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Summary of the final report: Macroeconomic effects and distributional issues of energy transition

Study on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi)

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TITLE

Summary of the final report: Macroeconomic effects and distributional issues of the energy transition. Study on behalf of the Federal Ministry for Economic Affairs and Energy

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1 INTRODUCTION

The aim of the energy transition is to transform the energy system into a climate-friendly system and at the same time to phase out nuclear energy while guaranteeing a more secure, economic and environmentally friendly energy supply. The increase of energy efficiency and the expansion of renewable energy are essential components. While clear and measurable indicators with quantified goals and intermediate targets are defined in the energy concept for the fields of efficiency (annual increase in final energy productivity by 2.1 %), renewable energy (increase to 60 % of gross final energy consumption by 2050) and climate protection (40 % GHG reduction by 2020; at least 80 % to 95 % by 2050), this is not the case for the economic dimension. Measuring the macroeconomic effects of the energy transition therefore is much more difficult from a methodological point of view.

Against this background, a consortium consisting of the Institute of Economic Structures Research (GWS), German Institute for Economic Research (DIW), German Aerospace Center (DLR), Prognos AG and Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI) has carried out a research project on the macroeconomic and distributional effects of the energy transition on behalf of the BMWi from July 2015 to November 2018. The project is divided into six work packages, which are briefly summarized in the following sections.

On the basis of a brief systematization of the effects at the beginning of the project in work package (WP) 1 (Chapter 2), the concept of national energy accounts has been further developed in WP 2 (Chapter 3). On the one hand, it covers the macroeconomic costs of energy supply. On the other hand, key parameters such as investment and employment are determined for the comprehensively defined energy sector (so-called gross effects). Reduced energy imports are also assessed.

WP 3 (Chapter 4) deals with the development of a counterfactual scenario, which describes a world without energy transition for the analysis period 2000 to 2050, and a target scenario in which the goals of the Federal Government are achieved. By comparing the target scenario with the counterfactual world, the net effects of the energy transition are determined both ex post and ex ante in macroeconomic model analyses.

In WP 4 (Chapter 5), the distributional effects of energy policy are further classified by their significance. Issues of personal income distribution and the regional effects of the energy transition are examined in depth. Additional advantages of the energy transition are identified alongside other work steps in WP 5 (Chapter 6). In WP 6 (Chapter 7), possible bottlenecks of the energy transition are discussed against the background of the good economic development in Germany.

2 SYSTEMATIZATION (WP 1)

The systematization of effects and terminology is the basis for the whole research project. The energy transition is understood as a comprehensive transformation of the energy system according to the target architecture, even if the reportage often takes place on the basis of renewable energy and the electricity sector, because previous research and the political discussion have concentrated on these sub-areas of the energy transition (Lutz & Breitschopf 2016).

In the first “Energy Transition” Progress Report, macroeconomic effects are shown according to triggered investments, impulses from foreign trade, price effects, growth impulses and employment effects (BMWi 2014). The analysis of the effects of the energy transition is set between the often conflicting economic relevance of energy for the macro economy and its effect on individual groups of actors. The changes triggered by the energy transition are considered at both levels.

The relevance of energy and the energy sector for the overall economy in terms of gross effects is usually larger than the differences that are recorded as net effects of the energy transition in complex model analyses, taking into account many different indirect and induced effects. To determine gross effects, it is necessary to allocate the indirect effects along the production chains.

Net effects represent the macroeconomic accounting of all effects which are induced by the energy transition or individual measures. Nationally and internationally, a largely uniform method has been established for measuring these net effects, which, however, is different for renewable energy in the electricity sector than for other parts of the energy transition, in particular energy efficiency. The expansion of renewable energy in the electricity sector has a major impact on the electricity market. The associated effects at system level have to be taken into account for a complete analysis. Modelling of the electricity market and the overall economy are linked for this purpose. On the other hand, the energy transition in energy efficiency measures is largely limited to individual actors.

Distributional effects can be represented for many different actors, markets and impacts. The range of these burdens and reliefs is larger than the range of the macroeconomic effects. The differentiation can be made spatially, temporally, according to individual consumers and consumer groups, with regard to companies and industries or combinations of these categories for the sectors of electricity, heat and transport. The variety of possible distributional effects requires a variety of methods for recording the specific distributional effect. In contrast to the macroeconomic effects, it is not possible to consider distributional effects in a comprehensive or summarised way.

When measuring the macroeconomic impacts and distributional effects, it must always be taken into account that changes triggered by the energy transition do not occur isolated but may encounter and increase existing macroeconomic relations, competitive conditions and distributional differences. Macroeconomic and distributional effects should always be considered together. If the energy transition brings macroeconomic advantages, negative distributional effects can be compensated or at least reduced in order to increase the acceptance of the energy transition. If distributional effects are addressed accordingly, they can lead to more positive macroeconomic effects.

3 INVESTMENT, EMPLOYMENT, NATIONAL ENERGY ACCOUNTS, REDUCED IMPORTS (WP 2)

3.1 ECONOMIC INDICATORS OF THE ENERGY SYSTEM: METHOD, DEFINITION AND RESULTS FOR THE PERIOD 2000–2017

In order to measure the progress of the energy transition, appropriate indicators are needed for the period from the year 2000 onwards. In addition to physical variables on energy use and emissions, indicators are also required that describe the economic dimension of the transformation of the energy sector.

Which economic sectors can be assigned to this energy system? Basically, the entire economic process is influenced by the supply or use of energy but it makes no sense to include all sectors of the economy in the indicator system describing the transformation of the energy supply. Therefore, the focus is on the supply of final energy, possible methods to capture the development of measures to increase energy efficiency and efficient consumers are proposed. With this approach, not only the energy industry in the stricter sense is represented, but also a broader section of the economy.

O'Sullivan, Edler, & Lehr (2018) describe which data are available for the relevant economic indicators and which data are used for which reason. When selecting the data used, the aim is to use existing official or other publicly available data whenever this seems methodologically justifiable. In cases in which this does not seem to be possible or appropriate, methods have been developed to derive the necessary indicators.

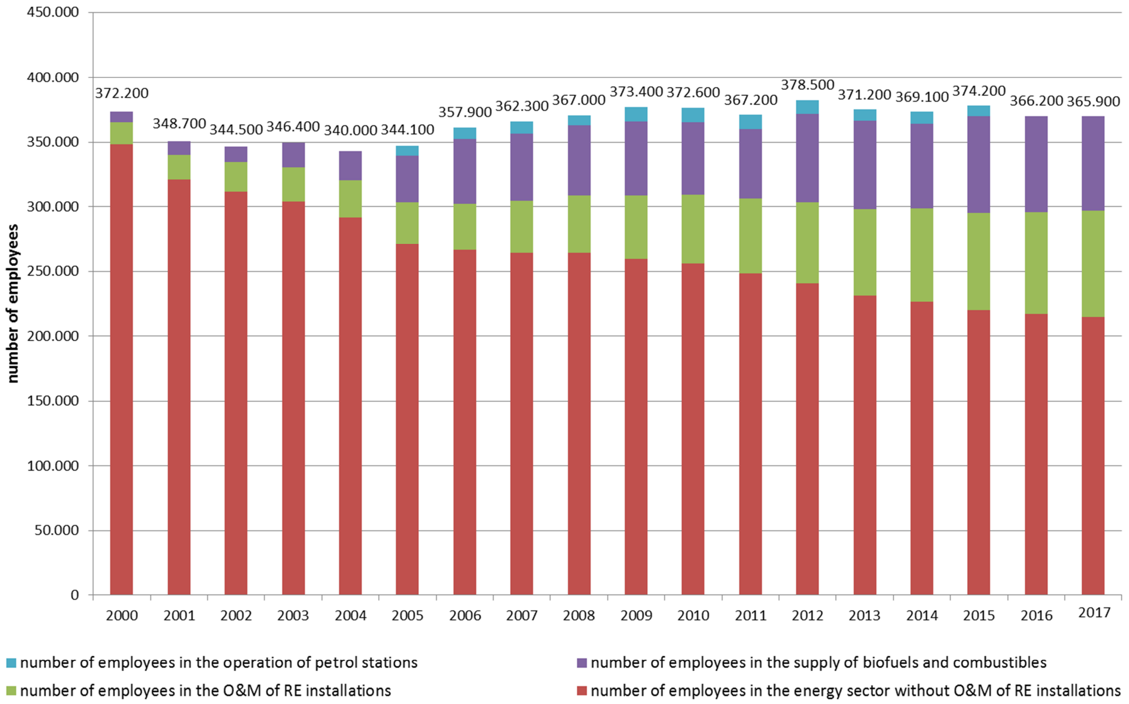
The best indicator to describe the immediate economic importance of this sector is employment. This can also be interpreted as the employment in Germany due to the operation and maintenance of energy generation, storage and distribution as well as the trading of final energy.

The employees who work directly in the technical departments of the classical energy sector are taken from the available "energy data" of the Federal Ministry for Economic Affairs and Energy, which are currently available data from the Federal Statistical Office.

For renewable energy, on the other hand, an independent calculation and estimation method is developed. The amount of the expenses for operation and maintenance of the plants is determined on the basis of a technology-specific percentage share of the respective annual investments. The employment associated with operating and maintenance expenses (direct and indirect) is calculated using the input-output analysis, for which specially developed technology-specific input-output vectors are used (see Lehr et al. 2015).

As not only direct but also indirect employment is taken into account in the sector of renewable energy for operation and maintenance on the basis of the methodical estimation approach, indirect employment has also been estimated for employment in the traditional energy sector. To determine employment in the field of trade services for petroleum products, a method developed in Böhmer et al. (2015) is used. Employment in the energy sector in the period 2000 to 2017 was relatively stable between 340,000 and 370,000 employees (see Figure 1). This development is associated with significant shifts in shares towards renewable energy.

Figure 1: Employment in the energy sector, rounded



Source: O’Sullivan, Edler, & Lehr (2018)

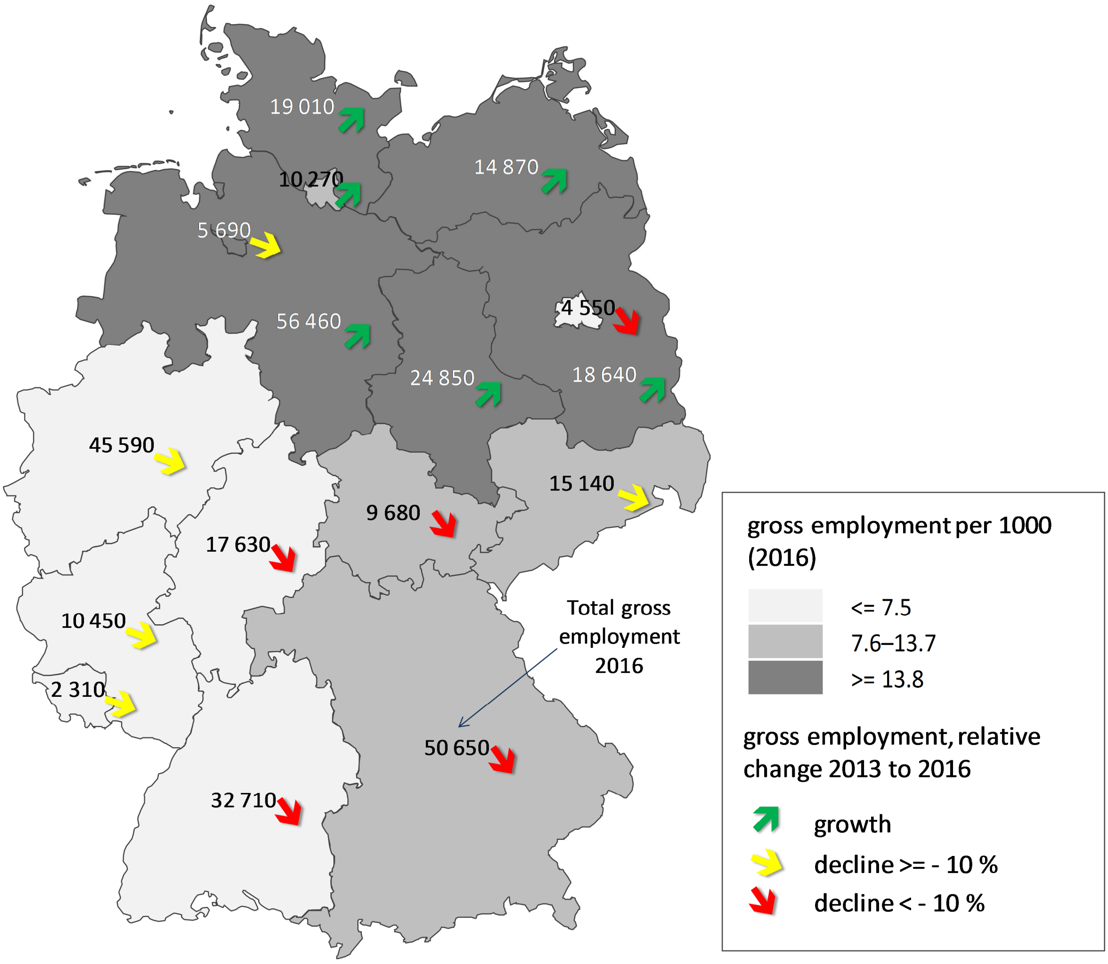
Existing data gaps have become apparent, indicating the need for further research. In general, the data situation on the expansion of renewable energy is better at the moment than in other fields of the energy transition.

3.2 GROSS EMPLOYMENT 2016 IN THE FEDERAL STATES OF GERMANY

Since 2006, the employment associated with the expansion of renewable energy has been determined. In 2016, almost 340,000 jobs can be assigned to the expansion of renewable energy in Germany, which can be found in all federal states. The federal states differ significantly regarding the importance attached to renewable energy employment there, the key technology sectors, the development over time and the most important drivers of this development. Differences become particularly clear when comparing gross employment with all employees in the respective federal state (Ulrich & Lehr 2018).

Each federal state in Germany show employment in all four groups of energy sources (wind energy, solar energy, bioenergy, other). The reason for this is that gross employment not only takes into account direct effects at the place of installation or production, but also indirect effects from the demand for intermediate goods. These can be supplied from all regions with the corresponding specialisations. Despite this interregional balancing, there are clear regional-specific focal points.

Figure 2: **Summary overview of the distribution of RE employment and ist change between 2013 and 2016**



Source: Ulrich & Lehr 2018

However, it also becomes clear that developments in the federal states themselves and not only the development of the overall RE market determine the dynamics of RE employment. Regional investment always supports to a certain extent RE employment in the respective federal state, which is particularly noticeable when installations in the federal state increase – in some cases at an above-average rate compared to the national average. A decline in the number of installations is therefore also associated with a corresponding decrease in employment. At the same time, renewable energy is becoming a sustainable employment factor due to the operation and maintenance of the installed systems in the region. In addition, there is employment for the supply of biomass for the corresponding plants, which in the case of biogas plants is created surrounding the site. Investing in renewable energy plants therefore has a positive effect on renewable energy employment in both the short and long term.

3.3 NATIONAL ENERGY ACCOUNTS – METHODS AND EXEMPLARY CALCULATIONS

In order to measure the economic efficiency of the energy transition, the Expert Commission on the Energy of the Future Monitoring Process (Expert Commission, EWK 2014) proposes the method of national energy accounts (EWGR): "In order to be able to properly assess the cost development of the energy supply as well as the additional costs caused by the energy transition, the annually aggregated total expenditure of the end-users in the fields of electricity, heat and transport must be collected in nominal monetary units (million euros)." In a narrow definition, total expenditure by end-users includes expenditure on energy use, in a broad definition, it also includes expenditure on reducing energy use (energy efficiency) or generation by renewable energy.

Since the first proposal, the Expert Commission has developed the approach further or submitted proposals for further development. The report summarizes these proposals and to critically review the reliability of the indicators and their data availability (Lehr, Walter, & Lutz 2017). In addition, it examines the significance of the indicators for the monitoring of energy transition and answers the question how far the proposed indicators can measure the progress of the energy transition with regard to the economic supply of energy. Calculations regarding heat consumption and fuels for transport can be found in Lehr, Walter, & Lutz (2017). The report also contains considerations on another major component of national energy accounts, the energy-related unit costs.

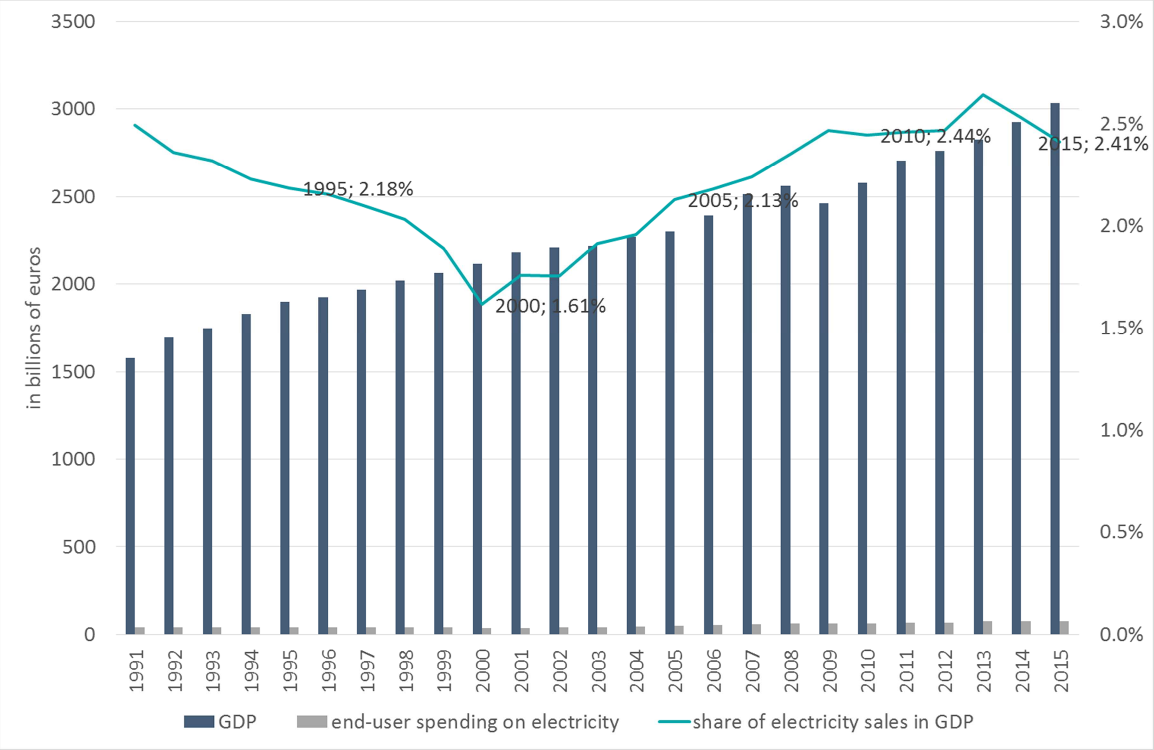
In relation to GDP (Destatis 2017a), end-user expenditure on electricity in 2015 corresponds to 2.41 %. Since 2013, end-user expenditure has grown much more slowly than GDP (see Figure 3) and therefore the share of end-user expenditure in GDP has fallen. The share in GDP in 2015 is thus slightly below the level of 2010.

The analysis of end-user expenditure is an important contribution to a better understanding of the cost burden due to energy consumption and energy transition. End-user expenditure provides additional information beyond price data, while the latter is available faster. In this respect, both indicators are complementary. The subdivision into the three fields electricity, heat and transport is comprehensible. For the heat sector, an additional, more profound disaggregation for process heat and space heat must be examined. Differentiations according to the consumer groups “households”, “trade, commerce, and services” and “industry” are suitable for electricity and heat. In the transport sector, the differentiation between households and companies is of more interest. All in all, the EWGR represents a very meaningful concept that improves the monitoring of energy transition. However, various points remain to be clarified more precisely.

In the electricity sector, the study follows the EWK and uses data on electricity sales. However, the gap between electricity consumption according to the energy balance and volume of electricity sales must be explained in the future.

For the heat sector, EWK's approach provides a good and comprehensible method for calculating end-user expenditure in the stricter sense, i. e. expenditure on heating. EWK's joint presentation of expenditure on heating and investments in energy efficiency in existing buildings must be reflected critically. Expenditure on heating and efficiency investments of one year should not be added up without more detailed analysis and annotation, because the latter lead to a permanent reduction in real expenditure on energy.

Figure 3: **Share of end-user expenditure on electricity in GDP**



Sources: Lehr, Walter, & Lutz (2017) auf Basis von Destatis (2017a) und Destatis (2017b)

The methods proposed by the EWK also need to be further developed with regard to end-user expenditure on transport. On the one hand, the correct identification of the value-added tax in road transport must be clarified. On the other hand, there remains the question whether and how other transport modes should be included.

In the long term, it remains to be clarified whether electricity use for heat and transport should not be included in the heat and transport sector on a permanent basis in order to define the three sectors as the sector coupling progresses. Various questions on the data to be used and their quality are also unanswered.

All in all, it would be good if the end-user expenditure for electricity, heat and transport sectors were regularly measured as part of the monitoring process and if the calculation could be adjusted and expanded in the future once the conceptual issues listed above have been clarified.

3.4 REDUCED IMPORTS OF FOSSIL FUELS

To measure the reduction of energy imports ex post for a development to date using the method presented in Lehr, Lutz, & Becker (2018), a counterfactual scenario for the past must be developed, which is characterised by a number of assumptions. The detailed modelling of a counterfactual development is very complex. It is less complex and very transparent to directly compare energy imports from the corresponding statistics of the Federal Statistical Office with the necessary energy imports without expansion of renewable energy and increasing efficiency.

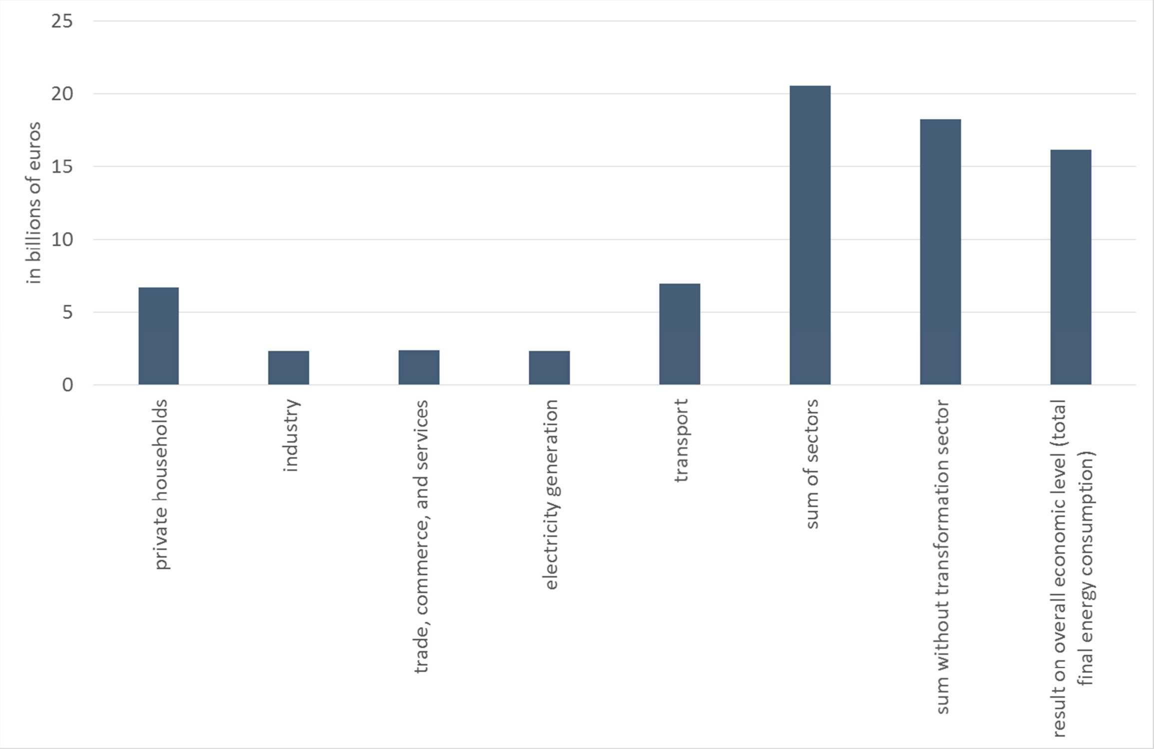
For the monitoring of the expansion of renewable energy, emissions saved by the expansion of renewables and the decline in imports (see Lehr, Lutz, & Becker 2018) are estimated annually. The basis for these estimations is the reduction in the use of fossil primary energy sources in the electricity, heat and transport sectors, as it is estimated and provided by the German Environment Agency (UBA). To determine the substitution factors, UBA compares two scenarios for the current year: one scenario with the real energy mix and one in which the entire primary and final energy input is supplied from fossil sources.

Following this approach also for energy efficiency, a simplified estimation approach is proposed based on the comparison of statistical data with a transparently constructed counterfactual energy consumption. Such an indicator can be easily extrapolated and provides a time series that illustrates the development of import reductions due to changes in the energy mix and in the overall energy demand. It must always be taken into account that energy efficiency is not exclusively triggered by the energy transition and the associated measures, but also takes place autonomously.

The comparison of quantities (energy input) and structures (energy sources) in the latest available year with the hypothetical quantities and structures of the past is characteristic for the approach. It does not compare two temporal developments, but answers the question of what would happen if the efficiency in the year 2000 and the energy mix in the year 2000 were used to provide and supply today's GDP, today's transport performance, today's living space and value added.

The reduction in imports of fossil fuels due to energy efficiency and the expansion of renewable energy is in the tens of billions, regardless of the chosen approach. From a sectoral point of view, the largest share is achieved by savings in electricity generation, in the transport sector and by private households (see Lehr, Lutz, & Becker 2018). There is no more detailed information available that would allow conclusions to be drawn regarding the respective drivers of the reduction.

Figure 4: **Sectoral import reductions, sum of sectoral reductions and reductions in the overall economic approach**



Source: Lehr, Lutz, & Becker (2018)

In total, according to the proposed approaches, the reduced imports for final energy consumption amount to 18.25 billion euros when considering sectors individually (excluding the energy transformation sector) and 16.14 billion euros on a macroeconomic level (see Figure 4). What is the reason for this difference? The macroeconomic view measures the efficiency of the economy in relation to GDP. All economic activities, goods and services contribute to the gross domestic product, so that, in principle, the various activities of the energy consumption sectors are included. However, the individual drivers in the energy consumption sectors often do not determine the GDP, but the living space or transport performance. As expected, the reduction in imports is therefore higher from a sectoral point of view.

Specifically, the approach does not allow to separate the efficiency effects attributable to energy policy measures from those that have arisen independently of them, e. g. from technological development or economic structural change.

4 MACROECONOMIC EFFECTS (WP 3)

In order to determine the macroeconomic impacts of the energy transition in the past and future, two model-based scenarios are compared (Lutz et al. 2018a). The Energy Transition Scenario (EWS) represents a world in which the energy transition since the year 2000 developed as it actually took place and in which the targets of the energy transition will be achieved in the future. The Counterfactual Scenario (KFS) represents a consistent alternative development that can be described as follows: Since the year 2000, no support for renewable energy and energy efficiency took place and will not take place in the future. From the year 2000 onwards, only those technologies will be used for energy transformation that are market-driven. The comparison of economic parameters under the respective scenario assumptions allows conclusions drawn from the macroeconomic advantages of one scenario compared to the other one.

4.1 SCENARIOS AND RESULTS OF BOTTOM-UP MODELLING

The focus is on the comparison of two scenarios. The starting points of a scenario are technology or process-related changes that are triggered by the implementation of individual measures or respective bundles of measures. On the one hand, they include investment differences including differences in the costs of operation and maintenance. On the other hand, energy consumption and thus energy costs change, which can be associated with changes in entire submarkets.

Specific bottom-up models are used to calculate these changes, which reflect the technologies behind the measures and the application of the technologies in detail. Subsequently, the results of all the measures and different developments that have to be considered are implemented into the macroeconomic model. The macroeconomic effects, in particular on GDP, employment and prices, are determined using the macroeconometric model PANTA RHEI. The bottom-up effects are calculated using the model system of Prognos, which considers energy transformation (especially the electricity market) and energy demand separately for individual sectors. The interfaces between the two models are energy consumption, differences in investments and different electricity prices in both scenarios. Harmonized assumptions on framework data, policy and technical developments form the different scenarios that are described in detail in Lutz et al. (2018a).

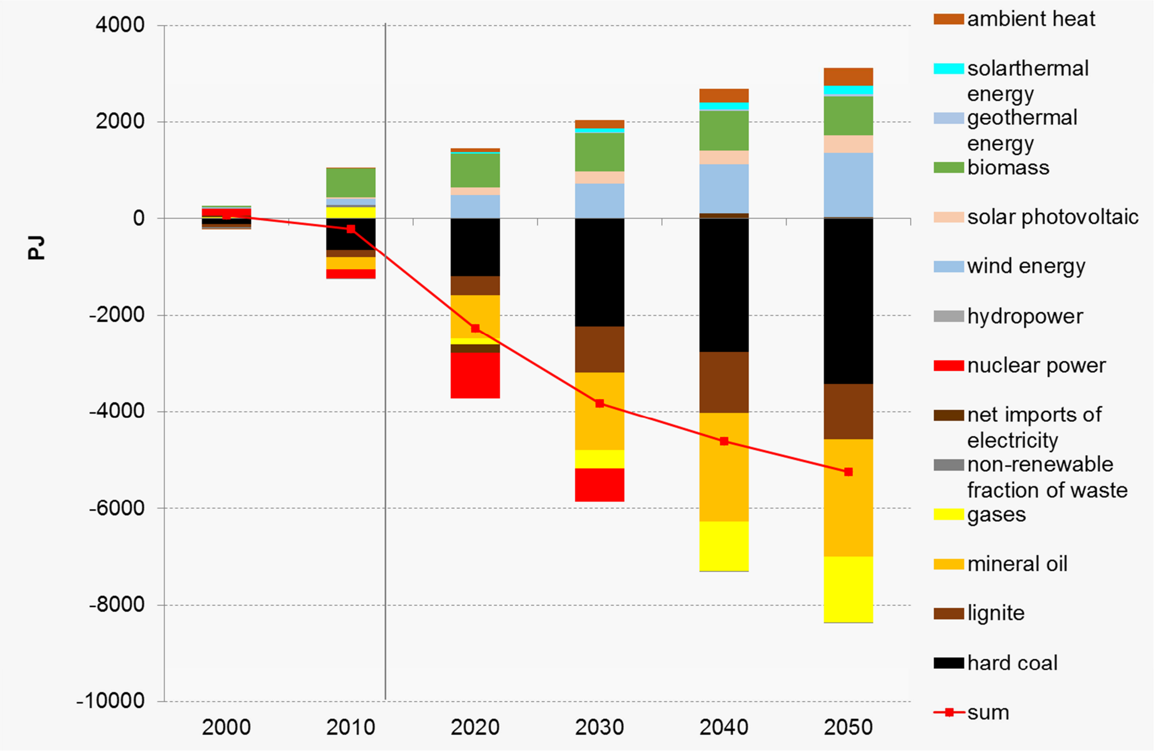
The Energy Transition Scenario (EWS) is based ex post (2000–2014) on the actual values, the variables of energy consumption, prices and investments in the energy system. The development of the years 2015 to 2050 is interpreted as the realization of energy transition. The EWS has the character of a target scenario in which the long-term reduction targets for greenhouse gases are achieved. The Counterfactual Scenario (KFS) describes an alternative development in which the path of energy transition is not followed from the year 2000 onwards.

The KFS is used to analyse the interdependency effects of the energy transition. By considering the differences between EWS and KFS, the effects of the energy transition completed so far in the ex-post period (2000–2014) and the foreseeable effects of the energy transition ex ante (2015–2050) can be shown.

The two scenarios are defined for the electricity market and energy demand. The definition of a scenario has a major influence on the model results. Their plausibility is therefore important for the acceptance of the results. For this reason, the scenarios were defined in consultation with the client and the scientific advisory board of the project.

Figure 5 shows the differences between the two scenarios for primary energy supply. The overall energy supply is significantly lower in EWS due to the higher energy efficiency. The share of renewable energy is rising sharply, while the use of fossil fuels is much lower.

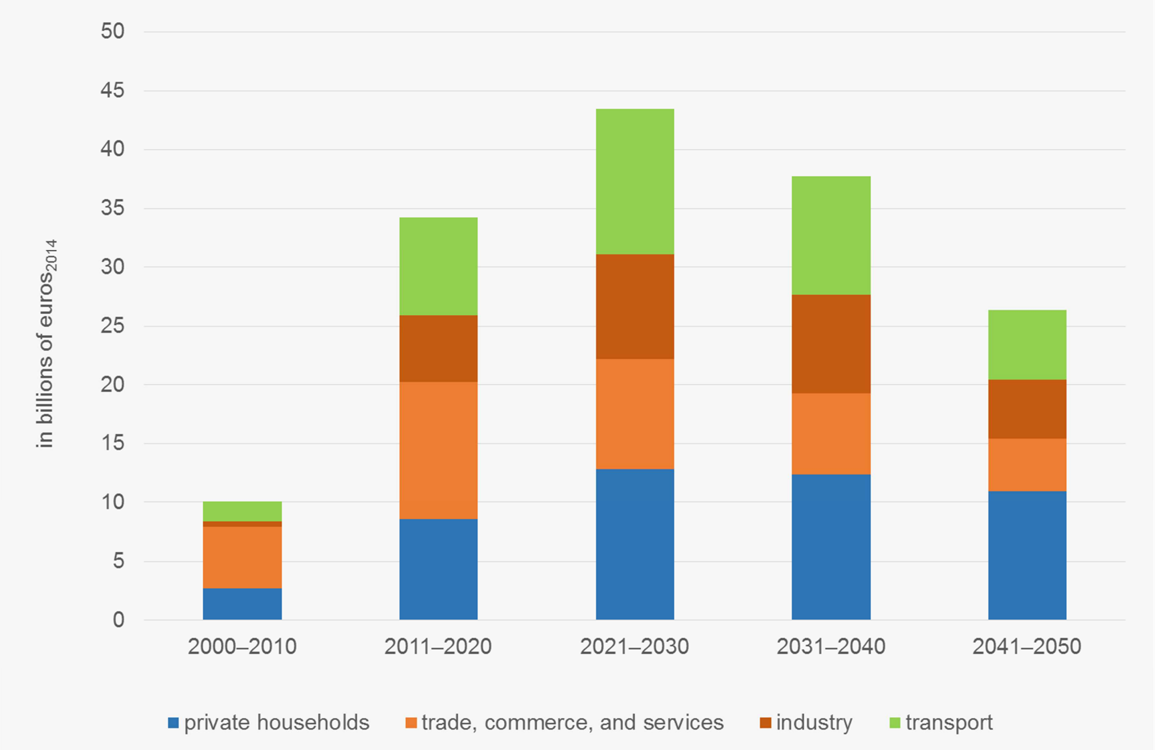
Figure 5: **Difference in primary energy supply between EWS and KFS, by energy sources, 2000–2050, in PJ**



Source: Prognos

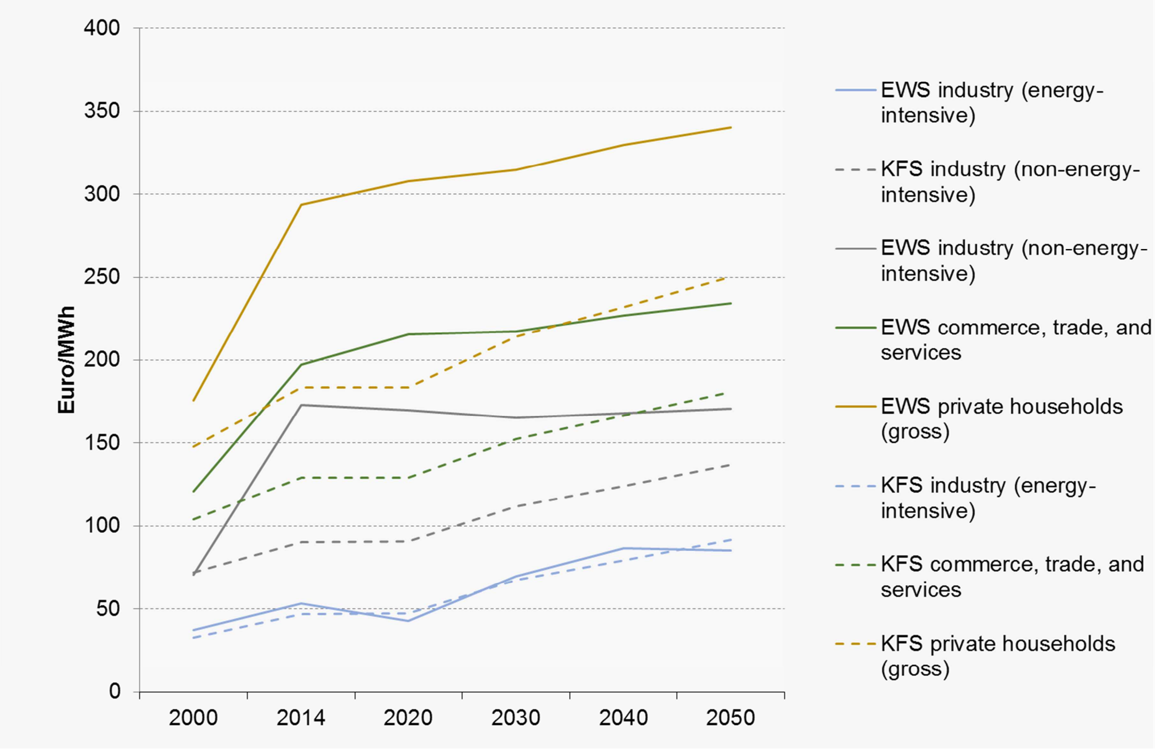
Figure 6 below shows the key differences in investments between the energy transition scenario and the counterfactual scenario in the four end-use sectors. 32 % of these additional investments are made in private households, 25 % in the sector of trade, commerce, and services, 19 % in industry and 24% in transport sector. About 30 % of the additional investments are accounted for the building envelope (building renovation) and 13 % in space heating (including water heater). Investments also vary in the electricity sector (see Lutz et al. 2018a).

Figure 6: **Annual additional investment in the end-use sectors in EWS compared to KFS, in billion euros, mean values per decade, by sectors (real prices 2014)**



Source: Prognos

Figure 7: **Development of electricity prices in EWS and KFS by consumer groups, 2000–2050, in euro/MWh (real prices 2014)**

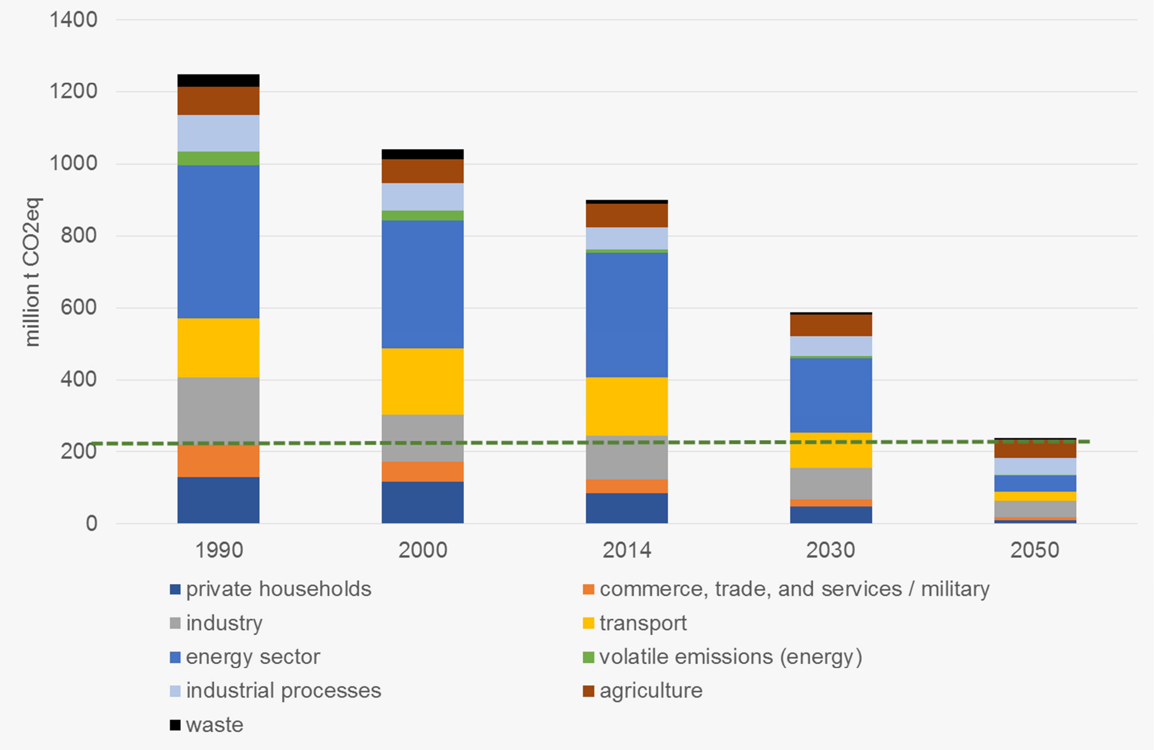


Source: Prognos

Under these assumptions, electricity prices for households in EWS increase from EUR 176/MWh to EUR 294/MWh in the ex-post period from 2000–2014 (Figure 7). From 2015 to 2050, the price increases only slightly compared to the past to 340 EUR/MWh (real prices). The flattening increase is due, among other things, to the fact that renewable technologies are becoming cheaper and the renewable energy levy (EEG) is becoming smaller and smaller. The electricity price for households in the KFS will also rise in the period 2000–2050 due to increasing energy prices for natural gas and hard coal. At 250 EUR/MWh, the price in 2050 is about 35 % lower than in the EWS. Value-added tax is not included in the prices in the sector of trade, commerce, and services.

In the energy transition scenario, GHG emissions will be reduced to 238 million t CO_2eq by 2050 (excluding LULUCF and international transport). Compared to 1990, this corresponds to a reduction of 81 % (Figure 8).

Figure 8: **Development of GHG emissions in EWS by sectors, in million t CO_2eq, and lower target in 2050 (green dotted line)**



Source: Prognos

4.2 MACROECONOMIC EFFECTS

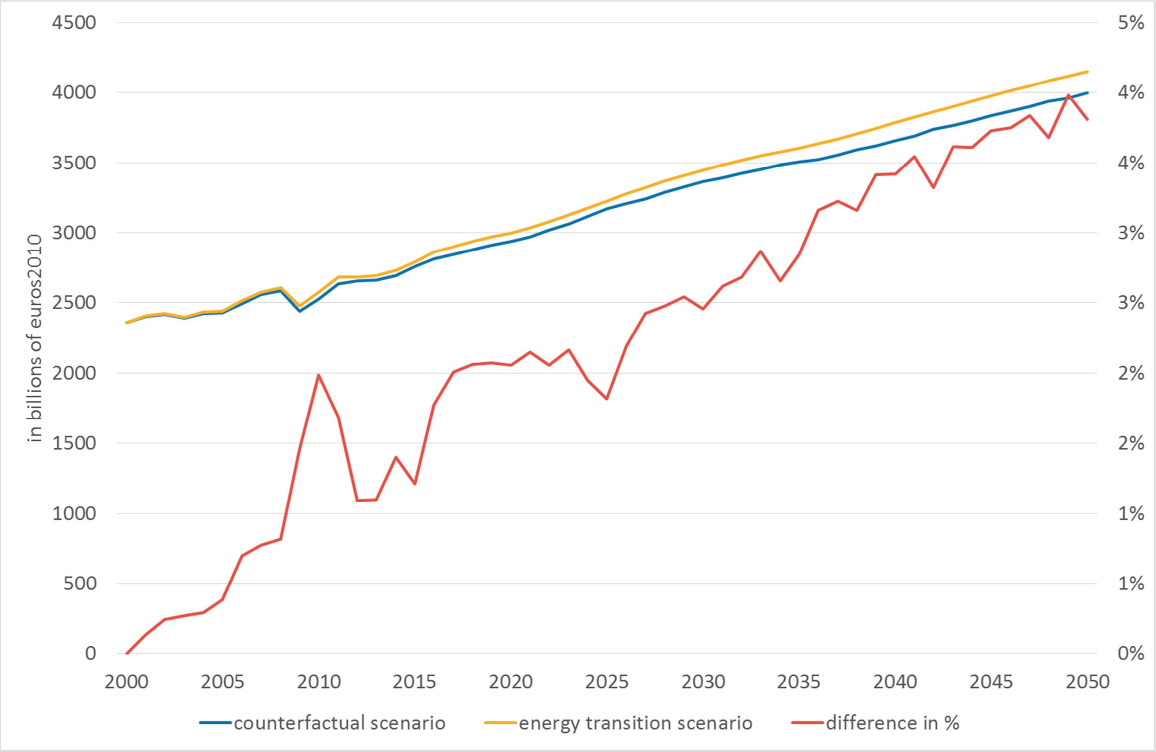
The EWS and KFS scenarios briefly described above are implemented into the macroeconomic model PANTA RHEI. The basic approach for determining the macroeconomic effects of the energy transition is to conduct comprehensive macroeconomic model analyses that show feedback between the energy system and the macro economy and can determine net effects at the macroeconomic and sector level. The model is fully interdependent and solved in annual steps, i. e. the effects of a measure on all model variables are recorded simultaneously and no effects are neglected.

Compared to a counterfactual development without energy transition since the year 2000, the energy transition leads to positive macroeconomic effects. The price-adjusted gross domestic product is higher due to the energy transition and the effects increase over the years (Figure 9). In the years 2009 to 2011, the high investment in photovoltaic (PV) installations in particular can be seen. In the economic crisis of 2009, the energy transition stabilized the economic development. With the end of the PV boom the positive macroeconomic effect has also decreased in the following years, but will remain clearly positive throughout at over 1 %.

In the long term, the macroeconomic effects triggered by the energy transition will continue to increase, reaching a level of just below 4 % by 2050 (Figure 9). The slight fluctuations are attributable in particular to investment in conventional power plants in the counterfactual scenario. Without energy transition, economic output in 2050 would therefore be 3.8 % lower.

The main reasons for the positive effect on GDP are the consistently higher overall economic investment, decreasing differences in electricity prices for small-scale users after 2020, the far-reaching exemption of the energy-intensive industry from the EEG-levy and thus small differences in electricity prices compared to the KFS. Growing final energy savings due to higher energy efficiency and thus also falling expenditure on energy imports also contribute. In the long term, energy will be substituted by capital and labour (energy efficiency) and the supply will stem more from domestic sources with a higher employment intensity (renewable energy). In the long term, these permanent, positive effects of the energy transition will determine the macroeconomic effects.

Figure 9: **Gross domestic product in billion euros 2010 and the relative difference between EWS and KFS**



Source: GWS

The comparison of the macroeconomic results in the two scenarios EWS and KFS in the PANTA RHEI model shows consistently positive effects of the energy transition. Employment is about 1 % higher. Real wages are also rising. No additional exports of goods for the energy transition are considered, which are likely to result if other countries adapt themselves to German policy and corresponding technologies.

The results depend on a large number of assumptions and model relations. Sensitivity analyses in Lutz et al. (2018a) offer the opportunity to examine the significance of sensitive variables on macroeconomic effects and to compare model characteristics with other analyses. The breakdown of the EWS into input data from the bottom-up models for the electricity market and for the field of final demand shows that the macroeconomic effects of the energy transition on the electricity market are much smaller than the effects triggered by the measures on the final demand side. The sensitivity analyses with restrictions on the labour market and on the financing of additional investments show that these aspects should also be observed more closely in the future, especially with regard to the very good economic situation in Germany.

The results are in the same order of magnitude and point in the same direction as our own previous studies and other related studies, both at the national and international level. However, it should be taken into consideration that these studies are optimistic with regard to the efficient governance and to the international cooperation in climate mitigation. The achievement of policy targets is expected without significant distortions with the exception of mining and energy supply, among other things because no concrete instrumentation of the energy transition is depicted.

5 DISTRIBUTIONAL EFFECTS OF THE ENERGY TRANSITION (WP 4)

5.1 DISTRIBUTIONAL EFFECTS OF ENERGY POLICY – PERSONAL DISTRIBUTION OF INCOME

The distributional effects of energy policy at the level of private households can be considered in different dimensions. Many instruments of the energy transition lead at least in the short term to higher burdens – either directly through higher energy costs or through higher costs for efficiency investments. Since energy consumption is part of basic needs, the analysis focuses on the burden effects according to the level of income, especially with regard to the poorer households or the recipients of basic social benefits. In the broader public discussion, this is often known under the less precise keyword "energy poverty". In addition, other dimensions can also be examined, for example household or family types (singles or couples, each with and without children), regions or settlement structure types (agglomerations, areas with urbanization tendency, rural areas) as well as the social position in the working life of the main income earner (employees, self-employed persons, pensioners, unemployed persons). For the housing and heating costs, the living status (residential property or rent), the equipment and the type of heating of the housing are important. For the transport costs, the equipment with vehicles or the ways to work are relevant.

The distributional effects of energy policy are analysed on the basis of the individual data from the German Socio-Economic Panel (SOEP) 2015 and the sample survey of income and expenditure (EVS) 2013 (Bach, Harnisch, & Isaak 2018). The use of the individual data bases allows a detailed linking of results from the macroeconomic analyses with the household and social structures as well as any analysis according to the socio-economic characteristics of the household surveys.

Expenditure on electricity is recorded in SOEP 2015 in connection with housing costs. The use of night storage heating is asked separately as well as the question whether electricity is used for water heating. It is also asked whether there is an eco-electricity contract and whether a solar thermal system or a photovoltaic system is available.

The total electricity expenditure of private households amounts to an average of 2.4 percent of the net household income (Table 1). Considering income groups, electricity costs are clearly regressive, i. e. the poorer households spend a larger proportion of their net income on electricity than the richer ones: In the 1st decile, households spend on average 6.5 percent of their net income on electricity consumption, in the highest decile only 1.0 percent. Therefore, electricity is an "inferior good" that is demanded relatively less as household income rises. At large, taxes on electricity consumption account for an average of 0.9 percent of household net income. The EEG-levy accounts for about half of this. The distribution across income groups is similar to the distribution of electricity expenditure.

Table 1: Electricity expenditures and tax burden of private households, SOEP 2014/15

decile of net household income (equivalents)$^{2)}$	electricity expen-ditures	taxes on electricity				share of households with				
		electricity tax	EEG-levy (2015)	VAT on electricity tax, EEG-levy	total	basic income support/ housing benefit	electricity / night storage heating	eco-electricity contract	solar thermal system	photovoltaic system
	percentage of net income					percentage				
by income group										
lowest 5 %	7,9	0,6	1,8	0,5	2,8	44,4	6,3	7,1	0,6	1,8
1st decile	6,5	0,5	1,5	0,4	2,3	43,5	10,6	6,1	0,6	2,5
2nd decile	4,5	0,3	1,0	0,3	1,6	22,6	6,7	6,3	1,3	3,0
3rd decile	3,7	0,3	0,9	0,2	1,4	11,9	8,4	8,6	2,1	5,9
4th decile	3,3	0,2	0,7	0,2	1,2	6,7	7,0	9,5	3,0	8,4
5th decile	2,9	0,2	0,7	0,2	1,1	5,1	7,8	11,8	3,6	8,8
6th decile	2,7	0,2	0,6	0,2	1,0	3,8	8,4	14,9	4,8	9,9
7th decile	2,3	0,2	0,5	0,1	0,8	2,7	6,8	13,8	4,9	10,8
8th decile	2,0	0,2	0,5	0,1	0,7	1,7	8,2	16,6	4,7	11,3
9th decile	1,6	0,1	0,4	0,1	0,6	1,2	5,4	18,9	7,9	14,0
10th decile	1,0	0,1	0,2	0,1	0,4	1,1	4,9	21,5	8,1	15,4
total	2,4	0,2	0,5	0,1	0,9	10,7	7,2	12,6	4,0	8,8
decile ratios										
10/1	0,16	0,16	0,16	0,16	0,16	0,02	0,46	3,51	13,59	6,27
10/5	0,36	0,35	0,35	0,35	0,35	0,21	0,63	1,82	2,27	1,76
5/1	0,45	0,45	0,45	0,45	0,45	0,12	0,73	1,93	5,99	3,56
by regional type of area										
densely populated agglomeration	2,3	0,2	0,5	0,1	0,8	10,9	4,5	4,5	0,0	0,0
agglomeration with main centre	2,2	0,2	0,5	0,1	0,8	11,4	8,6	2,9	0,0	5,7
high population density	2,4	0,2	0,5	0,1	0,9	9,9	1,9	0,0	0,0	0,0
medium population density with high order centre	2,6	0,2	0,6	0,2	1,0	10,9	11,8	5,9	2,0	3,9
medium population density without high order centre	2,6	0,2	0,6	0,2	0,9	5,0	7,0	7,0	0,0	4,7
rural area with high population density	2,8	0,2	0,6	0,2	1,0	11,7	5,6	5,6	2,8	0,0
rural area with low population density	2,7	0,2	0,6	0,2	1,0	14,2	2,8	11,1	11,1	16,7
by households type										
singles	2,8	0,2	0,6	0,2	1,0	12,8	7,3	11,2	1,3	4,5
single parents	3,3	0,3	0,8	0,2	1,2	34,0	6,0	13,1	2,2	5,5
couples without children	2,2	0,2	0,5	0,1	0,8	4,3	6,4	13,6	4,7	10,0
couples with 1 child	2,0	0,2	0,5	0,1	0,7	5,8	6,9	14,5	6,5	12,7
couples with at least 2 children	2,3	0,2	0,5	0,1	0,8	10,2	5,8	16,7	9,4	16,1
other	2,5	0,2	0,6	0,1	0,9	22,1	6,3	7,1	2,8	5,6
by social position of the main income earner										
self-employed persons	1,5	0,1	0,3	0,1	0,5	4,3	5,9	21,8	6,7	12,1
employed persons	2,2	0,2	0,5	0,1	0,8	7,1	6,7	15,1	4,7	10,2
unemployed persons	4,3	0,3	1,0	0,2	1,5	76,5	8,2	6,9	0,8	3,3
apprentices/students	3,5	0,3	0,8	0,2	1,2	15,6	6,1	15,3	0,1	1,6
pensioners	2,8	0,2	0,6	0,2	1,0	5,6	7,9	8,4	3,1	7,4
other non-employees	2,7	0,2	0,6	0,2	1,0	19,2	7,7	11,8	4,2	8,1
by basic income support										
basic income support	4,1	0,3	0,9	0,2	1,5	100,0	6,3	8,4	3,7	9,6
only housing benefit	4,2	0,3	1,0	0,2	1,5	100,0	7,1	8,6	5,4	11,7
without basic income support	2,3	0,2	0,5	0,1	0,8	0,0	7,3	8,7	4,3	8,8

1) Annual income of the previous year 2014.
2) Equivalence-weighted with the new scale of OECD, in relation to the population in private households.
Source: German Socio-Economic Panel Study (SOEP), v32.

Source: DIW

On average, private households spend 2.9 percent of their net income on heating costs. Considering the income groups, heating costs are also clearly regressive. Couples with children have on average lower burdens despite larger flats, because they have on average significantly higher net incomes. The same applies to employed people in comparison to pensioners and in particular to unemployed persons and apprentices/students.

Private households spend on average 3.6 percent of their net income on fuels. The energy tax on fuels accounts for 1.4 percent of net income. This expenditure also has a significant regressive effect, although being less distinctive than for electricity or heating costs. External transport services for public passenger transport excluding air transport amount to 0.7 % of net income on average for all households. A stronger regressive effect results from the income classes. Details on heating and transport expenditure can be found in Bach, Harnisch, & Isaak (2018).

Simple simulations of future energy price changes also confirm the regressive effect of energy prices. The regressive effect is strongest for increases of electricity price, less strong for the fuel prices and least for the improvement of energy performance of buildings under the assumptions made on the savings effects. Single parents and couples with two or more children are subject to above-average burdens, singles and self-employed persons are subject to below-average burdens, but unemployed persons and recipients of basic social benefits also have lower burdens on average. The regional distribution results in slightly higher burdens for rural areas and slightly lower burdens for agglomeration areas.

5.2 REGIONAL EFFECTS – DISTRIBUTIONAL EFFECTS OF THE ENERGY TRANSITION BETWEEN THE FEDERAL STATES OF GERMANY

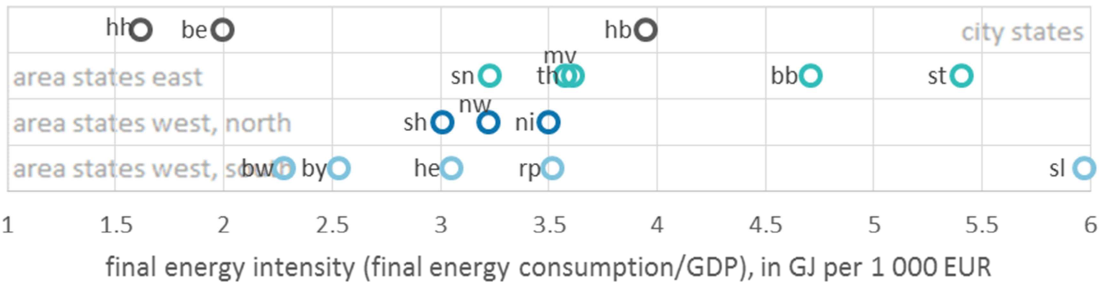
Effects of the energy transition from the federal level are projected to the federal states of Germany (Ulrich, Lehr, & Lutz 2018). For this to go beyond a simple distribution of the effects, a large number of assumptions, economic-structural considerations and specific data of the federal states are necessary. The LÄNDER model is based on an abundance of regional data such as the federal states' accounts. An evaluation of the national scenarios using this set of instruments provides an insight into the structural effects of the energy transformation in the federal states of Germany. Using the example of building insulation and the infrastructure of power generation in the federal states, the economic reactions to changes caused by the energy transition are shown and examined.

For the evaluation of indicators, the federal states of Germany are divided into four groups. 2014 is generally chosen as the year of evaluation. On the one hand, data of energy balances for more recent years are currently not available for all federal states; on the other hand, this year represents the final year of the time series for many central data in the model.

For the majority of the evaluations, the federal states of Germany are marked on a scatter diagram with their abbreviations (see Figure 10). The energy use has different focal points in the individual consumption sectors.

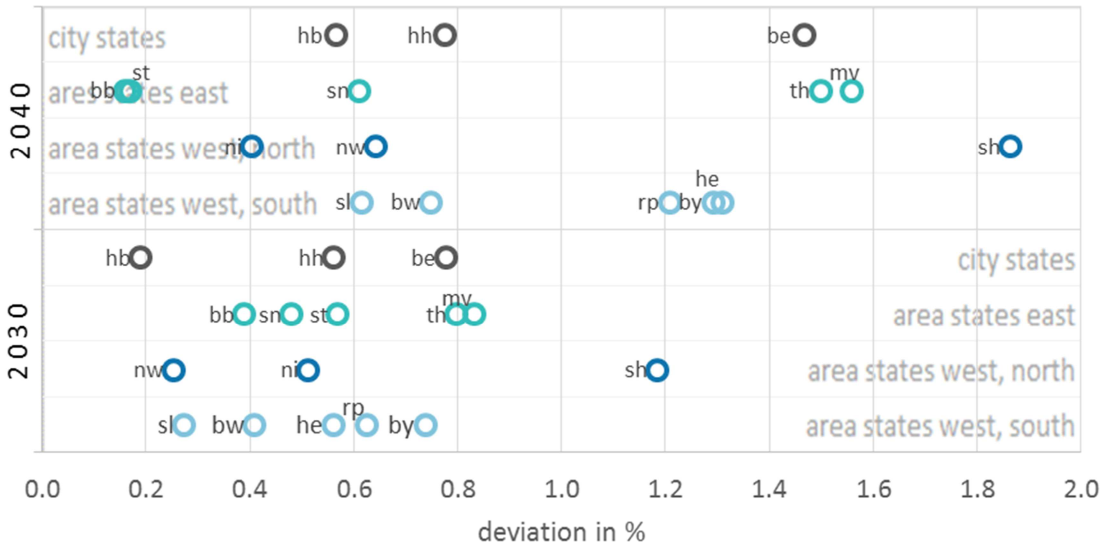
The report evaluates the macroeconomic effects in the federal states on the basis of gross domestic product and the number of employed persons. Structural effects and influences of the specific drivers are strongly mixed. Their influence shifts over time, especially in interregional comparisons. In addition, business cycle effects within the federal states have varying degrees of impact.

Figure 10: Final energy intensity in the federal states of Germany



Source: Working Group on Energy Balances for the federal states

Figure 11: Relative difference between energy transition scenario and the counterfactual scenario in the federal states of Germany, number of employed persons



Source: GWS

Since the majority of the economic sectors in the model are primarily explained by the development of employment, the deviation of the number of employed persons and then gross domestic product is presented and discussed. The deviation of the number of employed persons between the energy transition scenario (EWS) and the counterfactual scenario (KFS) is on average +0.5 % in 2030 and +0.9 % in 2040. The relative differences – shown in Figure 11 – are less than 0.3 % in Bremen, North Rhine-Westphalia and the Saarland in 2030, and more than 0.7 % in Bavaria, Berlin, Thuringia, Mecklenburg-Western Pomerania and Schleswig-Holstein. Saxony and Brandenburg as the only federal states of East Germany show below-average deviations.

6 FURTHER ADVANTAGES OF THE ENERGY TRANSITION (WP 5)

The energy transition has further advantages beyond the positive effects on employment and GDP, some of which are difficult to quantify in quantitative and monetary terms (Lutz et al. 2018b). In some cases, the connection with the energy transition cannot be seen immediately. The focus is on Germany, but international aspects of transformation are also addressed. In addition, there are further advantages of the energy transition, such as increased living comfort in an insulated house, which are not discussed in more detail in the following.

The sharp decline in the costs of technologies relevant to the energy transition is an impressive effect and an advantage of energy transition, particularly in a global context. On the one hand, the development is an important aspect in the implementation of the energy transition, but on the other hand it is also an important driver for technical development and innovation. Bloomberg New Energy Finance (Liebreich 2017), for example, publishes annual price trends for various generation technologies of renewable energy and assesses them in relation to the cumulative expansion. These costs show a global learning rate for wind energy and photovoltaics of 19 % and 24–28 % respectively, i. e. a doubling of the globally installed capacity will reduce the costs according to these rates.

With the cost reductions, the change in the structure of energy generation as well as the change in energy consumption and its structure induce partly extensive changes in production processes, possible profits and costs in industry, so that it can be considered as the structural change due to the energy transition. The international competitiveness of many companies depends on the fact that they have developed and tested the new technologies on the domestic market. New business concepts and areas arise. Thus, the energy transition is part of a comprehensive and continuous modernisation and structural change of the national economy.

Energy security has always been a focus given the sharp rise in oil prices. The Russia-Ukraine crisis has stirred up fears of supply bottlenecks for natural gas. In the meantime, the topic has again created interest, so that the main results and arguments are summarised. Foreign policy issues are also relevant here.

Using diversity indices, it can be shown that the security of supply in Germany increased between 1998 and 2013. Since the index is based, among other things, on the distribution of primary energy sources, it can mainly be explained by the expansion of renewable energy, which led to a more diverse and equal distribution of energy sources and contributed to an increase in security of supply in Germany compared with energy imports from countries with lower country risk categories.

The energy transition reduces air pollutant emissions, which will improve the health and well-being of many people. In addition to health costs and premature deaths, crop failures, damages to nature and the biosphere, as well as damage to buildings, which will be reduced by the energy transition, have to be mentioned. The risk of a nuclear accident or noises from combustion engines are also reduced. These effects can be assigned conceptually to the reduced external effects.

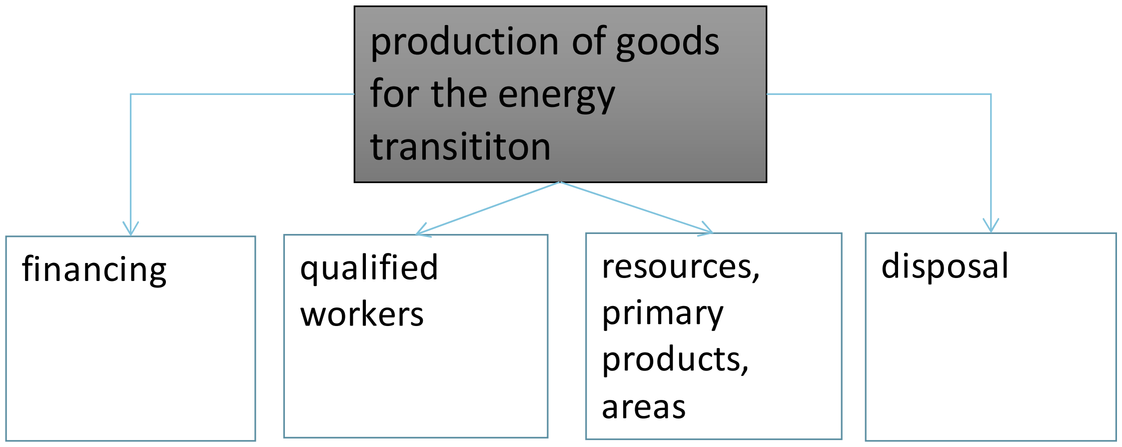
7 POSSIBLE BOTTLENECKS OF THE ENERGY TRANSITION (WP 6)

In the context of the very robust macroeconomic development in recent years, the question increasingly arises whether bottlenecks and restrictions can partially impede the success of the energy transition either now or in the future. Investment in the energy transition is important in order to achieve the targets of the energy transition. Lutz, Becker, & Lehr (2018) examine the macroeconomic and socio-economic interrelationships that need to be taken into account for Germany on the basis of a literature review. Essentially, there are two possible mechanisms that affect the energy transition:

- Necessary, planned investments cannot be realized due to missing input, restrictions in implementation or the effects of the energy transition.
- RE investment is not made and approved or implemented RE investments cannot be completed or do not work as intended due to system inertia for technological and behavioural reasons.

For the implementation of the energy transition, goods such as wind turbines, efficient machinery or electric cars are required. The production and operation of these goods can be affected by bottlenecks. According to a survey by EC (2017), the financial bottleneck is the most frequently identified one by companies after decreasing demand and weather conditions. Lack of raw materials, intermediate products or land, a shortage of qualified employees, lack of planning capacities and approvals or waste disposal are also possible important reasons (see Figure 12). Therefore, qualified employees represent an important bottleneck both now and in the future. Certain raw materials that are important for the energy transition such as lithium or cobalt for batteries, may also run short in the future.

Figure 12: **Possible bottlenecks in the production of goods for the energy transition**



Source: Lutz, Becker, & Lehr (2018)

In addition to the bottlenecks in the production of goods for the energy transition, there are also restrictions that are the result of the energy transition itself and the necessary transformation process. On the one hand, these are path dependencies of the infrastructures and of goods for the energy transition, which lead to the fact that present technologies are used for a long time and investments in goods for the energy transition are slowed down. On the other hand, these are behavioural patterns that limit the effectiveness of the energy transition, such as the rebound effect, which reduces energy consumption less than expected.

Because of the long lifetime of many infrastructures, industrial plants, vehicles, heating systems and household appliances, the investment decisions will determine the future development of energy use in the long term. This is known as the lock-in effect. In the future, these restrictions will have to considered and integrated in policy-making more strongly than in the past.

8 REFERENCES

BMWi (2014): Die Energie der Zukunft. Erster Fortschrittsbericht zur Energiewende. Bundesministerium für Wirtschaft und Energie (BMWi), Berlin.

Böhmer, M., Kirchner, A., Hobohm, J., Weiß, J., & Piégsa, A. (2015): Wertschöpfungs- und Beschäftigungseffekte der Energiewirtschaft, Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi).

Destatis (2017a): VGR des Bundes – Bruttowertschöpfung, Bruttoinlandsprodukt (nominal/preisbereinigt), 81000-0001.

Destatis (2017b): Erhebung über Stromabsatz und Erlöse der Elektrizitätsversorgungsunter-nehmen und Stromhändler, 43331-0001.

EC (2017): Case study – technical analysis on capacity constraints and macroeconomic performance. Technical Study on the Macroeconomics of Climate and Energy Policies. Brüssel.

EWK [Expert Commission on the Energy of the Future Monitoring Process] (2014): Stellungnahme zum zweiten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2012. Expertenkommission zum Monitoring-Prozess „Energie der Zukunft“, Berlin, Mannheim, Stuttgart.

Lehr, U., Ulrich, P., Lutz, C., Thobe, I., Edler, D., O’Sullivan, M., Simon, S., Naegler, T., Pfennig, U., Peter, F., Sakowski, F., & Bickel, P. (2015): Beschäftigung durch erneuerbare Energien in Deutschland: Ausbau und Betrieb, heute und morgen. Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie, Osnabrück, Berlin, Stuttgart.

Liebreich, M. (2017): London summit 2017. London. URL: https://data.bloomberglp.com/bnef/sites/14/2017/09/BNEF-Summit-London-2017-Michael-Liebreich-State-of-the-Industry.pdf [accessed august 22nd, 2018].

9 PROJECT REPORTS

Report on WP 1, section 2 of the final report:

Lutz, C. & Breitschopf, B. (2016): Systematisierung der gesamtwirtschaftlichen Effekte und der Verteilungswirkungen der Energiewende. GWS Research Report 2016/01, Osnabrück, Karlsruhe.

Report on WP 2, section 3 of the final report:

Lehr, U., Walter, H., & Lutz, C. (2017): Energiewirtschaftliche Gesamtrechnung – Methoden und exemplarische Berechnungen. GWS Research Report 2017/02, Osnabrück.

O'Sullivan, M., Edler, E., & Lehr, U. (2018): Ökonomische Indikatoren des Energiesystems. Methode, Abgrenzung und Ergebnisse für den Zeitraum 2000–2016. GWS Research Report 2018/01, Stuttgart, Berlin, Osnabrück.

Ulrich, P. & Lehr, U. (2018): Erneuerbar beschäftigt in den Bundesländern. Bericht zur aktualisierten Abschätzung der Bruttobeschäftigung 2016 in den Bundesländern. GWS Research Report 2018/02, Osnabrück.

Lehr, U., Lutz, C., & Becker, L. (2018): Zur Berechnung der durch den Ausbau erneuerbarer Energien und durch Energieeffizienz verminderten Importe fossiler Brenn- und Kraftstoffe. Methode und Ergebnisse für die Jahre 2000 bis 2015. GWS Research Report 18/3, Osnabrück.

Report on WP 3, section 4 of the final report:

Lutz, C., Flaute, M., Lehr, U., Kemmler, A., Kirchner, A., auf der Maur, A., Ziegenhagen, I., Wünsch, M., Koziel, S., Piégsa, A., & Straßburg, S. (2018a): Gesamtwirtschaftliche Effekte der Energiewende. GWS Research Report 2018/04, Osnabrück, Basel.

Report on WP 4, section 5 of the final report:

Ulrich, P., Lehr, U., & Lutz, C. (2018): Gesamtwirtschaftliche Effekte der Energiewende in den Bundesländern. Methodische Ansätze und Ergebnisse. GWS Research Report 2018/05, Osnabrück.

Bach, S., Harnisch, M., & Isaak, N. (2018): Verteilungswirkungen der Energiepolitik – Personelle Einkommensverteilung. Endbericht, Berlin.

Report on WP 5, section 6 of the final report:

Lutz, C., Lehr, U., Becker, L., & Breitschopf, B. (2018b): Vorteile der Energiewende über die gesamtwirtschaftlichen Effekte hinaus – eine literaturbasierte Übersicht. GWS Research Report 2018/06, Osnabrück, Karlsruhe.

Report on AP 6, section 7 of the final report:

Lutz, C., Becker, L., & Lehr, U. (2018): Mögliche Engpässe für die Energiewende. GWS Research Report 2018/07, Osnabrück.