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ReCap Working Report 2

Rebound effects in macroeconomic models

Approaches to cover and reproduce

Imprint

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This paper is part of the research project "ReCap - Reconsidering the Role of Energy and Resource Productivity for Economic Growth, and Developing Policy Options for Capping Macro-Level Rebound Effects". The project is part of the funding measure „Rebound-Effekte aus sozial-ökologischer Perspektive", funded by the Federal Ministry of Education and Research (BMBF) in Social-Ecological Research (SÖF).

Funding code 01UT170

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

For more information about the project: www.macro-rebounds.org

Osnabrück, February 2019

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

FONA Sozial-ökologische Forschung BMBF

Abstract

In the following, a selection of the three established model types used for the estimation of rebound effects at the macroeconomic level is presented according to detailed publications: These are analyses using a macroeconomic growth model, two CGE models and a macroeconometric model. The examination provides insights for own simulations with the macroeconometric model PANTA RHEI for the analysis of macroeconomic rebound effects and policy measures limiting them.

The methodological approach is comparable: an initial scenario that represents the status quo is compared with an alternative scenario in which energy efficiency is increased. When considering the model approaches, however, relatively large differences can be noted between the models: Model parameters and thus also the results differ significantly, although the causal shocks of an increase in energy efficiency are largely the same.

For the upcoming modelling of rebound effects, the overview provides important insights regarding the mapping of the rebound effect itself and central parameters for sensitivity calculations. Thus, an autonomous increase in energy efficiency and an increase in energy efficiency triggered by investments will be analysed separately in the further course of the project. Important elasticities are varied in order to isolate the impacts on the overall effects. However, the synopsis is of little help to the project's central question of mapping policy measures that reduce the rebound effect.

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List of abbreviations

CES .... **constant elasticities of substitution**

CGE .... **computable general quilibrium**

CPI .... **consumer price index**

EC .... **European Commission**

Et al. .... **et alii**

GDP .... **gross domestic product**

GTAP .... **Global Trade Analysis Project**

i.e. .... **id est**

IEA .... **International Energy Agency**

KLEM .... **Capital, Labour, Energy, Material**

MDM-E3 .... **Multisectoral Dynamic Model – energy-environment-economy**

n.a. .... **not available**

ROW .... **rest of world**

UK .... **United Kingdom**

US .... **United States of America**

1 Introduction

In the constantly growing 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 come to the little concrete statement that the effects range from near zero (no rebound) to greater than one (backfire). Chakravarty et al. (2013) serves as an example. 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. Certainly not (only) the methods can 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 considered when considering the respective levels. Microeconomic effects act on the individual level of an economic unit, i.e. a consumer or company. Here a distinction can be made between direct and indirect as well as substitution and income effects (for detailed explanations 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 and location decisions by companies, energy prices and macroeconomic multipliers should also be mentioned here.

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 1) macroeconomic (growth) models that are closely linked to economic theory, 2) 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 3) 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 studies and simulation models with integrated assessment models being distinguished as a fourth model type. A current study for the EC (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).

In this paper, 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 are analyses using a macroeconomic growth model, two CGE models and a macroeconometric model. Their similarities and differences are highlighted in this publication. The aim of the considerations is to gain insights for our own simulations for the analysis of macroeconomic rebound effects and for the definition of policy measures limiting rebound effects in the project using the macroeconometric model PANTA RHEI.

On the basis of the template shown in the appendix, various model-based analyses of rebound effects were selected and interesting approaches were classified with regard to the envisaged modelling in ReCap. Against this background, the selection of the publications was based on the following criteria: the model under consideration 1) examines a macroeconomic or economic-wide rebound as defined in Lange et al. (2019), 2) is explained in sufficient detail, which allows the examination of individual influencing factors, underlying assumptions, and variables, and 3) is presumably of relevance for the modelling approach aimed at in the ReCap project not only because of this detailed information but also because of the spatial boundary and the capturing and mapping of the rebound effects.

While the analysis of rebound effects at the micro level, especially with regard to the analysis of direct rebound, is now a widely studied subject in the literature, the analysis of macroeconomic rebound effects is less common (Lange et al. 2019). For studies that go beyond the company or household level, highly aggregated empirical models are also sometimes used (e.g. Antal et al. 2014, Holm et al. 2009), whose depth of modelling naturally does not meet the needs of the intended project. Another problem is that findings for economies that are difficult to compare with Germany may not be transferable, which further limits the choice. This applies to 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).

In addition to the above criteria, the selection of the research contributions described in detail below fulfils the objective of covering the range of different model types and theoretical approaches. The four models examined based on a publication as comprehensive as possible 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 used by Barker et al. (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 can also fully capture global effects of national energy efficiency measures. All publications are characterised by a relatively high level of detail in the model description. They are briefly described in section 2 with a view to key model properties for determining rebounds. Section 3 then describes the efficiency shocks that are introduced into the models. By comparing the initial situation or a development without this shock, section 4 shows size and characteristics of the rebounds. Section 5 concludes with findings that ensue for the own modelling with PANTA RHEI in the context of ReCap.

2 Model approaches

The approach of Saunders (2000) can be classified as a macroeconomic model that only considers the total economy. Although the impact of energy efficiency improvements on GDP of a national economy is not explicitly determined in the analysis, the approach applies theoretical considerations and plays through different sets of assumptions. This yields potential insights into determinants of the rebound, i.e. the influence of certain settings on the macro rebound.

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, serve as examples of CGE modelling. Like Saunders (2000), the models are based on neoclassical assumptions, although they are oriented towards microeconomics. Following the optimisation decisions of households and companies, 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 would be underestimated (cf. also Sorrell et al. 2004).

In both cases, the economy does not consist of an aggregated total, but 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 of which represent energy production.

The MDM-E3 developed by Barker et al. (2008) combines econometric time series data and input-output data. The modelling of demand and investment is (post-) Keynesian motivated, 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 over 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.

The underlying production functions are explicitly specified with the exception of the MDM-E3 model. Saunders (2000) uses a Cobb-Douglas function that considers labour, capital, and energy as input factors. UKENVI uses multi-level production functions with constant elasticities of substitution. The energy component is composed of an electricity and a non-electricity component, the first of which is divided into renewables and non-renewables, the latter additionally between oil, coal and gas. The energy component together with the non-energy component, which contains all other goods, results in the component produced in the domestic economy (in this case the UK). Together with the activities of the rest of the world, the intermediate consumption results. Together with value added - differentiated into capital and labour – it adds up to output. Exports and imports are determined using an Armington structure (cf. Armington 1969), which makes them sensitive to relative price changes. The goods of the domestic economy compete with imports from other countries, whereby a preference for domestic goods prevails, i.e. they are imperfect substitutes. Both imports and exports have an Armington elasticity of 5 for electricity and 2 for goods in all other sectors. Koesler et al (2016) use a KLEM production structure in a similar way. Capital and labour at the lowest level are initially combined with energy for the production of goods and other materials (intermediate consumption) at the highest level. Here, too, foreign trade is modelled on the basis of the Armington structure; the associated elasticities are taken from GTAP7 (Badri et al. 2007). In MDM-E3 different factor demand functions are estimated separately and the energy demand for different energy sources and consumer groups is explicitly mapped in an energy module. As a rule, energy savings are only possible through corresponding investment and thus changes in the capital stock.

The importance of the substitution elasticities of energy and other input factors for the model results and the level of rebound is not only emphasized by Saunders (2000). Their influence can be found in all models considered and is partly investigated in sensitivity analyses. In Saunders (2000), in addition to energy, labour and capital also enter the production (GDP) determination equation. Using the Cobb-Douglas function mentioned above results in the implicit assumption of a substitution elasticity of 1 for the variables under consideration. 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. The elasticities are constant for the whole course of the respective function (CES, constant elasticity of substitution) and usually < 1. 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 country under consideration. The value of the elasticity of the energy component to labour and capital is on average between 0.15 (construction) and 0.72 (coke, refined petroleum and nuclear fuel), in the manufacturing sector the median value is 0.53. The value of the elasticity of the energy component to labour and capital is between 0.15 (construction) and 0.72 (coke, refined petroleum and nuclear fuel).

Table 1: Overview over central characteristics of the presented models

	Saunders (2000)	**Allan et al. (2007a)**	**Barker et al. (2008)**	**Koesler et al. (2016), nach Sektoren**
Model type	Theoretical macroeconomic model	E3-CGE (UKENVI)	National macroeonometric 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)		Electricity and Gas: 0.46 Services: 0.28 Transport: 0.5 Construction: 0.15 Manufacturing: 0.53 Coke. Refined Petroleum and Nuclear Fuel: 0.72 Food, Drink and Tobacco: 0.19 Primary: 0.39 (between Energy and Capital & Labour, median values over all countries)

It is to be seen critically that the substitution possibility of energy and other production factors is assumed to be given in the CGE models, although econometric estimates, depending on country and industry, do find evidence for both substitution and complementarity of energy and capital (Broadstock et al. 2007).

In MDM-E3 the elasticities are determined by time series estimates. Long-term output elasticities are in the range of 0.1 to 0.75, with particularly high elasticities in transport and metal production. If the respective (physical) activity such as output, income or transport performance is increased by 1%, energy consumption increases by 0.1% to 0.75%. Quantifications on price elasticities are not found in the publication.

Three of the four models examined concentrate their analysis on a single national economy. Both Barker et al. (2006) and Allan et al. (2007a) examine the rebound using the example of the United Kingdom. In Koesler et al. (2016), Germany is the starting point, but the European and global regions are at the centre of the further investigations.

With regard to the time dimension, Saunders (2000) and Allan et al. (2007a) are similar to the extent that in both cases short and long-term effects are contrasted in the future - the latter estimate the period referred to as "long-run" at more than 25 years. Koesler et al. (2016) also simulate a hypothetical development in the future, but remain uncertain here. In principle, CGE models do not represent a concrete time. Barker et al. (2008) examine the concrete period from 2000 to 2010, i.e. it covers both the past and the future at the time of the work.

As a conclusion of the comparison, the large differences between the models have to be noted: Model parameters and thus also the results differ significantly, although the causal shocks of an increase in energy efficiency are largely the same. If possible, assumptions and settlements should be checked for their significance for the results by means of sensitivity analyses.

3 Central scenarios and shocks to capture rebound effects

Fundamental cause of the rebound effect is an increase in energy efficiency in all models, with the source, extent and sectors affected differing from model to model. Table 2 gives a schematic overview in this respect. 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 concrete terms, it takes the form of a change in the parameter τ_F which enter the production function as *fuel efficiency gain* multiplicative to the fuel parameter: $Y = f(K^a, L^b, \tau_F * F^{1-a-b})$, with total output Y being dependent on capital (K), labour (L) and fuel (F). An increase in τ_F increases the marginal productivity of energy. Saunders is not primarily interested in the size of the rebound, but in the change in production. In the short term, an increase in energy efficiency under the assumption that capital and labour remain unchanged increases both production and energy consumption. Thus, backfire is implicitly applied in the model. Under neoclassical assumptions, the short-term increase in production leads to a higher output level of the economy in the long run.

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. It is then examined how this affects the physical amount of energy used by these sectors and how it relates to efficiency gains. In the simple case that energy prices are kept constant, the impact chain is as follows: According to the authors, the increase in energy efficiency has a direct effect on the price of energy measured in efficiency units, while the price of energy measured in physical units remains unchanged. The extent to which energy consumption increases or decreases as a result is determined by the price elasticity of energy demand. For values greater than 1, the sum of energy expenditures increases, resulting in an increase in energy consumption. In addition, there is a substitution effect caused by companies increasing the energy intensity of their processes because energy has become relatively cheaper. This also has an impact on output as companies increase their production against the background of lower production costs and increased competitiveness. The more energy-intensive an industry is, the stronger its competitive advantage is through an increase in energy efficiency, because the relative price of its produced goods decreases. Both effects increase the energy consumption of the sector. When looking at consumers, it should also be noted that real income increases as a result of lower energy prices. This also applies to real wages and labour supply, so that overall output continues to rise. The authors also draw attention to the fact that if energy production is mainly domestic, the price of energy in physical units is endogenously determined by the model, which increases the extent of the rebound effect. Other determinants of the extent of the rebound are the degree of openness of the economy, elasticities of other production factors, the energy intensity of single production sectors and of final demand, the substitution elasticities between consumption goods, and the income elasticity of demand.

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 8 sectors under consideration, scenario 2). The amount of the rebound is then calculated for the individual sector (only possible in the first case, since in the latter one 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 the world. This is done by multiplying the resulting changes in energy consumption by their share of the aggregate under consideration and relating them to the original impulse. For each of the eight sectors considered, as a result of the increase in energy efficiency, substitution towards energy (measured in efficiency units) as an input factor occurs, as energy has become more competitive. The energy input, measured in physical units, decreases relatively to the output. As in the case above, the competitiveness of the sector also increases, as it is assumed that the price of these products decreases as a result of the decline in input costs. The lower price in turn leads to higher demand. In the case of energy efficiency improvements in all manufacturing sectors (scenario 2), the increase in competitiveness depends on the energy intensity of the respective sector. Koesler et al (2016) make the assumption that production factors are given and fully utilised, implying that output cannot increase in all sectors at the same time. The factors become more expensive as a consequence, so that individual sectors lose competitiveness, even though their energy efficiency has improved. If the scope of the analysis is extended to include effects abroad, the efficiency shock operates through three channels: The relative competitiveness of the other countries changes when the output prices of a domestic sector change. As a result, there are also shifts in energy demand, so that energy imports and exports change. Changes in trade demand in turn affect the entire value chain of corresponding products and thus influence energy demand. The authors also cite as possible, but less important, consequences relative changes of energy prices as a result of a change in the energy intensity of production and changes in demand due to changing terms-of-trade.

In the MDM-E3 model, the increase in efficiency is measured 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 consideration of the direct rebound, taken from other studies. 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. While both nominal incomes and energy prices remain constant for the time being, a resubstitution to energy takes place against the background of lower energy costs and, in addition, the income effect increases expenditure on all goods, both energy and other consumer goods. In the case of energy efficiency increases by companies, this is a cost reduction for the use of energy, which results in a drop of prices and an increase in profits for companies that now produce more efficiently. The original decline in energy use is reduced by higher energy demand resulting from increased demand for products of the more efficiently producing company. The substitution effect cited here is the replacement of labour by energy, which depends on respective price and wage elasticities. Whether lower costs are also passed on to the final consumer in the form of lower prices depends on the price-setting behaviour of companies. If prices are oriented towards the world market, they remain unchanged and companies achieve higher profits. If prices are determined by the domestic market, they fall and real incomes of consumers and export demand rise. Consumers then substitute the cheaper products; the higher demand increases the output and thus also the demand for energy. In this regard the model differs from the CGE models in which prices always react to efficiency increases.

With the exception of Barker et al. (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. In concrete terms, 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.

4 Model results

Barker et al. (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 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 alternative scenario 2 (47%). Depending on the chosen scope, the rebound can reach up to 57% (rebound in manufacturing in scenario 1). In the authors' view, the thesis that an extension of the scope of investigation goes hand in hand with a higher value of the rebound can be rejected on the basis of the model results. In both scenarios the worldwide rebound is lower than the EU-wide rebound.

In all models, an increase in energy efficiency 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) also come to the 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), 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 results for the rest of the European Union are less clear: the rest of the European Union subsequently experiences a decline in GDP, albeit relatively small (-0.001 % and -0.005 %, 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 et al. (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 et al. (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%
Employment effect	n.a.	+0.21%	+0.8%	n.a.
Price effect	n.a.	CPI: -0.27%	GDP-deflator (end of the period; 2010): -2.4%	Scenario 1: Prices of goods in German manufacturing fall (-0.08%), while rising in all other sectors Scenario 2: Energy prices decrease world wide

Both Barker et al. (2008) and Allan et al. (2007a) note 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 et al. (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), although the prices of the industry affected by the efficiency increase are falling, the consumer price index, on the other hand, is rising both in the context of the national economy and EU-wide in both scenarios. The consumer price index for the rest of the world remains constant in both cases.

5 Conclusion and outlook - findings for modelling in ReCap

Rebounds at mesoeconomic and macroeconomic level are determined in ex ante analyses carried out using macro, CGE- and macroeconometric models. A selection of the three established model types was presented above based on detailed publications. On the basis of the raster shown in the appendix, various model-based analyses of rebound effects were selected and interesting approaches were classified with regard to the intended modelling in ReCap.

In each of the model analyses, a scenario with an increase in energy efficiency is compared with a reference without this assumption. In all cases, this autonomous increase in efficiency has a direct effect on the production function of the economic unit under consideration. It thus also refers - partly exclusively, partly only directly - only to the production part or the companies of an economy. With the exception of Barker et al. (2008), private households are only indirectly affected, if at all, by efficiency gains through lower prices of consumer goods and more employment and thus disposable income. If the increase in efficiency is accompanied by additional investment by companies, Allan et al. (2007a) show in a sensitivity that this has a drastic effect on the size of the rebound and can even counteract it completely - but this at the expense of output and employment growth.

In all cases, elasticities along the cause-impact chain are responsible for the size of the rebound effects. The substitution elasticities of energy in the production process are of great importance, regardless of the type of production function used.

If foreign countries are also included in the analysis, Armington elasticities, which describe the preference for domestic products, influence bilateral trade. In the studies by Koesler et al. (2016) at least, a specific analysis of private households shows that the size of rebound increases with increasing elasticity of substitution in consumption. The possibility that energy and capital in individual industries could be complementary and not substitutive to each other is not considered (Broadstock et al. 2007).

While the majority of the models considered model the causal shock as an autonomous increase in energy efficiency, Barker et al. (2008) point out the possibility of specifically attributing energy savings to individual policy measures (with associated costs and behavioural adjustments). For this approach, however, a comprehensive analysis of each considered policy measure seems to be unavoidable, which will be carried out within ReCap for various sets of measures. Ideally, such an analysis already includes the consideration of direct rebound effects.

Another aspect highlighted by the authors as significant for the level of rebound is the value chain of the energy producing sector(s) itself. Both Allan et al. (2007a) and Koesler et al. (2016) point out that energy production is usually energy-intensive. A decline in the demand for electricity in a sector whose energy efficiency is increasing results in a lower demand for energy in the power generation process itself. So, the rebound is weaker. At the same time, it can be assumed that the competitiveness of this sector will increase disproportionately as a result of an efficiency shock due to its high energy intensity, which, as explained above, leads to higher demand in the event of a price reduction, i.e. potentially increases the rebound. In this context, Allan et al. (2007a) show that energy prices fall more sharply in the short term than in the long term.

According to Allan et al. (2007a), the level of rebound effect also depends on the share of domestic energy production. Since this share is significantly higher in Great Britain and the USA than in Germany, smaller effects would be expected in quantifications for Germany.

Barker et al. (2008) emphasize the importance of treating technical progress in models and the consideration of learning curve effects. The size of substitution elasticities between competing technologies is of crucial importance here. The authors argue in favour of linking top-down and bottom-up modelling.

When looking at an individual economy, it is also important which products are additionally consumed due to increased household income. Barker et al. (2008) point out that these may contain a very small proportion of domestic energy, which makes the national rebound appear low, but increases energy consumption abroad. In the case of the UK, this applies in particular to imported cars and long-distance travel. For similar reasons, a differentiation should also be made in the sources of energy considered, savings in gas and electricity produced in the UK would be offset by a higher use of petroleum products. However, Koesler et al. (2016) limit the hypothesis that the size of the rebound effects will increase with the spatial extension of the model boundaries, since the results of their model contradict this.

For the envisaged modelling of rebound effects in the macroeconometric model PANTA RHEI, this overview provides important insights into the mapping of the rebound effect itself and central variables for sensitivity analyses. Thus, an autonomous increase in energy efficiency and an increase in energy efficiency triggered by investments will be analysed separately in the further course of the project. Important elasticities are varied in order to isolate the impacts on the overall effects. However, the synopsis is only of limited little use for the project's central question of mapping policy measures that reduce the rebound effect. On the one hand, the literature on policy measures against rebound (Lange et al. 2019) should be reviewed more closely in this respect. On the other hand, further modelling work should be considered that explicitly included policy measures, presumably also those that did not explicitly concentrate on rebound effects.

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7 Appendix

Evaluation template for model-based rebound analysis

Publication (authors, source)

Subject of investigation

- Spatial (country, international)
- Institution (economy, sector(s))
- Temporal (short-term, long-term)
- Definition of rebound
- Which kind of rebound is referred to?
- Effects besides market price effect, explaining the macro rebound?

Model approach

- Model type (CGE, macroeconometric,…)
- Production function (/structure)
- Elasticities of substitution
- (Further) sensitive assumptions/parameters (e.g. labour market modelling,…)
- Number of sectors
- Link to more detailed model documentation

Central scenario/shocks

- How is the rebound modelled?
- What is the comparison (autonomous increase of energy efficiency, policy measures, reference case)?
- Energy price reaction
- Sensitivity analysis (and its conclusion for impact on rebound effects)

Results

- Rebounds (economy-wide, macroeconomic)
- GDP
- Employment
- Prices
- Sectors? (not detailed, e.g. „particularly high rebounds for energy-intensive industry“ or similar)

Authors' own assessment ((dis)advantages of the approach, placement of own results in the literature)

Special aspects