How to catch the rebound effect in interindustry modelling

Christian Lutz[1,*], Lara Ahmann[1], Maximilian Banning[1], Markus Flaute[1]

[1] *Gesellschaft für Wirtschaftliche Strukturforschung mbH, Osnabrück, Germany*

* *Corresponding author. Tel: +4954140933120, Fax: +4954140933110, E-mail: lutz@gws-os.com*

Abstract

Increases in energy efficiency are reduced by the rebound effect. Efficiency gains on the micro level do not lead to proportionate reductions of energy consumption on the macro level. Most of the empirical approaches assume an autonomous increase of energy efficiency and analyze rebound effects on macro and sector level. Any cost and investment needed to reach additional energy efficiency in already highly efficient market economies are often neglected. In the applied CGE models the economy and its sectors adjust smoothly to the positive efficiency “shock” via reduced costs and prices in the more efficient industries, as substitution between factor inputs is possible in no time according to substitution elasticities. Sometimes lower short-term and significantly higher long-term substitution elasticities are used to calculate the respective effects. Rigidities due to long-life cycles of energy intensive capital stocks are thus accounted for quite generically. There is some understanding about how the rebound effect on the sector and macro level will change with assumptions about the central parameters in sensitivity analyses. Policies and their additional effects on top of energy efficiency are only rarely considered in these approaches.

The German energy-economy INFORUM-type model PANTA RHEI, including a time series of national IO tables, will be applied to better understand the rebound effect in this type of model by a set of simulations. Starting from an autonomous increase in energy efficiency in some industries, the analysis will be broadened towards necessary investment for energy efficiency improvement and the role of technical progress for the effects. The impact of different model characteristics and scenario assumptions will be shown.

1. Introduction and background

In the literature on rebound effects, there is a broad consensus that rebound effects exist and are a major reason why energy efficiency increases do not translate into a reduction in energy consumption to the same extent. In general, survey articles such as Chakravarty et al. (2013) show a range of these effects from near zero (no rebound) to greater than one (backfire). However, it is not only the estimates of the size of the rebound that vary considerably, but also macroeconomic models and modelling approaches used by authors differ in many cases. The methods can certainly not (only) explain most of this range. In a comparison of eight CGE models for different countries, Allan et al. (2007a) come to the conclusion that the economy-wide rebounds range considerably from 37% to over 100%. A comprehensive literature review can be found in Lange et al. (2019), in which various forms of rebound effects and methods for capturing them are discussed. Impacts can be divided into micro-, meso- and macroeconomic rebound effects, whereby all underlying effects have to be included when considering the respective levels. Microeconomic effects take place on the individual level of an economic unit, i.e. a consumer or company, where a distinction can be made between direct and indirect as well as substitution and income effects (see Lange et al. 2019). Mesoeconomic effects are those that affect the next higher level of aggregation, i.e. groups of individual actors as markets and sectors. Finally, macroeconomic effects have an impact at the national or international level. In addition to effects on international trade, energy prices and macroeconomic multipliers are taken into account.

As depicted by Lange et al. (2019), three fundamentally different methods are suitable for the analysis of rebound effects: theoretical approaches, empirical ex post studies and model-based ex ante analyses. Macro rebounds are generally determined using economy-wide models in ex ante analyses. There are macroeconomic (growth) models that are closely linked to economic theory, computable general equilibrium (CGE) models that assume optimisation behaviour of companies and households at the microeconomic level according to neoclassical theory and emphasize the supply side, and macroeconometric models that set the behavioural parameters on the basis of empirical observations and include the demand side more strongly. The latter two model types contain the industrial structure of the economy on the basis of input-output tables. (Neoclassical) growth models go back to Solow and describe on an aggregated level the interaction of the production factors labour, capital, materials, sometimes also energy and technical progress, all of which lead to the growth of aggregate production.

Following the explanations of Chakravarty et al. (2013), there are even four different model types that are suitable for calculating the macro rebound (orig.: economy-wide rebound): Macroeconomic models, CGE models, econometric models and hybrid models. However, the term "hybrid" remains unclear in the publication. In a similar manner, Colmenares et al. (2018) differentiate between neo-classical growth models, econometric models and simulation models with integrated assessment models being distinguished as a fourth model type. A current study for the EC (Pollitt et al. 2017) distinguishes between (static) input-output models used for multiplier analyses, supply-oriented CGE models based on neoclassical theory, assuming benefit and profit maximisation of households and companies and starting from cleared markets, and macroeconometric models in which behavioural parameters are determined on the basis of time series estimates, thus extrapolating past behaviour into the future, to which a post-Keynesian, demand-side oriented approach is generally ascribed. For the classification of the model types further overviews can be found e.g. in West (1995) and IEA (2014).

The literature is briefly summarized in section 2 with a view to key model properties for determining rebounds. It describes the efficiency shocks that are introduced into the models and the modelling results concerning rebounds. The aim of the considerations is to gain insights for simulations of macroeconomic rebound effects and for the definition of policy measures limiting rebound effects in the project using the macroeconometric model PANTA RHEI, which is described in section 3. Section 4 concludes with a set of own simulations to better understand rebound effects and to design policies to cap or reduce the rebound effects.

2. Literature review of modelling approaches

This literature review summarizes results from Banning, Lutz (2019). A selection of the three established model types is presented based on detailed publications that were used to estimate rebound effects at the macroeconomic level: These make use of a macroeconomic growth model, two CGE models and a macroeconometric model.

Various model-based analyses of rebound effects were selected in Banning, Lutz (2019) based on the following criteria: the model considered i) examines a macroeconomic or economic-wide rebound as defined in Lange et al. (2019), ii) is explained in sufficient detail, which allows for the examination of influencing factors, underlying assumptions, and variables, and iii) is presumably of relevance for the modelling approach in section 4 not only because of this detailed information but also because of the regional coverage and the capturing and mapping of rebound effects.

In contrast to the micro level, the analysis of macroeconomic rebound effects is less common (Lange et al. 2019). To go beyond the company or household level, highly aggregated empirical models are sometimes used (e.g. Antal et al. 2014, Holm et al. 2009), which are not further considered. Findings for economies that are difficult to compare with Germany may not be transferable, which further limits the choice. This applies to studies looking at a rapidly growing emerging market economy such as China (Lin et al. 2014) as well as to an economy with high energy production such as the US, which is oriented towards the domestic market (Böhringer et al. 2018, Rausch et al. 2018).

Additionally, the selection of the research contributions is intended to cover the range of different model types and theoretical approaches. The four models examined are the macro model used by Saunders (2000) to assess the general impact of an energy efficiency shock on GDP, the macroeconometric model MDM-E3 applied by Barker, Foxon (2008) to analyse rebound effects of energy efficiency measures in the UK, and two CGE models. Firstly, the national UKENVI model, with which Allan et al. (2007a) simulate an energy efficiency shock for the UK. Secondly, a multiregional, global CGE model used by Koesler et al. (2016), which fully captures global effects of national energy efficiency measures in Germany.

The approach of Saunders (2000) can be classified as a theoretical macroeconomic model that only considers the total economy. A Cobb-Douglas production function is used with labour, capital, and energy as input factors. Elasticities of substitution are set to (minus) 1.

Both Allan et al. (2007a), in the context of a national economy, and Koesler et al. (2016), which shift the focus to the international context, apply CGE models, which are based on neoclassical assumptions. Following the optimisation decisions of agents markets generally clear and reach equilibrium via price changes (EC 2017). Allan et al. (2007b) cite the strong anchoring in (neo) classical economic theory with a firm microeconomic basis, appropriate treatment of supply-side changes and good comparability of counterfactual analyses as advantages of CGE modelling. However, they draw attention to the difficulty of comparing models with each other, because a change in fundamental assumptions has far-reaching effects on the results. Moreover, especially in the context of energy efficiency, the barriers to the implementation of new technologies could be underestimated (cf. also Sorrell et al. 2004).

In both cases, the economy is divided into different sectors. The UKENVI model used by Allan et al. (2007a) differentiates between 25 sectors, five of which are explicitly assigned to energy generation. Using an input-output table, the interactions between individual sectors can be taken into account. In the international model, Koesler et al. (2016) distinguish eight sectors for each country (each region) considered, two representing energy production.

The MDM-E3 developed by Barker, Foxon (2008) combines econometric time series data and input-output data. The modelling of demand and investment is (post-) Keynesian, whereas the supply side is also represented by equation systems. In general, four energy consuming sectors of the economy, households, industry, transport and commerce, with various subsectors according to the energy balance, and 50 industries are distinguished: The model is classified as macroeconometric corresponding to the international model system E3ME, which is used intensively for the EU Commission (EC 2017). Macroeconometric models generally offer comprehensive explanations of the adjustments of an overall economy to changing conditions (Allan et al. 2007b). The parameters of the equation systems are derived from historical data using established empirical methods. Allan et al. (2007b) cite as advantages compared to CGE models the possibility of testing the quality of the model and of mapping dynamic developments, such as the depletion of resources. In contrast, the microeconomic database is less disaggregated and may offer less insight into the effects of policy measures on welfare and income distribution. Table 1 gives an overview of major characteristics of the four models:

Table 1 Overview over central model characteristics

	Saunders (2000)	**Allan et al. (2007a)**	**Barker, Foxon (2008)**	**Koesler et al. (2016), nach Sektoren**
Model type	Theoretical macroeconomic model	E3-CGE (UKENVI)	National macroeconometric model (MDM-E3)	Multi region CGE world model
Production function	Cobb-Douglas	Multi-level production functions (CES, sector specific)	No explicitly stated production function: factor demand estimated individually	KLEM (CES, sector/country specific)
Number of sectors	Holistic economy	25 (5 of which energy)	50 industries, 4 sectors: 50 fuel users	8 (2 of which energy) per country
Elasticity of substitution	1 (between labour, capital, and Energy)	0.3 (between energy and non-energy components)		Between 0.15 – 0.72 depending on sector (median values over all countries)

Source: Banning, Lutz (2019)

The importance of the elasticities of substitution of energy and other input factors for the model results and the level of rebound is emphasized. Using the Cobb-Douglas function in Saunders (2000) results in the implicit assumption of a substitution elasticity of 1 for the input factors. Allan et al. (2007a) assume a value of 0.3 for the elasticity of substitution between energy and non-energy components, as well as for the elasticity of substitution between intermediate consumption (in which the energy component is included) and value added. Koesler et al. (2016) use a substitution elasticity for each of the eight sectors of their model at each of the three levels of their production function in each depicted country. The value of the elasticity of the energy component to labour and capital ranges between 0.15 (construction) and 0.72 (coke, refined petroleum and nuclear fuel), in the manufacturing sector the median value is 0.53. Barker, Foxon (2008) estimate different factor demand functions, i.e. there is no explicit production function in the model.

Barker, Foxon (2008), Allan et al. (2007a) as well as Koesler et al. (2016) quantify the size of the rebound investigated in concrete terms, while Saunders (2000) limits itself to determining a rebound effect of more than 100% - so-called backfire. This size is not achieved in the other models, even under variation of different assumptions. The MDM-E3 model shows a macro rebound (by their definition; sum of indirect and economy-wide effects) of 11 %. To calculate the total rebound, the exogenous direct rebound effects found to be 15% are added to the model, so that the total rebound amounts to 26%. The long-term rebound in the UKENVI model is comparable. At 62% and 55%, respectively, the short-term rebound effects for electricity and other energy are significantly higher, but these fall to 27% (31%) in the long term. In Koesler et al. (2016), the values are generally higher, although they vary depending on the scenarios. In scenario 1, the efficiency shock is only assumed in the German manufacturing sector, in scenario 2 the increase in efficiency occurs across all production sectors. In scenario 1, the system-wide rebound of 48% is marginally higher than in scenario 2 (47%). Depending on the chosen scope, the rebound can reach up to 57% (rebound in manufacturing in scenario 1.

Fundamental cause of the rebound effect is an increase in energy efficiency in all models, with the cause, extent and sectors affected differing from model to model. Table 2 gives a schematic overview of the causal efficiency shocks. The methodological approach is generally the same: an initial scenario that represents the status quo is compared with an alternative scenario in which energy efficiency is increased. The changes in energy consumption compared to the original value are then compared with the increase in energy efficiency to calculate the rebound.

For Saunders (2000), the increase in energy efficiency (synonymous to fuel efficiency) has a system-wide effect, i.e. on the economy as a whole. In the UKENVI model, the increase in efficiency assumed by Allan et al. (2007a) is expressed by an increase in energy productivity of 5%, which affects all producing sectors of the economy - the energy efficiency of households, the government and rest of world remain unchanged. Koesler et al. (2016) proceed in a quite similar way: Depending on the scenario under consideration, an (autonomous) increase in efficiency of 10% affects the German manufacturing industry (scenario 1) or total German production (i.e. all differentiated 8 sectors, scenario 2). The amount of the rebound is then calculated for the individual sector (only possible in the first case, since in the second a sector cannot be examined in isolation), the German economy as a whole and, in the international context, both for the rest of the EU and for the rest of world.

In the MDM-E3 model, the increase in efficiency is mapped by various policy measures or programmes that have actually been adopted. The macro rebound examined by the authors as the sum of the indirect and economy-wide rebound results from the difference between the energy savings calculated by the model and the expected net savings by the policy programs after considering the direct rebound as reported from other studies more technically oriented. The scope of the study is limited to the UK, where both imports and exports react, i.e. there is a link to the rest of the world. In the case of increases in household energy efficiency, a reduction in energy expenditure leads to an increase in real income.

In all models, an increase in energy efficiency improves the productivity of the economy and leads to an increase in GDP or output. Saunders (2000) estimates the growth induced by a 20% increase in energy efficiency to be 1-2% in the short term and around 14% higher in the long term, i.e. up to 2.28%. Allan et al. (2007a) come to the same conclusion that long-term growth exceeds short-term growth. The 5 % increase in energy productivity leads to a 0.11 % increase in GDP in the short term, while the difference increases to 0.17 % in the long term. In Koesler et al. (2016) the results for the rest of the European Union are zero, although the increase in efficiency in both scenarios leads to higher GDP in the country in which the increase in efficiency took place (+0.13 % and +0.51 %, respectively). The GDP of the rest of the world remains unchanged in the scenario of an efficiency shock in the German manufacturing sector. If the efficiency shock affects German production as a whole, it will decline slightly (-0.002 %). In absolute terms, the positive effect of increased domestic production in the more efficient country predominates in both cases, with the result that more is produced worldwide in the aggregate than in the initial situation. Barker, Foxon (2008) show an increase in GDP in the UK of 1.26% compared with the reference scenario induced by the energy efficiency measures.

Table 2: Model Results

	Saunders (2000)	**Allan et al. (2007a)**	**Barker, Foxon (2008)**	**Koesler et al. (2016)**
Rebound effects	Not quantified	Electricity production: 62% short term, 27% long term Remaining energy production: 55% short term, 31% long term	Macro rebound (by their definition): 11% Direct rebound: 15% (exogenous to the model) Total rebound: 26%	47%- 57%, depending on scope and scenario
Causal shock	Rise in energy productivity by 20%	Rise in energy productivity by 5%	Various policy measures	Rise in energy productivity by 10%, Scenario 1: in German manufacturing, Scenario 2: in all producing German sectors
Effect on GDP	Short term: +1-2% Long term: 14% higher than short term (i.e. 2.28% instead of 2%)	Short term: +0.11% Long term: +0.17%	+1.26%	Scenario 1: Germany: +0.13% ROW: +0% Scenario 2: Germany: +0.5% ROW: -0.002%

Source: Banning, Lutz (2019)

Both Barker, Foxon (2008) and Allan et al. (2007a) report a positive impact on employment. Employment is 0.8 % and 0.21 % higher, respectively, than without an increase in efficiency. With the exception of Saunders (2000), all models also show effects on the general price level or the consumer price index. Barker, Foxon (2008) and Allan et al. (2007a) observe a system-wide decline in prices of 2.4% (GDP deflator) and 0.27% (consumer prices), respectively. In Koesler et al. (2016) the consumer price index, on the other hand, is rising both in the context of the national economy and EU-wide in both scenarios, although the prices of the industry affected by the efficiency increase are falling. The consumer price index for the rest of the world remains constant in both cases.

With the exception of Barker, Foxon (2008), the increase in energy efficiency is achieved in all models at no cost (autonomously), i.e. without higher expenditures by government, households or companies. This is explicitly the case in the baseline scenario of the studies by Allan et al. (2007a). The assumption is modified in the context of sensitivity analyses: here cost increases occur in the manufacturing sectors. Specifically, the costs of labour rise in the form of lower labour productivity. This takes account of the increased amount of work required to implement the efficiency measures. In the MDM-E3 model, each of the implemented policy measures is associated with specific costs and thus investments. This concerns the public sector in the form of incentive payments, subsidies, investments and administrative costs, companies in the form of investments and administrative costs, which are, however, partly offset by subsidies and incentive payments received, and households making investments.

3. Model PANTA RHEI

The national economy-energy-environment model PANTA RHEI, which will be applied in section four, is an environmentally extended version of the econometric simulation and forecasting model INFORGE for Germany (Ahlert et al., 2009, Zika et al. 2018). A detailed description of the economic part of the model is presented in Maier et al. (2015). For detail of the complete model see Lutz (2011) and Lutz et al. (2005). Among others it has been used for economic evaluation of different energy scenarios that have been the basis for the German energy concept in 2010 (Lindenberger et al., 2010) Applications include an evaluation of employment impacts of renewable energy promotion (Lehr et al., 2012), socio-economic impacts of the German energy transition (Lutz et al. 2018, Lehr et al. 2018, Lutz, Lehr 2016), and impacts of the transition to a green economy (Lutz et al. 2017).

The behavioral equations reflect bounded rationality rather than optimizing behavior of agents. All parameters are estimated econometrically from time series data (1991 – 2016). Producer prices are the result of mark-up calculations of firms. Output decisions follow observable historic developments, including observed inefficiencies rather than optimal choices. The use of econometrically estimated equations means that agents have only myopic expectations. They follow routines developed in the past. This implies in contrast to optimization models that markets will not necessarily be in an optimum and non-market (energy) policy interventions can have positive economic impacts.

The model is empirically evaluated: The parameters of the structural equations are econometrically estimated. In the model-specification stage various sets of competing theoretical hypotheses are empirically tested. As the resulting structure is characterized by highly nonlinear and interdependent dynamics the economic core of the model has furthermore been tested in dynamic ex-post simulations. The model is solved by an iterative procedure year by year.

Structural equations are modeled on the 63 sector level (according to the European 2 digit NACE classification of economic activities) of the input-output accounting framework of the official system of national accounts (SNA) and the corresponding macro variables are then endogenously calculated by explicit aggregation. In that sense the model has a bottom-up structure. The input-output part is consistently integrated into the SNA accounts, which fully reflect the circular flow of generation, distribution, redistribution and use of income.

The core of PANTA RHEI is the economic module, which calculates final demand (consumption, investment, exports) and intermediate demand (domestic and imported) for goods, capital stocks, and employment, wages, unit costs and producer as well as consumer prices in deep disaggregation of 63 industries. The disaggregated system also calculates taxes on goods and taxes on production. The corresponding equations are integrated into the balance equations of the input-output system.

Another important outcome of the macro SNA system is net savings and governmental debt as its stock. Both are important indicators for the evaluation of policies. The demand side of the labor market is modeled in for 63 industries. Average hourly wages are explained using Philips curve specifications. The aggregate labor supply is driven by demographic developments.

The energy module describes the interrelations between economic developments, energy consumption and related emissions. Economic activity such as gross production of industries or final consumer demand influence respective energy demand. Vice versa, the expenditures for energy consumption have a direct influence on economic variables, as they represent demand and costs.

The energy module contains the full energy balance with primary energy input, transformation and final energy consumption for 20 energy consumption sectors, 27 fossil energy carriers and the satellite balance for renewable energy. In total, the balances divide energy consumption into 30 energy carriers. Prices, also in Euros per energy unit, are modeled for different energy users such as industry, services and private households for all energy carriers. The energy module is fully integrated into the economic part of the model.

Final energy consumption of industries is explained by sector output, the relation of the aggregate energy price – an average of the different carrier prices weighted with their shares in the energy consumption of that sector – and the sector price and time trends, which mirror exogenous technological progress.

For services, the number of employees turned out to be a better proxy for economic activity than gross output. Average temperatures also play a role for the energy consumption of the service sector. For private households, consumption by purpose as heating or by fuels is already calculated in the economic part of the model in monetary terms. Additional information can be taken from stock models for transport and heating from the specific modules, as only new investments in cars, houses or appliances, or expensive insulation measures will gradually change average efficiency parameters over time.

Final demand of each energy carrier for industries can be calculated by definition, multiplying the share of the carrier with overall final energy demand of the sector. For the shares, the influence of relative prices, the price of the energy carrier in relation to the weighted price of all energy inputs of the sector, and of time trends are econometrically tested.

Energy carrier prices depend on exogenous world market prices for coal, oil and gas and specific other price components such as tax rates and margins. For electricity different cost components such as the assignment of the feed-in-tariff for electricity are explicitly modeled. For services, households and transport specific prices are calculated, as for example tax rates partly differ between end users.

For energy-related carbon emissions, fix carbon emission factors from the German reporting to the United Nations Framework Convention on Climate Change (UNFCCC) are applied. Multiplication with final energy demand gives sector and energy carrier specific emissions. All detailed information in the energy balance for 30 energy carriers is consistently aggregated and linked to the corresponding four industries of the IO table.

4. Envisaged model simulations and outlook

At least four different sets of policies will be implemented in PANTA RHEI additional to the baseline to measure rebound effects and to show possibilities to reduce the magnitude of the rebounds by policy design. The different model simulations include for the manufacturing industries (and maybe also for transport and heating):

1. Autonomous increase in energy efficiency,
2. increase in energy efficiency by investment in more efficient technologies,
3. regulation for more energy-efficient production, and
4. carbon prices to induce more energy-efficient production.

The first simulation follows the literature in section 2 by assuming an autonomous increase in energy efficiency in some industries. This will reduce energy demand of the respective industry. Reduced energy costs will lower costs and prices in the industry and in all other industries, which use the respective product as an intermediate input. Demand for these products will increase. This will induce higher production, employment and investment in these industries. These positive impacts will induce further positive and negative macroeconomic effects such as higher wages, higher consumption, and cost increases in other industries. The total effects are assumed to be positive. But higher economic activity and lower energy costs will increase energy demand, i.e. they will induce rebound effects on a meso- and macroeconomic level.

The second approach builds on the first, but assumes that the energy efficiency improvement is driven by higher investment in more efficient capital stock. If overall investment remains constant, impacts should by very similar to simulation 1. Increased overall investment will have positive short-term effects on demand, while increasing capital costs in the long-term. The industry will be able to reduce its costs depending on the economic efficiency of the investment. Macroeconomic effects depend on various model specifics. Rebound effects on the macro and meso level are possible due to reduced prices of energy (intensive) products and increased economic activity.

The third simulation assumes policy regulation for more energy-efficient production. It is probably less economically efficient than 2. The direction of effects and dependencies should be close to the second approach or less economically positive. Macro and meso rebounds are possible due to reduced prices of energy (intensive) products and increased economic activity.

In the fourth simulation carbon prices will induce more energy efficient production in industries. This will induce effects as described in approaches 1 to 3., but also lead to overall increases in carbon and energy prices. Cost will get higher for carbon-intensive industries, while other industries may profit depending on recycling mechanisms of carbon tax revenues. Macro and meso rebounds are still possible due to increased economic activity, but increased prices of energy-/carbon-intensive products will limit them.

According to Lange et al. (2019) there are three central effects at the meso and national level, which cause rebound effects: The price effect, the macroeconomic multiplier and an increase in total factor productivity: Lower energy demand due to an increase in energy efficiency can induce price reductions on energy markets. Lower prices mean from a demand side perspective lower energy costs for companies and households, which leaves room for spending on other products. In a supply side view, an increase in energy efficiency will increase total factor productivity, which allows for higher production and higher energy consumption. International effects can also take place, either on international energy markets, when national demand is reduced, or due to higher energy intensive production due to lower energy prices. It will be difficult to trace the international impacts in a national model, however.

The magnitude of these effects will be simulated in the next months. The national macroeconomic model ensures that indirect and induced effects will be accounted for. Rebound effects will be traced on the mesoeconomic and the macroeconomic (national) level according to the classification developed in Lange et al. (2019). Rebound effects are expected to be highest in case 1) - autonomous energy efficiency improvement, and lowest in 4) - energy efficiency driven by prices. Different sensitivity analyses and different model specifications (e.g. regarding consumption functions, investment, international trade) will be tested concerning their impact on measured rebound effects. Elasticities of substitution for industry from ex-post estimations (using very detailed cost structure data from German manufacturing) will be also tested. Finally, it is planned to develop rebound-proof policies with stakeholders.

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References

Ahlert, G., Distelkamp, M., Lutz, C., Meyer, B., Mönnig, A., Wolter, M.I., 2009. Das IAB/INFORGE-Modell, in: Schnur, P., Zika, G. (Eds.), Das IAB/INFORGE-Modell. Ein sektorales makroökonometrisches Projektions- und Simulationsmodell zur Vorausschätzung des längerfristigen Arbeitskräftebedarfs. IAB-Bibliothek 318, Nürnberg, pp. 15-175.

Allan, Grant; Hanley, Nick; McGregor, Peter; Swales, Kim; Turner, Karen (2007a): The impact of an increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom, in Energy Economics 29, 779-798.

Allan, Grant; Gilmartin, Michelle; Turner, Karen; McGregor, Peter; Swales, Kim (2007b): UKERC Review of Evidence for the Rebound Effect. Technical Report 4: Computable general equilibrium modelling studies.

Antal, Miklos; van den Bergh, Jeroen (2014): Re-spending rebound: A macro-level assessment for OECD countries and emerging economies, in Energy Policy 68, 585-590.

Banning, Maximilian; Lutz, Christian (2019): Rebound effects in macroeconomic models. Approaches to cover and reproduce, Working Report 2 of the research project ReCap.

Barker, Terry; Foxon, Tim (2008): The Macroeconomic Rebound Effect and the UK Economy – Research Report.

Böhringer, Christoph; Rivers, Nicholas (2018): The energy efficiency rebound effect in general equilibrium, Oldenburg Discussion Papers in Economics, No. V-410-18, University of Oldenburg, Department of Economics, Oldenburg.

Broadstock, David; Hunt, Lester; Sorrell, Steve (2007): UKERC Review of Evidence for the Rebound Effect. Technical Report 3: Elasticity of substitution studies.

Chakravarty, Debalina; Dasgupta, Shyamasree; Roy, Joysahree (2013): Rebound effect: how much to worry?, in Current Opinion in Environmental Sustainability 2013 5, 216-228.

Colmenares, Gloria; Löschel, Andreas; Madlener, Reinhard (2018): The Rebound Effect and its Representation in Energy and Climate Models, FCN Working Paper 16/2018, Aachen.

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

Holm, Stig-Olof; Englung, Göran (2009): Increased ecoefficiency and gross rebound effect: Evidence from USA and six European countries 1960-2002, in Ecological Economics 68, 879-887.

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

Koesler, Simon; Swales, Kim; Turner, Karen (2016): International spillover and rebound effects from an increased energy efficiency in Germany, in Energy Economics 54, 444-452.

Lange, Steffen; Banning, Maximilian; Berner, Anne; Kern, Florian; Lutz, Christian; Peuckert, Jan; Santarius, Tilman; Silbersdorff, Alexander (2019): Economy-Wide Rebound Effects: Policies based on theoretical and empirical bottom up and top down analyses.

Lehr, U. & Lutz, C. (2016): German Energiewende - quo vadis? In: Bardazzi, R., Pazienza, M. G., Tonini, A. [eds.]: European Energy and Climate Security. Public Policies, Energy Sources, and Eastern Partners, pp. 203-232, Springer.

Lehr, U., Lutz, C., Edler, D., 2012. Green jobs? Economic impacts of renewable energy in Germany. Energy Policy 47, 358-364.

Lehr , U., Ulrich, P, Lutz, C., Blazecjzak, J. & Edler, D. (2019): Beschäftigungschancen auf dem Weg zu einer Green Economy – szenarienbasierte Analyse von (Netto-) Beschäftigungswirkungen, im Erscheinen.

Lin, Boqiang; Li, Jianlong (2014): The rebound effect for heavy industry: Empirical evidence from China, in Energy Policy 2014.

Lindenberger, D., Lutz, C. & Schlesinger, M. (2010): Szenarien für ein Energiekonzept der Bundesregierung. Energiewirtschaftliche Tagesfragen, 60(11), S. 32-35.

Lutz, C., 2011. Energy scenarios for Germany: Simulations with the model PANTA RHEI, in: Mullins, D, Viljoen, J, Leeuwner, H. (ed.). Interindustry based analysis of macroeconomic forecasting. Proceedings from the 19th INFORUM World Conference, Pretoria, pp.203-224.

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

Lutz, C., Meyer, B., Nathani, C., Schleich, J., 2005. Endogenous technological change and emissions: The case of the German steel industry. Energy Policy 33, 1143-1154.

Lutz, C., Zieschank, R. & Drosdowski, T. (2017): Measuring Germany's Transition to a Green Economy. In: Low Carbon Economy, 8, pp. 1-19.

Maier, T., Mönnig, A., Zika, G. (2015): Labour demand in Germany by industrial sector, occupational field and qualification until 2025 - Model calculations using the IAB/INFORGE model. Economic Systems Research, 27, 19-42.

Pollitt, H., Alexandri, E., Anagnostopoulos, F., De Rose, A., Farhangi, C., Hoste, T., Markkanen, S., Theillard, P., Vergez, C., Boogt, M. (2017): The macro-level and sectoral impacts of Energy Efficiency policies. Final report. European Union, July 2017.

Prognos, EWI, GWS, 2010. Energieszenarien für ein Energiekonzept der Bundesregierung. Study commissioned by the Federal Ministry of Economics and Technology (BMWi), Basel, Köln, Osnabrück.

Rausch, Sebastian; Schwerin, Hagen (2018): Does Higher Energy Efficiency Lower Economy-Wide Energy Use? CER-ETH Working Paper 18/299, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3272225 [07.03.19].

Saunders, Harry D. (2000): A view from the macro side: rebound, backfire and Khazzoom-Brookes, in Energy Policy 28, 439-449.

Sorrell, Steve; O'Malley, Eoin; Schleich, Joachim; Scott, Sue (2004): The Economics of Energy Efficiency – Barriers to Cost-Effective Investment. Edward Elgar, Cheltenham.

West, G.R. (1995): Comparison of input-output, input-output + econometric and computable general equilibrium impact models at the regional level, in Economic Systems Research 7, 209-227

Zika, G., Helmrich, R., Maier, T., Weber, E. & Wolter, M. (2018): Arbeitsmarkteffekte der Digitalisierung bis 2035: Regionale Branchenstruktur spielt eine wichtige Rolle. (IAB-Kurzbericht, 09/2018), Nürnberg.