Wirkungen des Ausbaus Erneuerbarer Energien
- Impact of Renewable Energy Sources -

ImpRES

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Impacts of Renewable Energy Deployment – Summary and Conclusions

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1 Introduction

Using renewable energy sources can make major contributions to reducing environmental pollution, protecting the climate, conserving exhaustible resources and increasing energy supply security. Renewable energy sources (RES) therefore play an important role as part of a sustainable energy supply, together with increased energy efficiency and energy savings. In the longer term, energy supply should be based predominantly or even completely on renewable energy sources. The necessary structural changes are also linked to opportunities for new growth markets and new jobs.

The German government has set itself ambitious targets for the medium and longer term expansion of renewable energy sources. Their share in total gross final energy consumption in Germany should increase to at least 18 % by 2020 under the EU Directive for the Promotion of Renewable Energy Sources. According to the German government's 2010 Energy Concept, at least 60 % should be reached in total by 2050, with a focus on electricity. Following the amendment of the German Renewable Energy Sources Act (EEG), the share of renewables in gross electricity consumption should increase to 40 – 45 % by 2025, to 55 – 60 % by 2035 and to at least 80 % by 2050.

In order to be able to meet such targets, renewable energy (RE) market development is being supported by various policies. In Germany, the main focus is on reimbursement regulations in the electricity sector under the EEG, financial aid and regulatory measures in the heat sector, and fuel quotas in the transport sector. The speed of deployment of renewable energy sources also depends on how the legal and administrative framework conditions are designed, e.g. building laws. In addition, promoting research and development serves to increase the longer term technical and economic utilization possibilities of renewable energy sources.

There are different economic impacts associated with the accelerated expansion of renewable energy sources. We distinguish between system-related costs and benefits, distributional effects and macroeconomic effects (cp. ISI, GWS, IZES, DIW 2010 and ISI, DIW, GWS, IZES 2015). Such impacts were analyzed in detail in the ImpRES project. This paper summarizes the results and conclusions of the ImpRES project.

Chapter 2 illustrates the costs and benefits of expanding renewable energy sources in Germany. The focus here is on the system-related cost differences and avoided damage to the environment compared to an energy supply based on fossil energy sources and nuclear power. On top of this, an analysis is made of the influence renewable energy has on technological change and the security of energy supply.

Chapter 3 presents an analysis of the different price and distributional effects linked to the expansion of renewable energy sources and the respective framework conditions.

Following a more general review of the political relevance of distributional effects, the distributional effects triggered by the deployment of renewable energy sources will be explored in detail. The focus here is on wholesale electricity price effects (merit order effect) and how they are passed on to electricity consumers, and the social distributional effects of the EEG surcharge, the level of which depends on the exceptions made for electricity-intensive enterprises among other things (under the special equalization scheme). There are further distributional effects for installation operators, who profit from market promotion policies in the electricity sector, and also effects due to the expenditure needed to expand the grid. Different policy options to reduce the distributional effects of the EEG are discussed against this background. Alongside the electricity sector, the specific distributional effects of expanding renewable energy sources in the heat and transport sectors will also be analyzed. Furthermore, the impacts on taxes and levies are examined, as are the distributional effects of funding research.

Chapter 4 explores the interactions between expanding renewable energy sources and electric mobility. An important question concerns the extent to which an increasing use of electric vehicles could support the integration of renewable energy sources into the electricity sector in the future. Relevant issues include the controlled charging of electric vehicles (grid to vehicle services) and possibly also the use of electric vehicles as decentralized energy storage units and to feed energy back into the grid (vehicle to grid services). There are potential synergy effects in the power sector for both the wholesale and the balancing markets.

Expanding renewable energy sources also has substantial macroeconomic impacts. Chapter 5 briefly describes the macroeconomic relevance of using renewable energy sources in Germany up to now based on macroeconomic indicators. Then the longer term macroeconomic impacts of future deployment are analysed in model-based scenarios. This approach differentiates between regional RE deployment and the economic structures and socio-economic aspects of RE use and shows the net impact of RE deployment by region, sector and income group.

Chapter 6 contains summary evaluations and policy conclusions.

2 Costs and benefits

2.1 Review

System-related costs and benefits cover all the direct and indirect costs of expanding RE that are related to direct or indirect resource consumption (cp. ISI 2010, Breitschopf, Diekmann 2015). The direct costs cover the resources needed to construct and operate an installation, while indirect costs describe the follow-up costs of constructing or operating installations, especially infrastructure costs (networks, storage). The system-related costs and benefits of renewable energy sources are always weighed up by comparing them to an energy supply that does not foster the expansion of RE and, independently of this, it is determined which actors have to bear the costs of RE expansion. Major benefits include the conservation of resources and avoided environmental damage. In addition, impacts on technological change and the security of energy supply have to be considered, although these can only be partially quantified.

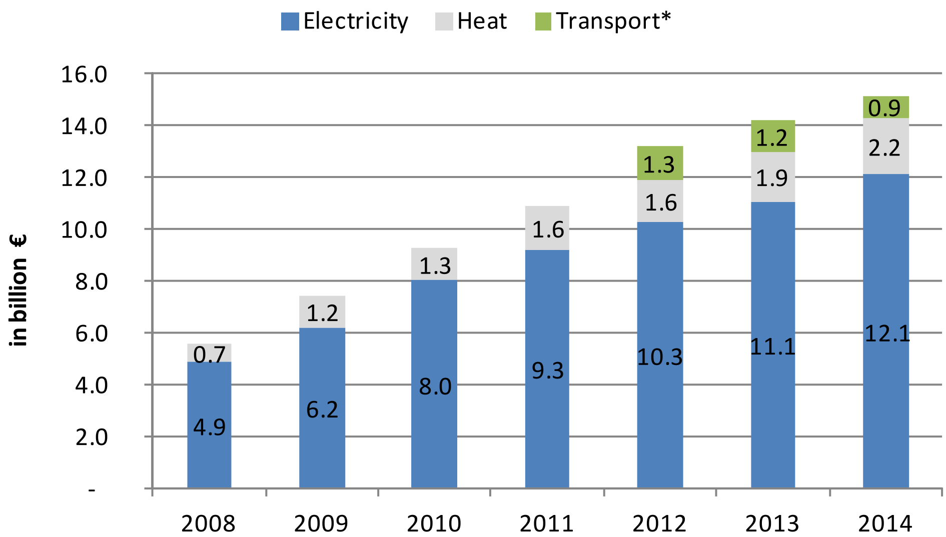
2.2 System-related additional costs

The system-related additional costs allow statements to be made about the total economic costs of energy from renewable sources compared to conventional energy sources. In principle, these cost differences can be either positive or negative. The difference between the production costs of electricity, heat and fuels from renewables and the production costs of fossil reference technologies equals the direct system-related additional costs. These are calculated using annuity investments and operating costs and, where applicable, fuel costs, independently of whether the investments in renewable energy are made based on legal requirements (such as those in the German Renewable Energy Heat Act (EEWärmeG)) or due to other incentives. Any funds or subsidies granted and the energy taxes levied on fossil fuels are not included in this analysis. Indirect additional costs have to be taken into account as well as direct additional costs. These result from the additional costs for balancing energy and expanding the grid network. The total system-related additional costs of using renewable energy sources in Germany were €16.1 billion in 2014 (ISI et al. 2015).

The electricity sector has the biggest share in total additional costs. The (direct) additional costs for power generation increased to €12.1 billion in 2014. These are mainly due to the increased deployment of renewable energy sources, the specific investment costs of renewable technologies and the costs of power generation from fossil energy that are heavily dependent on the prices for coal and gas. The costs for expanding the power grids and networks are also becoming increasingly relevant. The annuity grid expansion costs are estimated at about €720 million for 2014 based on already realized measures to expand the transmission network in the onshore and offshore sectors. On top of this are the costs for balancing energy of approx. €188 million for the power transmission network operators and direct marketers to market EEG power. In total, therefore, the system-related additional costs of electricity from renewable energy sources amounted to €13.1 billion for 2014.

Determining the system-related additional costs of renewable energy sources is more complex in the heat sector than in the power sector because decentralized heating systems are the norm in residential and non-residential buildings. Alongside technological parameters, building-specific parameters also have to be considered. Based on calculations for different types of buildings, the additional costs in the heating sector are estimated to be around €2.2 billion for 2014.

The additional costs in the transport sector are calculated from the difference between the manufacturers' prices of biofuels and the respective fossil fuel being substituted (petrol or diesel). In total, additional costs of €0.85 billion resulted for 2014, of which about 27 % is due to bioethanol and almost 73 % to biodiesel.



Source: ISI, DIW, IZES, GWS (2015) Note: * Estimate first conducted for 2012.

Figure 1: System-related additional costs

2.3 Avoided environmental damage

The system-related additional costs are offset against the benefits, in particular avoided environmental damage due to the use of renewable energy. Reducing greenhouse gas emissions, especially CO_2, is the most important effect. Germany is making a major contribution to global environmental protection by expanding its use of renewable energy sources. The environmental damage avoided due to renewable energy sources (including air pollution) is estimated at a total of €11.6 billion for 2014; of this €10.2 billion are related to electricity, €1.3 billion to heating and €0.1 billion to transport (ISI et al. 2015). The environmental damages due to fossil energy sources are partially reflected in the certificate prices (mainly in the electricity sector) of the European Emissions Trading Scheme (EU ETS). The net benefit of avoided environmental damage due to renewable energy amounts to around €10.9 billion (2014) if this is adjusted to account for this partial internalization.

2.4 Technological change

The role of innovations in the field of renewable energy sources

There is widespread agreement in the literature that specific policy instruments have to be employed to overcome the market failures and obstacles that are hindering technology innovations for the utilization of renewable energy sources (Groba, Breitschopf 2013). Technology-specific measures promoting renewable energy sources such as reimbursement regulations, tenders or quota systems are necessary supplements to general instruments like emissions trading or the introduction of taxes on emissions. In addition to such demand-based (market pull) instruments, supply-based (technology push) instruments are also required, especially in the early stages of technology development. Successful technological change therefore requires a bundle or combination of different policy measures (policy mix) that promotes both the development and application of new energy technologies.

There are various methodological approaches available to measure the efforts and success of policies concerning technological change. Here, it is important to analyse different levels of impacts and stages of the technology change process.

The literature review shows that, according to the experiences made so far, environmental policies and the innovations they trigger are able to strengthen the international competitiveness of particular economic branches. The costs of new technologies can be reduced by learning effects and search processes among other things.

An international comparison of technological change

Different indicators can be used in an international comparison to examine the dynamics of technological change in the field of renewable energy sources (Groba 2014). Whereas analysing R&D expenditures maps the efforts made concerning investments in the innovation process (innovative input), analyses of patent applications and foreign trade indicate the success of this policy (innovative output).

Compared to other countries, renewable energy is a strong research focus in Germany and the country ranks among the leaders with regard to the amount of spending and research intensity in the fields of photovoltaics and wind energy. It only drops to a middle ranking concerning the level and intensity of research in biofuels and concerning the growth in spending in all three technology fields analysed.

At the same time, it becomes clear that the investments in R&D and knowledge are also accompanied by success. Germany has been one of the biggest exporters of technology products to use renewable energy since 1990. This position further improved until 2011 compared to other OECD countries. All the analysed technology fields experienced strong growth in exports, although this was even more marked in photovoltaics and wind power than in biofuels and relevant technology products. Overall, therefore, an increasing foreign trade specialization can be observed in Germany's trade with renewable energy technology components. Germany's exports in this field are higher than the global average. The general implication is that the support given to the expansion of renewable energy sources in Germany has made a major contribution to its success here. Nevertheless, it must be noted that German producers of photovoltaic and wind power components have not succeeded in penetrating foreign markets more than is possible for their foreign competitors in Germany. The reason for this is that imports in these fields have increased more than exports over the last few years. Furthermore, the analysis revealed that export specialization does not necessarily mean a comparative advantage. A comparative disadvantage can be seen in the fields of photovoltaics and wind power because the exports related to imports are lower than the average of all industrial goods. This applies to a smaller extent to the trade with biofuels. A comparative advantage is only visible in the trade with technology products for supplying biofuels.

The analysis of innovation indicators based on patent applications underlines the good position of Germany in technological change in the field of renewable energy. Looking at the number of annual patent applications and their dynamics, Germany was the most innovative country between 1990 and 2008 in the fields of photovoltaics and wind power.[1] Germany is only less innovative in biofuel technology in an international comparison. This view is confirmed by analysing patent specialization, i.e. the share of renewable energy patents in total patents, and above all by looking at research intensity, measured as renewable energy patents per inhabitant. This again suggests that the EEG's support for RE expansion is an important driver of patent applications – and promotes innovation.

To sum up, based on measurements made with the selected indicators, Germany scores highly in the field of renewable energy and is one of the leaders in an international comparison of technology change. A cause and effect relationship between research promotion, the market support of RE or between RE expansion and Germany's

[1] Groba (2014) analyzes patent applications up to 2008, trade data and R&D spending up to 2011.

innovative output cannot be identified in a descriptive analysis. However, this analysis is able to identify several fields of activity to further develop Germany's international position in the future. A stronger focus on R&D in the field of renewable energy could help Germany to remain competitive with Denmark, for example, in the field of wind power. In addition, manufacturers are facing the challenge of increasingly having to develop markets outside OECD countries.

Decreasing technology costs - the example of photovoltaics

One major motivation for promoting RE are the anticipated learning effects and the associated falling costs of technology. Technology costs have declined with increasing installation since promotion has been practised. This cost development is especially visible for photovoltaics, but it is unclear which share can be attributed to the promotion (Breitschopf 2016). The estimates made so far are based on the learning curve approach that takes cumulative capacity and possible expenditure for R&D and material prices as explanatory factors for cost development. The actual contribution of promoting expansion – learning by doing – is documented via the installed capacity. However, this frequently applied approach has several weaknesses. Technology costs themselves are not recorded, but ultimately the market prices for technologies. Since market prices are the result of supply and demand, they are influenced by both demand-side and supply-side factors. Policies that influence demand through promotion trigger different price-setting mechanisms that ultimately bring about short-term and long-term price changes. In this paper, the selected approach to estimating the influence of policy on technology costs or prices assumes the following mechanisms: feed-in reimbursement increases the profitability of RE projects so that demand, measured in annual installations, rises. This increase first brings about a shortage of RE technologies so that their prices go up temporarily. This price climb attracts new suppliers onto the market who can offer the technology at lower prices possibly due to new production technologies and economies of scale effects. Thus, in the medium to long run, prices decrease. More favourable technology prices increase the profitability of investing in RE if policy (feed-in reimbursements) remains the same. In addition, technology costs are also influenced by R&D expenditures as a measure for R&D efforts, material prices, the size and structure of the RE technology market as well as global technology developments (beyond the analysed country).

This approach was illustrated and estimated for photovoltaic technology using a simultaneous structural equation model (see Breitschopf 2016). The technology prices are estimated using market characteristics (total domestic module production, production scales), global annual installations, annual state R&D spending for PV (learning by researching), silicium prices, cumulated domestic capacities (learning by doing) and annual domestic installations (demand); the annual installations are simultaneously also determined by domestic growth, technology costs, profitability of the PV investments and environmental policy values. In addition, the profitability of the investment is estimated using the support impact and the technology prices. The specific production costs were taken as technology costs/price variable because these take efficiency developments into account. However, the estimated results based on system costs are not very different to the results based on production costs.

The result shows that the costs or prices of technology are obviously influenced by demand (annual domestic installations) and by silicium prices, but that learning (by doing) effects do cause price reductions. The global development of demand for PV installations (global annual installations) also contributes to price reductions, while market characteristics and R&D do not play a significant role in this analysis. Demand is clearly determined by technology costs, while profitability is only weakly significant. The coefficient of election returns of the green party does not seem to reflect properly environmental preferences; its value is negative. Technology costs dominate when looking at profitability of an investment, while the effect of support is less relevant in comparison, but does become significant if technology costs are omitted as an explanatory variable. However, it should be noted that this analysis is based on only a small number of observations and chooses an approach requiring stationarity, which is not given in these data (time series data). To this extent, the results have to be treated with certain reservations. Nevertheless, they do seem to support statements in the literature that learning effects caused by expansion, in particular, do contribute to cost reductions.

2.5 Energy (supply) security

There is agreement in the current literature that import dependency and diversification are important parameters of energy (supply) security. The influence of the Energiewende on energy security can be measured using different diversity indicators. In an extended analysis, the impacts of import dependency can be determined along the entire value chain (Lehr, Nieters 2015, Lehr 2009). Due to the fact that Germany's energy mix has become more balanced over the years, the simplest version of the indicator (focusing on the number of sources and their distribution) has improved. If additional factors such as country risks are considered, composite indicators report higher energy security impacts than simple ones. The scenarios with larger shares of renewable energy lead to superior adjusted indicators even when including the technology costs of power generation during high price phases of PV, i.e. the indicator is larger than in a scenario without RE. Ultimately, however, diversity indicators depict only the advantages of a strategy aiming at greater variety and neglect other dimensions.

When taking further dimensions into account, energy security can be understood as an overarching goal of national energy policy, while supply security focusing on external supply is one aspect of energy security. Energy security can be related to the different areas in which risks occur: economic, social, political, ecological, technical and natural dimensions. A risk's effect can be detected via its influence on characteristics like increasing or reducing availability, disparity, affordability etc. (Schlotz 2013).

The impacts on energy security of expanding renewable energy sources in the heat market were analysed specifically as part of this project (Breitschopf, Schlotz 2014). The indicators selected to do so cover the following aspects:

• Import dependency or risk with a view to external supply security and availability

• Price volatility with a view to acceptance and uncertainty about costs

• Short-term availability in the sense of a reliable supply

• Production costs with a view to affordability and acceptance

• Conversion efficiency with regard to the required volume of an energy source

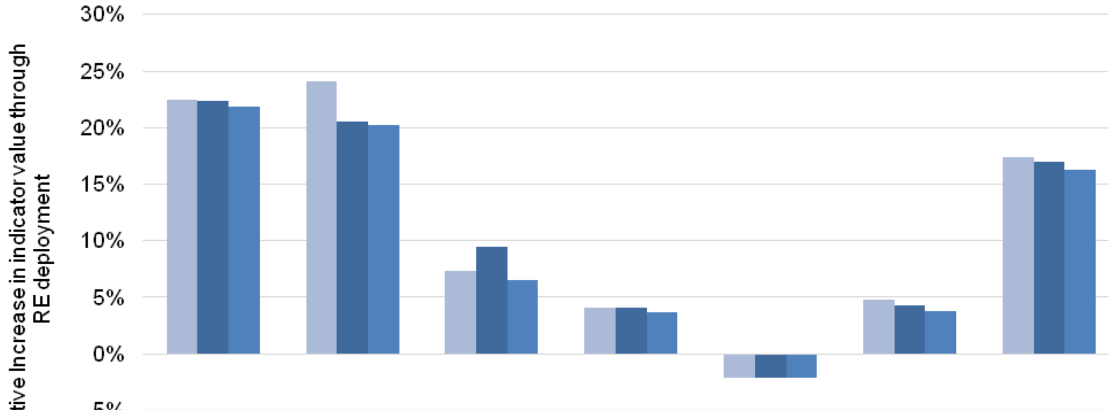
• Variety and availability of resources, also with respect to reliability and diversity.

In each case, a scenario featuring renewable energy sources is compared to a scenario with fossil energy sources. There is no aggregation of the different indicators to a single total value, but each indicator is aggregated across sectors or applications.

The scenario analyses show that import dependency/risk is clearly reduced and price volatility is still visibly reduced due to the use of RE in heat generation; resource variety and system diversity clearly increase and, overall, energy security is increased as a result of this. Because the conversion efficiency of RE still has scope for development, the effect of RE on energy security measured using this indicator is slightly negative. The production costs at system level drop in total due to the use of RE, i.e. the slightly higher costs of generating heat with RE in households and the tertiary sector are offset by the positive cost effect of RE in industry.

The concept developed here is not to be understood as an approach to estimate the impact on energy security of RE expansion in monetary terms. On the contrary, the approach indicates how this impact can be detected or energy security can be measured using different characteristics, dimensions or indicators – without a measurement unit - and also shows that a clear definition or demarcation of this term does not exist, or rather that how this term is defined depends on the respective situation (policy, price development, infrastructure etc.).

The overall result of the analysis is that renewable energy sources in the German heating sector in 2011 make a visible contribution to energy security measured using the different indicators selected here, but that the extent of this effect depends on the selection of the indicators and the variety or diversity of the resources or technologies regarded.



	Import Risk	Import Dependency	Price Volatility	Production Costs	Conversion Efficiency	Resource Availability	Diversity of Availability
2011	22%	24%	7%	4%	-2%	5%	17%
2012	22%	21%	9%	4%	-2%	4%	17%
2013	22%	20%	7%	4%	-2%	4%	16%

Source: Breitschopf et al. (2016)

Figure 2: Indicators measuring energy security in the heating sector

3 Price and distribution effects

3.1 Political relevance of distribution effects

Distribution analyses pursue the main question of whether and to what extent political measures enhance or reduce inequalities.

As a basis for analysing the distribution effects of expansion or of the promotion of renewable energy sources, first of all, general questions of justice and distribution are presented from the point of view of different disciplines or policy areas. Furthermore, more specific questions about the distribution impacts of energy and environmental policy measures are explained. Relevant design features of the instruments and impacts are systematized and methodical approaches towards quantitative assessment are outlined for the distribution impacts of renewable energy sources (Breitschopf, Diekmann 2013).

Justice, welfare and competitiveness as key objectives for analyses of distribution effects

Distribution effects have huge social significance because they are linked to fundamental questions of justice. This applies on the micro level of small groups as well as the macro level of larger organisations. There is a close connection between a group's well-being and its cohesion. Different distribution principles can dominate such as equity, equality or need, which may be in conflict with each other. Distribution problems can occur at different levels. Attention has to be paid to values, regulations, and issues of implementation and not least to decision making procedures.

From an economic point of view, the focus is mostly on questions of efficiency, e.g. the Pareto efficiency criteria, while questions of justice and the measurement of inequality require additional value judgements. It is particularly difficult to judge the just distribution between different generations and nations in economic terms, although this is essential, particularly for long-term and global policy issues such as climate protection.

Questions of distribution are highly significant in the field of finance as taxes and transfers change the distribution of income or wealth. The classical principles here are the ability-to-pay principle and the equivalence principle. It must be remembered that the effect of tax burdens also depends on possible price impacts and adaptation reactions (effective incidence). The goal to generate income to finance government expenditures can be in conflict with distribution goals. Indirect taxes, for example, can have a regressive effect, i.e. that their burden in relation to the available income – contrary to the ability-to-pay principle – diminishes with increasing income. The same applies to many economically relevant measures which result in a financial burden. Conversely, distribution impacts can arise in the case of tax relief. This is why distribution effects should ultimately be considered in all policy areas.

The government's social policy includes different measures for redistribution and safeguarding against risks. This primarily concerns people at risk of poverty. The risk of poverty is disproportionately high for certain groups of the population. These include women, people from former East Germany, 18 – 24 year olds, single parents and the unemployed. Particular attention has to be paid to these groups when analysing distribution effects.

As well as distribution impacts between people or households, distribution impacts between households and companies and between companies have to be considered. Possible economically-relevant influences of policy measures on international competitiveness are particularly significant.

Distribution impacts of energy and environmental policies

As in all other policy areas, energy and environmental policies can trigger significant distribution effects. An important issue here is to what extent the economic net burdens have a regressive impact on income distribution. In these cases, it is particularly likely that conflicts arise between efficiency-oriented allocation goals and justice-oriented distribution goals. Regardless of the instruments used, energy and environment policy measures can have relevant distribution effects at different points or via different factors: when consuming energy- or environmentally-intensive goods, when producing these goods, through scarcity rents, in the context of the environmental benefits, through capitalisation effects and the triggered structural change. This makes it clear that there can be a large number of different distribution effects which have to be considered when making an overall assessment of energy and environment policy measures that depend on how these are designed.

In general, energy or electricity taxes in the household sector have a direct regressive distribution effect. It is, however, important to consider how the tax revenue is used. As part of the ecological tax reform in Germany, in addition to the financial burden of energy consumption, it was planned to lower the non-wage labour costs at the same time in order to at least partially compensate the regressive effect.

Some distribution effects are also caused by the European Emissions Trading Scheme (ETS). These are triggered by transferring the opportunity costs of emission allowances that were allocated free of charge, the windfall profits of the operators of nuclear power stations, special regulations for enterprises where the risk of carbon leakage is suspected, as well as electricity price effects for enterprises and households. The (currently rather low) electricity price effects of the ETS have a directly regressive effect in the household sector. However, once again, the possible compensating effects of how auction proceeds are used have to be taken into account.

Against the background of rising energy prices, energy poverty is increasingly becoming a relevant topic in Europe. According to the criterion used to date in Great Britain, energy poverty occurs when a household's spending on energy (for fuel and electricity) accounts for more than 10% of its disposable income. In Germany, this would be 14% of all households. According to the current debate, the relative risk of poverty should be considered alongside the level of energy costs. Power disconnections are also taken as an indicator for energy poverty; in 2011, this affected less than 1 % of households in Germany.

The concept of energy poverty encompasses both social and energy policy aspects. It is controversial to what extent the related problems concerning energy poverty should be recorded and addressed as such, or whether the social and energy policy issues should be addressed separately. Regardless of this, however, it is obvious that households at risk of poverty will be more heavily affected by energy prices that are high in relation to their income. Energy and environmental policy measures have the potential, therefore to result in social problems and may jeopardise the social acceptance of such measures.

Systematic assessment of distributional effects of renewable energy sources

The EEG and financial funding are the main energy policy measures in the electricity sector that cause significant distributional effects. Significant design features of the EEG that have a considerable impact on economic activities and actors are the feed-in remuneration, market premium, EEG surcharge, special equalisation scheme and technology- and system-specific degression of the feed-in remuneration. In the heat sector, in contrast, distributional effects are the consequence of financial support and the obligation to use renewable energy sources. Special effects can occur particularly in plant production and installation, electricity generation and marketing and end use. In addition, distributional effects are possible in research and development as well as co-operation.

On the one hand, distributional effects occur directly in the form of changes in prices, expenditures or revenues and, on the other hand, indirectly through transition effects (Fullerton 2011). Changes in prices, expenditures or revenues cover a broad group of effects: changes in consumer and producer revenues, capitalisation effects which can occur through quality changes to a factor and benefits due to environmental protection (reduced emissions). On the other hand, transition effects include all (structural) changes representing an adjustment reaction to the new situation, such as for example production, price, demand, competition, tax, employment effects as well as infrastructure adaptations and technological learning.

Current discussions about distributional issues were triggered in particular by the time-delayed adjustment of the feed-in remunerations for PV electricity to the system costs, the electricity price reductions on the power exchange due to merit order shifts and lessening the burden of the EEG surcharge on energy-intensive industry as part of the special equalisation scheme. These all contributed to the final RE-levy paid by households. In this context, there are questions regarding (1) the regional distribution of burden and relief, (2) the distribution of the burden between households and enterprises, (3) the distribution between household groups and (4) the distribution between different enterprises.

Specific methodological approaches to quantification

The methodological approaches to map the distributional effect of different burdens and reliefs caused by energy policy differ considerably according to the question, data availability and relevant effects. As part of the ImpRES project, they were described in detail in the corresponding work packages (AP 2.2 to 2.8). The following sections summarize the results of these specific analyses with regard to the policy relevant conclusions.

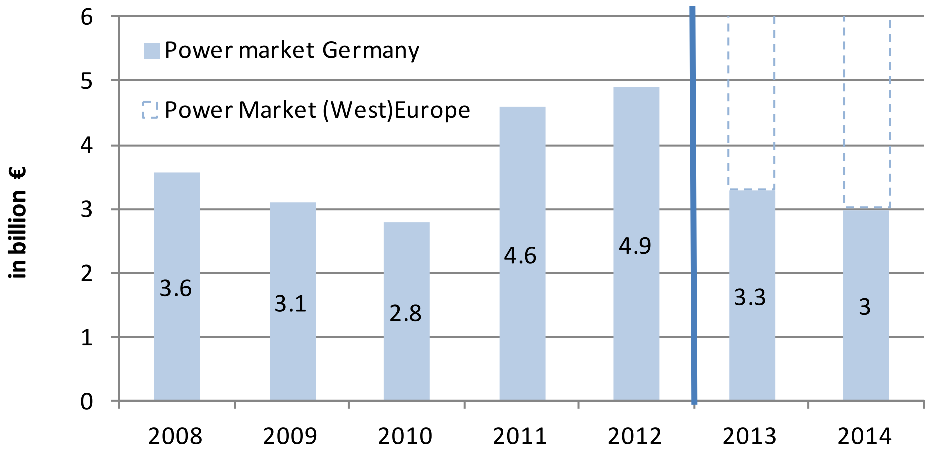
3.2 Distributional effects of expanding renewable energy sources in the electricity sector

3.2.1 Electricity price effects

The merit order effect describes a price and distribution effect which is triggered by the expansion of renewable energy sources. Decreasing wholesale prices reduce the revenues of electricity producers and favour electricity suppliers or consumers. In addition to our own calculations with the PowerACE model (now: Enertile model: http://www.enertile.eu/enertile-en/), different studies confirm that this effect reaches a significant scale (see Figure 3). It has been shown that the merit order effect in Germany even under rather conservative assumptions and considering European foreign trade in the years 2013/2014 is in the range of 3.3 or 3 billion euro (Sensfuß 2015). The decline of the unweighted average market price is approx. 6.2 or 5.8 €/MWh. Overall, the European analysis shows that the merit order effect of the German EEG has also reached a significant scale abroad due to increased electricity exports. The question of how much the individual final customers profit from this effect ultimately depends on the competition on the power market and the structure of power procurement. This makes the analysis challenging. Other methodological challenges when determining the merit order effect result from defining the alternative generation system for the counterfactual scenario without EEG electricity and considering the European market.

This project also focused on how much the price lowering effects of renewable energy sources on the power exchange are passed on to electricity consumers (Pudlik 2015): In a period between 2010 and 2013, daily data on the residential tariffs offered were used differentiated by postal code areas. In a first step, the time series were adjusted for different price components such as VAT, EEG surcharge, concession fee and network charges. In a second step, the power exchange prices were compared with the remaining sum of procurement costs, distribution costs as well as the margins of the energy supply companies.

The result shows that the sum of margins and distribution costs remains more or less constant for the competitors supplying the final customers. This indicates that price reductions on the electricity exchange are passed on to new customers in the residential sector. However, this trend is less marked for general tariffs (basic supply tariffs). Customers with existing contracts profit from price reductions on the electricity exchange only with a time delay. It appears that consumers in rural areas tend to benefit from price deductions to a smaller extent.



Source: Sensfuß (2015) and ISI, DIW, IZES, GWS (2015); Note: since 2013 consideration of the effects on the European power market

Figure 3: Merit-order effect in Germany

A similar investigation (Ecofys and ISI 2015) showed that, for customers from industry, the procurement prices for electricity-intensive industries are relatively closely oriented to price developments on the electricity exchange. According to the results of this study, this applies to the tariffs offered to customers in the residential sector with certain restrictions.

3.2.2 Social distributional effects of the EEG surcharge

Distributional effects play an important role in the general public's perception, particularly for the acceptance of the Energiewende. The increase of the EEG surcharge from 3.6 ct/kWh in 2012 to 5.3 ct/kWh in 2013 has sparked extensive public debate. The DIW (Neuhoff et al. 2012) and IW (Bardt et al. 2012) have calculated the distributional effects of this increase. For the year 2013, RWI (Frondel, Sommer 2014) presented calculations which focused particularly on low income households.[2]

In the ImpRES research project, the average costs were extrapolated by household type using estimates and simulations (Lehr, Drosdowski 2015). Rising electricity prices increase what a household spends on electricity and consumers can only counteract this by reducing consumption. For the future development, it is examined to what extent the distributional effects continue if the EEG surcharge develops either along the upper or the lower path of the medium-term forecast made at that time. Such a future-oriented analysis can only be done based on a model. An analysis of the financial burdens by household type (based on electricity expenditures due to higher EEG surcharge payments) was carried out with the aid of the PANTA-RHEI module DEMOS according to household size and the socio-economic position of the main income earner.

The results of the model confirm that the distributional effects of increasing energy prices are relatively low and regressive, i.e. related to income, they affect low income households more than higher income ones. In 2015, an EEG surcharge that is 1 ct/kWh higher in the upper scenario compared to the lower scenario, increases electricity prices for households, and causes an additional average spending of 33 euros per household, the equivalent of approx. 0.08 per cent of the available income if adjustment reactions to increasing prices are not taken into consideration. If this is done, the average increase is only approx. 24 euros or 0.06 per cent of the available income. The adjustments affect primarily higher income households (better equipment and money for new technologies, possibly a higher level of environmental awareness and level of education), but they also ease the financial burden for less solvent households (households of pensioners). An additional calculation by income group to make the results more plausible confirms them in terms of the direction and magnitude, with the additional expenditures of approx. 30 euro or 0.08 per cent of the available income due to a higher EEG surcharge in 2015.

Slightly regressive distributional effects can also be observed for other environmental policy instruments such as ecological taxes. As the European Environmental Agency

2 The authors point out, however, that low income households are seriously under-represented in the survey of the RWI on the energy consumption of private households.

(EEA 2012) found out when investigating the ecological tax reform in Europe, this should result in possibly cushioning the effects. Overall, there are substantial benefits of expanding renewable energy sources with regard to saving greenhouse emissions, reducing fossil imports, increasing employment and decreasing the electricity wholesale price (for a regularly updated overview cf. ISI, DIW, IZES, GWS (2015), which might contribute to individual additional benefits to differing degrees.

3.2.3 Special EEG equalisation scheme

The objective of the special EEG equalisation scheme (BesAR) is to prevent the EEG surcharge adversely affecting the international competiveness of electricity-intensive enterprises as well as the intermodal competitiveness of railways. The regulation allows enterprises whose competitiveness may be threatened due to the EEG surcharge to apply for exemption from part of the EEG surcharge. The sum of relieving the financial burden on these enterprises is spread over all the other electricity consumers. The special equalisation scheme can result in substantial distributional effects (Horst 2015).

The scientific studies done so far on the EEG progress report could not prove that the special EEG equalisation scheme has not fulfilled its task. However, lowering the privilege threshold over the years while expansion costs have continued to increase on the one hand, and the nominally fixed privileged contribution of 0.05 ct/kWh for a large share of the privileged volume of electricity on the other hand have contributed to non-privileged final electricity consumers shouldering an increasing burden from this cost redistribution from year to year. The special EEG equalisation scheme has occasionally contributed to a distortion of competition on a national level due to rigid privilege thresholds. In the non-privileged EEG surcharge in 2014 of 6.24 Ct/kWh, approx. 1.35 ct/kWh alone are owed to the special EEG equalisation scheme. In 2015, the redistribution effect or the additional burden on the non-privileged final consumers caused by the special EEG equalisation scheme rose to approx. 1.37 ct/kWh. This resulted in spite of an overestimation of the EEG costs in 2014, which had a dampening effect on the transmission network operators' (TNO) estimates of the costs to be passed on. The main reason is the estimated total amount of power purchased, which fell slightly.

This relief of the financial burden on industry has been denounced in public discussions as the former system of privileges under the special EEG equalisation scheme was not specific enough when considering the competitive situation of the enterprises and sectors, and simply assigned privileges in a relatively undifferentiated manner as soon as the defined thresholds were reached or exceeded. Over the years the privileged amount of electricity has grown significantly. The European Commission therefore also launched a notification procedure in order to check whether these benefits are contrary to Community law. In this context, the German government was largely able to reach a consensus with the European Competition Commission in April 2014 about the new design of the special EEG equalisation scheme. The revised version of the special equalisation scheme in the EEG 2014 now restricts the rebate to the sectors defined by the Commission. The selection was made based on two key indicators: the share of electricity expenditure in gross value added at factor costs and the trade intensity (based on the competition criterion in the EU Emission Trading Scheme). It is debatable whether these key indicators and the selected threshold value variants are suitable to illustrate competitiveness. However, at least there is agreement on a European level, which meant levelling out unfair competition between the EU Member States in relation to economic rebates when passing on the costs of supporting renewable energy sources.

In addition, every German enterprise has to prove itself that it reaches or exceeds the privilege threshold. There are transitional regulations in place until 2019 for enterprises that received rebates in 2014, but are no longer eligible under the new regulations of the special EEG equalisation scheme. The government estimates the impacts of the EEG surcharge to be at the same level as the special equalisation scheme of the EEG in 2012 (special EEG equalisation scheme, government draft 2014).

In 2012 as in the preceding year, the special EEG equalisation scheme resulted in savings of approx. €2.5 billion for the privileged enterprises. In 2013, there was a substantial increase of approx. €1.4 billion to roughly €4 billion. This can be explained primarily by the increased EEG surcharge. The additional capacity increase in renewable energy sources accounted for only part of the increase. Significant cost factors include the reduced forecasted revenue, the increase in the liquidity reserve to 10% and the reduction of the deficit on the EEG account (from 2011). For 2014, there was a further increase to almost €5 billion. In contrast, a decrease to €4.8 billion is expected in 2015 due to the new framework conditions of the EEG 2014, but also to the high revenues on the EEG account.

These savings for privileged enterprises are an additional financial burden on all other electricity consumers. According to the EEG’s annual accounts for 2014, private households shoulder €1.3 billion of this burden; other, non-privileged industrial companies €2.2 billion and the public sector, transport as well as industry, trade and services €1.5 billion.

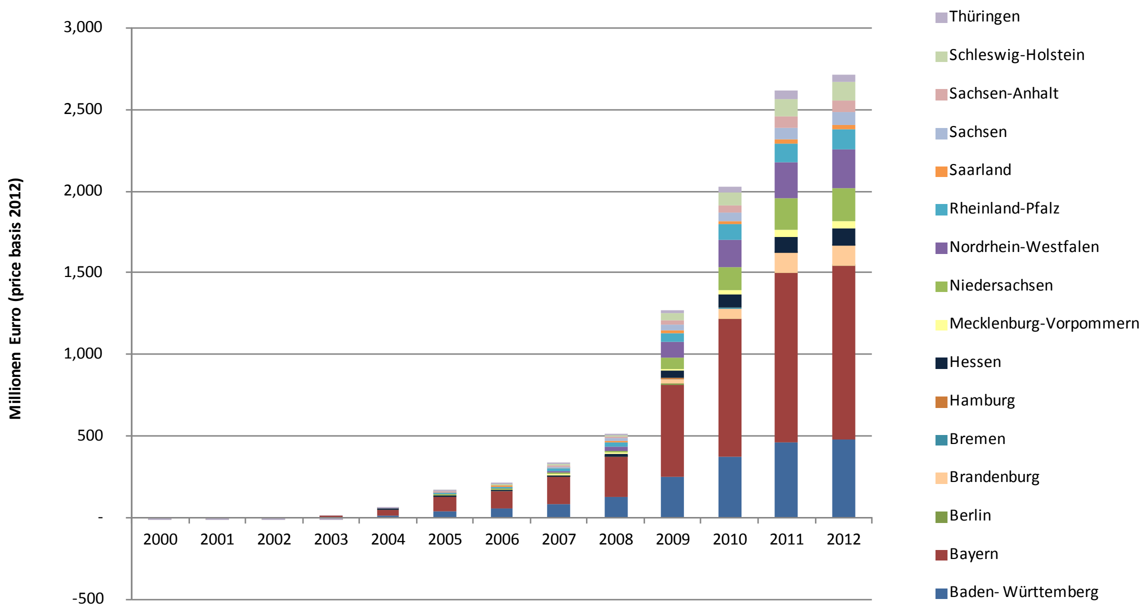
Regarding the revenues from the EEG reimbursements or the market premium, Bavaria and Lower Saxony are in the lead due the large expansion of biomass and photovoltaic or wind power. In addition, both states are able to register large benefits for their industries under the special equalisation scheme. The industrial state of North Rhine-Westphalia, where a large number of electricity-intensive companies are located, shows the largest sum of benefits under the special equalisation scheme, but the revenues from renewable power generation plants are lower than in the aforementioned states.

Compared to the percentage effect of the special equalisation scheme on the gross value added, the states of Brandenburg and Saxony-Anhalt are in the lead. In 2013, the electricity-intensive companies in North Rhine-Westphalia received the highest benefits in million euros; but the other electricity purchases were so high that the effects of the special equalisation scheme were comparatively low.

3.2.4 Impacts of the EEG on operators of photovoltaic and wind turbines (onshore) by federal state

The analysis of the market promotion of renewable energy sources in the electricity sector aims to assess the electricity production from PV and wind turbines as well as the resulting profits by federal state (Breitschopf, Bürer, Lürich 2014). The assessments are done based on models with appropriate assumptions of revenue-relevant factors. The results of both assessments show a clear regional pattern: While the two most southern German states account for two fifths of the installed capacities of solar electricity, the northern states have more than three quarters of the wind turbines. A similar picture emerges for earnings and profits. This unequal distribution is primarily due to natural conditions, whereby the availability of roof tops (agricultural buildings) has an obvious influence particularly for PV installations, and spatial and structural planning for wind turbines.

Although the installed capacities are roughly the same for wind turbines and PV installations, and PV produces significantly less electricity, pre-tax profits in 2012 totalled 750 million euros for wind turbines and around 2.7 million euros for PV. These profits do not necessarily have to remain in the federal state of the plant's location, but can go to investors in other (federal) states.



Source: Breitschopf et al. (2014); note: pre-tax profit

Figure 4: Annual profit from PV plants by federal state (price basis 2012)

While the production or installed capacity shares of the federal states' PV installations correspond to the population shares and shares of net total assets and single family homes, no regional correlation can be seen for wind turbines – with the exception of wind speeds. The share of private individuals, farmers, citizen participation, initiatives or cooperatives in investments or installed capacities is particularly high for PV installations (roughly 63% in 2010, TrendResearch 2011) and is identical with the existing structure of the installed capacity classes (46% or 68% of the capacity with installations <30 kW or <100kW in 2010). However, there is a decreasing tendency in both investments in new installations – with a 30% share of citizens investing in 2012 (TrendResearch et al. 2013) – and installation size (28% of the capacity installed in 2012 are installations of up to 40 kW). A similar development can be observed for wind turbines, although here citizens tend to be financially involved through citizen participation groups and less through cooperatives or as individual owners. It is not possible to differentiate wind parks into different installation sizes over time as wind turbines are recorded as partly aggregated and partly individual systems. It can be assumed, however, that in the early years of wind turbine expansion, first of all installations with small capacities were installed by citizens, but that institutional investors and energy suppliers became more active with the increasing capacities and sizes of wind parks.

Ultimately, the profits of PV electricity production are distributed among a large number of installations and citizens, so that a much wider audience can probably profit directly from EEG support. On the other hand, the direct proportion of citizens who invest in wind turbines is smaller, but they might profit indirectly by purchasing shares in institutional investors or energy suppliers. It can be concluded that citizens can participate directly in PV profits due to its market support, and more indirectly in wind profits through shares or investments. In both cases they might benefit from higher margins, but in some cases certainly from smaller margins compared to alternative investments.

With a view to the cost-benefit concept, a distinction has to be made between the indirect and direct impacts of market promotion as a result of the EEG. The direct effects considered here include the profits of the operators or investors of PV installations and wind turbines. The indirect effects on the other hand are knock-on effects of the increased demand for installations and lead to increased revenues or value added in upstream and downstream sectors of plant creation by trade, services and industry. The effects of the demand for installations, plant construction, operation etc have not been captured here. This means, however, that the high demand for PV installations in Bavaria could have indirect effects on the plant manufacturers in the Eastern federal states, for example. This applies in reverse also to wind turbines. Both effects have an impact on tax revenues, such as electricity tax; value added tax, income and business tax in the area of electricity production (Diekmann et al. 2013), but also to upstream areas such as plant creation, maintenance and repair. These aspects will be covered by the macroeconomic modelling in Chapter 5.2.

Another distributional effect is created by burdening the electricity consumers such as households, industry and trade with the EEG surcharge. The relatively unequal burden (see Lehr, Drosdowski 2013) on households and companies is not compared to the profits which can be achieved due to the EEG market promotion.

A final assessment of the distributional effects identified here depends on which assessment criteria were considered relevant. With a view to the efficient use of the existing (natural) resources, the north-south distribution has to be evaluated positively because the installations are allocated efficiently according to the availability of resources. On the other hand, if the aim is an equal distribution of the environmental impact (landscape, noise), a huge regional inequality manifests itself concerning the distribution of the installed plants – high concentration of installations in certain regions. This can result in a regional, very unequal possible burden on the population. As well as allocation efficiency and environmental impacts, socio-economic aspects such as (regional) distribution of income, capital formation or financial returns can be considered. It is only partly possible to assess this since the revenues and profits from installations do not necessarily have to be documented in the federal state of the installation’s location. They can exhibit a different regional pattern to the installations’ locations due to investments in companies, funds, initiatives or cooperatives. Overall, a different regional distribution of profits is not a problem as long as these are not excessive which, together with the regionally different feed-in payments, could result in extreme shifts of capital between regions.

Regarding the social pattern of distribution by actors, it can only be assumed for PV installations that a major share of the investments so far have been made directly by home owners who would have otherwise invested their money in savings deposits or other investments – possibly also in indirect investments in renewable energy installations. It is not possible to assess whether direct or indirect investments of certain groups is preferable. However, it has to be considered that particularly home owners have not only used or mobilised their own capital, but have also taken out attractive loans for investments in renewable energy installations. With a view to the allocation efficiency, large scale investments are preferable to small scale ones due to scale effects. When assessing the regional and social distribution of the impacts, a socio-political discussion has to clarify whether the principle of equality, efficiency or even need should ultimately be used.

3.2.5 Grid expansion costs

In connection with the greater use of renewable energy sources, developing and expanding the power grid involves additional system costs and also causes distributional effects that depend on how network charges are structured (Klobasa, Mast 2014).

Grid expansion and grid costs

Increasing renewable power generation has radically changed the distribution and transmission tasks of the power grid. In the past, the transmission grids were primarily designed for transregional electricity transmission and the distribution networks for delivering power to end consumers. With an increasing RE share, the grids have to be modified or developed into higher network levels because of the volatile amounts of power being fed into or recovered from the grid. To some extent, grid expansion in the transmission grid takes place at legally stipulated bottlenecks (measures under the German Power Grid Expansion Act and Grid Expansion Acceleration Act (EnLAG/NABEG)) and there is additional demand for transregional HVDC corridors ("electricity highways") to transport electricity over long distances from the wind-rich North to consumption centres in the South and West.

According to current studies, grid expansion in the distribution network affects regions with high global radiation (PV) or high wind velocities (wind turbines) and those where there is already high RE density, i.e. wind farms in the North and East and PV installations particularly in the South. The necessary investment in the distribution network is generally higher in regions with greater RE deployment. The investment burden per inhabitant, on the other hand, is also high in the more sparsely populated German federal states of former East Germany and is even higher here than in the former German states in the West and South.

At 1.6 million km, the distribution network makes up 98 % of the total length of the German power network. The transmission grid has around 35,000 km. The analysed studies predicted an additional grid expansion demand of up to one quarter of the already existing grid length for both cases. The investment volume in the transmission grid has already increased from 0.5 billion €/a in 2007 to approx. 1 billion €/a in 2013. Additional investments of up to 1.8 billion would be added to this due to the planned grid expansion up to 2023. Investments in the distribution network have risen from approx. 2.1 billion €/a in 2007 to more than 3 billion €/a in 2013. Additional investments of up to 3 billion €/a would be caused due to the planned expansion measures in the distribution network. German network operators would then reach investment levels as they were prior to the liberalization of the internal electricity market in 1996. After liberalization, the annual investments decreased continuously and this trend has only changed in recent years.

Due to the introduction of revenue caps as part of the incentive regulation, grid operators were induced to make greater efficiency efforts that first resulted in the advantage of falling network charges for network users. From 2006 to 2011, network charges fell by 20 %, but have since been rising slightly again. From 2012 to 2013, there was an average price increase for network charges at the low-voltage level of 8 to 10 % and even of 13 % for commercial clients in the medium-voltage level. Simultaneously, electricity-intensive enterprises have been given discounts since 2011 when paying network charges or were temporarily completely exempt from paying the charges (§19 German Electricity Network Tariff Regulation (StromNEV)). The revenues lost as a result of these exemptions are passed onto all final consumers via a surcharge, which means a greater burden on private households and small commercial users. The volume of this burden for network charges increased from 440 million euros in 2012 to 805 million euros in 2013 and was around 640 million euros in 2014.

High network charges and network charge increases are correlated with the high investments needed per federal state and inhabitant. This results in a greater burden on final consumers, especially in the new federal states of former East Germany.

The exemption from network charges was originally intended for electricity-intensive enterprises whose power demand has a stabilizing effect on the grid. Analysing the applications for this exemption and the permits granted, however, reveals a very broad portfolio of sectors that includes individual golf courses, supermarkets and social institutions alongside the expected energy-intensive industries. In addition, application behaviour varies widely among the federal states, with a remarkably large number of applications coming from Bavaria.

The total volume of relief on network charges of 440 million euros in 2012 represents only part of the additional relief for energy-intensive enterprises that amounted to around 13 billion euros in 2012.

Cost distribution

The electricity prices for private households and the tertiary sector (commerce, trade and services) have risen over the last ten years. This can be mainly attributed to the increase in generation costs and the rising EEG surcharge. The network charges that are used by grid operators to finance their costs for grid expansion and operation account for one quarter of the electricity price of household customers and for one third in the tertiary sector. Special tariffs usually apply to electricity-intensive enterprises. It is true that the electricity price for large consumers also increased until 2009, but it has fallen again since then because it is strongly oriented on the wholesale prices at the power exchange. In addition, large consumers are usually exempt from paying network charges and other taxes and levies or only pay a minimum share.

With the introduction of the incentive-based regulation, the network charges fell for all electricity customers by up to 20 % and only began to increase again from 2011. The increase is particularly high for private household customers and smaller commercial and industrial enterprises and will continue to rise in the future according to estimates by the German Federal Network Agency, because the costs for investments in grid expansion have to be factored into the prices. The network charges are higher on average for household customers in the new federal states of former East Germany than for those in the old federal states. In federal states that are sparsely populated and economically underdeveloped, high network charges correlate with high investments required per resident. High RE expansion also correlates with higher rates of increase in network charges in Bavaria (PV) and Lower Saxony (wind turbines).

The majority of electricity-intensive companies is exempt from paying network charges or only pays a reduced share of the charges non-privileged companies have to pay. However, weak points are emerging in how applications and exemptions are handled in practice, as are unequally distributed network charge reductions by sector or federal state. The high numbers of applications for reduced charges, the majority of which are not from energy-intensive industries, took a long time to be processed by the German Federal Network Agency, because the legal situation and transitional regulation were unclear for a while due to the abolition of a full network charge exemption and transition to reduced levels of network charges for energy-intensive industries. In the meantime, all the applications have been processed.

Concerning electricity prices, alongside the network charge exemption, energy- and electricity-intensive enterprises profited to the tune of around 13 billion euros in 2012 under numerous other levy or tax relief schemes. With 440 million euros in 2012 (and 805 million euros in 2013), the exemptions from and discounts on network charges actually only constitute a small share of the financial relief. Easing the financial burden on these enterprises is frequently co-financed by passing on the costs to the other non-privileged final consumers like households and the tertiary sector.

Adjustments to the network charge system

The network charges vary regionally and are an indicator for the required investment of a grid operator. Under the current regulation scheme, the distribution network operators are at a disadvantage concerning the approval of investment budgets and hence also large investment expenditures. Especially in view of the need to expand the grid across the whole of Germany, it should be analysed to what extent local or regional grid expansion projects are actually of transregional or national interest and the costs can be passed on nation-wide.

Under the present law, RE installation owners are exempt from paying network charges if they consume the energy produced themselves and they receive a guaranteed reimbursement for any energy fed into the grid. Although they generate some of their own electricity, they also benefit from the security of knowing they can draw power from the public grid should their own renewable generation be insufficient. Because the network charges so far are mainly consumption-based, RE installation owners participate less in financing the grids in the low-voltage level due to their self-consumption of power which leads to higher network charges for the remaining final consumers. More performance-based network charges or a fixed charge for grid users with self-consumption would ensure a stronger participation of these users and are one possibility of adapting the system of network charges.

3.2.6 Policy options to reduce the distributional effects of the EEG surcharge

The social acceptance of the support policy depends on how large the total financial burdens are and how these are distributed between companies and households and within these sectors. Different approaches have been discussed over the last few years on how to ease the financial burden on electricity consumers due to the EEG, both overall and for specific consumer groups (Diekmann, Breitschopf, Lehr 2015):

- Reducing the EEG’s additional costs,
- Broadening the surcharge basis,
- Alternative financing of the EEG from public budgets,
- Partial financing of the EEG from an EEG fund,

- Reducing the tax on electricity,
- Increasing social benefits and
- Improving energy efficiency.

Reducing the EEG's additional costs is the main way to lessen the burden on consumers. This includes achieving the predefined long-term expansion targets at the lowest possible costs. Besides R&D support, market development and learning effects, this includes a proper design of policy elements such as the remuneration or setting mechanism. Apart from how the support model is designed, the additional costs also depend on the electricity market structure and how efficiently emissions trading functions.

The financial burdens on non-privileged final consumers could be lessened by broadening the basis of those paying the surcharge. This is why the exceptions for energy-intensive companies under the special equalization scheme and for self-consumption should be restricted to the absolutely necessary level. The adjustments made so far to the special equalization scheme in §§ 61 and 64 EEG 2014 have a cost-cutting effect on the EEG surcharge compared to EEG 2012. But they can hardly result in the burden of the EEG surcharge on non-privileged electricity consumers being noticeably lightened compared to the current situation. To achieve this, the group of beneficiaries would have to be limited and privileged electricity consumers would have to bear larger shares of the surcharge.

Financing the EEG from public budgets instead of the surcharge would change the EEG's basic character and would also be linked with considerable problems. There would be the danger of a stop-and-go policy. Private households would bear a heavier burden in total than in the case of a surcharge. The regressive distributional effect in the household sector would only be prevented if (progressive) income tax were raised, something that would be very controversial. Furthermore, this would lower the financial incentives for energy efficiency and energy savings.

Partially financing the EEG from a special EEG fund could make sense if the EEG costs were only temporarily high and would drop substantially after several years. A fund could then help to even out the burdens and ultimately contribute to a more equitable intertemporal distribution. However, the scenarios show that a substantial reduction of the EEG's additional costs cannot be expected any time soon so that future electricity consumers would bear heavier burdens.

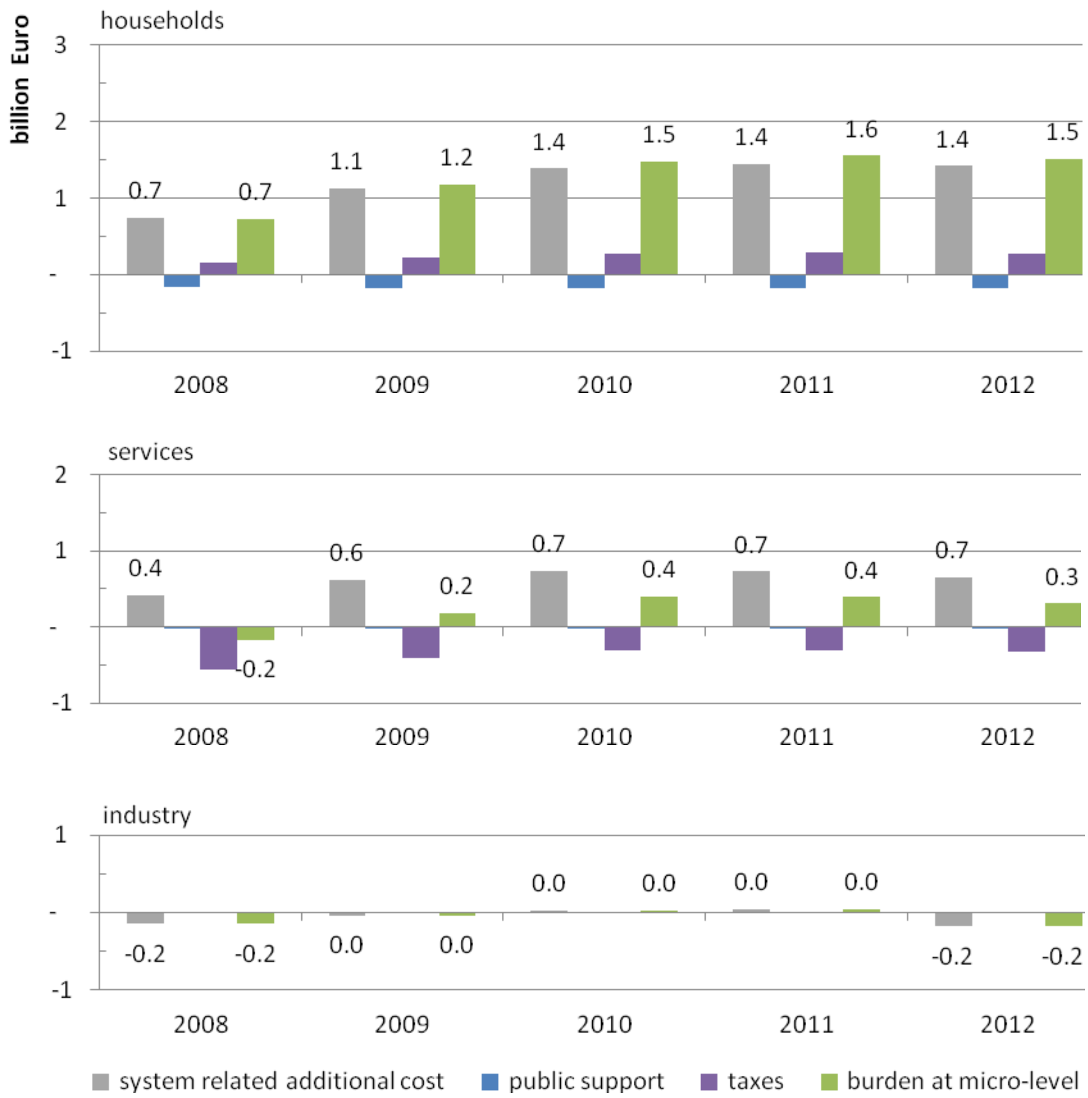
The tax on electricity could be reduced to partially compensate the financial burden on electricity consumers due to the rising EEG surcharge. A tax exemption for all households would ease the electricity tax burden for low-income households. However, the effects would be very limited.

Because the effect of electricity price increases as a consequence of expanding renewable energy sources can have a relatively high impact on low-income households, it has to be asked to what extent adaptations in social policy are required. The existing regulations governing basic social security ensure that electricity price increases ultimately lead to corresponding increases in social security benefits, although these increases only take place with a delay and are incomplete in this respect. In view of a relatively stable EEG surcharge, however, it does not seem necessary at present to adapt the general rules of social benefits to take increased electricity prices into account.

At least to some extent, electricity price increases can be offset by decreased consumption. Providing information and advice can effectively strengthen the reduction of electricity consumption. In addition, especially financial incentives for low-income households can help to reduce their power consumption and therefore also their spending on electricity.

3.3 Distributional effects of expanding renewable energy sources in the heating sector

In contrast to the power sector, less attention has been paid to the costs of expanding renewable energy sources in the heating sector. System-related and microeconomic burdens and reliefs should be distinguished here (Kockat, Treske, Breitschopf 2015). These should be estimated wherever possible differentiated by sector, energy source (solar, biomass, geothermal and ambient heat) as well as by building category and region.



Source: Kockat et al. (2015)

Figure 5: System-related and microeconomic additional costs in the heating sector

The system-related additional costs of renewable energy sources in the heating sector equalled €1.7 billion in 2012. Of this sum, about €1.4 billion is accounted for by households and €0.65 billion by the tertiary sector, while costs in industry were reduced by almost €0.2 billion.

The microeconomic additional costs that result from the system-related additional costs taking the support into account are lower than the system-related additional costs due to state support through the market incentive programme. Almost €0.2 billion of the system-related additional costs were compensated by the market incentive programme in 2012. Microeconomically, around €1.6 billion additional costs remain when renewable energy sources are used to generate heat. The microeconomic additional costs are additionally influenced by tax effects. The tax effect can have a decreasing effect if fuel costs and the associated value added tax and energy tax fall due to the use of renewable energy sources. However, this can also be contrasted by an increasing tax effect due to value added tax on the money spent on investments.

Private households bear the lion's share of the additional costs with an increasing trend, while some parts of industry are experiencing cuts in their costs due to the use of renewable energy sources. This distribution is mainly due to the fact that primarily profitable measures have been implemented in industry, whereas individual households invest for idealistic reasons and may employ technologies that are not profitable in a microeconomic perspective. Idealistic reasons regarding environmental/climate protection and status symbols might be the motivation behind these decisions. Different support programmes may reduce the households' microeconomic additional costs, but this effect is partially compensated by higher fiscal expenditure (VAT due to higher investments). On the other hand, fiscal expenditure has hardly any influence on microeconomic additional costs in the tertiary sector or in industry.

The empirical results support this argumentation: Solar thermal is increasingly used because it enables a relatively cost-efficient supply of hot water. The success of regional support programmes for heat pumps is visible in North Rhine-Westphalia in the high rate of heat pump deployment here. In contrast, solar thermal is spread equally, especially in the old federal states. The solar thermal systems installed so far are not always the most cost-efficient way of generating heat for private households. The additional burdens are distributed differently across the various building types. With 46 % over the entire period of analysis from 2000 to 2012, one-family homes and terraced homes bear the biggest share of the additional costs in residential buildings using solar thermal.

It can be observed that metropolitan districts have a relatively low share in the Germany-wide distribution of the additional costs. This observation can be explained by the fact that it is harder to use renewable energy sources in urban areas. For example, it is much easier to access and store biomass in rural areas. Furthermore, the use of solar thermal systems in urban areas with predominantly rented accommodation is rare because the incentive to invest in such systems is very low for tenants due to the high initial investments and the low income for landlords.

The additional costs in the tertiary sector are mainly driven by biomass. However, it is difficult to estimate the energy costs for this (especially in the agricultural sector), because it often occurs as a by-product or waste product here.

In the industrial sector, co-products or waste products are often used as renewable energy sources (biomass) to produce heat that would otherwise have to be disposed of. In this respect, some cost savings (could) even occur.

Overall it can be concluded that in spite of high installation investments for renewable production technologies, the consumption-based costs of the fossil reference systems (fluctuations in oil and gas prices) have a major influence on the level of additional costs.

3.4 Distributional effects of expanding renewable energy sources in the transport sector (biofuels)

Sievers, Spieth, Schaffer (2014) analysed the distributional effects of fuel blending regulated under the German biofuel quota based on data for 2012. The differential costs of substituting fossil fuels by biofuels were estimated at €1.3 billion in 2012 (ISI, DIW, GWS, IZES, 2014). This is a comparatively large sum when compared to the quantified benefits of avoided emissions of €0.1 billion. However, there are currently few alternatives in the transport sector. In the longer term, biofuels might become necessary in shipping and aviation, while for cars, e-mobility or natural gas can be used.

Because the energy content of biofuels is lower per unit of volume than oil-based fuels, the spending on fuel and the associated taxes increase even assuming that the volume-based prices remain unchanged. The effect is correspondingly higher if, in addition, different volume-based prices are assumed. Econometric ex post analyses show that extra fuel spending due to biofuels was between €1.2 and 4 billion in 2012. Private transport, i.e. households, face an over proportional increase, as they shoulder extra value added tax on top of the additional expense for the fuel itself. Unlike the heat and power sector, higher income households bear a larger burden here in relative terms. In contrast, the state benefits from tax revenues on the additional consumer spending of at least €0.6 billion.

The German biofuel sector generates revenues of €4.3 billion through sales of biofuels and other by-products, while the German agricultural sector makes €1.5 billion. In contrast, the oil industry’s decrease in production due to the biofuel quota can be quantified at €2.2 billion. Because of the oil industry’s high degree of integration, it is not clear overall whether the biofuel quota has minor or major negative impacts on this industry. Overall, at macroeconomic level, it can be stated that those sectors supplying biofuels or their primary products benefit from the quota, while the oil industry faces decreasing value added. The scale of the production growth depends strongly on whether other agricultural products are substituted by energy crops (Sievers and Schaffer, 2015). The macroeconomic effects are assessed using an input-output model.

It is very difficult to assess the distributional impact of RE deployment in the transport sector because this requires data from a wide variety of different sources and assumptions have to be made if data are not available. This analysis therefore focuses on the main effects and does not consider indirect effects like changes in land use, food prices or freight costs.

3.5 Impacts of expanding renewable energy sources on taxes and levies

There are many economic activities linked to the expansion of renewable energy sources that contribute to the volume of taxes and social security payments. As part of the ImpRES project, it was determined how much of the volume of taxes and social security contributions in the years 2008 to 2012 can be attributed to renewable energy sources (Diekmann, Großmann, Lehr 2013). Tax-relevant activities include the production of installations, systems and components, the operation of plants, the associated services and the sales or levies and consumption of renewable energy sources.

Important *indirect taxes* include the tax on electricity, the energy tax and sales tax (value added tax). The electricity tax is collected mainly independently of which energy carriers are used to generate the power. The volume of electricity tax allocated to renewable energy sources therefore increases with an increasing share of power from renewable energy sources. Energy taxes are not due in some renewable energy sectors. However, they are mainly significant for biofuels, whose initial promotion via energy tax benefits has since been essentially replaced by fuel quotas. The sales tax mainly affects private households (taking into account the pre-tax deduction for businesses). It should be noted that private persons operating photovoltaic systems, for example, and feeding power into the grid can also usually be counted as entrepreneurs in terms of the sales tax. Sales tax is very important for electricity from renewable energy sources, in contrast, and for the overall EEG surcharge. In the heating sector, the expenditure of private households on installations and fuels is subject to the sales tax. In addition, there is sales tax on biofuels in the transport sector. Given the total volume of indirect taxes in the field of renewable energy sources of €6.9 billion in 2012, the sales tax is the most relevant with €2.9 billion; two thirds of this are due to electricity from renewable energy sources and the EEG surcharge. Energy taxes of €2.3 billion and electricity taxes of €1.7 billion are added to this.

The volume of *direct taxes* is mainly related to the value added in the production and operation of installations to use renewable energy sources. The type of taxation depends on the legal form. Personal income is subject to income tax. Taxed incomes include wages or salaries from employed labour, any profit from self-employed labour or running a business as well as any income from leases and rents. Further taxes on income include corporation tax on the one hand (for legal entities), and the German solidarity surcharge, on the other hand, which is levied from taxpayers on their income tax and corporation tax. The trade tax levied by municipalities is also significant. This is a tax on the earning power or profit of a business. Given the total volume of direct taxes of €4.2 billion in 2012 in the field of renewable energy, the wages tax was the most relevant with €2.1 billion. The total income tax has also increased due to rising profits from businesses in the field of photovoltaics.

The total volume of both indirect and direct taxes has risen strongly in the field of renewable energy sources over the past few years. Overall, it increased by 62 % to €11.2 billion between 2008 and 2012.

Renewable energy sources also contribute substantially to the volume of statutory social insurance contributions with €4.1 billion in 2012 (without contributions to the statutory accident insurance of around €0.1 billion). At €2 billion, the contributions to the statutory pension insurance are the most important here.

The presented contributions of renewable energy sources to the volume of taxes and social security in Germany are based on calculations made using various official and non-official data sources. The heterogeneous design of tax law and the many varied tax-relevant activities in the field of renewable energy sources sometimes require estimates to be made using simplifying assumptions, each of which is documented. If an exact calculation of the proportional volume is not possible, at least the magnitude of taxes and social security contributions allocated to the field of renewable energy sources can be quantified with sufficient reliability.

In general, it must be pointed out that the calculated contributions of renewable energy sources are results from an analysis in gross terms that allows taxes and social security contributions to be allocated to specific economic activities, but does not allow a net analysis of their effects. This is especially true for the indirect taxes (with the exception of the sales tax on the EEG surcharge), because the taxes on renewable energy sources in a net analysis are contrasted by tax losses from the substituted fossil fuels to a greater or lesser extent. In this respect, the net effects may be heavily dependent on cost and price effects. In addition, with regard to the sales tax, it should be noted that rising consumer spending in the field of renewable energy sources partially replaces consumer spending in other areas so that there is no increase in tax revenue – assuming an unchanged tax rate - in a net analysis. When looking at the net impacts of expanding renewable energy sources on the revenue from direct taxes and social security contributions, it is crucial to what extent it is managed to trigger macroeconomic growth impulses at the same time as the structural change needed for sustainable development.

3.6 Distributional effects of funding research for renewable energy sources

Data on the development and structure of research expenditure, especially public research spending, were evaluated to examine the direct distributional effects of funding research and development in the field of renewable energy sources (Diekmann, Niemeyer 2015). Here, it is of particular interest how expenditure is distributed by funding body, federal state, technology focus, application, recipient group and economic branch. Alongside statistical reports on energy research, the analysed data basis included above all detailed information on the individually funded projects taken from the federal government's funding catalogue (FÖKAT).

The federal funds for energy research amounted to €819.2 million in total in 2014, of which €303.3 million or 37 % were for renewable energy sources. While renewables only have a share of 18 % (2013) in the Helmholtz Association's institutional funding, they play a major role in project funding with 47.9 % (2013). Application-oriented research and development projects dominate here; these were funded until 2013 by the former Federal Ministry for the Environment (BMU). The federal states funded non-nuclear energy research to the tune of €311.7 million in 2013; €84.8 million or 27.2 % of this was for renewables. In addition, for non-nuclear energy research, on average, there were €40.3 million available under the 7th EU Framework Programme (2007-2013) for project applications from Germany, of which €23.4 million or 58.1 % was for renewables. Therefore, the sum of public spending on renewables in Germany in 2013 amounted to €406 million. In a longer term comparison, the share of renewable energy sources in the energy research expenditure in Germany was constantly higher than the average of OECD countries. However, public spending on renewable energy source research has risen noticeably in many other countries in recent years.

The more detailed analysis of the federal government's project funding examined projects that started in the years between 2005 and 2014. The field of renewable energy sources[3] covers a total of 2,693 projects with total funds of €1,712 million. This is equivalent to 43 % of the projects or 34 % of the government's project funds for energy research. The majority of these projects come under the responsibility of the Federal Ministry for Economic Affairs and Energy (BMWi), including the former BMU application-oriented research and development projects. BMWi projects account for around 85 % of the funds for renewable energy. The basic research projects of the Federal Ministry of Education and Research (BMBF) have a funding share of about 14 %.

3 For the detailed analysis of the government's project funding, the funding focus of renewables was redefined compared to the FÖKAT database in order to include, in particular, several basic research projects that the database allocates to efficient energy transformation.

There has been a recent rise in the share of renewable energy sources in total project funding in the field of energy.

The federal states of Baden-Wuerttemberg (26 %), Lower Saxony (15 %), North Rhine--Westphalia (10 %) and Bavaria (8 %) have the biggest shares in the government's project funds for renewable energy in the period regarded. Based on GDP, the majority of funds go to Bremen, followed by Saxony, Baden-Wuerttemberg, Lower Saxony and Berlin, who profit more or less equally from project funds in the field of renewable energy sources with regard to their economic strength. In several federal states like Lower Saxony, Berlin and Bremen, the funding shares for renewable energy sources are much higher than their share in total energy research, i.e. these states are specialized in renewable energy projects.

Looking at how the funds are split between technologies, it is clear that photovoltaics and wind power are the most important with 26 % and 21 %, respectively. Systems engineering projects account for 12 %, and studies and others for almost 6 % of the funds. A total of about 14 % of funds go to basic research. The share of photovoltaics in funding has dropped noticeably during the period observed, while the shares of systems engineering and basic research have increased over the last few years. Photovoltaics (45 %), biomass (29 %) and systems engineering (17 %) have high shares of funding within the basic research on renewable energy sources, while other technologies play no or only a minor role. The structure of the funding for renewable energy sources varies widely by technology between the individual federal states. Photovoltaics, for example, has relatively high shares in the respective funds in Baden-Wuerttemberg, Bavaria, Saxony and Saxony-Anhalt, while Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony and Schleswig-Holstein focus on wind power projects. In Hessen, on the other hand, systems engineering projects dominate. In Berlin, funds for basic research, studies and others predominate.

A distinction is made between power, heat and transport as the applications for renewable energy sources. Power clearly dominates here with 73 % of the funds. In contrast, only 6 % of funds can be clearly allocated to heating, and only 2 % to transport. 3.5 % of funds are for general projects (e.g. comprehensive system studies). In addition, 16 % of funds cannot be clearly assigned to any one field because they can serve several applications (e.g. cogeneration of heat and power). The proportion of power applications has increased slightly over the last few years.

When distributing the project funds available for renewable energy to recipient group, non-university research institutions play the biggest role with a total of around 45 %. Of this, almost half (22 %) goes to the Fraunhofer Gesellschaft. The Helmholtz Association has a share of around 11 %. In comparison, the funds that the Max-Planck Society receives are relatively small at 0.4 %. The German Biomass Research Centre has a share of almost 1 %. 11 % of the funds are allocated to other research institutes. 22 % of funds are assigned to the higher education sector (including universities and academies). Manufacturing companies benefit to a similar extent with 21 %. In the period analysed, the shares of the higher education sector, the Fraunhofer-Gesellschaft and the Helmholtz centres have grown, while the share of other research institutes declined after 2011. The share of industry decreased noticeably between 2008 and 2010; but has increased again among the projects that began in 2013 and 2014.

A clear sectoral profile emerges when examining how the funds are distributed to manufacturing companies. Electrical engineering (with around 52 %) and mechanical engineering (with around 35 %) dominate the funding here. The electrical engineering focus is on photovoltaics, while mechanical engineering concentrates on wind power. Baden-Wuerttemberg, Bavaria and Saxony have the biggest shares in funds for industry. 62 % of the projects are in large enterprises with at least 500 employees and 78 % of the funding for renewable energy is in the manufacturing sector.

All in all, the analyses show clear distributional effects of public expenditure on research and development in the field of renewable energy sources that are linked to federal states, technologies, applications, recipient groups, economic sectors and different sized companies. The annual volume of research funding, however, is relatively low from a macroeconomic viewpoint. In particular, it is noticeably smaller than the levy payment under the German Renewable Energy Sources Act (2015: €21.8 billion). Further, the research funding is not financed by electricity consumers, but by public budgets, or taxpayers. Institutions in research, development and education benefit directly from the research funding as well as parts of industry and some service enterprises. On top of this, however, research funding also contributes to innovations that are able to lower the total costs of sustainable energy supply.

4 Interactions between the expansion of renewable energy sources and electric mobility

There are a large number of technological, economic and instrumental interactions when using renewable energy sources that are relevant for assessing the costs and benefits of expanding renewable energy. As part of the research project ImpRES, we specifically examined the interactions between electric mobility and integrating renewable energy into the power system. Existing approaches to electricity market modelling were further developed and applied to selected future scenarios.

There are interactions especially when charging electric vehicles (grid to vehicle, G2V) and possibly also when feeding stored power in the vehicles' batteries back into the grid (vehicle to grid, V2G). Possible synergy effects in the power sector include lowering the costs of integrating renewable energy sources into the system. This affects both wholesale and balancing power. Optimized charging and discharging of electric vehicles could be used for energy arbitrage on the wholesale market, reduce load changes in the power system (residual load gradients), provide peak power and utilise temporary renewable power surpluses either in the power system or for mobility purposes. In addition, negative and possibly also positive balancing power can be provided. This means other flexibility options could be substituted like grid-connected electricity storage or fossil-fuelled back-up power stations.

Two complementary model types are used to capture these kinds of interactions: a mixed-integer dispatch model and a linear dispatch and investment model. The first model is used to explore the impacts of different charging modes with a given power plant portfolio; the second to examine different G2V and V2G charging strategies, especially with respect to the provision of balancing reserves. This approach is also able to analyse their effects on the composition of the power plant portfolio.

4.1 Impacts of electric mobility on power plant use

An extended model of power plant and storage use is employed to explore the possible influence of future fleets of electric vehicles on power plant dispatch and CO_2 emissions in Germany up to the year 2030. The possibility of feeding power back into the grid is abstracted (only grid to vehicle, no vehicle to grid). Exogenous scenario assumptions are made about thermal generation portfolio and its flexibility restrictions are represented in detail (Schill, Gerbaulet 2015).

Based on this analysis, several conclusions can be drawn that are relevant for policy making. For instance, the annual power demand of a growing electric vehicle fleet is actually quite low in terms of overall energy. If, however, vehicles are charged in an uncontrolled way, this could cause considerable load peaks. From the perspective of system security, therefore, optimised vehicle charging based on electricity system costs (i.e. the wholesale price) is clearly preferable to uncontrolled charging. The possibilities to charge vehicles in an uncontrolled way might have to be restricted by regulatory measures in the future if this problem does not resolve itself by power suppliers passing on the high wholesale prices of uncontrolled vehicle charging to the respective vehicle owners. In addition, the analysis shows that cost-oriented vehicle charging can improve the integration of renewable energy sources into the system. However, under certain circumstances, it also has the potential to substantially increase the capacity utilization of conventional power plants with high specific CO_2 emissions (Figure 6). This applies in particular as long as considerable but increasingly under-utilized capacities of coal-fired power plants are still present in the system within the context of the energy transition.

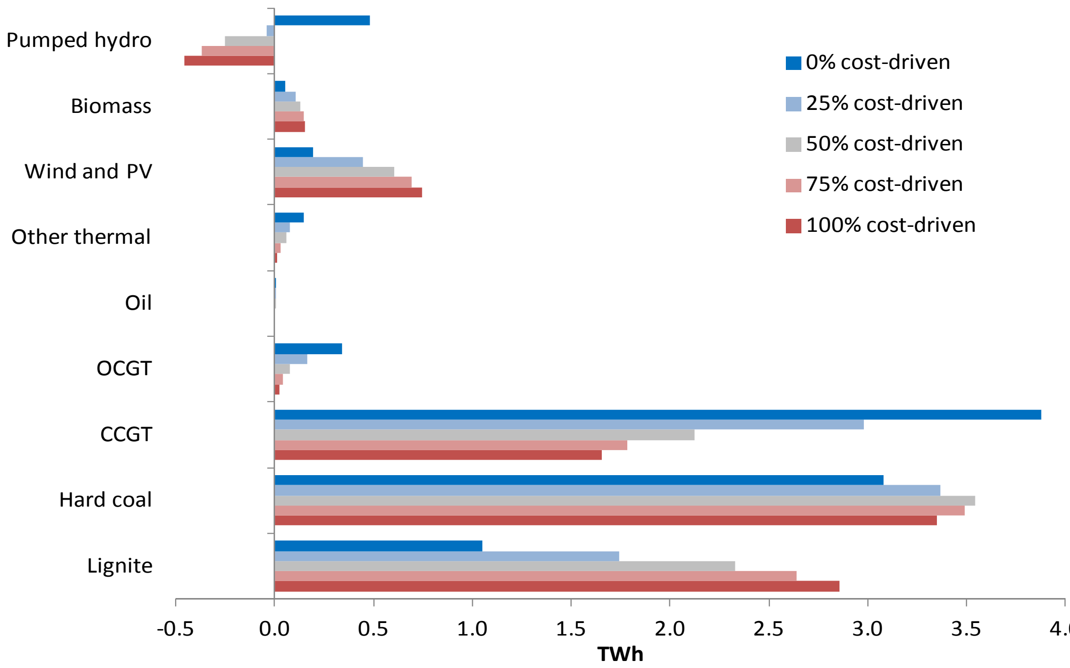


Figure 6: Influence of electric mobility on power plant dispatch compared to a scenario without electric vehicles in 2030 (source: Schill, Gerbaulet 2015)

In energy policy terms, electric mobility is often linked to using renewable energy in the transport sector. However, this requires additional development of renewable power generation plants. This should result in as much additional renewable power being fed into the system as the electric vehicle fleet consumes as an annual average. A direct real-time coupling of renewable power generation and vehicle charging does not seem necessary from a system perspective. In this context, the model analysis also makes it clear that controlled vehicle charging oriented to system costs or market prices can only lead to desirable results with regard to CO_2 emissions if these emissions are adequately priced. Otherwise, the additional flexibility of electric vehicle fleets in the power system could result in a greater use of emissions-intensive (but comparatively cost-efficient) power generation technologies.

4.2 Impacts on the power generation system and the market for balancing power

Complementary analyses are made using a linear dispatch and investment model that can be used to examine not only the influence of electric vehicles on the use of existing power plants, but also their effect on the composition of the entire power plant portfolio. In doing so, not only the wholesale market is analysed, but also the balancing power market. In addition, the option is also taken into account of feeding electricity back into the grid from the vehicles' batteries (Schill et al. 2016). To do this, an existing model – the "Dispatch and Investment Evaluation Tool with Endogenous Renewables" (DIETER) – is extended, calibrated and then applied. The extended version with all the input data is provided as version 1.1.0 under an open-source license on the homepage of the German Institute for Economic Research, DIW Berlin (www.diw.de/dieter). This model is used to explore which role electric vehicles could play in providing balancing power in Germany in future scenarios for the year 2035.

Two different scenarios of the power generation system and different ways of providing balancing power are examined with and without feeding electrical energy back into the grid from the vehicles' batteries. The model calculations show that electric vehicles could make a substantial contribution to providing balancing power cost-efficiently in 2035. This applies even without feeding power back into the grid from the vehicles' batteries, i.e. in a pure G2V mode. The volumes of energy used for balancing power are relatively low compared to the power consumption of the vehicles' drives. The amount of energy vehicles provide for wholesale trade (V2G arbitrage) is more or less negligible under the given baseline assumptions, so that the electric vehicle fleet is not playing a significant role as a bulk power storage option to temporarily shift larger volumes of energy. In this respect, the model calculations confirm other analyses, according to which it is more advantageous to use a flexible electric vehicle fleet in the balancing power market than in the wholesale market.

However, this finding is fundamentally changed if – for example as the result of technologcal progress – no additional battery wear and tear costs are incurred for feeding back power to the grid. In this case, the electric vehicle fleet provides even more balancing power and is also used on a large scale for arbitrage on the wholesale market. Here, it is strongly competing with pumped hydro storage. Future technological advances in reducing cyclic battery ageing and battery cost reductions could thus greatly increase the system benefits of the electric fleet.

The role of electric vehicles in the power system is also bigger if the balancing power and flexibility potential of the vehicle fleet is at least partially considered in the composition of the power plant portfolio. Electric vehicles could then not only influence the use of all other supply- and demand-side capacities, but also affect the reserved capacities of these technologies. Electric vehicles are then in direct competition with other generation and demand-side flexibility options.

Under baseline assumptions, i.e. for a given power generation system and an average estimation of the costs of V2G, the system cost savings of the additional balancing power and arbitrage activities of electric vehicles are low when considered both as a whole and per vehicle (Figure 7). The reason for this is the existence of many other flexibility options in the power system. In particular, there are large capacities available to provide balancing power on the supply and the demand side, so that the value of the additional balancing power provision due to electric vehicles is much lower than in earlier studies based on historical market prices. Creating the relevant business models is probably also a considerable challenge given these conditions. Significantly higher savings are shown in a scenario in which the power generation system is adapted to at least partially take into account the additional flexibility of electric vehicles. In this case, lower capacity reserves have to be provided because the capacity value of electric vehicles is partially reflected in the system as a whole. Even larger effects are shown in sensitivity analyses in which no additional costs are assumed for battery wear and tear for feeding power back into the grid. Then they can be used to a much larger extent for balancing power and arbitrage activities.

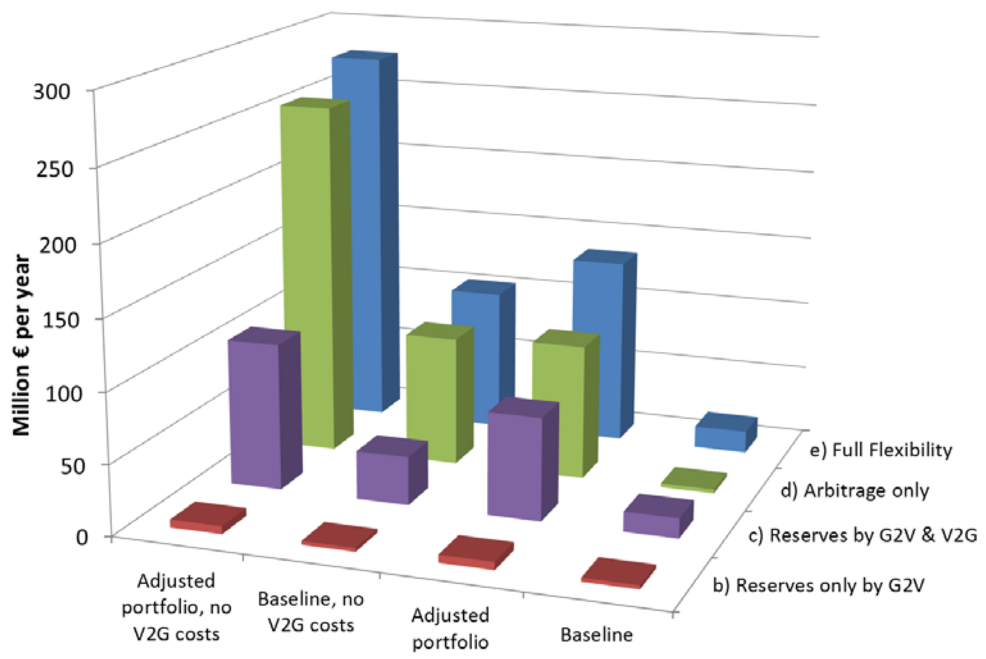


Figure 7: Cost differences in different scenarios compared to respective cases without provision of balancing reserves and vehicle to grid (V2G) in 2035 (source: Schill et al. 2016)

It should be noted that all calculations already assume controlled vehicle charging in the comparative case which presumes the existence of the corresponding infrastructures and organisational arrangements. Accordingly, the *additional* activities on the balancing or wholesale market of an electric vehicle fleet that is already charged in a system-oriented way should not cause excessive additional costs. Important preconditions for this would be adequate prequalification procedures and market entry conditions as well as the acceptance on the part of the respective vehicle owners or users. In principle, to encourage this, vehicle owners could be offered a share of the system cost savings. However, these kinds of financial incentives should not be too high if the cost savings simulated here are interpreted as upper limits.

4.3 Further analyses

Further analyses determine how the size and flexibility characteristics of the electric vehicle fleet influence the capacity requirements of renewable power plants as well as storage and other flexibility options. Once again, we use the dispatch and investment model developed in Schill et al. (2016), but assume different fleet sizes and different shares of renewable energy.

Preliminary results suggest that the value of the additional flexibility the electric fleet contributes to the power system can outweigh the costs of the additionally required deployment of renewable energy sources, at least for smaller fleets and moderate shares of renewable energy. If the electric fleet grows, however, the additional benefit of its flexibility declines noticeably due to simultaneity effects. The robustness of these findings is still being explored in further analyses.

5 Macroeconomic impacts

Macroeconomic effects can be captured using different indicators such as investments, turnover, imports/exports, growth and employment. A distinction is made here between simple indicators related to individual sectors and those that cover the national economy as a whole.

To estimate the macroeconomic importance of a sector like that of renewable energy, reference is made first of all to the investments, turnovers and employment of the respective sector. These are often referred to as gross figures in the literature, for example, gross employment.

If, in addition to this, the intention is to measure the macroeconomic impacts of expanding renewable energy sources, the development of the economy with RE expansion has to be compared to its development with less expansion or with no RE expansion. The differences derived from comparing two developments contain all the macroeconomic adaptation reactions and are therefore referred to as net impacts. To estimate these macroeconomic net effects of RE expansion, alongside statistics and company surveys, macroeconomic models are needed that comprehensively illustrate the many varied economic interrelationships between actors and economic sectors.

5.1 Macroeconomic importance of renewable energy sources

Investments provide an important economic impulse for macroeconomic growth. The investments in installations to use renewable energy in Germany (totalling €14.5 billion in 2015 (BMWi 2016)) encompass all the expenditure to produce the installations, i. e. for manufacturing, constructing and installing the systems. Alongside domestic investments, investments abroad as well as demand from abroad also influence the turnover of German manufacturers. The total turnover of manufacturers of installations and components of RE technologies or RE systems in Germany was around €22.7 billion in 2013 (see ISI, DIW, GWS, IZES 2015). Based on these company turnovers, it is possible to estimate the employment due to the manufacture of systems using renewable energy. This comprises direct employment in the manufacturing companies as well as what is often referred to as indirect employment in companies further up the supply chain. The employment associated with the operation and maintenance of RE installations is calculated in a similar way. It is derived from the operating costs. Direct employees work in the maintenance companies and indirect employment occurs again due to the supply along the value chain. Employment due to public R&D funds and in public administrations is also included in the estimation. Overall, the so called gross employment results from this. This totalled around 355,400 employees in 2014 (BMWi 2015a).

When looking at supply security, but also at the account balance activities of a country, the amount of fossil fuels imported is relevant. As a consequence of expanding the use of renewable energy sources, there is less demand for fossil fuels. However, the amounts of saved energy sources in the power, heat and transport sectors vary by energy sources. Because most of the fossil fuels are imported, their international price co-determines the energy imports in monetary units. The fossil fuel savings in the three sectors of power, heat and transport amounted to around €8.8 billion in 2014. Adjusting the decreased imports to account for the increased biogenic fuel imports yields a net value of reduced fossil fuel imports of around €8.1 billion (2014) (see ISI, DIW, GWS, IZES 2015).

5.2 Macroeconomic effects by region and sector – a model-based analysis

In order to ensure the success of the Energiewende its impact on the national economy as a whole is crucial. On the one hand, this includes the positive effects on value added and employment in the production of installations to generate renewable energy and their operation and upstream stages of value added as described above. However, lost value added and employment in the substituted conventional energy carriers and their respective upstream stages also contribute to the macroeconomic effect, as do the changed energy prices confronting private households, the tertiary sector and industry. Induced effects, for instance an increase in the level of final demand due to additional growth, are an additional component of the net macroeconomic effects.

Whereas the net effects are often shown for individual economic sectors or areas, the distribution of the macroeconomic net effects of the Energiewende on regions and income groups is missing from the existing literature. Within the project ImpRES, the ASTRA model was therefore developed further to quantify the net effect on the national economy as a whole, economic sectors, regions and income groups of the future expansion of renewable energy (Sievers 2016). The results complement the database for the discussion of the distributional effects of the Energiewende; this is highly significant for its acceptance and ultimately its success.

5.2.1 Methodology

ASTRA[4] is a dynamic, macroeconomic simulation model. It depicts the economy as a combination of individual subsystems, based on macroeconomic cycle logic. The implementation into systems dynamics allows the depiction of non-linear effects through the interaction of different feedback loops. The model applied in this study is based on

4 For additional information on ASTRA see http://www.astra-model.eu/

the structure of ASTRA and includes 72 sectors; their interconnections are shown in the input-output module. Consumption, state consumption, investments and exports are dependent on the macroeconomic development and are included as the last use in the input-output module. The sectoral gross value added is calculated there and the employment module is connected by labour productivity. In the model, the supply side is illustrated by aggregated production functions. These are modelled using Cobb-Douglas production functions and largely depend on the factors of labour and capital as well as factor productivity. These three variables are calculated endogenously. The interaction between the supply and demand sides determines the long term macroeconomic development.

Quantifying the macroeconomic net effects in Germany is done by comparing two future scenarios (time horizon 2030) that were prepared within the project "Long-term scenarios" (BMWi 2016b): The reference scenario describes a development in which the Energiewende is no longer promoted after 2010; in the basis scenario (Energiewende-scenario), however, the Energiewende's objectives are met. Enertile[5] was used to model the energy system; this model has a particularly high resolution of renewable energy on a regional level. The model uses the following inputs from the scenarios: (new) installed capacity as well as electricity generation by technology and region (administrative districts), electricity prices, investments in energy-related building renovation or RE heating technologies, heating expenditures according to energy carriers and fuel costs.

The investments in energy-related building renovation are attributed to the building sector and the region where measures are implemented. In a first step, the energy production technologies are broken down into single components. In a second step, it is established which proportion has been imported or whether the impulse can be directly assigned to a region (either the place of energy production or the main producer of the component based on the regional distribution), or whether a direct regional assignment is not possible. In a third step, the investments related to the individual components are assigned to economic sectors. Alongside investments, the operating costs for the individual technologies that differ in amount and sectoral structure and the value added from operating the plants are analysed. Here also the relevant vectors are filed in the model, which are differentiated into regional and supraregional impulses as is the case for investments.

All domestic impulses (regional and supraregional) are included in the macroeconomic core of the model, where the gross value added of the economic sectors is calculated including direct, indirect and induced effects. The relevant value added is derived from

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[5] For additional information on Enertile see http://www.enertile.eu/enertile-en/index.php

the previously allocated regional impulses. The remaining value added is allocated to regions by means of a distribution key. This is based on time series for employment and value added and the resulting labour productivity by region and economic sector. Forecasts of how the regional labour potential is going to develop are also taken into account; that is to say that the differences of the individual regions in terms of economic power and structure and their dynamic development are taken into account. The aggregation of the regional value added serves as the regional GDP. This regional economic approach is therefore a bottom-up, top-down approach: Impulses enter on a regional level and develop a regional impact; supraregional impacts, in turn, are translated into regional impacts.

The distribution of the macroeconomic net impact to income groups (deciles) starts with the change in value added of individual economic sectors. This influences the functional income distribution as the proportion of employees' compensation of the value added varies between the economic sectors. Employees' compensation is used to determine gross wages, while the change in profits is used as an indicator for the change in investment and entrepreneurial income. As the distribution of wages among income groups is different to investment and entrepreneurial income, the functional income distribution has an effect on personal income distribution. Owning a PV installation or participating in a fund, energy cooperative or something similar is no longer analyzed separately; the respective profits are already included in the value added. For the distribution to the deciles, it is assumed that these correspond to the general distribution of investment and entrepreneurial income. Here, the national accounts form the data basis for modelling as well as a special analysis of the Income and Consumption Survey. The expenditures for energy (power, heat, fuel) come directly from the scenarios and are distributed to the deciles based on the data of the Income and Consumption Survey. In this way, the share of energy expenditure on consumption and the net income per decile can be determined, which is a common indicator in the literature to assess energy poverty.

5.2.2 Results

The Energiewende scenario features a slightly higher gross domestic product of 0.5% in 2020 and 0.7% in 2030 compared to the reference scenario. Total employment is also higher by about 0.4% in 2020 and 0.3% in 2030.

The main drivers behind this economic growth are additional investments that are primarily due to measures in buildings and only to a lesser extent due to additional investments in power generation technologies. The latter stimulate demand especially for capital goods from the manufacturing industry, but trade/transport and consulting services are also given a significant boost. The overall investment stimulus is enhanced by multiplicator and accelerator effects.[6]

Effects by economic sectors

Figure 8 illustrates the relative change to the gross value added for groups of economic sectors. The biggest relative (and also absolute) value added growth is in construction (F). The additional investments in buildings (which can be explained mainly by increased efficiency measures) therefore not only dominate the investment stimulus, but also the results. The equally large relative change to value added in real estate (L) can be explained by the fact that 11 percent of the additional building investments in renovations can be passed on and added to the rent so the actual and (for homeowners) hypothetical rents increase accordingly. In the energy supply sector (D) itself, the value added also increases significantly due to the system transition. Due to the decreased demand for fossil energy sources, especially coal, there are large negative effects for mining and quarrying (B). A clear relative decrease is also visible in the arts, entertainment and recreation, other service providers, and private households with domestic staff (R-T). This can be explained by the reduction of household budgets due to higher energy expenditures and higher rents, which has an especially strong curtailing effect on demand in this sector. In analogy to this, the catering trade also experiences a corresponding decrease in demand so that, in spite of positive investment impulses in trade/transport, the overall effect on the group of trade, transport, catering (G-I) is neutral. A similar effect can be observed in manufacturing (C), in spite of a significantly positive investment impulse, the total effect across all areas in 2030 is slightly negative. Individual sectors (e.g. manufacture of electrical equipment, manufacture of machinery and equipment) do profit from additional investments or from the operation of the systems. However, overall, these positive effects are lower than the decrease in value added in other sectors (e.g. manufacture of chemical products, manufacture of wood, paper and print products) because of higher energy prices and altered consumption patterns.

The employment effects are spread across the groups of economic sectors following a similar pattern to the changes in value added. Real estate should be mentioned separately here; the increased rents do raise the value added, but do not lead to additional employment.

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6 Multiplicator effect: public payment or spending (transfers, purchases) increase national income, which in turn induces further demand. Accelerator effects: increased investments of companies because of growing deman which has been triggerd by additional public spending.

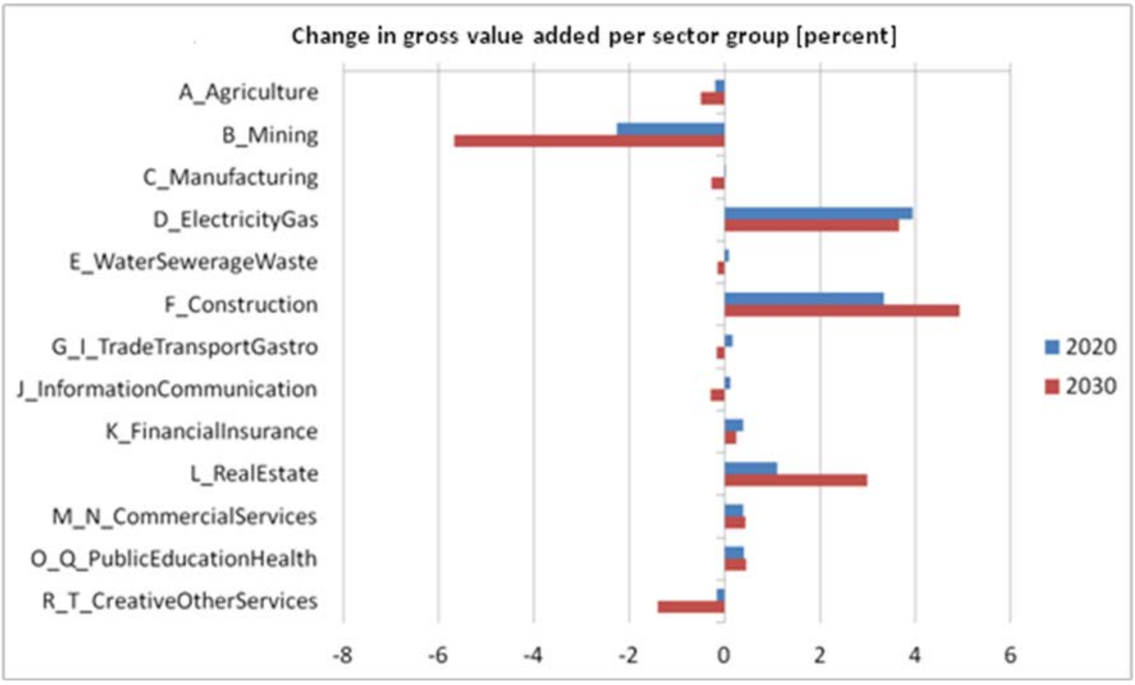

Figure 8: Relative change in gross value added between the Energiewende scenario and the reference scenario in percent for groups of economic sectors

Regional effects

The gross value added in the Energiewende scenario is higher than in the reference scenario in total and for the majority of federal states and therefore mirrors the increase of the German gross domestic product. The regional differences are illustrated in Figure 9 (left).

It is immediately obvious that Mecklenburg-Western Pomerania experiences an enormously high relative increase in value added in 2030. This is partly due to how the relative figures are displayed; the value added in the reference case in 2030 is much lower in Mecklenburg-Western Pomerania than in other federal states. However, on top of this, the absolute change is also clearly positive and similar to other federal states that have much greater economic power. There is a significant expansion of renewable energy in Mecklenburg-Western Pomerania between 2020 and 2030 which is associated with additional investments and value added from servicing and operating the installations. At the same time, there is hardly any electricity production from fossil energy sources in Mecklenburg that could be displaced so that the net effect here is clearly positive. Mecklenburg-Western Pomerania is also less strongly affected by higher electricity prices. The investment stimulus in construction due to efficiency measures has hardly any impact in this federal state.

Negative net effects on growth (value added) in 2030 are visible in Brandenburg and the Saarland as well as in Baden-Württemberg and Hesse. This is especially due to the loss of conventional energy production in these states that cannot be compensated by the positive investment stimulus in construction or by the expansion of renewable energy sources in these regions. Given its economic structure, Baden-Württemberg is especially badly affected by the negative impacts of higher electricity prices.

The relative change in employment in the regions is illustrated on the right-hand side of Figure 9. This depends on where, in which sectors, increases or decreases in value added take place and how labour-intensive these sectors are in the respective region. For many regions, the employment effects are of a similar magnitude to the value added effects, but it is also certainly possible that the net effect on the value added of a region is negative, while the net effect on employment is positive. This is the case, for example, in Brandenburg, where negative effects occur in the less labour-intensive energy sector and positive effects in labour-intensive construction. The negative effects dominate with regard to value added, the positive effects with regard to employment.

However, it should be noted that in this case domestic work forces might be replaced by labourers coming from other EU countries. Then, part of the income in the construction sector might be transferred to other EU countries (not Germany).

Energy efficiency measures in buildings increase additional rents and trigger an increase in the value added in real estate, but not employment. In sum, slightly negative employment effects can occur in regions whose increases in value added are based on a high share of value added in real estate. This is the case, for example, in Bavaria and Rhineland-Palatinate.

Comparing the changed regional value added with the current regional value added per capita clearly shows that (with the exception of Brandenburg), especially the less productive northern and eastern German federal states stand to gain, while the more productive western and especially the southern federal states experience hardly any growth, but partially even a slight decrease in value added. Under the given model and scenario assumptions, therefore, the Energiewende could also actually contribute to the cohesion of German regions. But it should be noted that this contribution is very small when viewed in the context of regional differences which will become even larger by 2030 (compared to 2012) according to the model results. Thus, the Energiewende could counteract this development.

To a large extent, the indirect and induced effects are calculated nationally in the model and then distributed based on the economic structures of the respective regions so that regions with high value added are more strongly affected. If it is assumed that the value added increase, e.g. in Mecklenburg-Western Pomerania results in additional demand for products from Mecklenburg-Western Pomerania, the equalizing effect could be stronger. However, it should also be noted that value added in a region does not necessarily mean income in the same region, because the distribution of profits depends, e.g. less on the location of the operating company and more on the hometown of the relevant shareholders. Regionally provided labour services do not necessarily increase demand because the earned income can also be transferred to and spent in other regions.

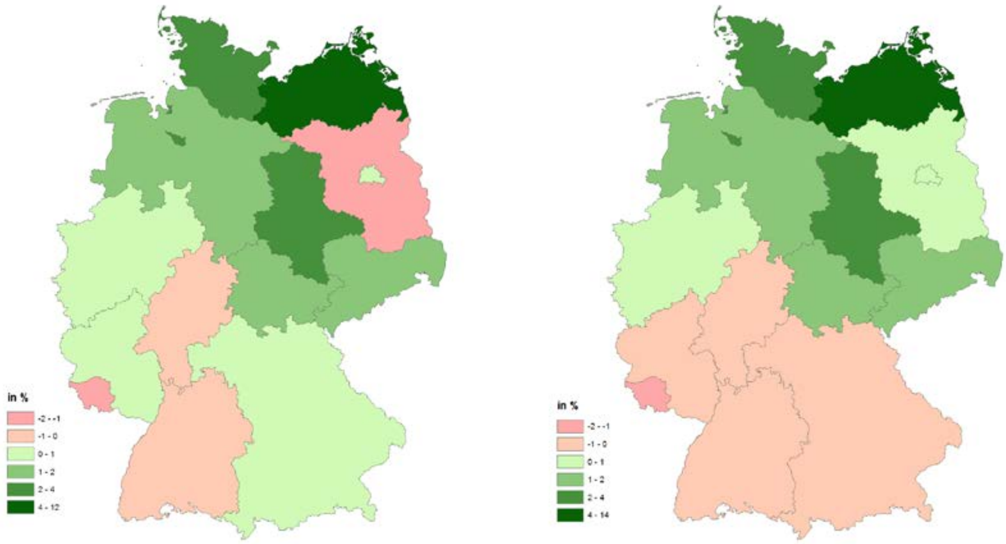

Figure 9: Relative change in gross value added (left) and employment (right) in the Energiewende 2030 scenario compared to the reference scenario 2030 in percent

Effects on income groups

The functional income distribution hardly deviates at all from the reference case and from the starting value in 2012. It is about 30% income from capital (e.g. company profits) and 70% income from human capital (e.g. wages) in every case; the share of income from human capital is about 0.2 percentage points higher in the Energiewende scenario.

With regard to the effect on personal income distribution, the top and middle income deciles show a higher growth which means that income distribution overall becomes more unequal. However, these results are based on the assumption that the sources of income and taxation are distributed in the same way as they were when the Income and Consumption Survey was conducted in 2008. By comparing the monthly real net income by deciles for the year 2012 and for the reference and Energiewende scenarios in 2030, it becomes apparent that the change up to 2030 is much greater than the change between the two scenarios.

Spending of households on energy increases by 9% in total between 2012 and 2030 in the Energiewende-scenario. The financial burden is heavier for the lower deciles measured as the share of energy expenditure in net income. The effect described above comes on top of this: That the higher income groups profit from higher income in the Energiewende scenario, but the lowest deciles do not. The overlap of these two effects is illustrated in Figure 10. The Energiewende therefore has a doubly regressive impact. This does not yet consider that the lower income groups also have fewer possibilities to react and adapt to increased electricity prices, because they are forced to remain in the expensive basic tariff, or because they do not have the money to purchase energy-efficient appliances. Relevant adaptation measures could be applied here (see Diekmann et al. 2015).

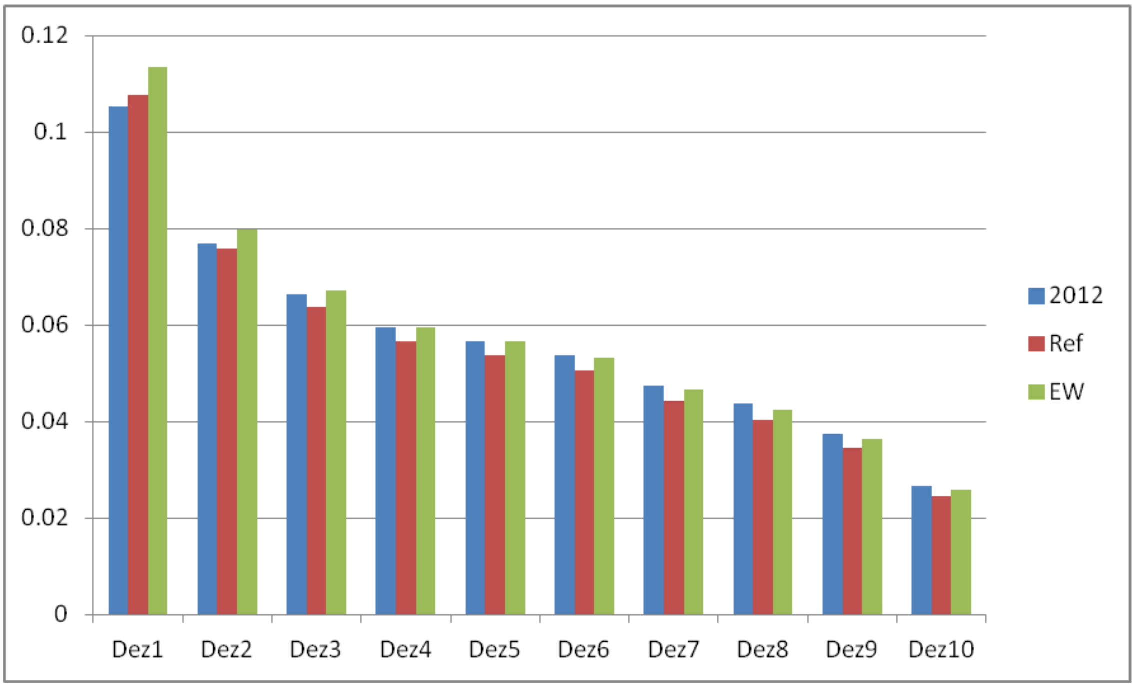

Figure 10: Share of energy expenditure (electricity and heat) in net income per decile (dimensionless) in 2012, in reference scenario 2030 and Energiewende-scenario 2030

6 Conclusions

Expanding the deployment of renewable energy sources is one main pillar of the Energiewende in Germany. This is already quite advanced in Germany, especially in the power sector, with a renewable share of 31.6 % in gross electricity consumption in 2015 (BMWi 2016). However, the shares of renewables still have to be substantially increased in the power, heat and transport sectors in the future.

The use of renewable energy sources is currently still linked to high costs. In 2016, electricity consumers have to pay a surcharge for the EEG promotion of renewable power of €22.9 billion (ÜNB 2015). The sum of this surcharge not only depends on the amount of premiums or reimbursement paid for the installed renewable energy generation, but mainly on the respective wholesale price of electricity. This is influenced by the prices for fossil fuels, among other things, but also strongly by the expansion of renewable energy sources. A growing share of renewables leads to falling electricity prices on the power exchange (merit order effect). The lower these prices are, the higher the EEG surcharge. Depending on how much of these electricity price decreases are passed on to final consumer, some of the burden on consumers due to the EEG surcharge could be compensated. A few large energy intensive producers in industry, which pay electricity prices based on the power exchange price and which are favoured by the exemptions scheme of the EEG, might even enjoy a lower electricity price with renewables than without them.

Energy consumers such as households or firms are paying for the Energiewende not only in the power sector, but also in the transport and heating sectors. The increasing financial burden and above all how it is distributed across economic sectors, households, social groups and regions is very important for the acceptance of the Energiewende. This is why, alongside the positive effects of expanding renewable energy, the question of how to distribute its cost burden is so significant.

Significant impacts of expanding renewable energy sources include lower air pollutants, fewer greenhouse gas emissions and reduced imports of fossil fuels, as well as the associated greater energy security due to greater diversification of energy carriers and supply sources. Overall, the impacts of renewable on the environment and the climate are positive, even though there are potential conflicts with nature and landscape conservation. However, individuals, private households for example, evaluate the benefits of these positive effects very differently, so that they may not be able to compensate the financial burdens at microeconomic level. A further positive effect of renewable use are dereasing technology costs.

The distributional effects of expanding renewable energy, or rather impacts of the Energiewende in a broad sense, are ultimately changes in the microeconomic costs and benefits of producers and consumers in the power, heat and transport sectors that are determined by politically established transfer or market mechanisms. These changes can include higher or lower expenditures or incomes, e. g. due to higher electricity prices or investments in installations to use renewable energy or investments into energy efficiency, which can vary for those affected in absolute or relative terms (measured against income).

The additional costs incurred by businesses and private households in 2014 for using renewable energy sources were around €2 billion (2014) in heating, almost €19 billion (2014) in the power sector and almost €1 billion (2014) in transport. In heating, these costs are borne mainly by private households. In the power sector, the cost burden is redistributed from electricity-intensive industries to non-privileged enterprises and private households. Like, e. g. electricity taxes, surcharges also have a regressive effect, i. e. they are a greater relative burden for low-income households based on their income. Electricity expenditures of households as a share of income ranges in the two lowest income decile at around 4.6 %, while the two highest deciles have a share of about 1.5% in average (Lehr, Drosdowski 2015). For heat and electricity, the expenditure share is between 3 and 4% for the highest decile, while the lowest decile faces about 11% (Sievers, Pfaff 2016).

The future deployment of installations to use renewable energy should be done as cost efficiently as possible. A large proportion of the surcharge is already predetermined for existing installations over the next few years due to historical obligations and only depends on the development of the electricity prices. The possibilities of easing the financial burden on consumers through more efficient support are restricted by the fact that this will reduce the costs for new installations, but not those for existing installations.

Different suggestions have been discussed in the literature for how to reduce the distributional effects of the EEG surcharge. It has become clear, however, that there is no single ideal solution. It should be noted that the average burden on private households due to the EEG surcharge is relatively low with a share of 0.6 % in total consumer spending. So there is no significant distribution problem for households with average income. For households at risk of poverty, in contrast, the increased electricity prices can lead to major burdens if they are not offset by continuously adapting the social benefits. Despite this, the surcharge scheme, which passes the costs of financing the EEG on to electricity consumption in keeping with the polluter-pays principle, should not be replaced by general tax funding. Nor do fund models promise a convincing solution. Apart from general efforts to keep the total additional costs low, the special rules applying to electricity-intensive enterprises should continue to be critically reviewed in order to limit the overall burden on non-privileged electricity consumers. In addition, particular attention should be paid to the financial burden on low-income households when discussing distributional effects. Social policy must ensure that the social benefits still meet the current requirements. As an accompanying supporting measure, energy policy could specifically target energy efficiency in low-income households.

Looking at electricity generation, significant profits were made by installation operators, in particular, in the years 2011 and 2012 in which the feed-in reimbursement was adapted too slowly to technology cost developments. These profits mainly occurred at photovoltaic installations. In the following years the feed-in tariff has been adjusted. The regional distribution of the installed systems does not necessarily reflect the regional distribution of the profits, as the location of generation and investors may not be identical. It is not expected that changes in distribution of capital income will result due to the market support because, without the support, investors would have invested in alternatives with slightly lower profits or higher risks instead of investing in photovoltaics and wind power. Given the adjusted design of the feed-in scheme that can promptly react to the cost development of technologies, it is expected – if there is a sufficiently strong competition – that the probatility of receiving high profits has been signficantly reduced. With regard to tenders the auction result for ground-mounted PV installations with a value of 7.4 cent/kWh in April 2016 (Bundesnetzagentur 2016) shows a significant price effect. In Germany no experience has been acquired regarding auctions with other types of renewable.

Coupling the power sector and e-mobility in the future could decrease the costs of integrating renewable energy into the system. Model analyses show that the annual energy demand of a growing electric vehicle fleet is low, but that uncontrolled vehicle charging can still result in substantial load peaks. From the viewpoint of system security, therefore, there is a clear preference for charging vehicles oriented on electricity system costs (i. e. wholesale price) rather than uncontrolled charging. In addition, cost-oriented charging can improve the integration of renewable energy into the system. However, under certain circumstances, it can also increase the capacity utilization of conventional power stations with high specific CO_2 emissions if the introduction of electric mobility is not accompanied by additional deployment of renewable generation capacity.

Moreover, electric vehicles can contribute on a large scale to supplying balancing power cost-efficiently in the future. However, any significant feed back of power from the vehicles to the wholesale market, i. e. using the vehicle fleet as a distributed electricity storage to temporarily shift larger amounts of energy, will only occur if no additional battery costs incurr for the wear and tear associated with feeding power back into the grid. In this case, electric vehicles compete strongly with pumped hydro storage. Future technological advances and cost reductions in batteries could thus greatly increase the systems benefits of the electric fleet. The role of electric vehicles in the electricity system is also bigger if the balancing power and flexibility potential of the fleet is reflected in the composition of the power plant portfolio. However, the systems cost savings that can be assigned to individual electric vehicles are relatively small and this means it will probably be difficult to create meaningful business models here.

The demands on the distribution and transmission networks increase with increasing electricity generation from renewable energy sources. Due to the network's long operating life and the possibility to avoid replacement investments in the grid, only moderate increases in grid costs and the associated network charges result in the future that can amount to an additional €3 – 4 billion/a up to 2022. These costs are passed on to consumers, whereas expanding the transmission network is usually financed by the users of the respective transmission networks. Certain costs are already passed on to all the transmission network operators, including the costs for offshore grid connections. At the distribution grid level, the costs are split among the users of the respective network and are not passed on supraregionally or even nationwide. The benefits resulting from the deployment of renewable energy, e.g. avoided emissions, secure energy supply, mostly have a supraregional effect, however, so that it makes sense to pass on more of the costs of the distribution networks to reduce regionally unequal monetary burdens resulting from the deployment of renewable energy.

As an energy consumer, to a small extent, the state is also directly affected by surcharges and investments in installations to use renewable energy. The spending on market support is more significant, however, especially in the heating sector. This was €0.3 billion in 2014 plus public research expenditure on renewable energy of around €0.3 billion, most of which goes to research institutions. On the other hand, the state also collects additional tax revenues in connection with the expansion of renewable energy sources, through the sales tax on the EEG surcharge among other things (€1.5 billion in 2014) and the energy tax on a higher volume-based consumption of biofuels (€0.6 billion in 2012).

Some of the impacts of expanding renewable energy sources are spread over several generations. For instance, the contribution that research and market support make to lowering the costs of technology will mainly benefit future generations, while today's generation bears the costs of development, e.g. in the form of surcharges. The final distributional effects on a microeconomic level – additional burdens as well as benefits – are therefore very difficult to capture because of these different evaluations.

Macroeconomic impacts are very important when evaluating the Energiewende in societal terms. These can be determined with the aid of macroeconomic models – partly by region or sector. The model analyses conducted show positive – albeit moderate - overall net impacts of the Energiewende on growth and employment. The gross domestic product is about 0.7% higher in the Energiewende scenario than in the reference scenario in 2030. This implies marginally higher annual economic growth. At the same time, the Energiewende is connected to structural changes that result in varying regional, sectoral and social effects.

Energy efficiency measures and expanding renewable energy sources in buildings clearly dominate the results and raise the level of demand. In comparison to this, the expansion of renewable power generation based on the “Long-term scenarios” study by the BMWi (2016a) results in a weaker change in the level of demand, but still changes to the demand structure due to the substitution of conventional electricity generation technologies. The biggest relative increases in value added are in the building sector and real estate. The decline in demand, especially for cultural and leisure-related services, is mainly due to higher rental expenses. The biggest decrease is in mining and is a result of the reduced demand for fossil fuels. The sectoral distribution of the changed demand for labour basically follows the same pattern as for value added. However, it should be noted that the labour intensities in the sectors vary.

The model results suggest that especially northern and eastern German federal states will draw economic benefits from the Energiewende in the future because they offer attractive locations for investments in renewable energy according to the BMWi‘s study “Long-term scenarios” (2016a). At the same time, they are less affected by impacts reducing the value added for conventional energy generation. Rising electricity prices have less impact here than in the other federal states because of the lower electricity intensity of production. The Energiewende therefore represents an opportunity for regions that are economically underdeveloped at present. However, the model does assume that a high share of the value added from renewable energy sources in the region remains with energy generation. This would have to be supported by suitable incentives.

The macroeconomic analysis shows that the Energiewende has a double regressive impact. On the one hand, higher income groups profit more from the growth in income; on the other hand, low income groups are affected more strongly by high energy expenditure. All the income groups spend a higher share of their income on energy in the Energiewende scenario than in the reference scenario because the energy price increase offsets any growth in income. But this effect is much more marked in the lower income deciles than in the upper ones. The share of energy expenditure in the Energiewende scenario is only higher in 2030 than in 2012 for the three lowest income deciles. The share of total income spent on energy is especially high in the lowest decile at around 11 %. It seems sensible to apply measures able to cushion the regressive impact here without losing the incentives for energy saving.

The studies show different approaches and results at macro and microeconomic levels concerning the costs and benefits of expanding renewable energy sources. From a policy viewpoint, mechanisms that avoid inequality when distributing additional burdens or couple these burdens with benefits are particularly important. Effects on value added and employment that vary regionally are non-critical as long as they do not further enhance already existing regional inequalities. The effects on individual industries of expanding renewable energy sources vary in strength. The associated structural change can be accomplished, however, without disturbing the macroeconomic balance.

From a scientific point of view, there continues to be a need for a differentiated examination of the macroeconomic and microeconomic impacts of expanding renewable energy sources - or rather transforming the energy industry. In particular, the theoretical and methodological approaches to identify and assess the distributional impacts have to be further developed. At the same time, further research is needed to improve the methodological basis concerning questions of technology cost development and supply security.

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