The macroeconomic benefits of ambitious energy efficiency policy – a case study for Germany

Sibylle Braungardt
Fraunhofer Institute for Systems and Innovation Research
Breslauer Str. 48
76139 Karlsruhe
Sibylle.Braungardt@isi.fraunhofer.de
Germany

Johannes Hartwig
Fraunhofer Institute for Systems and Innovation Research
Breslauer Str. 48
76139 Karlsruhe
Johannes.Hartwig@isi.fraunhofer.de
Germany

Wolfgang Schade
Fraunhofer Institute for Systems and Innovation Research
Breslauer Str. 48
76139 Karlsruhe
Wolfgang.Schade@isi.fraunhofer.de
Germany

Judit Kockat
Fraunhofer Institute for Systems and Innovation Research
Breslauer Str. 48
76139 Karlsruhe
Judit.Kockat@isi.fraunhofer.de
Germany

Keywords

economic impact, benefits, scenario study

Abstract

Energy efficiency has been recognized as one of the fastest and cheapest contributions to a sustainable, secure and affordable energy system. The multiple benefits of energy efficiency strategies are receiving increasing consideration both from policy makers and the scientific community. Among the various benefits of energy efficiency initiatives, the macroeconomic benefits such as direct, indirect and induced economic effects play an important role. In order to pave the way for a large-scale deployment of energy efficiency strategies, it is essential to understand, quantify and communicate the macroeconomic effects. Our study presents a detailed analysis of the long-term macroeconomic benefits of German energy efficiency policy including the industry and service sectors as well as residential energy demand. We quantify the macroeconomic effects of a scenario with ambitious energy efficiency policy as compared to a reference scenario by combining bottom-up projections of energy efficiency policy implementation with an extended dynamic input-output analysis. This allows us to study sectoral shifts within the economy regarding value added and employment compared to the baseline scenario. We provide an in-depth analysis of the effects of energy efficiency policy on consumers, individual industry sectors, and the economy as a whole and account for technological change both regarding its impact on energy demand as well as its macroeconomic effects. Our study finds significant positive macroeconomic effects resulting from energy efficiency initiatives and is expected to provide further impulses towards ambitious energy efficiency policy. Our methodological approach can be extended to other countries and regions and provides a comprehensive framework to the analysis of the macroeconomic benefits of energy efficiency.

Introduction

Energy efficiency policy is one of the main pillars for climate change mitigation. The International Energy Agency has highlighted energy efficiency as "the first fuel" (IEA, 2014), meaning that energy savings can contribute to climate change more than any other energy technology.

In order to achieve climate targets, significant energy efficiency improvements are required in all energy-consuming sectors including industry, transport and the residential sector. Measures to increase energy efficiency include the accelerated adoption of energy efficient technologies, large-scale building retrofits and the optimization of industrial production processes.

Ambitious energy efficiency policy measures have a strong impact on the economy on micro-, meso and the macro level. On the micro level, consumers and firms are required to increase energy efficiency investments and as a result show changed (energy) consumption patterns. On a meso-level, the sectoral interactions change as new technologies and organizational structures replace old ones. Lastly on the macro level, the structural changes have a considerable impact on economic performance.

Estimating the macroeconomic effects of energy efficiency policy requires a detailed understanding of how the policy measures act on micro- and meso level. For example, in order to investigate the macroeconomic effects of a given set of energy efficiency policy measures, the micro-level (decision-making) perspective provides information on the investor (consumer or business) and the technologies that are chosen. On a meso- or sectoral level, energy efficiency measures can induce technology shifts, leading to different sectoral interaction which in turn have effects at the macro-level.

Our methodological approach applies a coupling of bottom-up energy demand models with a macroeconomic system dynamics model, using a dynamic input-output structure and thus combines technology-based engineering knowledge in the relevant energy-using sectors with a macroeconomic perspective. Our study therefore addresses one of the shortcomings of macroeconomic modelling, which generally represents sector details, but does not support technology details (IEA, 2014).

This paper presents a case study for Germany, where an ambitious energy efficiency scenario is compared to a reference scenario with respect to the results on energy savings, sectoral shifts and macroeconomic impacts. The effects of the policy scenarios are analysed by connecting the energy demand models FORECAST and INVEST-EE with the macroeconomic model ASTRA-D.

Macroeconomic impacts of energy efficiency policy

The macroeconomic impacts of energy efficiency policy have received increasing interest from policy makers, consumers and the scientific community in recent years. Especially in times of economic recessions, it is essential to assess the effects of energy efficiency policy on economic output, employment as well impacts on the sector level.

The main drivers determining the macroeconomic effects of energy efficiency measures are on the one hand the reduction of energy cost and on the other hand investments in energy efficiency technologies and services (see Figure 1). Table 1 highlights the differences of the effects from investments and energy cost reduction for final consumers and energy-using producers.

There are a number of different approaches to assess the macroeconomic impact of policy measures, and the results and conclusions may depend on the approach that is applied and its underlying assumptions. A well-known demonstration of the fact that applying different macroeconomic models leads to contrasting results was provided in the Impact Assessment of the Commission (European Commission, 2014), where one model predicted a significant positive impact on GPD growth, whereas the other model predicted a negative impact.

The differing results can at least partly be explained by the differing general assumptions underlying the modelling approaches. One type of model that is applied widely is the Computable General Equilibrium (CGE) model, which is characterized by the neoclassical concepts of optimisation and rationality (Perman et al., 2003). It has been observed that such models have shortcomings in modelling true dynamic, transitional paths of economic policies (Scrieciu, 2007). For example, incorporating learning curves is a major challenge in CGE models (Köhler, 2011). Structural change is an unresolved problem in economic analysis.

For evaluating sectoral impacts, the methodological framework of Input-Output-(IO) Analysis methods has been almost exclusively used (Miller and Blair, 2009). Static IO models are the most basic ones, but there are possibilities to render them dynamic by updating the Final Demand matrix (Richter, 1991), which is the second quadrant of an IO table. Despite the need for delivering reliable analyses of the impacts of major policy changes there is no methodology that can be universally employed (Scrieciu, 2007). This is especially true for medium- to long-term impact assessment, which static IO models are clearly less suited for (Common and Stagl, 2012), since the technical coefficients used for calculating the indirect (and sometimes induced effects) of policy changes can differ quite substantially for longer time horizons (Pietroforte and Gregori, 2003).

This study applies the model ASTRA-D, a dynamic input output-based macroeconomic model which allows for explicit imbalances of the supply and the demand side (Schade, 2004) and, since the implementation is done with System Dynamics, also for delays, feedback effects and nonlinearities (Sterman, 2000), enabling a broader spectrum of policy impact reactions than econometrics (Sommer, 1981). However, CGE models may have a comparative advantage in the analysis of monetary flows, since they incorporate Social Accounting Matrices (Rose, 1995), but it should be noted that the calibration is performed using one base year (Scrieciu, 2007) and that the Federal Statistical Office in Germany has only once published such matrices in 2000. ASTRA-D, on the other hand, has a calibration procedure which extends over several years (Schade, 2004).

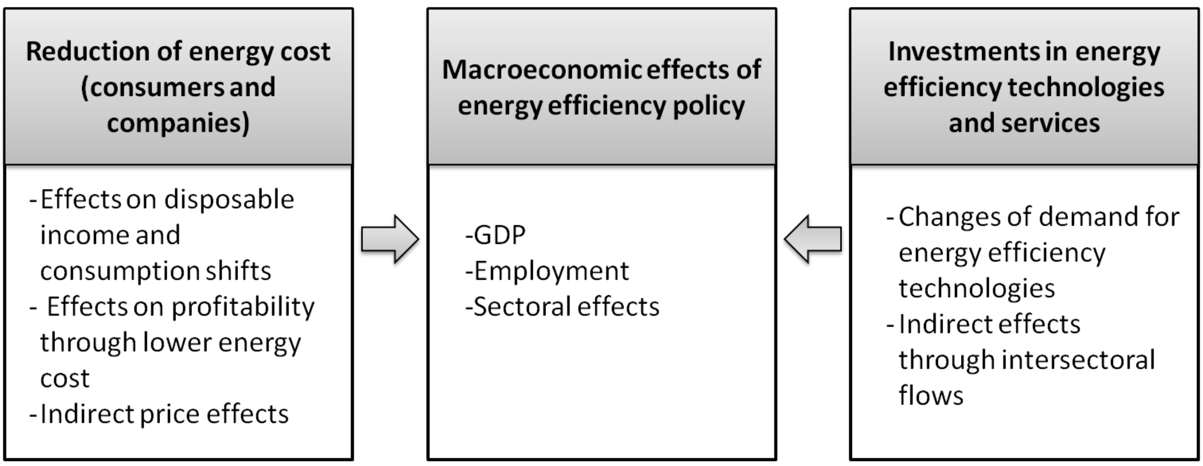

Figure 1. Direct and indirect economical effects of energy efficiency policy.

Table 1. Effects resulting from investments and energy cost reductions for consumers and producers.

	Consumers	Producers
Effects resulting from investments	Energy efficiency investments increase demand in sectors providing energy efficiency technologies and services leading to increased production and employment in these sectors. At the same time, investments may reduce the disposable income and thus the consumption in economic sectors not related to energy efficiency.	Investments imply a rise in demand for energy efficiency goods or services. At the same time, for the sector undertaking the investment, the ability for investing in other sectors may be reduced. Second-round effects include increased employment in sectors delivering energy efficiency-related goods and services.
Effects resulting from energy cost reductions	Energy savings reduce spending on energy and increase the disposable income and presumably the consumption in other sectors. The increased consumption induces increases economic activity in these sectors.	Energy cost reductions lead to higher profits that can be reinvested in the business or passed through as lower prices for goods and services to consumers, potentially driving consumption and GDP growth.

Scenario definition

Our study investigates the macroeconomic effects of ambitious energy efficiency policy in Germany until 2050 in comparison to a reference scenario (RS) projecting the current policy framework considering energy demand of industry, the service sector, buildings and residential appliances. The energy efficiency scenario (EES) considered here is based on the targets of the German energy concept and compares it to a reference scenario including all energy efficiency measures in place until 2012. A detailed description of the scenario assumptions as well as the measures included can be found in (BMUB, 2013), where the socioeconomic drivers and price projections have been updated for the current study.

The German energy concept was adopted by the Federal Government in September 2010 setting out Germany's energy policy until 2050 and specifically laying down measures for the development of renewable energy sources, power grids and energy efficiency (BMWi/BMU, 2010). The rather ambitious energy efficiency targets included in the energy concept were confirmed by the "Energiewende" decisions from 2011 and additional policy measures were announced in order to accelerate the transformation of the energy system (Schlomann & Eichhammer, 2012). At the level of the whole economy, the targets specify a reduction of primary energy consumption by 20 % until 2020 and by 50 % until 2050, both compared to 2008. Electricity consumption targets are set to a reduction of 10 % until 2020 and by 25 % until 2050, again compared with 2008. In addition, the following sectoral energy efficiency targets have been set in the Energy Concept: for buildings a doubling of the refurbishment rate from about 1 % to 2 % and a reduction of the heating requirements by 20 % until 2020 and by 2050 a reduction of the primary energy demand by 80 %, for transport a reduction in final consumption by about 10 % by 2020 and 40 % by 2050, in this case compared to 2005.

The policy scenario used in this study is a normative scenario that indicates the efforts that are required by each of the energy end-use sectors in order to meet the targets set in the energy concept. Both for buildings and industrial and service sector consumption, ambitious energy efficiency measures are required to meet the targets. For buildings, the main contributions are achieved by increasing the thermal retrofit rate, by enhancing the quality of thermal retrofits, and by replacing inefficient heating systems. The main policy measures that drive energy efficiency in buildings are energy codes (EnEV) and the subsidy schemes provided by the KfW bank. For industry, the main contributions result from increasing energy efficiency in processes and products driven by minimum energy efficiency standards specified in the ecodesign directive, fostering the diffusion of energy management systems, the EU emission trading scheme, information based policies and energy taxes.

Methodological approach

The direct and indirect effects are analysed in this study using a three-step methodology (see Figure 2). In the first step, the cost reductions resulting from and investments leading to energy savings are calculated using a detailed bottom up modelling approach. In a second step, the investments and savings are allocated to the affected economic sectors. In a third step, the macroeconomic impacts are calculated using the dynamic input-output based macroeconomic model ASTRA-D. The methodological approach that is applied in each of the three steps is outlined in the following subsections.

STEP 1: BOTTOM-UP ENERGY DEMAND PROJECTIONS

The energy demand projections are provided using bottom-up simulation models that capture the diffusion of energy efficiency technologies including assumptions about barriers and heterogeneous expectations among decision makers (households or companies). The energy demand modelling platform FORECAST[1] is used for projecting the energy demand of industry, the service sector and residential appliances. The modelling platform INVERT-EE[2] is used for projecting the energy demand for buildings. The modelling approaches for the energy efficiency scenario includes a mix of policy measures to support an accelerated diffusion of energy efficiency technologies, including minimum efficiency requirements and standardization, taxes, subsidies and a range of information-based measures.

1. www.forecast-model.eu
2. www.invert.at

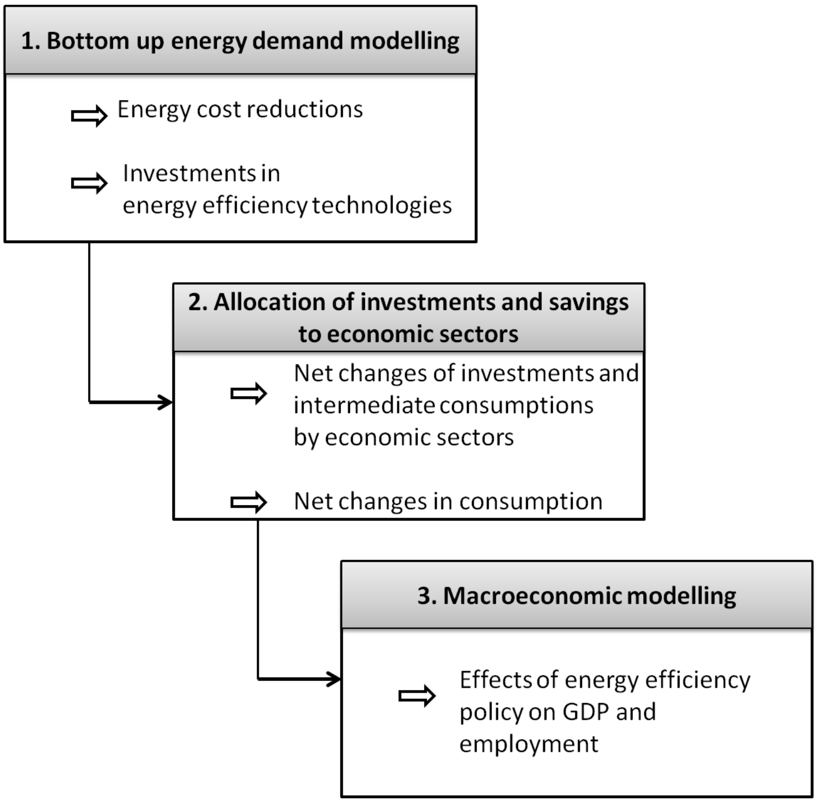

Figure 2. Methodological approach.

The most relevant results that are transferred to the following steps are the energy cost reductions as well as the investments. The energy savings are provided for households and for individual industry sectors and processes, which in the next step are transformed to inputs for the macroeconomic calculations. Rebound effects are estimated and are taken into account in the bottom-up energy demand models. The investments are distinguished between investments undertaken by private households and industry sectors and the energy efficiency technologies and services involved. Figure 3 shows the projected additional energy savings resulting from energy efficiency investments in industry, the service sector, buildings and residential appliances. A more detailed description of the results (distinction between energy carriers and individual technologies) is found in (BMUB, 2013).

STEP 2: ALLOCATION OF INVESTMENTS AND SAVINGS TO ECONOMIC SECTORS IN INPUT OUTPUT ANALYSIS

For transferring the outputs of the bottom-up modelling, inputs to the macroeconomic model ASTRA-D, and the changes in investments, consumption, energy demand and subsidies have to be allocated to the economic sector classification of in the Input-Output tables used in ASTRA-D (Destatis, 2003). The input-output tables that are used in ASTRA-D contain 57 economic sectors. The intermediate deliveries between the economic sectors are described in the input output table, a square matrix in which each element describes the deliveries (in monetary terms) between two sectors. Furthermore, additional rows and columns describe the final deliveries (including final consumption and investments), imports and exports as well as additional cost components of companies.

In the bottom up models, investments and energy savings are calculated considering individual energy efficiency measures and are not necessarily in the same sectoral classification as the economic sectors in the Input-Output tables. For each energy efficiency measure, it is therefore necessary to transform the results from step 1 to the official nomenclature of economic activities of the Input-Output-tables. Furthermore, it is necessary to determine the sectoral splits of the changes in the consumption bundle. The following sections outline how the results are transformed for each energy end-use sector.

Industry and Service sector

The drivers for the macroeconomic effects of energy efficiency measures in industry and the service sector are different for sectors conducting energy efficiency measures and sectors producing energy efficiency technologies and services. For sectors that conduct energy efficiency measures, the investments result in a negative effect on profitability, whereas the energy cost reductions have a positive effect. For sectors producing energy efficiency technologies and services, the effect on profitability is positive. The energy cost reductions are included in the input-output matrix, investments in energy efficiency technologies are included as additional deliveries in the investment vector of the final demand matrix.

Residential appliances

For residential appliances, the macroeconomic effects are driven by the (individual) investments in energy efficient appliances undertaken by consumers (whose investments are consumption from a macroeconomic point of view) and the energy cost reduction for consumers. Both the investments and the energy cost reductions are included in the consumption vector, where the investments lead to increased consumption in sectors producing energy efficient residential appliances and the energy cost reduction leads to decreased consumption in the electricity providing sector. The consumption changes are not simply additive; they are multiplied by sectoral elasticities and overall consumption shares are re-normalised, so that there is no aggregate consumption change. This distinction is important since we do not assume that bottom-up policies change the marginal propensity to consume.

Buildings

For buildings, deriving the inputs for the macroeconomic modelling is more complex due to the variety of investors and financing mechanisms and the landlord-tenant structure. The derivation of the macroeconomic impulses for the different constellations of ownership and inhabitation of buildings are described in detail for residential buildings in the following, however, the same methodology applies for non-residential buildings.

In Germany, the percentage of rented dwellings is rather high with respect to other EU countries (see e.g. Behring 2003). At the time of the census in 2011, 57 % of all household inhabited rented dwellings, where 37 % were rented from private landlords and 20 % from the housing industry and residential building cooperatives (see Figure 4).

For modelling the macroeconomic impacts of energy efficiency measures in buildings it is therefore essential to distinguish between the different constellations of landlords and tenants (private households and companies). The most relevant combinations are described in the following list and are summarized in Table 2.

- The energy efficiency investments of **private residing home owners** enter the input output analysis through the consumption vector, where the element corresponding to the construction sector and credit services increases. The

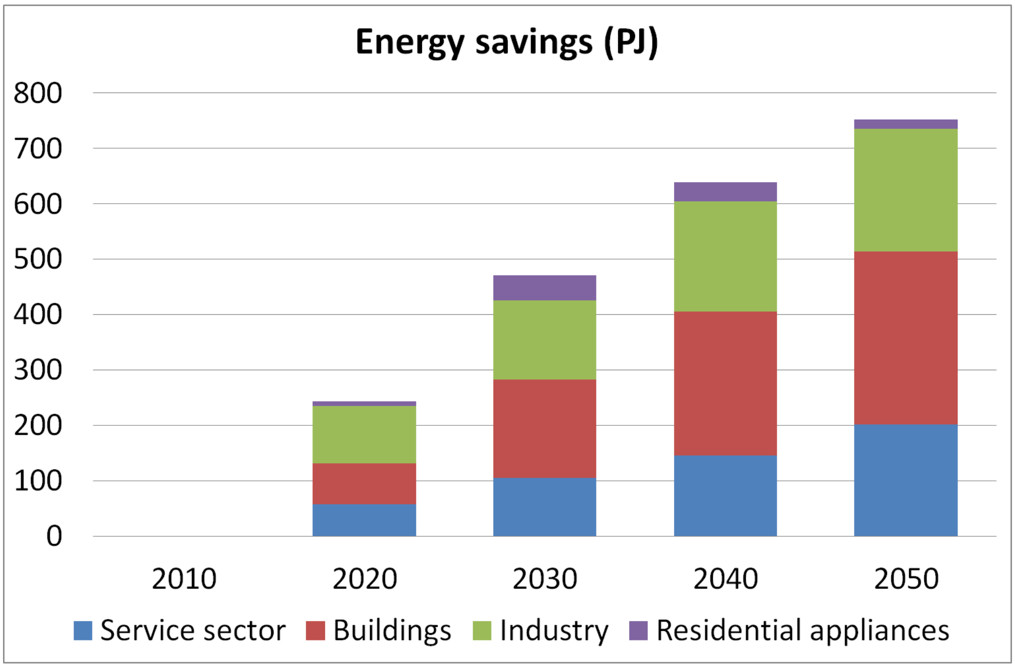

Figure 3. Projected additional energy savings in the energy efficiency scenario with respect to the baseline scenario.

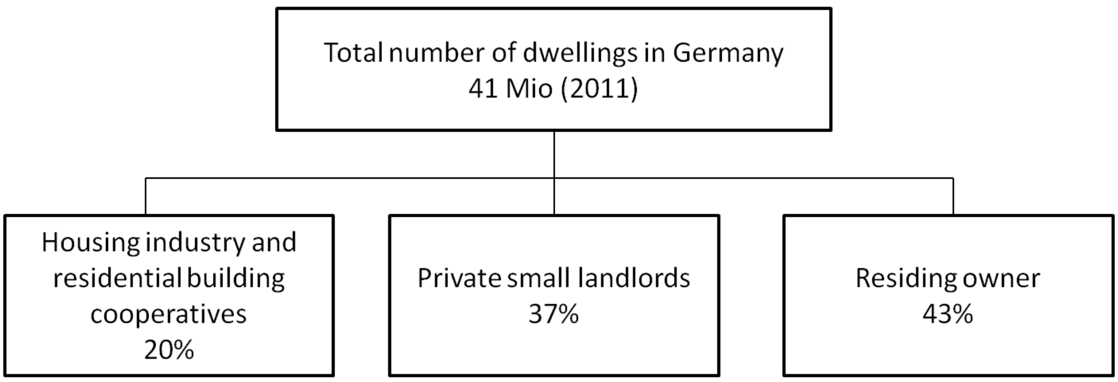

Figure 4. Share of different ownership types for dwellings in Germany. Source: GdW Wohnwirtschaftliche Daten und Trends.

Table 2. Macroeconomic impulses from energy efficiency measures for buildings.

	Drivers for macroeconomic effects	Representation in macroeconomic model	Relevant sectors	
Residing home owner	Investments	Consumption vector	Construction, credit services	Increase
	Energy savings	Consumption vector	Energy	Decrease
	Financing	Consumption vector	Banks	Increase
Private landlords	Investments	Consumption vector	Construction, credit services	Increase
	Energy savings	Consumption vector	Energy	Decrease
	Financing	Consumption vector	Banks	Increase
	Rent	Consumption vector	Rental services	Increase
Commercial landlords (residential buildings)	Investments	Investment vector	Construction, credit services	Increase
	Energy savings	Consumption vector	Energy	Decrease
	Financing	Investment vector	Banks	Increase
	Rent	Consumption vector	Rental services	Increase
Commercially owned non-residential buildings	Investments	Input output matrix	Construction, credit services	Increase
	Energy savings	Input output matrix	Energy	Decrease
	Financing	Input output matrix	Banks	Increase

energy savings that are generated are described by decreasing the element of the consumption vector corresponding to the energy sector. The investments in thermal building retrofits are typically financed through varying combinations of subsidies (programs of the KfW bank), credits, and private capital. Subsidies are represented in the input output analysis in the primary input matrix; thus a sector receiving subsidies has a lower gross value added. Furthermore, government expenditures rise. Credit financing increases the consumption vector element corresponding to the financial sector. Saving level decreases as well as the increased value of the building are not considered in the model.

- Energy efficiency investments of **private landlords** are represented by increasing the consumption vector element corresponding to the construction sector. The energy cost reduction of the tenant is represented by decreasing the element of the consumption vector corresponding to the energy sector. The landlord allocates the costs of the investment by increasing the rent by 11 % according to §559 of the German civil code (BGB). The additional costs for renting is reflected in the consumption vector element corresponding to the sector real estate activities. The financing of the investment is represented equally for private residing home owners.
- **Commercial landlords for residential buildings:** Energy efficiency investments of the housing industry and residential building cooperatives are represented by increasing the element of the investment vector that corresponds to the construction sector as well as credit services. The energy savings of the tenant (private household) are represented by decreasing the value of the consumption vector element corresponding to the energy sector. The landlord (housing industry) allocates the costs of the investment by increasing the rent by 11 %, which is represented by decreasing the element of the consumption vector corresponding to the sector real estate activities.
- For **company-owned non-residential buildings**, both the investments and the energy savings are represented in the input output matrix.

STEP 3: MACROECONOMIC MODELLING

The impulses derived from the bottom-up energy demand models were implemented in ASTRA-D the following manner:

1. Investments were added to the investment vector in the final demand matrix of the Input-Output table. Only net investments were considered.
2. Consumption changes were evaluated as relative changes to the BS, so they did not change overall consumption. In addition, before altering the consumption vector in the final demand matrix, they were multiplied with sectoral elasticities.
3. Subsidies entered the government sector and changed the government expenditures and thus budget.

4. Energy demand changes resulted from both a change in energy consumption, subject as well to electricity price changes in the EES; prices for imported goods like coal or oil did not change. These energy demand changes were considered differently for private households and firms.
   a. In private households energy was regarded similar as an ordinary consumption good and changed the consumption vector, after having been multiplied with the respective elasticity.
   b. For firms these changes have an impact on the intermediate deliveries of the Input-Output table. Here, energy demand changes differ according to the size of the technical coefficient of energy in the respective sector.

Figure 5 provides a simplified illustration of the modelling logic of ASTRA-D and shows how the main policy impact derived from the energy demand models enter the macroeconomic modelling. The energy efficiency measures considered in the energy demand models lead to changes in investments (e.g. investments in energy efficiency technologies) and consumption (e.g. reduced energy demand). As indicated in Figure 5, these bottom-up impulses are integrated in ASTRA-D by changing consumption, investments and the input-output coefficients. Consumption and investments (together with government expenditures and exports) forms the second quadrant of the Input-Output tables, which is equivalent to final demand, when imports are subtracted. This demand side of the economy is complemented by the supply side, which is fed by capital, labour and technological progress. A balance between both sides gives then Gross Domestic Product (GDP) and GDP growth enforces a further growth in consumption, triggering investments to meet this new consumption demand. These feedback effects between GDP, income, consumption, investments and GDP are a key feature of ASTRA-D and allow for modelling indirect effects arising from the implementation of energy efficiency measures. Taking into account the second-round effects is particularly important when modelling the long-term macroeconomic effects of energy efficiency policy.

Changing the investment vector in the Energy efficiency scenario, however, is not the only effect of the investments made in energy efficiency technologies:

I. Additional investments introduced a price effect on goods and those price increases were handed over to the consumers and altered the consumption vector, after being multiplied with their respective elasticities.

II. Investments in energy efficiency technologies also have an effect on overall productivity. However, these productivity gains differ depending on the sector where they are introduced. In ASTRA-D these investments enhanced total factor productivity, which changes the overall growth path of the economy.

III. The investments are either paid by financial reserves of the firms or by credit uptake, which is the most common case. In the latter case, the payment flows needed to finance the investment are subtracted from the earnings, lowering gross

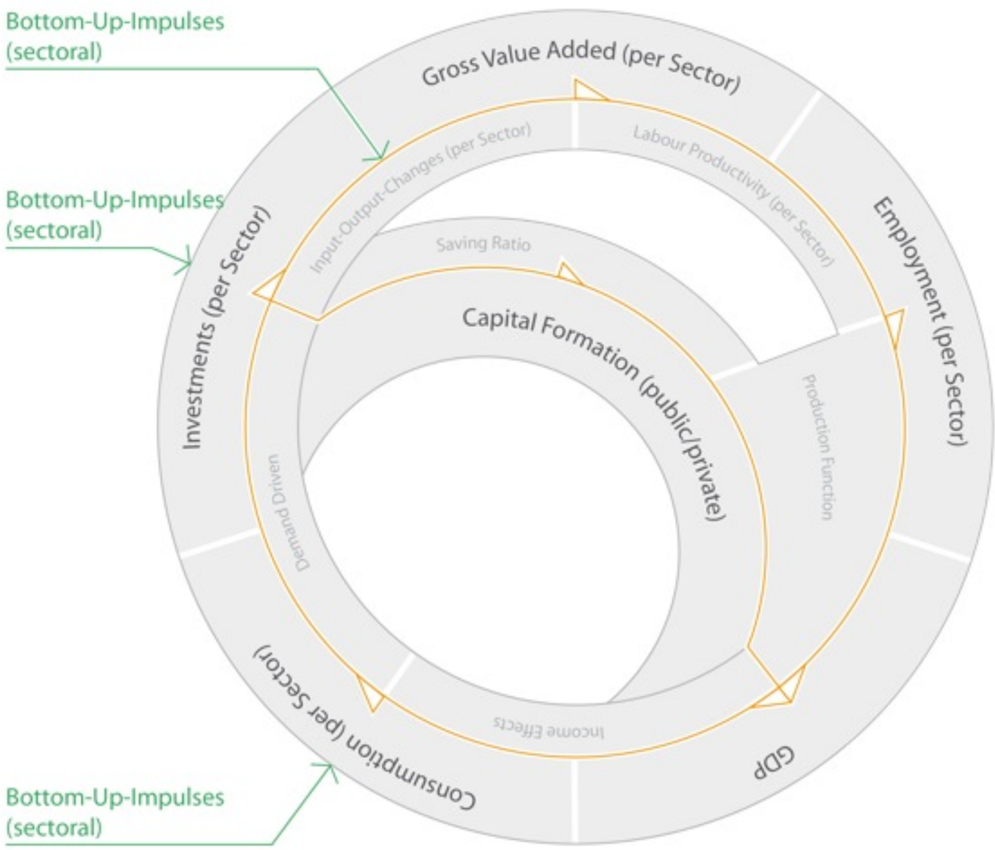

Figure 5. Macro-economic modeling logic in ASTRA-D (arrows: implementation of policy impulses). Source: Hartwig et al. (2012).

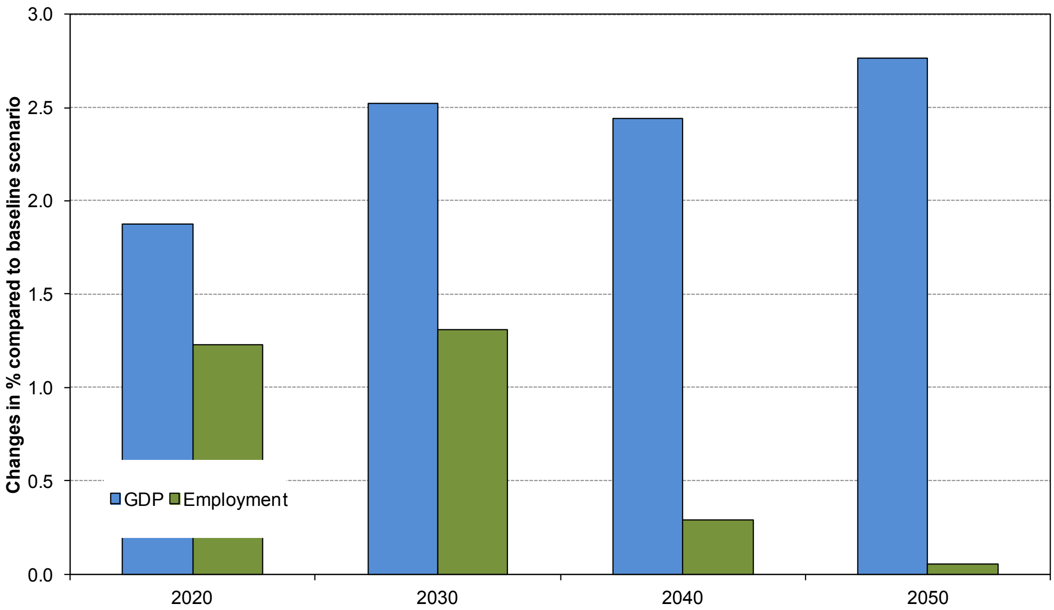

Figure 6. Changes in GDP and Employment in the EES. Source: own calculation.

value added of the respective sector. In some cases, the investments are paid by foreign investors, which then change the trade balance as well.

IV. Generally, all investments feed into the capital stock of the economy, and so are additional investments in the EES. Capital is one production factor in the equation for the supply side and thus changing the production potential of the economy.

Macroeconomic effects of the energy efficiency scenario

Figure 6 shows the changes energy efficiency policies have in the energy efficiency scenario, compared to the baseline scenario. In this figure one can see that the overall effect of the policies is positive, compared to the baseline. The figure can be interpreted in the way that, for example, in 2050 GDP in the EES is 3.4 % higher than in the BS, which is equivalent to a change in growth rate of 0.08 %. Overall employment has a slightly different path than GDP growth: here, then main effects happen before 2030 and after that they gradually fade out. One explanation is that those policy changes impose some permanent effects on the economy, as in the case of changing the production potential, which leads to a reinforcing process. Employment changes, on the other hand, happen also in sectors where labour productivity is quite high, like most manufacturing sectors, so a higher overall demand will not automatically lead to an equivalent increase in employment.

Figure 7 shows the development of sectoral employment, aggregated to main sectors. Mainly the sectors with additional investment gains in the energy efficiency scenario compared to the baseline scenario show an increase in employment and mainly the energy sector looses employment, leading to the negative effects in the manufacturing sector. The loss in employment in the energy sector reflects the fact that in this work we do not consider the investments in renewable energies, which would change the picture. If additional investments in renewable energy production are also considered, this negative employment effect diminishes. Furthermore, it must be stated that labour productivity high in this sector, which is both caused by the high capital intensity and high centralisation of production. With a detailed consideration of the full effects of a shift towards renewable energy production, labour productivity will also be lowered, thus requiring a bigger sectoral labour force.

However, there are also macroeconomic effects resulting from consumption changes. The consumption changes (see Figure 8) result both from effects resulting from decreased energy consumption and additional consumption in sectors providing energy efficiency products and services. For example, the trade sectors experience a boost in the early years of the simulation due to a changed consumption pattern of private households, which switch to more energy-efficient household appliances. The losses in trade sectors after 2040 are mainly due to losses in wholesale and retail trade, stemming from consumption. Overall consumption will still be higher in the EES, and even if retail trade may lose a bit of ground compared to the BS, the overall growth path with a higher GDP in 2050, despite a smaller population, results in a considerable improvement in standard of living. The energy efficiency measures in buildings lead to increased rents. Here it is important to note that this effect is particularly strong in Germany, where the percentage of residing home owners is rather low compared to other European countries. Furthermore, in order to achieve the ambitious policy goals, we assumed that the legal maximum rent increase is applied by private and commercial landlords. However, the currently observed increases are far below the maximum value of 11 %, such that we quite possibly overstate the effect. As rents increase, the consumption in other sectors diminishes, having substantial impacts on employment. It would be desirable to

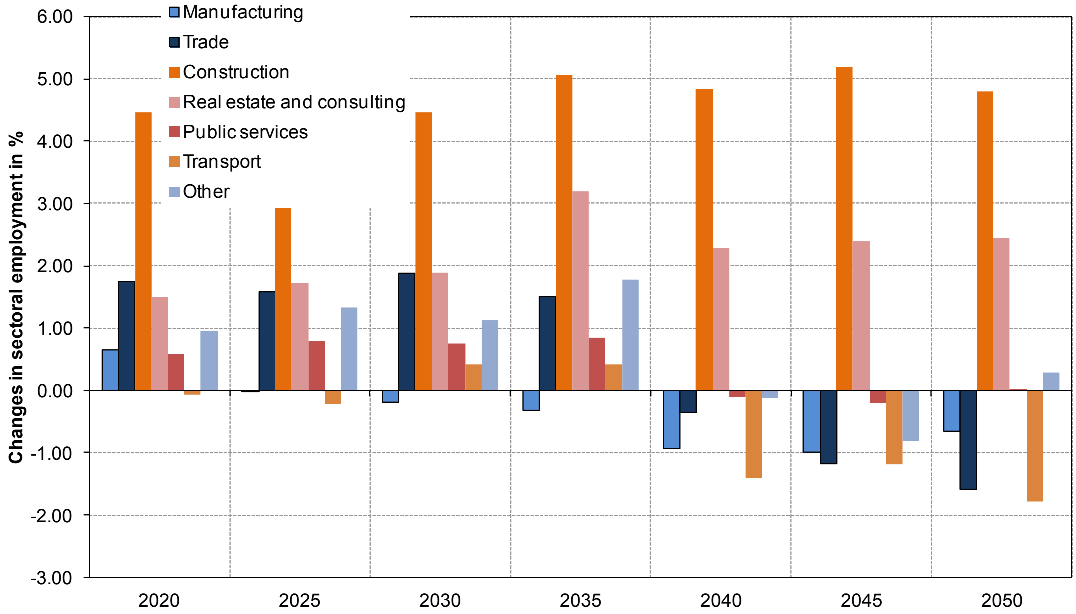

Figure 7. Sectoral employment changes in both scenarios. Source: own calculation.

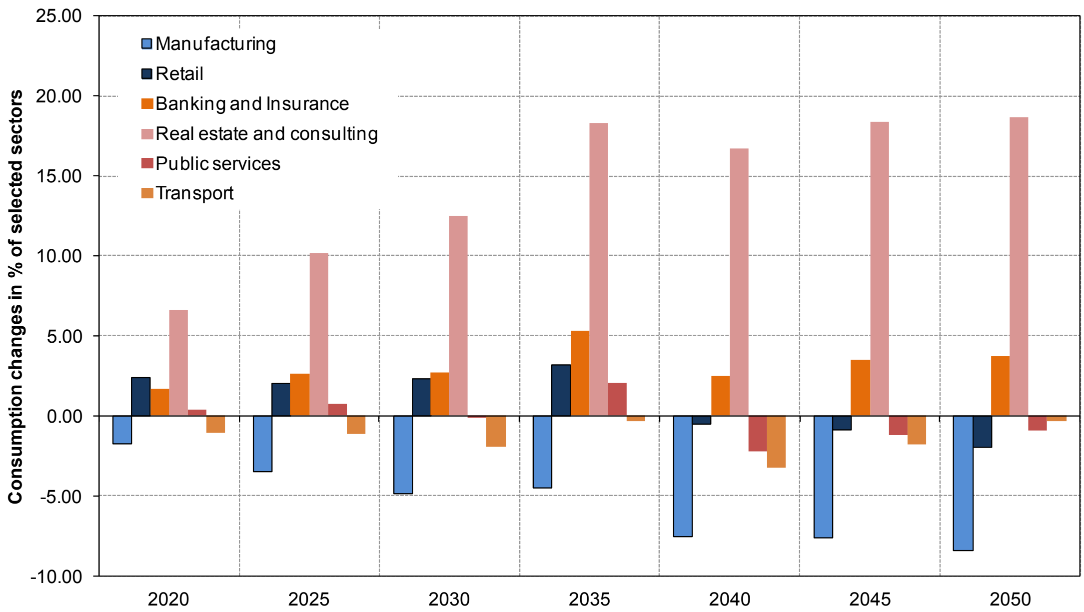

Figure 8. Consumption changes of selected sectors. Source: own calculation.

examine further possible income distribution effects, resulting from the policies. Our results can provide a basis for further research on the distribution of the effects for different groups of the population.

Summary and Conclusions

We provided a projection of the estimated macroeconomic effects of ambitious energy efficiency policy in Germany and found considerable positive impacts on employment and GDP in the energy efficiency scenario. The impacts result both from additional investments and energy cost reductions. Investments in energy efficiency technologies lead to increased demand in sectors providing energy efficiency technologies and services. For sectors that invest in energy efficiency, the reduction of energy intensity leads to increased profitability. Furthermore, macroeconomic effects result from consumption shifts induced by energy savings in households.

The positive effects on employment are particularly pronounced in sectors that produce energy efficiency technologies and services, in particular the construction and manufacturing sector as well as real estate and consulting.

The reduction of energy consumption in households leads to increased consumption in other sectors, however, at the same time the expenses for real estate and consulting increase as rents increase. Here it is important to note that this effect is particularly strong in Germany, where the percentage of residing home owners is rather low compared to other European countries. Furthermore, in order to achieve the ambitious policy goals, we assumed that the legal maximum rent increase is applied by private and commercial landlords. However, the currently observed increases are far below the maximum value of 11 %.

Our methodological approach included a coupling of detailed energy demand models with a dynamic input-output based macroeconomic model and therefore provided a step forward towards an integrated modelling of the impacts of energy efficiency policy on energy demand and technology development and the macroeconomic effects of a transition to a high-efficiency economy.

While presenting the advantage of providing a detailed estimation the macroeconomic effects of energy efficiency policy efforts, our methodological approach has some limitations:

- At the current stage, feedback effects of the increase in GDP on energy demand are not taken into account in the bottom-up models. From the energy demand perspective, this corresponds to the macroeconomic rebound effect. Macroeconomically, this effect is modelled, but for actually accounting for it, several iterations between the models would be necessary.
- We do not consider capital mobility effects: cost increases through necessary investments may motivate production capacities to be allocated elsewhere, hence opening up for carbon leakage effects. For the energy efficiency measures that are considered in this study, however, this is unlikely to happen as investments are cost-effective.
- Since we do not look at individual households, distributional effects alleviating the policy impacts are not considered. This may especially be the case for the increase in rents.
- Our approach cannot be subsumed into general equilibrium theories, thus methodological controversies between neoclassical economists and our approach are unavoidable.
- The IO core of the model is only insofar dynamical as we update the final demand matrix; true dynamics would require an update of the technical coefficients, something which is not easily done in empirical studies due to confounding effects in the statistical nature of the IO tables and inherent uncertainties of technological developments.
- We do not make a predictive claim; thus, our results ought to be interpreted as indicators of directions rather than point predictions of policy impacts, since we do not conduct a detailed sensitivity analysis of all relevant parameters.

References

Barker, T., Ekins, P., & Foxon, T. (2006). Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000–2010. Energy Economics, 29 (4), 760–778.

Behring, K., I. Helbrecht 2002 unter Mitarbeit von G. Goldrian, J. Schmauß, T. Frey: Wohneigentum in Europa. Ursachen und Rahmenbedingungen unter-schiedlicher Eigentumsquoten im Vergleich. Hrsg. von der Wüstenrot Stiftung. Ludwigsburg

BMUB. (2013). Klimaschutzszenarien 2050, http://www.oeko.de/oekodoc/2065/2014-638-de.pdf.

BMWi/BMU. (2010). Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply.

Common, M., Stagl, S. (2012). Ecological economics: an introduction, vol. 5. Cambridge University Press.

Destatis (2003). Klassifikation der Wirtschaftszweige mit Erläuterungen. Technical report, Statistisches Bundesamt (Federal Statistical Office).

European Commission (2014). Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy [COM(2014) 520 final] .

Hartwig J, Schade W, Sievers L. (2012). Kurzübersicht des Modells ASTRA-D. Working Papers Sustainability and Innovation S 10/2012. Fraunhofer ISI, Karlsruhe.

IEA. (2014). Capturing the Multiple Benefits of Energy Efficiency.

IEA. (2014). Energy efficiency market report. International energy agency IEA.

Köhler, J. (2011). A paradigm shift in economics: endogenous technological change in economic models of climate change policy. In The Political Economy of the Environment. An interdisciplinary approach, S. Dietz, J. Michie, and C. Oughton, Eds. Routledge.

Miller, R. E., Blair, P. D. (2009). Input-Output analysis. Foundations and extensions, 2 ed. Cambridge University Press.

Perman, R., Ma, Y., McGilvray, J., Common, M. (2003). Natural Resources and Environmental Economics. Pearson, Third Edition.

Pietroforte, R., Gregori, T. (2003). An input-output analysis of the construction sector in highly developed economies. Construction Management and Economics 21, 319–327.

Richter, J. (1991). Aktualisierung und Prognose technischer Koeffizienten in gesamtwirtschaftlichen Input-Output-Modellen. Physica-Verlag.

Rose, A. (1995). Input-output economics and computable general equilibrium models. Structural Change and Economic Dynamics 6, 295–304.

Schade, W. (2004). Strategic Sustainability Analysis: Concept and application for the assessment of European Transport Policies. PhD thesis, Institut für Wirtschaftspolitik und Wirtschaftsforschung (IWW), Universität Karlsruhe.

Schlomann, B., & Eichhammer, W. (2012). Energy Efficiency Policies and Measures in Germany. ODYSSEE- MURE 2010.

Scrieciu, S. S. (2007). The inherent dangers of using computable general equilibrium models as a single integrated modelling framework for sustainability impact assessment. A critical note on Böhringer and Löschel (2006). Ecological Economics 60, 678–684.

Sommer, M. (1981). System Dynamics und Makroökonometrie. Dynamische und makroökonometrische Modellierung in multimethodologischer Sicht. Haupt.

Sterman, J. D. (2000). Business Dynamics. Systems Thinking and Modeling for a Complex World. McGraw-Hill.