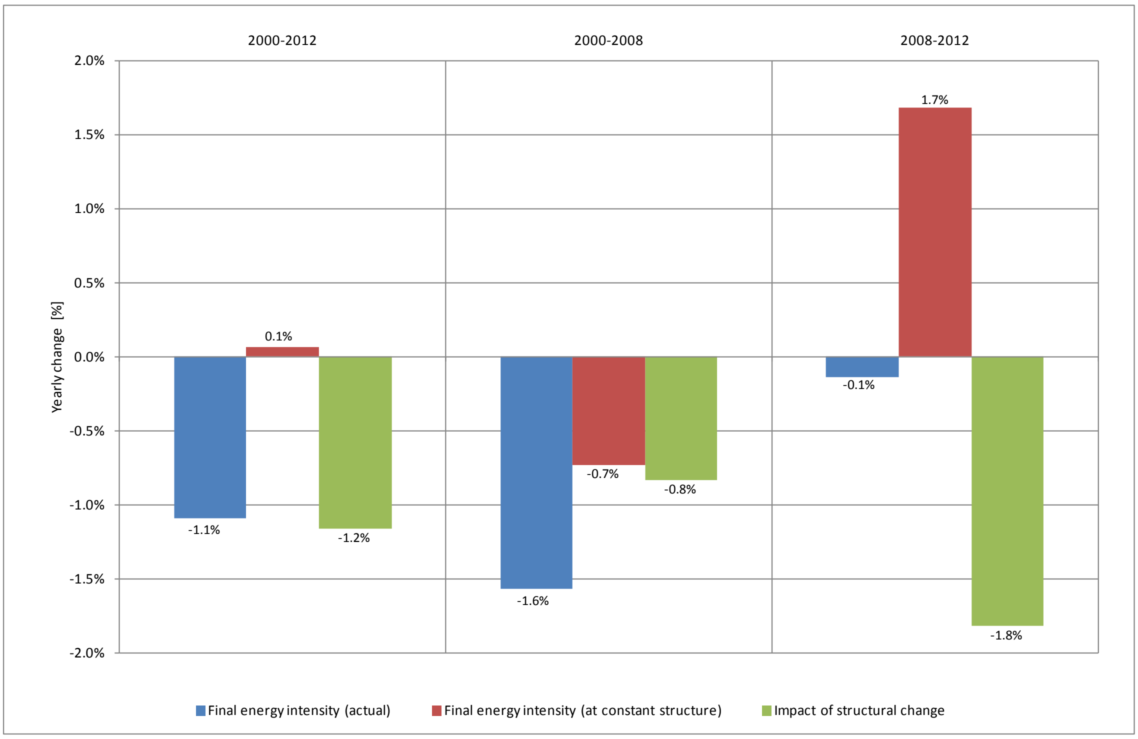


Figure 14: Change of energy intensity in manufacturing in the periods 2000-2012, 2000-2008 and 2008-2012

The meaningfulness of final energy intensity of manufacturing is further restricted by the fact that it is calculated based on added value, i.e. activity calculated in monetary units. The use of physical factors is widely advocated, since they better reflect the energy efficiency development (see e.g. Worrell et al. 1997; Farla and Blok, 2000b; Neelis et al., 2007; Salta et al., 2009). Therefore, we calculate – in addition to energy intensities – unit consumption indicators (defined as energy consumption per ton) for some energy-intensive products in manufacturing (see Figure 15).

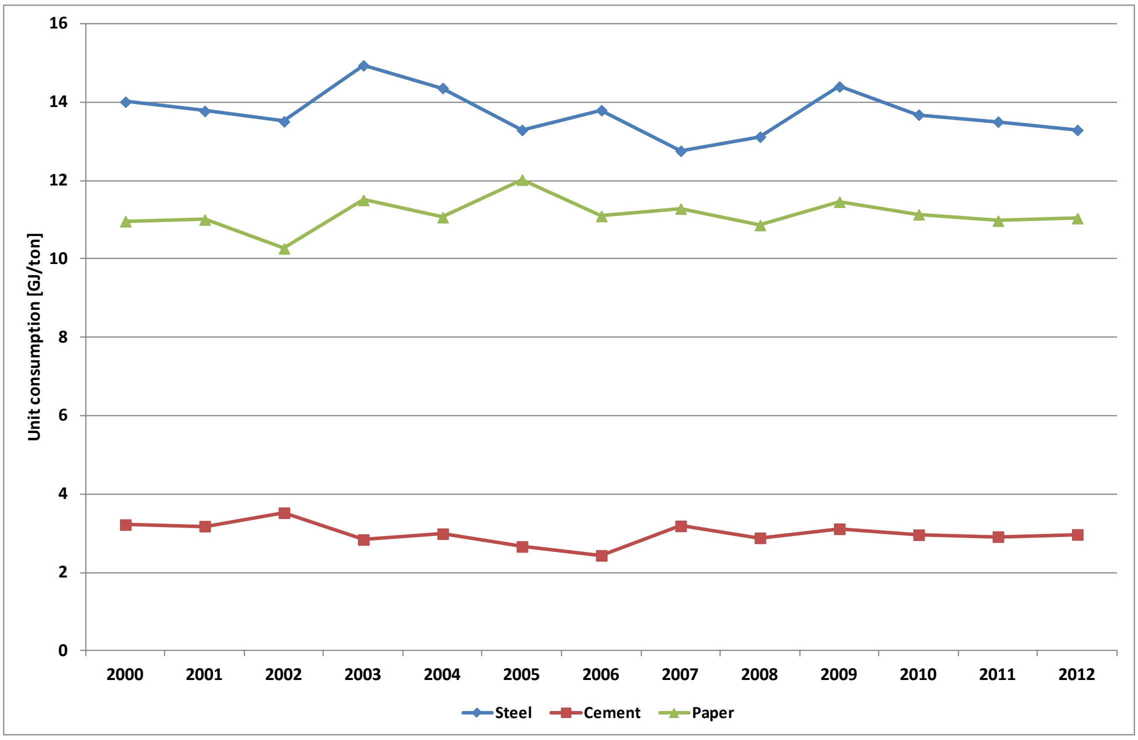


Figure 15: Unit consumption of energy-intensive products 2000-2012

Over the whole period 2000-2012, unit consumption of the selected products (crude steel, pulp and paper, cement) did not change significantly. In fact, in some years an increase was observed, especially in the case of steel and paper, and this was mainly linked to business cycles. The trend in unit consumption confirms the observation of rather modest or no energy efficiency improvement in industry which was already shown by the intensity indicator. This was also a reversal of the trend during the 1990s, when both energy intensity and unit consumption of energy-intensive products considerably decreased and a clear improvement in energy efficiency was observed (see Schlomann and Eichhammer, 2012).

ODEX indicator

In addition to the energy intensity at constant structure and the unit consumption of energy-intensive products, the efficiency progress in the industrial sector is also measured with the ODEX. It measures the efficiency development at the level of 10 industrial branches, and aggregates this development to the whole sector (Figure 16). For the energy-intensive products (cement, steel, paper), the calculation is based on unit consumption per ton. For the other branches, the energy used per production index is used instead of added value, in order to exclude the impact of a changing value of products from the ODEX. This impact, which is not primarily attributable to energy efficiency, is then separated in the decomposition analysis (see Figure 17).

Over the whole period 2000 to 2012, the total ODEX for manufacturing remains almost constant, with the total improvement amounting to less than 1%. The development within the 10 industrial branches, however, varied significantly, both between the branches and over the whole period under review (Figure 16). There were some branches with a considerable energy efficiency progress (e.g. non-ferrous metals, cement, machinery, transport vehicles), and others with an increasing ODEX, i.e. a worsening of energy efficiency (e.g. paper, non-metallic minerals, chemicals, food). Since the second half of the 2000s, the increasing trend of the ODEX has strengthened in several branches.

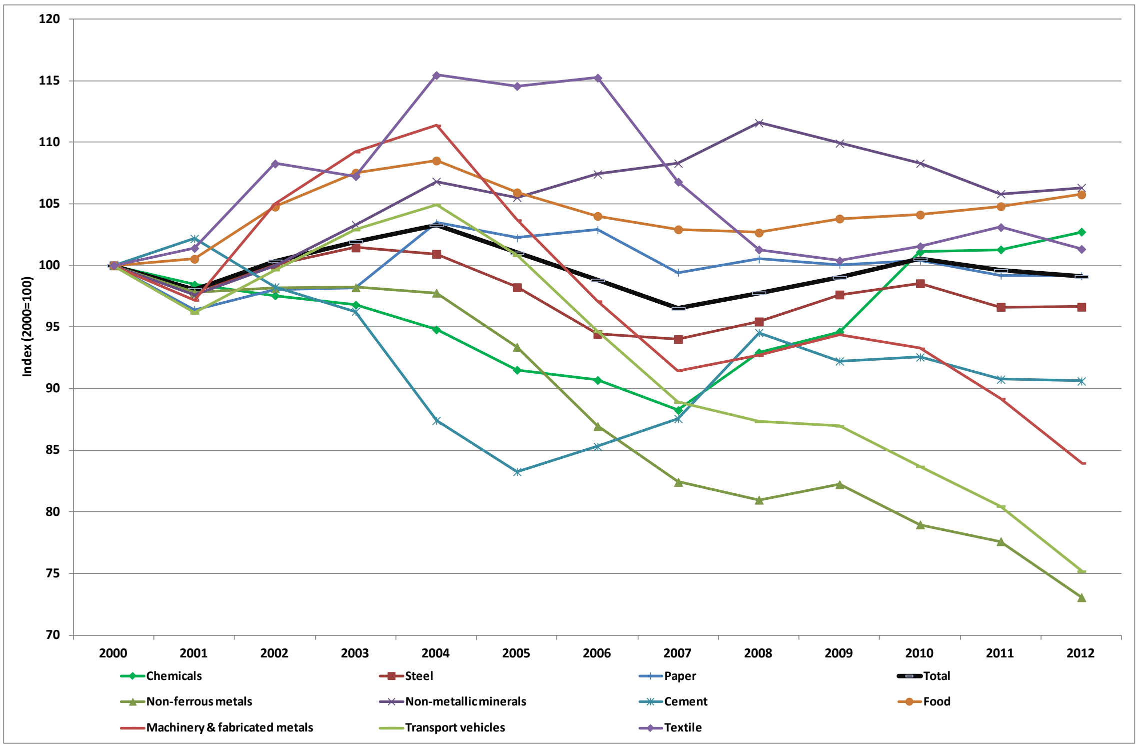


Figure 16: Development of the energy efficiency index ODEX in manufacturing for the period 2000-2012

Decomposition of energy consumption of manufacturing industry

The decomposition of energy consumption confirms the minimal progress in energy efficiency which was achieved in manufacturing industry over the period

2000-2012. The activity effect, i.e. the industrial growth, had an increasing impact on energy consumption, whereas structural changes towards less energy-intensive branches caused a significant reduction (Figure 17). In the period 2008-2012, the decreasing impact of structural change was further strengthened, whereas the energy efficiency impact caused negative energy savings, i.e. an increase in energy consumption. Changes in the "value of the product", which is measured through the ratio of added valued to physical production or the production index respectively, also caused a slight increase in industrial energy consumption. As a result of these effects, total energy consumption in industry slightly increased in both periods (Figure 17). As already explained in Section 4.1, this trend in industry is due to the fact that during an industrial recession, the energy consumed per unit of production tends to increase as process energy does not decrease in proportional to activity (as the efficiency of equipment drops when not used at full capacity) and as the other energy uses (e.g. for heating and lighting of the premises) remains roughly constant.

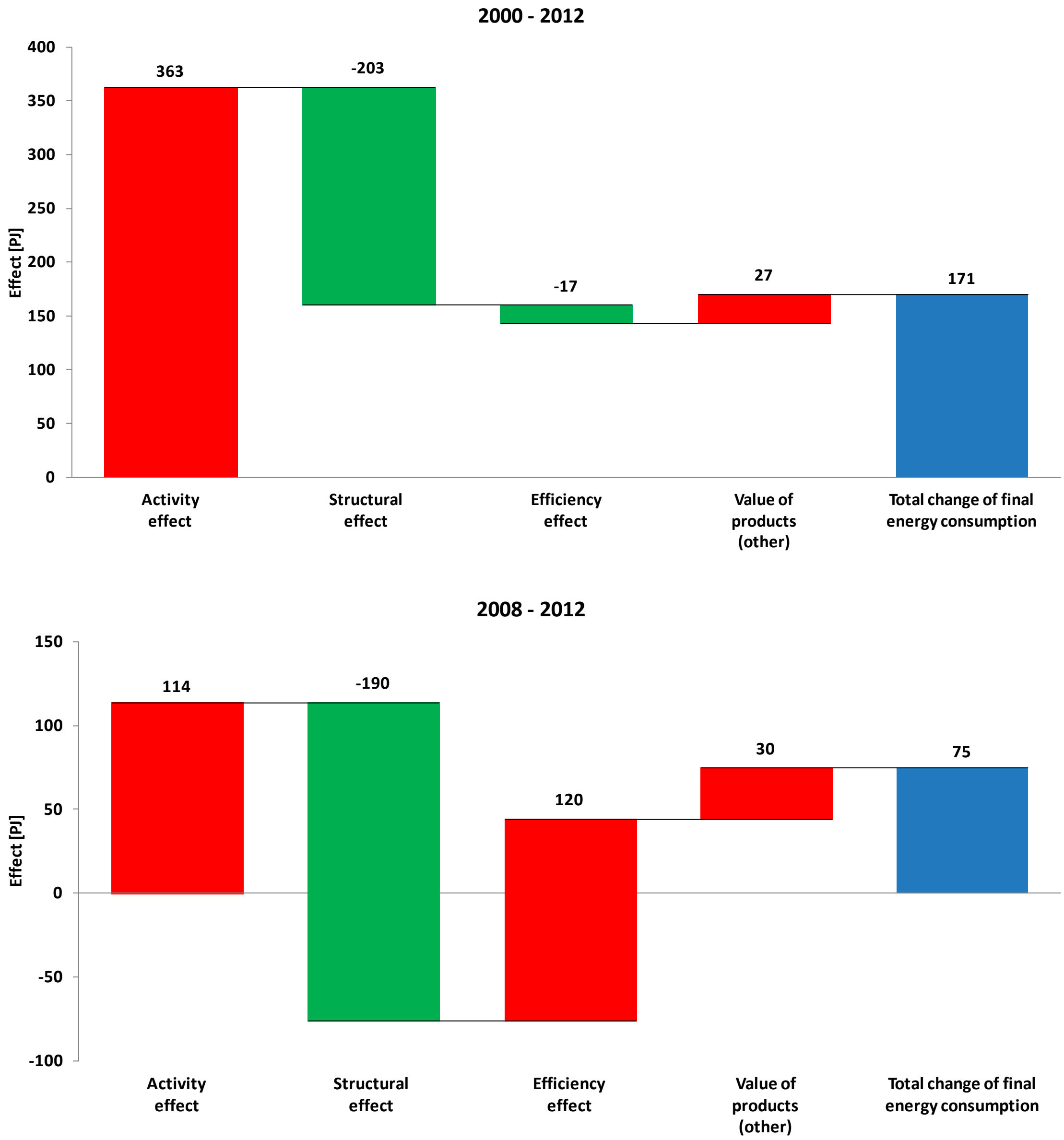


Figure 17: Decomposition of final energy consumption in industry for the periods 2000-2012 and 2008-2012

4.5 Indicators for the tertiary and service sector

Total energy consumption

The German energy balance (AGEB, 2013) only shows energy consumption for the total tertiary sector, defined here as private and public services, agriculture, construction industries and military. In 2012, energy consumption of this aggregate amounted to 1,397 PJ which is around 15 % of total final energy consumption in Germany (Figure 2). The main focus of the ODYSSEE database is on energy consumption of the service sector only, including private and public services. For Germany, energy consumption data for this aggregate are available from a regular survey (see Section 3.2 and Appendix B). In 2012, energy consumption of the service sector amounted to 1,149 PJ, i.e. around 80% of total consumption of the tertiary sector as defined in the German energy balance.

The number of indicators, which are calculated for the service sector in ODYSSEE, is smaller than for the other final energy consumption sectors. This is due to data gaps at the level of end-uses and sub-sectors in most of the EU countries (see Section 3.2). In the following, some energy intensity and unit consumption indicators as well as a decomposed indicator are calculated for Germany.

Energy intensities and unit consumption

Over the whole period, both the energy intensity of services per unit of added value and unit consumption per employee (both temperature-corrected) show a decreasing trend, with a few periods of stagnation especially during the mid 2000s (Figure 18). Electricity intensity, on the other hand, was relatively stable and even increased between 2008 and 2010, i.e. in the years of the recession and the following revival of the economy. This is the same trend also observed in industry and transport (see Sections 4.3 and 4.4).

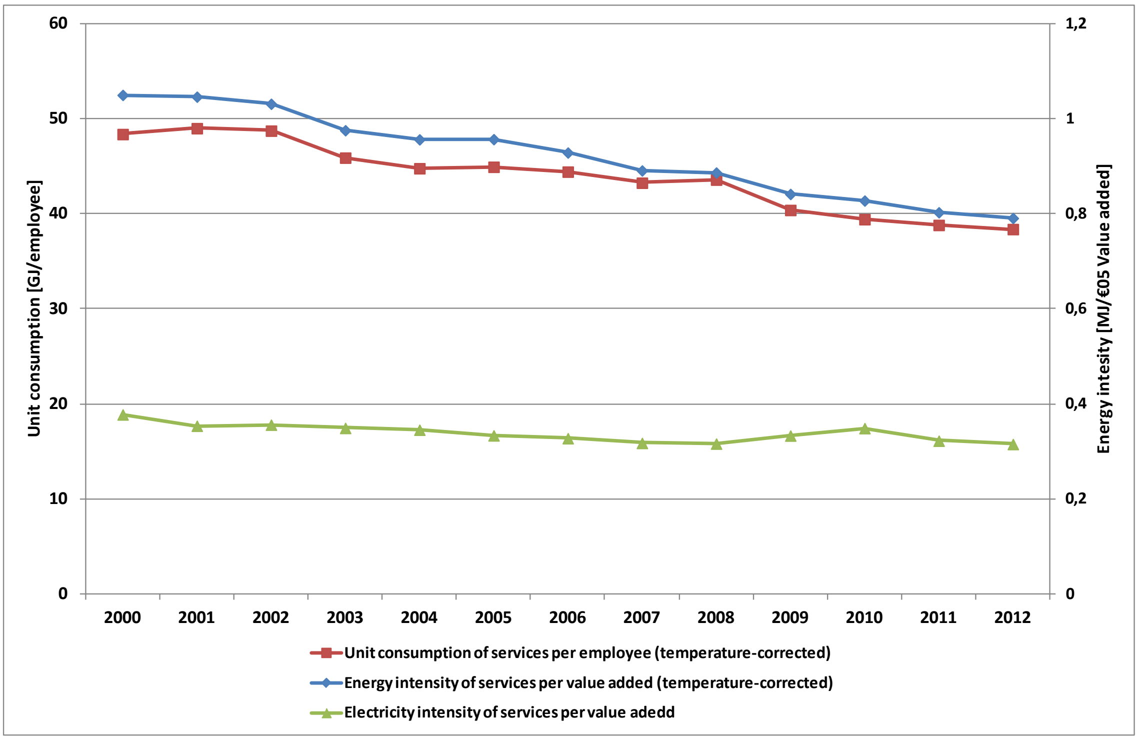


Figure 18: Energy intensity and unit consumption in the service sector

Decomposition of energy consumption of services

The decomposition of energy consumption in the service sector is shown in Figure 19. In both periods, total final energy consumption decreased by around 80 PJ. The activity effect, which is measured by changes in added value, contributed to an increase in energy consumption. Due to the recession, it was less pronounced in the period from 2008. Weather fluctuations also contributed to an increasing consumption. The decrease in total consumption was mainly caused by the efficiency effect, which counteracted the increasing effect of the other factors in both periods. Over the whole period, the productivity effect, which measures the change in the ratio of added value to employment, also had a reducing impact on energy consumption. In the period 2008-2012 however, the direction of this impact changed.

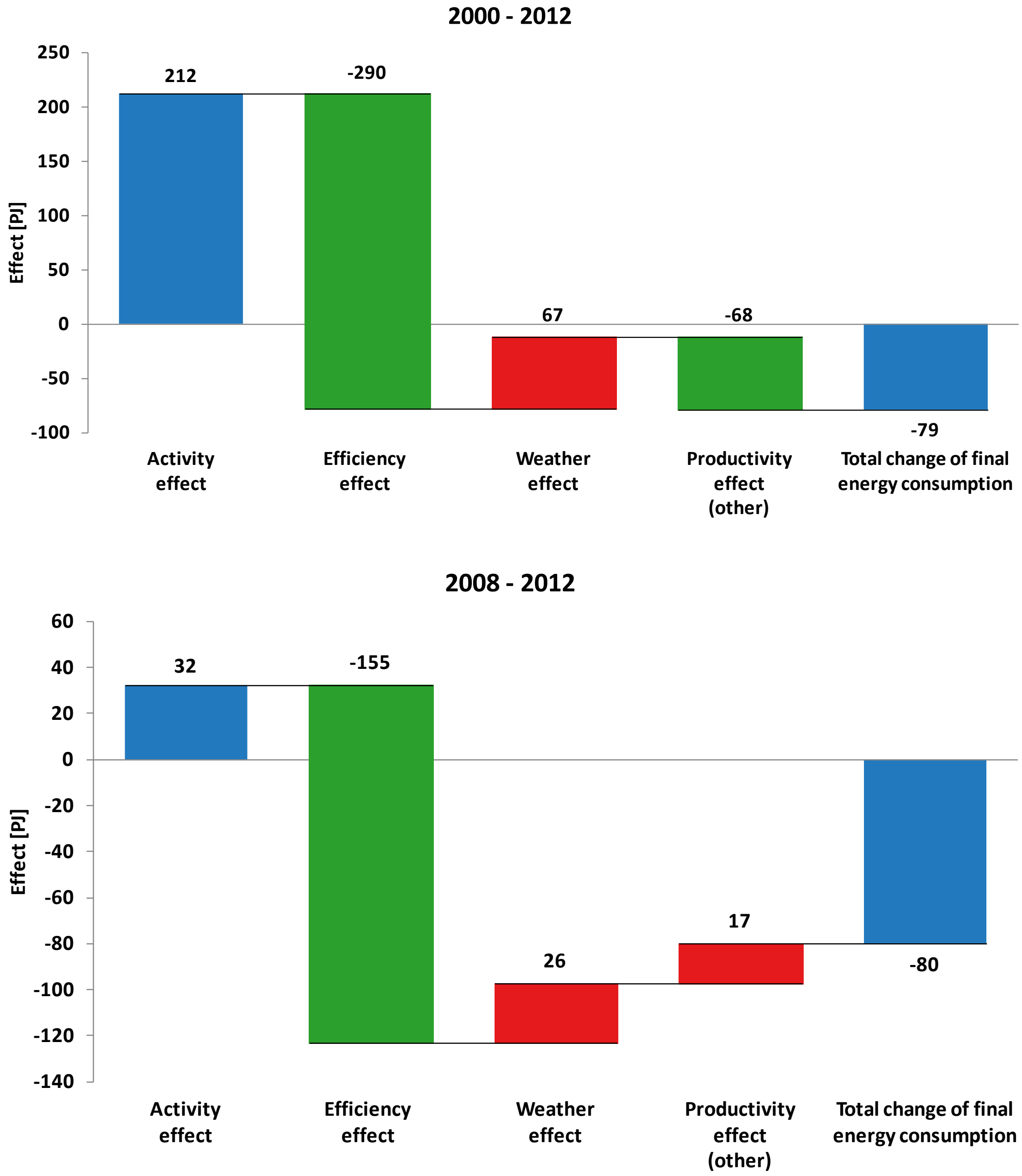


Figure 19: Decomposition of final energy consumption in the service sector for the periods 2000-2012 and 2008-2012

5 Discussion

5.1 Discussion of results

In the frame of the "Energiewende", Germany has decided on targets for an absolute reduction of energy consumption and an improvement of energy efficiency. We used several types of energy efficiency indicators to monitor the progress achieved towards these targets. First we showed that there is still a considerable gap to close to meet the overall targets, which are the reduction of primary energy consumption by 20% and of electricity consumption by 10% by 2020 (both compared to 2008) and an improvement in energy intensity by 2.1% per year (Table 4).

The gap becomes smaller when using temperature-corrected data for the monitoring of the targets, which are in any case more meaningful. A strengthening of the current trend is necessary for all overall targets, but especially for the final productivity and the electricity reductions targets. In the period 2008-2012, the temperature-corrected final energy intensity only improved by 1.2% per year on average (Table 4). In order to achieve the target of 2.1% per year, an even stronger improvement of around 2.6% (Löschel et al., 2014, p. Z-9) is required in the remaining years. During the last twelve years, total final electricity consumption in Germany has increased by 5%. Although a slight decrease by 1% in the period 2008-2012 is observed, i.e. compared to the reference year of the target, this trend needs to be strengthened to reach the 10% reduction target. This is even more imperative since recent energy forecasts for Germany show a slightly increasing trend for electricity consumption up to 2030 in a reference scenario without additional policy efforts (German government, 2013)[14].

14 The main reasons for this development are additional electricity uses e.g. electric mobility (which is also a target of the "Energiewende") and heat pumps in buildings which counteract electricity efficiency improvements.

Table 4: Reflection of our results at the targets of the „Energiewende“

Sector	**EE-related target for 2020**	**ODYSSEE indicator**	**Results 2000-2012**	**Results 2008-2012**
Overall Economy	Primary energy consumption:’ **-20%** (comp. to 2008)	Primary energy consumption -actual -temperature-corrected	 **-4.5%** **-5.9%**	 **-4.3%** **-4.8%**
	Final energy productivity : **+2.1%**/year (eqv. to a respective decrease in energy intensity)	Final energy intensity -actual -temperature-corrected	 **-1.3%**/year **-1.5%**/year	 **-0.9%**/year **-1.2%**/year
		Overall ODEX	**-11.9%** or **-1.0%**/year	**-1.8%** or **-0.5%**/year
	Gross electricity consumption: -**10%** (comp. to 2008)	Total electricity consumption	**+5.0%**	**-1.0%**
Households	Heating requirement: **-20%** (base year not specified)	Final energy consumption for space heating -actual -temperature-corrected	 **-14.6%** **-20.8%**	 **-12.0%** **-9.3%**
		ODEX households	**-20.2%** or **-1.7%**/year	**-4.0%** or **-1.0%**/year
Transport	Final energy consumption in transport sector **-10%** (comp. to 2005)	Final energy consumption of transport	**-6.5%**	**-0.6%** (2005-2012)
		ODEX transport	**-16.2%** or **-1.4%**/year	**7.5%** or **-1.1%**/year
Industry	No specific target	Final energy intensity of manufacturing -actual -at constant structure	 **-0.8%**/year **+0.4%**/year	 **-0.1%**/year **+1.7%**/year
		ODEX industry	**-0.9%** or **-0.1%**/year	**+1.3%** or **+0.3%**/year
Tertiary/ Services	No specific target	Energy intensity of services (temperature-corrected)	**-2.3%**/year	**-2.8%**/year
		Unit consumption of services per employee (temperature-corrected)	**-1.9%**/year	**-1.3%**/year

At the level of primary energy consumption, the progress towards the targets is more pronounced than in the case of final energy. Nevertheless, the (temperature-corrected) reduction in primary energy consumption by almost 5% since 2008 (Table 4) also needs to be accelerated in order to achieve the 15% reduction required in the remaining eight years. This is even more important since our analysis shows that most of the reduction achieved since 2000 and especially since 2008, was due to the increasing share of renewable energies in the power mix, and not primarily a result of energy efficiency gains at the level of final energy or in the power sector.

By applying energy efficiency indicators, from which external factors not primarily attributable to energy efficiency have been removed, we have also shown that the energy efficiency progress slowed down in the period 2008-2012 compared to the whole period under review. This is true for both total final energy and the final energy consumption sectors. We mainly used the energy efficiency index ODEX to measure the pure energy efficiency progress at the level of the total economy and the main energy consumption sectors. At the level of the whole economy, the progress in energy efficiency has exactly halved since 2008 (from 1% per year to 0.5% per year; see Table 4). This was largely as a result of the reversed development of energy efficiency in industry. In the period 2008-2012, the industrial ODEX showed an increase of 0.3% per year. Although this trend was mainly an effect of the industrial recession[15], our analysis also showed very slow progress in energy efficiency in industry since the year 2000. The observed decrease in the final energy intensity of the industrial sector by 0.8% per year was in fact only caused by structural changes and not by an energy efficiency improvement. In the household and transport sector, the ODEX still improved by around 1% per year, which was, however, a lower rate than over the whole period (Table 4). A similar trend could be observed for unit consumption per employee in the service sector, which improved by 1.3% per year in the period 2008-2012 compared to 1.9% per year over the whole period under review.

5.2 Discussion of methodology

Although our analysis gives more insight into the factors behind the development of overall primary and final energy consumption and energy intensity, such a top-down monitoring approach, which is based on statistical data at a relatively highly aggregated level, also has its limits. There are two types of restrictions, which have to be tackled in a different way. On the one hand, there are limits due to data gaps and methodological problems which can be handled by a further improvement of the statistical data and the calculation method. On the other hand, there are limits of principal in using a top-down monitoring approach, which can only be addressed by the use of additional methods.

For statistic-based top-down indicators, detailed, complete, timely and reliable statistics are essential to monitor the energy situation at a country level (IEA,

15 In times of decreasing industrial production, the energy consumed per unit of production tends to increase as energy consumption does not decrease proportionally to the activity.

2005, 2014b). The data demands generally grow with a higher degree of disaggregation of the analysis. In our German case study, the main data gaps, which also limit the meaningfulness of the respective indicators, are noted for buildings (especially cooling) and electrical appliances (Löschel et al., 2014; BMWi, 2011). An improvement of these data is strongly recommended. Another problem of top-down indicators, which makes regular and current monitoring difficult, is the long delay encountered in supplying the statistical data for a specific year. Depending on the type of data, the time delay lies between 0.5 and 2 years in Germany (BMWi, 2011). In order to bridge this data gap, there are initial attempts in the ODYSSEE database to develop short-term indicators based on energy intensities or unit consumption as a proxy for energy savings (Boonekamp, 2012).

There is also a question around the reliability and ability to replicate such breakdown analyses. For example, for the household sector the ODYSSEE decomposition tool estimates that other factors such as behavioural changes related to indoor temperatures and appliance use contributed about 14% to the total reduction observed in the period 2000-2012 (excluding weather influence; see Figure 9). Similar analysis by Galvin and Sunnikka-Blank (forthcoming) concludes that more than 45% of the reduction of space heating energy consumption in the household sector in the period 2000-2011 was the result of behavioural changes such as skilful heating behaviour and lower indoor temperatures. It is unclear as to why the results of the ODYSSEE tool and the estimates by Galvin and Sunnika-Blank differ to such an extent but this highlights the uncertainties involved in top-down analyses. However, our analysis also shows a strengthening of behavioural influences on household energy consumption in the period 2008-2012, which may support the observations from Galvin and Sunnikka-Blank (forthcoming).

In order to measure the pure energy efficiency progress from which external factors such as weather, activity, structural changes or behaviour have been removed, we make use of the energy efficiency index ODEX. The data demands of this indicator are, however, relatively high, compared to simple energy intensities or unit consumption ratios. This is due to the fact that the ODEX is calculated at the level of each sector and then re-aggregated for the whole economy. This may hinder a broader use of this indicator in official monitoring processes as it is implemented for the German “Energiewende”. Though the ODYSSEE database provides the necessary data for Germany and all other EU Member States, so that in principle the ODEX could be used for a parallel monitoring of national or EU-wide energy efficiency targets (e.g. under the EED).

The ODEX indicator is, however, also discussed in literature from a methodological point of view. Cahill and O'Gallachoir (2010) refer to the fact that the ODEX uses physical activity data for the analysis of energy consumption rather than added value. They argue that this makes a comparison with other methods of analysis, especially for the industrial sector which relies on added value (see overviews in Ang, 1995 and 2004), more difficult. They present a new analysis method called VALDEX which is based on the existing ODEX methodology, but uses value added data instead of physical output data. Other authors recommend the use of activities measured in physical instead of monetary units for the calculation of energy efficiency indicators, especially in the manufacturing industry (see e.g. Worrell et al., 1997; Farla et al., 1998; Farla and Blok, 2000a, b; Neelis et al., 2007; Salta et al. 2009). They argue that this contributes to a better understanding of energy efficiency developments. We see the ODEX in this line of argument and assess the use of physical instead of monetary outputs as a methodological advantage of the ODEX compared to other methods of analysis.

Pérez-Lombard et al. (2013) take up some general methodological problems in the construction of energy efficiency indicators, which have also been discussed by Patterson (1996). They particularly refer to value judgement (i.e. the assessment of the amount and quality of service output to which the energy input is related), the quality of the energy input, boundary definition, and the problems of aggregation of energy efficiency gains calculated at the level of sectors or end-use and structural effects. All these methodological issues also concern the energy efficiency indicators which we applied in our paper. They are addressed in the ODYSSEE database in a certain way, as it is described in Appendix A in detail. In their paper, Pérez-Lombard et al. (2013, p. 251) propose a sequence of actions to tackle these problems in an ordered fashion: (i) setting the service quality, (ii) identifying aggregation levels on the efficiency pyramid, (iii) defining a magnitude for consumption measurement and (iv) choosing a suitable magnitude to quantify the service provided. We assess that our indicator approach is not far from these recommendations.

Even if the impacts of activity, structural, behavioural, weather and other external factors can be analytically separated from the actual energy efficiency development, it is still not possible to determine at this level whether the change in energy efficiency is induced by policy instruments, or by autonomous or price-driven improvements in energy technologies. For more advanced corrections of price or economic influences as well as the influence of technology progress, predominantly econometric approaches are used which involve a regression analysis based on a pure energy efficiency indicator (see e.g. Schüle et al., 2011, Thomas et al., 2012). These econometric approaches, however, have not gained general acceptance for target monitoring up to now, which is mainly due to the lack of long enough time series for this kind of analysis and the relatively demanding methodological approach.

Another key characteristic of purely top-down monitoring approaches is the lack of a direct relationship between the effect of a specific policy instrument and the energy efficiency indicator. This limits their use if the monitoring also aims to evaluate individual policy instruments or programmes. This fundamental shortcoming, making energy efficiency indicator approaches unsuitable for estimating policy impacts, was demonstrated, for example, by Horowitz (2008). He advocates the use of other additional methods, i.e. statistical and engineering models, in order to evaluate such policies. By applying top-down indicators calculated at the level of end-uses (as they are provided in ODYSSEE for space heating or electrical appliances or specific transport modes), it is possible to map the influence of policy instruments (e.g. for space heating or electrical appliances). It is however, usually the impact of a bundle of instruments which is being applied to a specific end-use which is then measured (e.g. regulatory and financial support instruments). Nevertheless, a complementary use of so-called bottom-up methods, accumulating energy savings for individual final consumers or pieces of equipment, is necessary (for a detailed description of these methods see, for example, Thomas et al., 2012).

6 Conclusions

In this paper, we studied in detail the energy efficiency developments in Germany at the level of the overall economy and all final energy consumption sectors for the period 2000-2012. We made use of the energy efficiency indicator toolbox that we have developed within the ODYSSEE database in recent years and applied these indicators to the targets of the German “Energiewende”.

First of all, we found that there is still a considerable gap to close to meet the overall targets, which can only be achieved by a considerable strengthening of the progress in energy efficiency for all final energy consumption sectors. This is, however, made more complicated by our second finding, namely that such progress slowed down in the period 2008-2012, i.e. since the base year of most of the German energy efficiency targets.

We found, in particular, a very slow improvement in energy efficiency in the industrial sector during the last decade. Without a significant contribution from this sector, which is responsible for around 30% of final energy consumption in Germany, it will be very difficult to close the existing gap in the remaining years. We also found a wide gap between the absolute energy reduction targets for electricity and transport consumption required, and the reduction which had already been achieved in 2012, compared to respective base year for the targets. Therefore, a further reduction of electricity consumption will be necessary in all sectors. For the transport sector, we demonstrated through our breakdown analysis, that the development of transport energy consumption is strongly dominated by the opposite impacts of an (increasing) activity effect and the (decreasing) energy efficiency effect; apart from a further strengthening of the progress in energy efficiency, policies to reduce traffic activity could also help close the gap.

Based on these findings we conclude that our analysis gives deeper insight into the factors behind the development of overall primary and final energy consumption. It can at least provide suitable starting points for additional policy activities at the level of sectors or end-uses to help achieve the targets. In this way, our approach can complement the official monitoring process of the German “Energiewende” (BMWi and BMU, 2012; BMWi, 2014) with regard to an in-depth analysis of the factors influencing the development of energy consumption. Since both monitoring approaches use generally the same data sources (see Section 3.2), the results are widely compatible.

We also discussed weaknesses and limitations of top-down monitoring approaches, which rely on factor decomposition and are based on statistical data. We think that the main strength of energy efficiency indicators, from which external factors are removed, is that they give more insight into the factors determining energy consumption. They can therefore complement the official monitoring process of the German "Energiewende" which only relies on highly aggregated indicators for energy efficiency. They also provide suitable starting points for new energy efficiency policies which are necessary to achieve the targets. Attention should especially focused to those sectors and end-uses, where a very slow progress of energy efficiency could be observed since 2000 and especially during the last years since 2008. According to our results, these are in particular the industrial sector and electricity consumption, where the gap to the target is rather pronounced.

Nevertheless, these top-down indicators have to be completed by additional methods in order to correct them for price influences as well as the influence of technology progress and to establish a direct link between an indicator and a policy instrument. Despite these limitations, top-down approaches are at least a useful calibration of the bottom-up evaluation of policy instruments.

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

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Appendix A: Detailed description of the calculation of indicators in the ODYSSEE database

Ratios at constant structure

Intensity at constant structure, which is calculated at the level of industry, reflects the variation of the energy intensity assuming a constant structure of added value, between the various branches or sub-branches, for a reference year, so as to leave out the influence of structural changes. Changes in this intensity at constant structure result from variations in the sectoral intensities

For the calculation, the Divisia method is applied on a yearly basis and splits the growth rate of the intensity between year t and t-1 into two components. The first one measures the influence of structural changes, and the second one measures the influence of changes in the sectoral intensities.

Calculation of the Divisia index:

$$\ln\left(\frac{ie_t}{ie_{t-1}}\right) = \sum_i w_i \ln\frac{s_{it}}{s_{t-1}} + \sum_i w_i \ln\frac{ie_{it}}{ie_{t-1}}$$

w_i = energy consumption weight = E_i / E

The variation of the intensity over a period can be expressed in index (I) as follows :

I = Is x Ie

Ie: index of sectoral intensity effect, which represents the index of the intensity at constant structure.

Is: index of structural effect which represents the variation of the intensity due to structural changes.

$$Ie = \exp\left(\sum_t \sum_i w_i \ln\frac{ie_{it}}{ie_{it-1}}\right) \times 100 \quad Is = \exp\left(\sum_t \sum_i w_i \ln\frac{s_{it}}{s_{it-1}}\right) \times 100$$

Re-aggregated energy efficiency index (ODEX)

The ODEX is an index developed for the ODYSSEE-MURE project for an advanced measurement of the energy efficiency progress by sector and for the whole economy of a country. For each sector, the index is calculated as a weighted average of sub-sectoral indices of energy efficiency progress.

Chosen indicators for the calculation of the ODEX for industry:

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

- 3 residual branches: other primary metals (i.e. primary metals minus steel), other non-metallic minerals (i.e. non-metallic mineral minus cement) and other pulp, paper and printing (i.e. mainly printing).

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

Indicators used for the calculations of ODEX for transport are:

- passenger transport by car: energy consumption per 100 km
- passenger transport by rail: energy consumption per passenger-km
- freight transport: specific energy consumption per ton-km
- air transport: energy consumption per passenger
- buses and motorcycles: energy consumption per vehicle

For households, the calculation is carried out based on three end-uses and five large appliances (refrigerators, freezers, washing machines, dishwashers and TVs):

- unit consumption for space heating per m^2 at normal climate
- unit consumption for water heating per dwelling
- unit consumption for cooking per dwelling
- specific electricity consumption per large appliance

These selected indicators are measured in physical units to provide the best "proxy" of energy efficiency progress from a policy evaluation viewpoint. The usage of indices allows the combination of different units for a given sector. The weight used to calculate the weighted aggregate is the share of each sub-sector of the total energy consumption of the superordinated sector. The variation of the weighted index of the unit consumption between year t-1 and t is defined as follows:

$$\frac{I_{t-1}}{I_t} = \sum_i EC_{i,t} * \left(\frac{IUC_{i,t}}{IUC_{i,t-1}}\right)$$

with:

IUC_i: unit consumption index of sub-sector i

EC_i: share of energy consumption of sub-sector i

To get the index value of year t the inverse value of $\frac{I_{t-1}}{I_t}$ is calculated.

The unit consumption index for each year t is calculated using this formula:

$$IUC_{i,t} = \frac{UC_{i,t}}{UC_{i,t_0}} * 100$$

with:
IUC_i: unit consumption index of sub-sector or end-use i in year t
UC_i: unit consumption of sub-sector or end-use i

The ODEX indicators represent a better proxy for assessing energy efficiency trends at an aggregate level than the traditional energy intensities, as structural changes and other factors not related to energy efficiency are removed.

The trends observed for some sectors or end-uses can result in strong fluctuations in the ODEX. Such fluctuations can be linked to various factors: imperfect climatic corrections (especially with warm winters), behavioral factors, influence of business cycles or imperfection of statistics, especially for the last year considered. To reduce those fluctuations the ODEX is calculated as the arithmetic mean of the years t^{-1}, t and t^{+1}.

Methodology of decomposition

The decomposition of the change of final and primary energy consumption used in this paper shows various effects on the total change of energy consumption per sector. These are aggregated for the decomposition of the whole economy. We use the year t^{-1} as the base year (moving base year) for decomposition.

Industry

The total change of final energy consumption for industry is analysed into four effects*: activity effect, structural effect, efficiency effect* and *other effects*, while the latter consists of the residual. The effects are defined by the following formulae:

***Activity effect**:* $EQ_{t/t_0} = \Delta VA_{t/t_0} * (\frac{C_{t_0}}{VA_{t_0}})$

with:
EQ: Activity effect,VA: added value of manufacturing,
t: year t (end year),
t_0: year 0 (base year),
C: energy consumption

This effect represents the impact of changing economic activity (value added) of the sector industry on the final energy consumption.

Structural effect: $SE_{t/t_0} = \Delta C_{f,t/t_0} - \Delta C_{t/t_0}$

with:
$C_f = IE_{c_t} * VA_t$, the fictive consumption based on the energy intensity with an assumed constant structure of the sector industry (IE_{ct}),
C: energy consumption,
VA: value added at constant prices
t: year t (end year),
t_0: year 0 (base year)

Hence, the structural effect shows the impact of changes in the sector industry to or from more energy intensive branches.

The calculation of the *energy efficiency effect*, which shows the change of final energy consumption due to efficiency progress, is based on the ODEX using the following formula:

$$ESI = C_t * \left(\left(\frac{100}{ODEX}\right) - 1\right)$$

with:
C_t:Energy consumption
ODEX: Energy savings measured by ODEX

The last effect – *Other effects* – consists of the residual and contains effects which cannot be directly attributed to a cause. It is calculated by subtraction of all other effects from the total change of final energy consumption of the subsector under consideration.

Transport

The variation of final energy consumption of the sector transport is analysed into four effects which show the impacts of *activity*, *modal shift*, *efficiency* and the residual *other effects*, which is the difference, calculated as in the sector industry.

The *activity effect* of transport shows the impact of changes in passenger and freight traffic and is calculated as the sum of the activity effects of using both the following formulae:

Passenger: $EQT_{t/t_0} = \sum_{i=0}^{n}\left(\Delta pkm_{n,t/t_0} * CU_{n,t_0}\right)$

Freight: $EQT_{t/t_0} = \sum_{i=0}^{m}\left(\Delta tkm_{m,t/t_0} * CU_{m,t_0}\right)$

with:
EQT: activity effect
CU: energy consumption per passenger-km or ton-km
t: year t (end year),
t_0: year 0 (base year)
n,m: mode of transport
pkm, tkm: passenger-km or ton-km by mode

The *efficiency effect*, which represents the impact of changes in energy consumption per passenger-km or ton-km in the sector transport, is calculated as the sum of these formulae:

Passenger: $EST_{t/t_0} = \sum_{i=0}^{n}\left(\Delta CU_{n,t/t_0} * pkm_{n,t}\right)$

Freight: $EST_{t/t_0} = \sum_{i=0}^{m}\left(\Delta CU_{m,t/t_0} * tkm_{m,t}\right)$

with:
EST: efficiency effect
CU: energy consumption per passenger-km or ton-km
t: year t (end year),
t_0: year 0 (base year)
n,m: mode of transport
pkm, tkm: passenger-km or ton-km by mode

The *modal shift effect*, corresponds to the difference between the sum of savings of each mode for passenger and freight respectively and the aggregate savings calculated directly for passenger or goods as a whole. This effect represents the change of final energy consumption due to changes in other modes of transport compared to the base year. As with the activity and efficiency effect it is calculated for passenger and freight transport separately and summed up for total transport:

Passenger: $MST_{t/t_0} = EST - (\Delta CU_{t/t_0} * pkm_t)$

Freight: $MST_{t/t_0} = EST - (\Delta CU_{t/t_0} * tkm_t)$

with:
MST: modal shift effect
EST: efficiency effect
CU: energy consumption per passenger-km or ton-km
t: year t (end year),
pkm, tkm: passenger-km or ton-km by mode

The modal shift effect is attributed to the total structural effect in the aggregated decomposition.

Households

The decomposition of final energy consumption in the sector households results in five effects. These are *demographic effect, lifestyle effect, efficiency effect, weather effect* and the residual labelled as *other effects* or *behavioural effect*. The lifestyle effect, which is shown in the aggregated decomposition, consists of two underlying effects: change of the number of appliances per dwelling and living space per dwelling. These are shown separately in the analysis for the household sector.

The demographic effect shows the changes in final energy consumption due to the change of the number of dwellings and is calculated as the variation of the number of dwellings multiplied with the energy consumption per dwelling in the base year t_0:

$$DEH_{t/t_0} = \Delta NOD_{t/t_0} * CU_t$$

with:
DEH: demographic effect
NOD: number of dwellings
CU: energy consumption per dwelling with temperature correction
t: year t (end year)

The two effects forming the lifestyle effect in the aggregated decomposition are number of appliances per dwelling and living space. These are calculated in a similar way to the demographic effect:

$$NAH_{t/t_0} = \Delta NOA_{t/t_0} * CU_t$$

and

$$LSH_{t/t_0} = \Delta SOD_{t/t_0} * CU_t$$

with:
NAH: number of appliances effect
NOA: number of appliances per dwelling
LSH: living space per dwelling effect
SOD: size of dwelling in m^2
CU: energy consumption per appliance or per m^2 with temperature correction
t: year t (end year)

The efficiency effect is calculated based on the ODEX for households, which includes the efficiency progress of these underlying indicators:

- unit consumption for space heating per m^2 at normal climate
- unit consumption for water heating per dwelling
- unit consumption for cooking per dwelling
- specific electricity consumption per large appliance

It is calculated by the following formula:

$$ESH = C_t * \left(\frac{100}{ODEX} - 1\right)$$

with:
ESH: efficiency effect
C: energy consumption
ODEX: ODEX for households

The weather effect, which represents the influence of the changes in temperature (difference in the number of degrees days) on the variation of final energy consumption of households, is calculated by

$$WEH_{t/t_0} = -\left((CC_t - CC_{t_0}) - (C_t - C_{t_0})\right)$$

with:
WEH: weather effect
CC: temperature corrected energy consumption
C: energy consumption
t: year t (end year),
t_0: year 0 (base year)

The last effect labelled as other effects is calculated by subtracting the sum of all other effects of households from the total variation of final energy consumption of the sector.

Tertiary / Services

For the tertiary and service sectors the change of final energy consumption is analysed into four effects: *activity effect, efficiency effect, weather effect*, and the residual *other effects*.

The activity effect in the tertiary sector, which shows the influence of changes in added value generated in this sector, is measured by the variation of the added value multiplied by the energy intensity by branch:

$$EQT_{t/t_0} = \sum_{i=0}^{n} \Delta VA_{i,t/t_0} * I_{i,t/t_0}$$

with:
EQT: activity effect
VA_i: value added of branch i
I_i: energy intensity of branch i
t: year t (end year),
t_0: year 0 (base year)

The effect of changes of energy efficiency on the final consumption is calculated by multiplying the number of employees by the variation of unit consumption per employee by branch.

$$ESH_{t/t_0} = \sum_{i=0}^{n} \Delta CU_{i,t/t_0} * EMP_{i,t}$$

with:
ESH: efficiency effect
CU_i: energy consumption per employee in branch i
EMP_i: number of employees of branch i
t: year t (end year),
t_0: year 0 (base year)

Influences of the variation in weather are represented in the weather effect, which is calculated in the same way as the sector households using this formula:

$$WET_{t/t_0} = -\left(\left(CC_t - CC_{t_0}\right) - \left(C_t - C_{t_0}\right)\right)$$

with:
WET: weather effect
CC: temperature corrected energy consumption
C: energy consumption
t: year t (end year),
t_0: year 0 (base year)

The residual other effects is calculated as the difference of total variation of final energy consumption of the sector tertiary and the sum of all other effects.

Aggregated breakdown of final energy consumption

The shown effects of the aggregated breakdown of the total change of final energy consumption are summed up from corresponding effects of the underlying sectors as shown in the matrix below.

Table A1: Aggregation of sectoral effects

Effect	Industry	Households	Transport	Tertiary/Services
Activity effect	X		X	X
Demographic effect		X		
Lifestyle effect		living space + number of appli-naces per dwell-ing		
Structural effect	X		Modal shift effect	
Efficiency effect	X	X	X	X
Weather effect		X		X
Other effects	X	X	X	X

Breakdown of primary energy consumption

The variation of primary energy consumption between year t and t^{-1} is the sum of the variation of final energy consumption, the variation of the net consumption of the power sector, the variation in the consumption of other transformations and the variation in the consumption for non energy uses. Total effects for the whole period from year t_0 to t are calculated by summation of the effects for the years in between.

The net consumption of the power sector is defined as the primary energy input minus the output of generated electricity and heat.

The variation of the net consumption of the power sector is analysed into three underlying effects, which contribute to the total change:

- Electricity penetration
- Efficiency of thermal power plants
- Power mix

Other influences such as the consumption for non-energy uses, which are not attributed to a certain effect are labeled as other effects.

While the effect "variation of final energy consumption" is the difference between final energy consumption of year t and t^{-1}, the other three effects are calculated based on a second analysis regarding the variation of the net consumption of the power generation sector. Here the factor "efficiency of thermal power plants" measures the impact of the change of primary energy per unit of electricity produced compared to the previous year and summed up for the time period in question.

The effect “electricity penetration” measures the impact of increased electricity consumption in terms of additional losses in power generation assuming constant efficiency of thermal power generation and constant power mix; it is calculated as a residual as the difference between the sum of all other effects regarding the power generation sector and the total change of consumption for power generation.

Appendix B: Data sources for Germany in ODYSSEE[17]

Data in ODYSSEE	Data source for Germany	Classification of data source*
Overall economy		
GDP, added value, private consumption	Federal Statistical Office (2014), National Accounts	A
Population	Federal Statistical Office (2013a), Statistical Yearbook	A
Primary and final energy consumption by sector	National energy balances (AGEB 2013)	A
Electricity generation by energy carriers	AGEB 2013; BMU 2013	A
Degree days	Based on Deutscher Wetterdienst (DWD)	B
Tertiary sector		
Value added/employment by sub-sectors	Federal Statistical Office (2014), National Accounts	A
Floor area by subsector Energy consumption by end-uses and subsectors	Regular surveys on energy consumption in the tertiary sector (Fraunhofer ISI et al. 2014; Schlomann et al., 2014))	B
Household sector		
Number of households and dwellings, floor area	Federal Statistical Office (2013a), Statistical Yearbook	A
Stock and sales of electrical appliances	ZVEI/GfK (2013)	B
Energy consumption by end-uses	National end-use balances (AGEB 2014)	A
Specific consumption of electrical appliances	Stock model data (Prognos, internal information)	B
Industry		
Value added by industrial branches	Federal Statistical Office (2014), National Accounts	A
Production index	Federal Statistical Office (2013a), Statistical Yearbook	A
Physical production	Statistics of industrial associations	B
Energy consumption by branches	National energy balances (AGEB 2013); Federal Statistical Office (2013b)	A
Transport		
Stock of cars and kilometres for passenger and freight traffic	Verkehr in Zahlen (DIW Berlin and BMVBS 2014)	A
Energy consumption by sub-sectors	National energy balances (AGEB 2013)	A
Energy consumption by vehicle types	Verkehr in Zahlen (DIW Berlin and BMVBS 2014)	A

* A = Official Statistics (Statistics/surveys by national Statistical Offices, Eurostat/IEA, Ministries; model estimations used as official statistics; data "stamped" by ministries)
B = Surveys/modelling estimates by research institutes, universities, consultants, industrial associations
C = Estimate / expert guess

17 For a more detailed description of the statistical database for Germany in ODYSSEE also see Schlomann and Eichhammer, 2012 (Annex 3).

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