POLFREE
Policy Options for a Resource-Efficient Economy

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Report about resource reduction cost curves for material consumption in different MS and sectors

WP 1 – Why have resources been used inefficiently?

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1. Introduction

Marginal Abatement Cost Curves (MAC) for the abatement of CO2-emissions play an important role in the discussion of alternative approaches in energy policy. They show the potential and the costs of alternative measures of CO2 abatement in a graph with the costs of the different measures on the y-axis and a horizontal aggregation of the abatement potential of the different measures on the x-axis. The information given with the graph can be based on expert knowledge or it can be derived from the application of a model. Kesicki & Strachan, 2011 gives an overview of the literature. Expert based cost curves are based on bottom-up information, i.e. on detailed technical descriptions of different technologies that allow direct calculations of their respective installation costs. A very popular example is the marginal abatement cost curve produced by the consultancy McKinsey Enkvist et al., 2007.

There are several problems with expert based curves: First the graph indicates the cost, which is induced by the abatement of the last unit of emissions. This needs a reference without an emission constraint, which the expert based information of course in the strict sense does not have. Further the assumptions behind the expert based curve are not made explicit Kesicki & Strachan, 2011. Kesicki & Ekins, 2012 stress the point that various types of interdependencies and inter industry relations, international interactions and the macroeconomic closure etc. are not mentioned. They argue that this information could also be condensed out of the simulations with an economic environmental model. Kesicki, 2010 concluded that model derived cost curves should always be used in the case of incentive based instruments.

The paper at hand transfers the conceptual MAC idea to global materials flows analyses by means of extensive model simulations. The applied approach builds on previous own research (see Meyer, 2012 and the references therein) which has most recently also been adopted by Cambridge Econometrics & BIO Intelligence Service, 2014.

Introductory details with regards to the study design will be outlined below. Before, we would like to provide some annotations in order to ease the interpretation of results. In the study at hand we document the simulation results for (changes in) “global resource extractions” and not the (changes in) “EU 27 raw material inputs (RMI) or raw material consumption (RMC)”. Background for this is the dynamic character of the analysis. Although the first tipping point of the different simulation experiments always occur within the EU27 the reactions of the different actors (producers, consumers) are widespread around the world. Therefore the right labeling of the results is the “change in global resource extractions” that is induced by initial changes in some specific technological changes within the EU27. In contrast to this RMI and RMC figures are always based on static MRIO-Analysis.[1] Despite these conceptual differences there is much to suggest that the change in global resource extractions and change in EU27 RMI are nearby. But on the other hand the change in global resource extractions should by no means used as an indicative for the change in EU27 RMC especially in those cases where the decrease of inputs in production refers to production processes with notable export shares.

In the study at hand we have been able to apply the $GINFORS_3$ model. $GINFORS_3$ represents a dynamic Input-Output simulation model which is based on a comprehensive MRIO database. Compared to its predecessor $GINFORS_2$, which has, i.a., been applied by Meyer, 2012, $GINFORS_3$ marks an extensive model relaunch. Substantial model features will be outlined within section 2. However, at this point we would already like to point out that $GINFORS_3$ covers the whole world (even the region "Rest of World" is now represented by a fully employed IO-model). Besides, input coefficients, e.g., have been endogenised for all modelled economies. In case of $GINFORS_2$ this applied only for 17 European economies. Moreover, as regards resource modelling, the underlying classification of product groups now allows for a much better fit between resource extractions (in physical units) and economic activities (in monetary terms) as $GINFORS_3$ maps bilateral trade shares for 59 product and service groups. In case of $GINFORS_2$ this applied only for 25 product and service groups.

The study starts with the identification of the 30 most important input coefficients in the EU27 with regard to global resource extractions (see chapter 3). Already this first step is quite ambitious and delivers new results:

- Thematically related previous applications of input-output-techniques/models tended to focus on selected final demand categories or individual sectors (see i.e. BIO Intelligence Service, 2013). The study at hand goes a step further: It identifies specific (technical) elements within the production processes of the different sectors that are most important for resource use.

- In a previous study of GWS with regard to the economic benefits or costs of resource use reductions (see Meyer, 2012) the execution of this first step was abandoned. Instead results from a study for Germany (see Distelkamp et al., 2005) were used for applications across Europe. Not only that the cited results for Germany are more and more out-dated. They were also derived on base of a model that from a contemporary perspective would not meet the needs for a comprehensive consideration of global supply chains. And last but not least, as our results for the different Member States show the transfer of results (for the importance of different IO coefficients) from one country to another is more than critical.

[1] The implementation of an algorithm that allows the calculation of the RMI and RMC indicator of single countries based on the GINFORS database (historical as well as scenario results) is subject of nearly finalised work within a research project funded by the German Federal Environment Agency.

In the second big step of this study (chapters 4 to 5) we ask for the economic and environmental impacts of changes in production structures within the EU. Each time we compare a hypothetical situation with lower input coefficients with a baseline case without these changes[2].

We start these model applications with two simulation experiments in which the respective input coefficients are lowered without asking for reasons, limitations or extraordinary costs to achieve these reductions. But is this a legitimate setting and what are the policy lessons that can be learned from the findings of these simulation experiments?

To answer this fundamental question with regard to main empirical results of the paper some hints may help:

- Although the first simulation experiments set aside specific assumptions about investment needs for a change in production technology (input coefficient reduction), indeed all direct and indirect effects (e.g. on other intermediate inputs and capital needs of the respective industry) are covered by the model due to the endogenous mapping of these interdependencies by GINFORS$_3$.

- The assumed reduction of input coefficients by 10% is far beyond the standard deviation of these input coefficients comparing the observations for one year in different countries. Although these differences between countries not only hint at differences in (resource in-) efficiencies but also can be attributable to the inhomogeneity of industries nevertheless a comparison of the 10% assumption with the standard deviations emphasizes the cautious character of the simulation settings.

- Nevertheless the empirical results of the two first simulation experiments should not be misinterpreted as results of profound scenario studies that analyze the impacts of efficiency changes based on detailed bottom-up information for specific technological options or the impacts of specific policy instruments that might impose a change in resource efficiency.

In summary the results of the two first simulation experiments should be interpreted as follows:

> "If at some very important (technological) intervention points (input coefficients) a limited reduction by 10% could be achieved rather by a more cautionary use of these inputs than by comprehensive re-arrangements of the whole production process the given effects (on the economy and environment) would occur."

Therefore the main policy lessons that can be learned from simulation experiments are:

[2] That we execute the analysis on an ex-ante basis rather than an ex-post view has solely technical reasons.

- If the simulation results indicate a remarkable potential for resource savings and a potential for economic benefits – and they clearly do so – the first policy goal should be to give support in the identification and remediation of inefficiencies.

- In a next step – and this is beyond the scope of this study - those intervention points (input coefficients) that prove to be resistant against (soft) policy measures should be investigated further. Are there specific needs or constraints that hinder progress towards a more resource efficient production?

Although it has been shown that the legitimacy of the first two simulation experiments is given not only from a scientific viewpoint the authors are well aware of some limitations of the set-up. Therefore in last step of this study the results of a sensitivity analysis are given. This sensitivity analysis asks for changes in the results if the assumptions of the (second) simulation experiment are changed:

1) If the reduction in input-coefficients cannot be achieved by voluntary learning processes but needs an increase of taxes to impose the intended behavioral change.

2) If the achievement of reductions in input-coefficients needs some initial investments and expenditures for external consultancy that are not covered by the endogenous reactions covered by the model.

The overall ambition of the study is to answer the following questions:

- What are the most important inputs in industrial production within EU27 for global resource extractions? This is the question announced in chapter 3 of this study.

- Will win-win situations occur for the EU as a whole, if we look at the results of the simulations for input coefficient changes? This is the question about the benefit (or cost) curves of resource efficiency increase.

- What kind of resource is affected by the different simulation experiments? Are there predominantly extractions within the EU27 territory affected or does the resource efficiency increase also contribute to a decrease of resource extractions outside the EU27? This analysis gives important hints if resource policy does not only want to look at the resource aggregate but rather focus on specific kinds of resources. And it gives hints with regard to the economic vulnerability issue.

- Who are potential losers and winners of resource efficiency increases if we look at the industry level?

- Are all EU27 Member States affected in the same way if we analyze the consequences of an efficiency increase? Or are there potential winners and losers at the country level?

Focusing on the production side of the EU27 economy, our results indicate the potentials of simulated sector-specific efficiency increases. Given our findings from more than 2000 simulation runs with the global simulation model $GINFORS_3$, we should rather speak of benefit curves: Our results predominantly illustrate win-win situations where sustained mitigation of global raw material use is accompanied by increases in EU27 GDP.

According to our view, these results are quite notable as they have been derived by applications of a dynamic Multi Region Input Output (MRIO) model. Thus, induced rebound effects due to (i.a.) lower cost dynamics, rising value added and resultant income increases are captured by our simulation settings, even those that occur in time (see, e.g., Sorrell et al., 2009 or Chitnis et al., 2014 for references to the active discussion of rebound effects in energy policy).

The political relevance of rebound or even reinforcing effects is widely recognised in the energy and climate literature (see, e.g., Alcott, 2005 or Sorrell, 2009). Accordingly, quantitative assessments of energy-efficiency related abatement potentials by means of dynamic model simulations (see, e.g., Allan et al., 2007) already received significant attention in the past. However, as regards the resource-efficiency literature, it seems that the discussion of rebound as well as reinforcing effects rose much less public attention until now. Whereas we do not want to explore the causes of these circumstances we are thus convinced that assessments of resource-efficiency related abatement potentials by means of dynamic model simulations illuminate a research object which demands further attention.

According to our simulation results, rebound effects tend to diminish initial reductions in EU27's global raw material use. Nevertheless, we are able to identify widespread opportunities to support sustainable growth developments by resource-efficient production technologies. The paper is organized as follows: Section 2 introduces our methodological framework. Section 3 outlines our basic top down simulation approach. Section 4 presents the findings from various reliability tests and section 5 concludes.

2. General Characteristics of the Model GINFORS

2.1 Methodological Annotations

From a methodological viewpoint GINFORS might be characterised as a dynamic Input-Output simulation model which is based on a comprehensive MRIO database. GINFORS evolved from the COMPASS model (see Meyer & Uno, 1999, or Uno, 2002, for references with regards to the

COMPASS model) in the course of the MOSUS project.[3] As a global input-output simulation model, aims and scope of the GINFORS model are generally closely related to GTAP applications. However, whereas the later follows a standard Computable General Equilibrium (CGE) approach, GINFORS does not rely on long run equilibria of competitive markets or Say's law for a macroeconomic closure. Moreover, GINFORS assumes that agents have to make their decisions under conditions of bounded rationality on imperfect markets.

Yet, this section is not intended to echo relevant distinctive features with regards to CGE models. Interested readers are referred to Giljum et al., 2009 for a short comparison of COMPASS/GINFORS with GTAP or the related annotations of Wiedmann et al., 2007. We would rather like to point out that the modelling of bounded rationality is not a straightforward task: Apparently, the models' reaction functions cannot be derived explicitly by applications of plain optimisation calculus. According to our view, an empirical analysis of historical developments therefore represents the natural starting point for model calibration. Economic theory provides competing behavioural hypotheses which, for each reaction function under consideration, are subject to statistical falsification tests. Accordingly, GINFORS is often also classified as an econometric model (see, e.g., Wiedmann et al., 2007).[4]

The availability of historical time series datasets therefore constitutes a necessary condition for the implementation of our bounded rationality philosophy. WIOD (World Input Output Data Base, see Timmer, M. P. (Ed.), 2012 and Dietzenbacher et al., 2013), provides national time series of fully harmonized Supply and Use Tables (SUTs) together with consistent sets of environmental time series data.[5] As the first release of this database had been published shortly before the POLFREE project started, we decided for exhaustive model revisions in order to incorporate its distinguished information on ongoing globalisation trends in our POLFREE modelling tasks. Completed by population and SNA datasets of the UN Statics Division and financial data of the International Monetary Fund, our model now enables us to simulate global developments until the year 2050, especially with regards to:

- the evolution of 35 industries in 38 national economies and a Rest of World region,
- international patterns of trade for 59 products,
- the resulting effects on main economic aggregates of national economies (e.g., public debt or disposable income of private households),

[3] The MOSUS project was funded by the Fifth Framework Programme (FP5) of the European Union. In this project GINFORS was used to simulate sustainability scenarios until 2020. See http://www.mosus.net/ for details.

[4] This paper should not be occupied by lengthy taxonomic discussions. Thus, we will retain to this well established label. But for being precise, we like to annotate that other research disciplines would most likely prefer a distinction between econometric textbook models, and (i.a.) models of the INFORUM type as suggested by Almon, 1991. Actually, GINFORS accrued from the INFORUM philosophy which is characterized by a comprehensive mapping of variable Input Output Coefficients by means of econometric regression techniques.

[5] WIOD is publicly availabe and was funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Grant Agreement no: 225 281.

- emissions stemming from 28 energy carriers
- and global resource demand (incl. water demand and agricultural land use).

Therefore, as will be outlined within the following subsection, our redesigned GINFORS model now features significant advancements compared to previous state of the art releases (for references to previous state of the art releases see, e.g., Giljum et al., 2008, Lutz, 2010, or Stocker et al., 2012).

2.2 The General Structure of GINFORS

The following pages are intended to ease the interpretation of the subsequent results section. In order to provide our readers with necessary information for an unambiguous appreciation of our simulation framework, we restrict the following annotations to an introductory overview of key features of the new GINFORS model. Readers with interests in more detailed model illustrations are referred to Meyer et al., 2013 or Meyer & Meyer, 2014.[6]

From a logical perspective, four interdependently linked modules can be distinguished: The economy module, the bilateral trade module, the energy-emissions module and the resource module.[7] The following paragraphs provide introductory insights into their respective modelling approaches.

2.2.1. The economy module

For 38 national economies[8] and a Rest of World region the economic relationships are modelled by individual economy modules with market clearing mechanisms. Suppliers set mark-up prices with regards to local currency denominated unit costs and demanders take these prices as one determinant of their decisions. Suppliers produce the demanded volumes. This structure ensures a balanced influence of supply and demand on the solution of the model avoiding the supply dominance of neoclassical modelling. All macro variables like GDP and its components as well as aggregate price indices or employment are calculated by explicit aggregation from sectoral variables. In this sense the model has a bottom up structure as outlined below.

As regards the supply side, the following modelling scheme applies for any of the 35 industries of a given national economy:[9] The 35 industries are an aggregation of 59 product groups. The aggregation scheme is variable and defined by a time series of so called supply matrices. Input

[6] Due to the exhaustive nature of our latest revision works, previous model documentations should be considered as out-dated.

[7] Besides these four modules within the POLFREE project the GINFORS model will be extended by a detailed farming module that captures demand and supply for different agricultural products as well as land use decisions and water demand. This module enables a hard link with the biophyiscal model LPJmL (see Delivarables 3.2 and 3.4 with regard to these model extensions).

[8] These 38 national economies include all EU-27 member states but not Croatia.

[9] The Rest of World region exhibits a slightly less complex modelling scheme.

Coefficients for intermediate inputs are modelled as price dependent variables. In the case of energy inputs these coefficients are driven by the inputs of related energy carriers (which are predetermined in physical units by the energy module). The capital stock is calculated from gross investment and the depreciation rate by definition. Gross investment is explained by gross production and the interest rate. Labour input in hours depends on gross production and sectorial real wage rates which are influenced by an average macroeconomic wage rate (Phillips curve approach). Compensation of employees is given by definition; the number of persons engaged can be derived from the average working time per person and the employment in hours. Unit costs are given by definition. Basic prices for sectors agriculture as well as mining and quarrying are calculated by definition from the aggregation of 5 exogenous product prices for fossil fuels and minerals. For all other industry prices, unit costs and prices of competing import goods represent the relevant drivers. Domestic prices for 54 product groups are disaggregated from the industry prices via the supply matrix. Basic prices for the 59 product groups are defined as weighted averages of import prices and domestic prices. Purchasers' prices for the 59 product groups are derived from basic prices adding tax rates and transport and trade margins. For all 35 industries value added can be calculated subtracting the sum of intermediate inputs from gross production. For 59 product groups total use is defined as the sum of intermediate and final demand. Import shares are depending from the relation of the import price and the basic price. Gross output for the 59 product groups can be calculated subtracting imports from total use. The imports in local currency are converted into dollars and given to the bilateral trade model.

With regards to the demand side, the following impacts are explicitly captured by our modelling scheme: Intermediate demand of 59 product groups for 35 industries is implicitly given by the inputs of intermediate demand in the 35 industries. Final demand for each of the 59 product groups is sub-divided to private consumption, public consumption, gross fixed capital formation, inventory investments and exports. For each product group of private consumption real consumption per capita is explained by real disposable income per capita and relative prices. Special attention is given to private mobility in relation to mobility services, which are separated for land, water and air traffic. Energy product groups are explained in the energy module. Real public consumption per capita is explained by the real sum of disposable income and net lending of the government and by relative prices of the product group. Gross fixed capital formation for 59 product groups can be calculated using the vector of gross fixed capital formation for 35 industries (see above) and a capital transformation matrix. Inventory investment is estimated by the change of gross output of the 59 product groups. Exports are given by the bilateral trade module (see below).

The Input-Output system is completely embedded in the "Sequence of national Accounts and Balancing Items (SABI)" for four institutional sectors (private households & non-profit organisations serving households; government; corporations; rest of world). This second major internally consistent national accounts data set provides a synthesis of the entire institutional sector accounts and it shows the amounts of uses and resources of each institutional sector for all transactions. Thus it provides figures with regard to extremely policy relevant variables like disposable income of households or net lending / net borrowing of general government which directly affects national debt.

2.2.2. The bilateral trade module

The bilateral trade module takes for 59 product groups the export prices and the import values from the country models and converts them from local currency into dollars. Our modelling strategy distinguishes import shares for intermediate inputs from import shares for final demand goods. Both types of import shares are determined according to the following procedure: For each product group the respective shares of exports from a delivering country within the imports of a receiving country are depending from the relation between the export price and the aggregated import price for that product in the receiving country. Multiplying the trade shares with imports and summing up over importing countries gives the exports by definition. The import prices are calculated as a weighted average of export prices with the trade shares as weights. The exchange rates between the different currencies are explained by the relation of the GDP deflators of the countries in question.

2.2.3. The energy and emissions module

For each country the demand of 35 industries and private households for 28 energy carriers in physical terms (TJ) is explained by the energy and emissions module. The conversion of primary energy into secondary energy is done by the sectors coke, refined petroleum and by electricity, gas, water supply. Final energy demand is modelled in a two stage approach: In a first stage the energy intensities (energy consumption in physical terms divided by real gross production) of an industry for mobility, heating and electricity are explained by the specific aggregated energy price in relation to the basic price of the industry. Energy for heating of a sector is the aggregate of the use of coal, gas, light fuel oils, heavy fuel oils and some waste, energy for mobility of a sector contains its use of diesel, gasoline, bio-diesel, bio-gasoline and electricity for e-mobility is mentioned. Energy for heating is in most sectors used for the heating of buildings. In the basic industries (steel, non-metallic minerals, chemicals etc.) heating also means process heat. In mobility the sector water transport is an exemption, because it uses light fuel oil and heavy fuel oil for mobility. Electricity is separated, because it is used primarily for the use of machines. One exemption is here is the electric arc furnace (EAF) technology in steel production, were electricity is used for process heat.

In the second stage the shares of the different carriers in energy demand for heating and for mobility purposes are determined by the relation of the price of the carrier in relation to the aggregated energy price of the activity in the industry.

Energy demand for private households is in the first stage separated for the three purposes heating, mobility and household appliances. The energy intensity for heating is defined as energy use per real capital stock of the real estate services industry. It´s evolvement is tested for dependency on relative price developments and time trends. Multiplication of the energy intensity with the real capital stock gives energy demand. Energy for mobility is explained by real disposable income of private households and the relation between the aggregated energy mobility price and the aggregated price for mobility services. A further differentiation between private mobility and public traffic services is modelled price dependent. Energy demand for household appliances depends from real disposable income and the relation between the household's electricity price and the price for aggregated private consumption. In the second stage in each purpose the relative prices of the energy carriers determine the structure of demand. At this point, energy demand and it´s structure have been determined for private households and all 35 industries.

Price dependent import ratios divide the demand for oil, gas, coal and electricity into imports and domestic supply.

In the case of electricity production competition between the different technologies is depicted: The level of nuclear in total electricity production is taken as exogenous since policy decisions determine the long run use of this technology to a large extent. The total share of the renewable energies is also modelled as a policy variable because the scenarios contain explicit targets for renewable electricity production. In the next stage the shares of the different renewable technologies (biogas, hydro, geothermal, photovoltaic, solarthermal heat, solarthermal electricity and wind) in the renewable total are modelled depending from unit costs with the exemption of hydro, which remains exogenous. Electricity production from fossil fuels is defined as the rest. The shares of electricity production from oil, gas and coal are depending from relative prices.

Energy demand in physical terms feeds back into the economic module as has been shown for intermediate and final demand. The gross energy used is transformed into CO2-emissions for 35 industries (and private households) and 14 energy carriers assuming constant emission factors as well as constant relations between gross energy uses and emission relevant energy uses. Last but not least the module explains the emissions for 7 further air pollutants (N2O, NOx, SOx, NMVOC, NH3, CH4) in 35 industries and private households using the information from the energy use side as well as from the other modules.

2.2.4. The resource module

For each country and Rest of World the resource use module explains material extractions for 7 kinds of abiotic resources and for 2 kinds of biotic resources in thousands of tons (see Table 7 in the Annex)[10].

To explain the extractions of fossils we use detailed information coming from the Energy module about domestic uses of energy carriers in Terajoule, physical information about the energy content in mass units for the different energy carriers and informations from the economy module about relationships between domestic uses and domestic production for the different energy commodities.

To explain the extractions of construction and industrial minerals we use information about the evolution of production at constant prices for the product group “Other mining and quarrying products” in combination with information about share of uses by the construction sector in total uses of the two product groups “Other mining and quarrying products” and “Non-metallic minerals”.

The extractions of ores are directly explained by the production at constant prices for the product group “ores”. Direct explanations of these kind are also exercised for the two biomass categories “animals” and “forestry”.

The structure of the resource module ensures that the energy system as well as the whole economic and bilateral trade system are consitently linked with the resource extractions in physical units. In comparision to previous work as well as to other models we see two main advantages and one disadvantage of the actual GINFORS model for the analysis of resource extractions:

- In comparison to older GINFORS versions the classification of product groups now allows for a much better fit between the resource extractions (in physical units) and the economic activities (in monetary terms).

- GINFORS in contrast to many other models (e.g. E3ME) is a model that covers the whole world. Even the region “Rest of World” is now represented by a fully employed IO-model. In every simulation the global resource extractions are explained endogenously. Therefore in scenario analysis all direct and indirect effects are included and there is no need for assumptions like “domestic technology” to derive figures for the resource inputs or consumption in raw material equivalents.

[10] The historical developments as well as the classifications used GINFORS are taken from the WIOD-Database. As already mentioned earlier the farming module of GINFORS is still work in progress. Therefore the resource categories “biomass food” and “biomass feed” are not explained yet and excluded from any analysis within the paper at hand.

- In contrast to the EXIOMOD model GINFORS contains lower detail with regard to the classification of resources. But up now availabilities of time-series data especially with regard to detailed economic (input-output) data are restricting factors for further developments in this direction.

3. The Selection of the most important Input Coefficients

This section outlines the basic setup of our applied simulation exercises. The applied top down approach focusses on the production side of the economy and might be understood as an explorative thought experiment intended to highlight promising candidates for industry-specific resource efficiency measures.[11]

3.1 The USE Tables

Figure 1: Demonstrative USE Table

		Final uses				
	Industries: 1, 2, …, n	**Final consump-tion**	**Gross fixed capital formation**	**Change in inventories**	**Exports**	**Total**
Products 1 2 : n	Matrix of the intermediate consumption of each product by each industry	Final consump-tion of each product	Gross fixed capital formation of each product	Change in inventories of each product	Exports of each product	Total use (intermediate consumption + final uses) of each product
Value added — compensation of employees — consumption of fixed capital — net operating surplus	Matrix of the value added components by each industry					Total value added of each product
Total	Total output by each industry: intermediate consumption + value added	Total final uses by category				Total use

source: eurostat, national accounts - an overview, http://epp.eurostat.ec.europa.eu/ statistics_explained/ index.php/National_accounts_-_an_overview#Supply.2C_use_and_input-output_tables

[11] The limitiation of this analysis on industry-specific measures in no circumstance should be misinterpreted as a plea to focus resource policy at the production side. Consumption patterns and policies that intend to influence them will be well aware in the scenario and modelling exercises (WP 3) of the POLFREE project.

The underlying framework of these model simulations is given by national USE Tables as visualised within Figure 1. “The use table is a product by industry based table with products and components of value added in the rows and industries, categories of final uses and imports in the columns. A use table shows the use of goods and services by product and by type of use, i.e. as intermediate consumption by industry, final consumption, gross capital formation or exports. Furthermore, the table shows the components of value added by industry, i.e. compensation of employees, other taxes less subsidies on production, consumption of fixed capital and net operating surplus.” EUROSTAT, 2008, p. 19)

For all economies covered by the GINFORS, national USE Tables are explicitly mapped by the model. With regards to the “matrix of the intermediate consumption of each product by each industry” of Figure 1, we are therefore (i.a.) able to simulate an isolated reduction of a selected flow of inputs (say, e.g., metal ores) in a chosen industry (e.g. basic metals and fabricated metal).

Please note that GINFORS-outcomes of such a simulation exercise should not be mistaken with findings from static applications of input-output algebra. Whereas it is inevitably impossible to account for induced price, substitution and income effects by static input-output calculus, these effects are always incorporated in each GINFORS simulation. Hence, the outcomes of an exemplary simulation of increased resource efficiency in the basic metals and fabricated metal industry (embodied in relatively lower inputs of metal ores) might, e.g., indicate that, due to lower cost dynamics, enhanced international competiveness, increases in value added and disposable income, the direct negative effects on global resource use tend to be diminished by rebound, or even overcompensated by reinforcing effects.

Referring to Figure 1 again we would like to recapitulate that (for any national economy under consideration) GINFORS’ USE Tables map the developments of intermediate demand for 59 product groups in 35 industries (see Table 5 in the Annex for full references to the 59 product groups). But, for being precise, only 55 of them are modelled as directly price dependent intermediate input variables. Apart from that, the following four energy-inputs are determined within the energy module:

- Coal and lignite, peat;
- Crude petroleum and natural gas;
- Coke, refined petroleum products and nuclear fuel;
- Electrical energy, gas, steam and hot water.

Consequently, the dynamics of these four input coefficients are always triggered by underlying changes in the industry-specific demand for energy carriers. See Table 6 in the Annex in this regard.

3.2 Why 2552 simulation exercises?

Hence, in order to illustrate the outcomes of isolated variations in all intermediate input flows for a single industry under consideration, we are basically able to run 55 separate simulations (each considering a pre-defined variation in one selected directly price dependent input coefficients) plus another set of 19 simulations (each considering a pre-defined variation in industry-specific demand shares for one selected energy carrier).

We acknowledge that this all-embracing (55 direct input coefficient variations plus 19 triggering variations in sectoral energy demand) top down simulation setup might appear implausible in selected cases. According to our view, this might essentially be the case for the energy transformation sectors “coke and refined petroleum” as well as “electricity, gas and water supply”.

In the first case strong limitational conditions of production are given, which do not allow options for dematerialization: crude oil is needed for the production of mineral oil, and coal is needed for the production of coke.

For electricity production the opposite case is given: Of course there are options for dematerialization, but the background that is needed for the interpretation of results is very complex because energy carriers are here close substitutes and climate policy influences the conditions for substitution as the following example shows: A reduction of coal inputs in electricity production may represent a reduction of global extractions, if it is substituted by gas. However, if renewables energy carriers like, e.g., wind power were strengthened, this would certainly trigger the demand for steel and other materials needed to install a necessary amount of wind turbines. We therefore decided not to run any energy carrier simulations for industries “coke and refined petroleum” and “electricity, gas and water supply”.

With regards to the remaining set of 2552 simulation exercises (55 intermediate input goods x 35 industries + demand for 19 energy carriers x 33 industries), we do not claim that further implausibility objections might not arise in selected cases. However, lacking sufficiently detailed bottom up information, we rather refrained from any further exclusions. Actually we cannot identify any objections against this comprehensive simulation setup as our study is generally intended as an explorative assessment of the overall prospects of resource efficiency measures in consideration of potential rebound effects. Nevertheless, to avoid any confusion it should be stressed that all subsequent results have to be interpreted in light of the question: “What would be the overall effects on global resource demand **if** EU27 Member States **were able** to increase their resource efficiency with regards to selected intermediate input structures?” - an appraisal whether and how these efficiency gains might be achieved ranges far beyond the scope of our study.

3.3 Identification of the 30 most important input coefficients

In a first step we thus conducted 2552 simulation exercises, each focusing on one selected intermediate input (or, respectively, one selected industry-specific energy demand share) only. For each simulation, we assumed that for a given year the selected input was simultaneously lowered by 10% in all EU27 Member States. We recorded the resulting immediate effects on global resource demand (i.e., the total deviation of global resource demand from its corresponding value in the simulated year). Finally, after rearranging these observations in proper order, we arrived at the findings (partly) reported within Table 1.

Table 1 illustrates our ranking of 30 most important input coefficients with regards to global resource extractions. The first column depicts respective rank orders. Columns two and three identify the examined input coefficient, with column two denoting the input (or energy carrier) and column three indicating the industry under consideration. Finally, for each selected simulation run, columns four and five demonstrate its individual impact on global resource demand.

Accumulated over all 2552 simulation runs, we observed an immediate reduction of global resource demand of roughly 3.8 billion tons. This amount represents about 7.4% of global resource extractions. Thus, perhaps not surprisingly, GINFORS indicates that a widespread break-through in Member States' industrial resource efficiency would immediately induce significant reductions in global resource demand. Somehow more interesting seems the fact that this overall potential for reductions in global resource demand is predominantly allocated to a selective set of input coefficients. Please note in this regard that column four reports the observed reductions in individual simulation runs in relation to the just mentioned 3.8 billion tons accumulated over all 2552 simulation runs. So, as might also be inferred from the last row of Table 1, the reported results for this 30 most influential input relationships-subset already account for almost 16.98% of our accumulated results. In other words: Barely 1% of all considered 2552 input coefficients already account for almost 17% of the immediate resource reduction potentials illustrated by our simulations.

Overall, we cannot identify any apparent rebound effects within these contemporary observations. But it has to be acknowledged that rebound effects evolve over time. Hence, further sensitivity analyses are necessary before we can provide a robust comment on this issue and corresponding results will be discussed within section 4. Nevertheless, these contemporary observations are interesting with regards to the identified drivers of European industrial resource demand. Hence, we close this section with a short comment on selected input coefficients which emerge from Table 1.

Table 1: The 30 most important input coefficients for resource extractions in EU27

Rank	The input of …	in the … industry	Δ global resource use in Mio. tons	Share in total
Accumulated change in global resource uses*			-3881	100%
1	Other mining and quarrying prod.	Other Non-Metallic Mineral	-76,3	1,96%
2	Other non-metallic mineral prod.	Construction	-74,3	1,91%
3	Other mining and quarrying prod.	Construction	-74,2	1,91%
4	Construction work	Construction	-45,7	1,18%
5	Basic metals	Basic Metals and Fabricated Metal	-33,8	0,87%
6	Metal ores	Basic Metals and Fabricated Metal	-29,6	0,76%
7	Chemicals, chemical prod.	Chemicals and Chemical Products	-25,7	0,66%
8	Other mining and quarrying prod.	Chemicals and Chemical Products	-18,9	0,49%
9	Prod. of agriculture, hunting	Food, Beverages and Tobacco	-18,9	0,49%
10	Prod. of forestry, logging	Wood and Prod. of Wood and Cork	-16,6	0,43%
11	Other mining and quarrying prod.	Mining and Quarrying	-16,5	0,43%
12	Motor vehicles	Transport Equipment	-16,2	0,42%
13	Radio, TV & Comm. Eq.	Electrical and Optical Equipment	-14,8	0,38%
14	Fabricated metal products	Basic Metals and Fabricated Metal	-14,3	0,37%
15	Other business services	Rent. of M&Eq and Other Business Act.	-14,2	0,37%
16	Construction work	Real Estate Activities	-14,2	0,37%
17	Fabricated metal products	Construction	-13,6	0,35%
18	Wood and products of wood	Construction	-12,9	0,33%
19	Electricity	Basic Metals and Fabricated Metal	-12,4	0,32%
20	Fabricated metal products	Machinery, Nec	-12,3	0,32%
21	Electricity	Chemicals and Chemical Products	-12,1	0,31%
22	Food products and beverages	Food, Beverages and Tobacco	-11,9	0,31%
23	Other non-metallic mineral prod.	Other Non-Metallic Mineral	-11,2	0,29%
24	Basic metals	Transport Equipment	-10,5	0,27%
25	Machinery and equipment	Machinery, Nec	-10,4	0,27%
26	Diesel oil for road transport	Inland Transport	-10,1	0,26%
27	Prod. of forestry, logging	Pulp, Paper, Printing and Publishing	-9,6	0,25%
28	Food products and beverages	Hotels and Restaurants	-9,4	0,24%
29	Other mining and quarrying prod.	Basic Metals and Fabricated Metal	-9,2	0,24%
30	Office machinery and computers	Electrical and Optical Equipment	-9,1	0,23%
∑ Top 30			-659,0	16,98%

* All 2552 simulation runs together

The most important input is that of “other mining and quarrying products” to which belong inputs like sand, stones, gravel, lime etc. They are used in “other non-metallic mineral” to produce ceramics, tiles, cement, plaster, glass and glass products etc. These products are to a high degree inputs in “construction”, where also the “other mining and quarrying products” are directly used. Rank 4 has been given to “construction work” as input to the sector “construction”. A part of the output of the sector is used as an input. In a quadratic I/O framework we would speak of a main diagonal element of the I/O matrix.

The next two ranks are given to the sector “basic metals and fabricated metal”. The manufacture of basic metals includes activities such as the manufacture of iron, steel and ferro-alloys, as well as basic precious and non-ferrous metals; it also includes first processing stages of metal manufacturing, the sector further includes the manufacture of fabricated metal products covering the production of structural metal products like boilers, metal containers and steam generators; forging, pressing, stamping and roll forming of metal; the treatment and coating of metal and general mechanical engineering; the manufacture of cutlery, tools and general hardware; and the manufacture of other fabricated metal products (such as metal drums, metal packaging, wire products, and household articles). So here we have several stages of production concentrated in one sector. The input of “basic metals” is the output of the first stage, which is used in the second stage of the sector. “Metal ores” are the main input of the first stage.

The sector “chemicals and chemical products” has a clear two stage structure. In the first stage basic chemicals are produced, in the second stage these are converted to final products like colors, cosmetics, drugs etc. The input of basic drugs in the second stage has rank 7, the use of “other mining and quarrying products” in the first stage of the chemical industry has rank 8.

The inputs of agricultural products in the sector “food, beverages and tobacco” are following on rank 9 although we do not account for changes in extractions of biomass food and feed. Rank 10 is given to the inputs of forestry products in the sector “wood and wood products”, which at least has two stages – the production of wood and that of wood products like furniture.

The extraction of other mining and quarrying products (sand, stones, gravel, lime etc.) by the sector “mining and quarrying” is in the EU27 on rank 11 of the most important resource inputs.

The sector “transport equipment” has at least two stages. The output of semi-finished parts of motor vehicles in the car producing second stage of the industry is on rank 12.

The goods and services made within the “electrical machinery and optical equipment” sector range from capital goods used in energy activities, transport manufacturing (motor vehicles, aeronautics and rail equipment producers) or process manufacturing sectors (agro-industries, chemicals, plastics or wood), through intermediate goods (such as electronic components or wiring) that are often used by other manufacturers, to consumer goods (such as consumer electronics, mobile phones, household appliances). In this sector the intermediate input of radio, television and telecommunication equipment has the rank 13.

Fabricated metal products are used in the last stage of the sector “basic metals and fabricated metal”, where structural metal products like boilers, metal containers and steam generators are produced, where further forging, pressing, stamping and roll forming of metal happens. This input has the rank 14.

Rank 15 is given to a service input called other business services in the sector “renting of machinery and equipment and other business activities”, the input of construction work in the sector “real estate activities” gets rank 16. Fabricated metal products (rank 17) and wood (rank 18) are of course central inputs in the sector “construction”. Electricity is needed in the sector “basic metals and fabricated metal” (rank 19) and in the sector “chemicals and chemical products” (21) to produce process heat. Fabricated metal products and machinery and equipment are central inputs of the sector “Machinery” (ranks 20 and 25). Food products and beverage are inputs of the last stage of the sector “Food beverages and tobacco” (rank 22) and the sector “hotels and restaurants” (rank 28).

The input of other non-metallic mineral products in the sector “other non-metallic mineral” is the output of the first stage consisting of raw materials, which are used to produce in the later stages of the sector glass products, ceramic products and other more finished goods (rank 23).

Basic metals as an input of the sector “transport equipment” (rank 24) is primarily dedicated to the first stage of the industry, which produces parts that are assembled to cars in the second stage.

Diesel oil for road transport is the most important input for mobility in the sector “inland transport” (rank 26). The central raw material for the production of pulp and paper are products of forestry (rank 27). Other mining and quarrying products are inputs for steel production in the sector “basic metals and fabricated metal” (rank 29). Office machinery and computers are very important intermediate inputs in the sector “electrical and optical equipment” (rank 30).

4. The macroeconomic benefits of resource efficiency increases in the EU

Based on extensive simulation experiments, section 3 already illustrated that the European potential for reductions in global resource demand by means of industry specific resource efficiency measures appears to be heavily concentrated on selective production steps. About 1% of all considered efficiency simulations already accounted for almost 17% of all identified immediate resource reduction potentials. Whereas these findings provide guidance towards focused environmental policy designs they have not discussed the issue of efficient starting points for resource efficiency measures by now. Nor did they provide any further sensitivity analyses.

For the selective set of 30 resource efficiency simulations identified within section 3, this section is therefore going to provide deeper insights concerning macroeconomic effects and inter-temporal rebound effects. Subsection 4.1 looks at the macroeconomic effects, illustrates the corresponding findings by means of model derived MAC curves and completes this representation of results by structural details with regards to industry- and country-specific findings. Subsection 4.2 discusses the significance of inter-temporal rebound effects.

4.1 Simulation experiment 1: The effects within one year

4.1.1. The setting

This subsection highlights the corresponding macroeconomic outcomes for the 30 most influential resource efficiency simulations identified within section 3. Subsection 4.1.2 introduces the MAC curve representation which is enriched by an analysis of impacts on resource uses in subsection 4.1.3 and by a detailed account of industrial results within subsection 4.1.4. Finally, subsection 4.1.5 outlines the macroeconomic effects per Member State.

4.1.2. The benefit curve

Before discussing the results we start with a short explanation of how to read the benefit curve. The benefit curve shows the effects of the simulation runs on real GDP (y-axis) and global resource extractions (x-axis). The diagram starts at the right with the simulation (input-coefficient reduction) that shows the highest positive effect on GDP. The next point to left shows the effect on GDP of the simulation run with second highest GDP change and the cumulated effect on global resource extractions of the two simulations together. This representation goes on and ends at the left with the simulation that shows the lowest (or most negative) GDP change. In addition the last point at the left shows for all simulations together the cumulated effect on global resource extractions.

The benefit curve for EU27 in Figure 2 provides clear indications that EU27 industrial resource efficiency increases predominantly raise wealth, even if we measure wealth by the classical indicator GDP, and can contribute notably to a reduction of worldwide resource extractions. 13 out 30 simulations show positive GDP variations above 0.01% (encircled in green in the figure).

Figure 2: Simulation experiment 1 – The benefit curve for the EU27

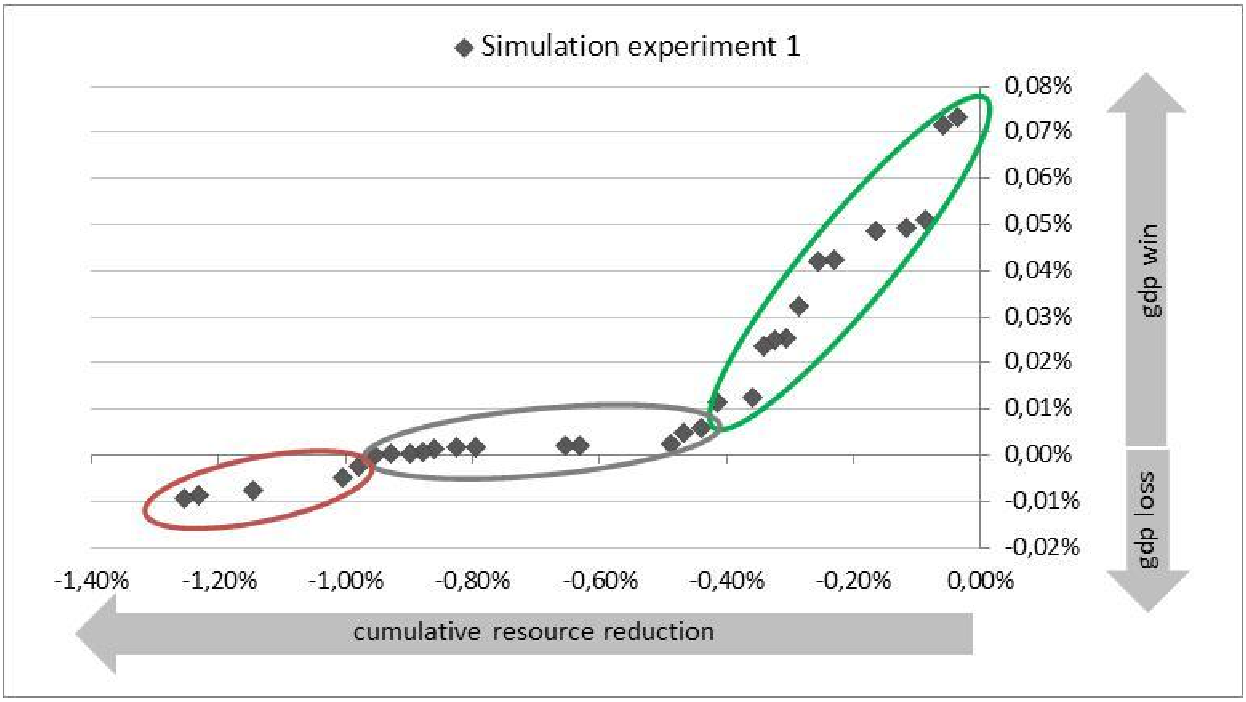


Table 2 provides a detailed summary of the underlying data. The first 13 rows are characterised by simulation runs whose reductions in resource demand would induce positive GDP variations of more than 0.01%. The grey circle in the figure indicates 12 simulations (input coefficient variations) that do not affect growth (GDP variations between 0 and 0.01%) at all but can contribute notably to a reduction in resource uses. Finally, five simulation experiments slightly negative GDP-effects. These five elements are related to three different inputs in the construction sector as well as to the use of electricity in two different sectors (basic metals / chemicals). One explanation for this observation is, that neither electricity nor construction are products/industries that can gain a lot with regard to international competitiveness by means of efficiency increases, that lead to an decrease in unit costs.

Table 2: Simulation experiment 1 – Data background of the benefit curve

Data background			Simulation exp. 1	
List element	Input of …	in industry …	Variation gdp in %	Variation global resource use in %
9	Prod. of agriculture, hunting	Food, Beverages and Tobacco	0,073%	-0,036%
22	Food products and beverages	Food, Beverages and Tobacco	0,072%	-0,023%
15	Other business services	Rent. of M&Eq and Other Business Act.	0,051%	-0,027%
12	Motor vehicles	Transport Equipment	0,049%	-0,031%
7	Chemicals, chemical prod.	Chemicals and Chemical Products	0,049%	-0,049%
5	Basic metals	Basic Metals and Fabricated Metal	0,043%	-0,064%
16	Construction work	Real Estate Activities	0,042%	-0,027%
13	Radio, TV & Comm. Eq.	Electrical and Optical Equipment	0,032%	-0,028%
25	Machinery and equipment	Machinery, Nec	0,025%	-0,020%
28	Food products and beverages	Hotels and Restaurants	0,025%	-0,018%
30	Office machinery and computers	Electrical and Optical Equipment	0,024%	-0,017%
26	Diesel oil for road transport	Inland Transport	0,013%	-0,019%
6	Metal ores	Basic Metals and Fabricated Metal	0,011%	-0,056%
20	Fabricated metal products	Machinery, Nec	0,006%	-0,024%
14	Fabricated metal products	Basic Metals and Fabricated Metal	0,005%	-0,027%
24	Basic metals	Transport Equipment	0,002%	-0,020%
1	Other mining and quarrying prod.	Other Non-Metallic Mineral	0,002%	-0,145%
23	Other non-metallic mineral prod.	Other Non-Metallic Mineral	0,002%	-0,021%
3	Other mining and quarrying prod.	Construction	0,002%	-0,141%
10	Prod. of forestry, logging	Wood and Prod. of Wood and Cork	0,002%	-0,032%
8	Other mining and quarrying prod.	Chemicals and Chemical Products	0,002%	-0,036%
29	Other mining and quarrying prod.	Basic Metals and Fabricated Metal	0,001%	-0,018%
27	Prod. of forestry, logging	Pulp, Paper, Printing and Publishing	0,001%	-0,018%
11	Other mining and quarrying prod.	Mining and Quarrying	0,000%	-0,031%
17	Fabricated metal products	Construction	0,000%	-0,026%
19	Electricity	Basic Metals and Fabricated Metal	-0,002%	-0,024%
18	Wood and products of wood	Construction	-0,005%	-0,025%
2	Other non-metallic mineral prod.	Construction	-0,008%	-0,141%
4	Construction work	Construction	-0,009%	-0,087%
21	Electricity	Chemicals and Chemical Products	-0,009%	-0,023%

In the following subsections these overall macroeconomic findings will be supplemented by a discussion of further resource-, industry- and country-specific results. But before continuing on this way, we would like to provide some additional comments with regards to the dimensions of our overall findings. The benefit curve shows a cumulated effect on global resource extractions of -1.26%. This relative metric represents a reduction of global used resource extractions of about 650 millions of tons.[12] In addition we have to bear in mind that:

- We only look at the 30 most important input-coefficients. Contributions to resource reductions that can be achieved by the other 2522 less important input-coefficients are not taken into account.

[12] Although due to conceptual differences a direct comparison of this figure with estimates for EU27 RMI figures (see EUROSTAT, 2012 and annotations in the introduction) is not permitted, the simulation experiment indicates that the induced reduction in EU27 RMI should be notably higher than 5%.

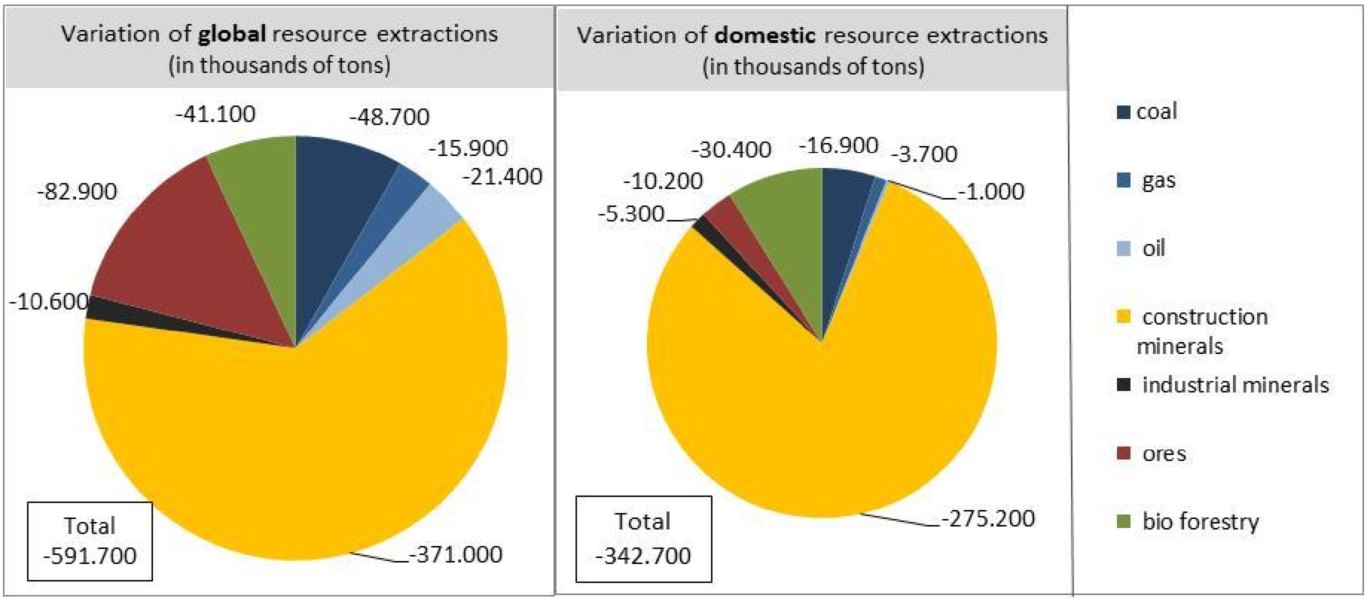
- The simulation experiment does not tell the story of a resource efficiency revolution but of a remarkable but although limited efficiency gain (input-coefficient reduction) by 10%.

4.1.3. The impacts on global resource extractions

To analyse the effects on resource extractions in more detail we next look on the results of an additional simulation run. In this simulation run we do not, as in the exercise before, look at the effects of reduction of a single input-coefficient by 10% but at the effects of a simultaneous reduction of all most important 30 input-coefficients by 10%. The results in Figure 3 show, that the total effect on global resource extractions (-591.700 thousands of tons) is about 10% lower than the cumulated effect of the 30 single simulation runs (-659.200 thousands of tons) presented in figure 4. This first finding is absolute consistent from a logical point of view: The more efficient the other elements of the economy are, the lower is the potential (for resource savings) of a single element (i.e. a single input-coefficient).

But let‘s take a look at the results. More than 60% of the global resource savings are construction minerals. But this is not a surprise as on the one hand construction minerals contribute more than 70% to global resource extractions of all seven material categories together and on the other hand 10 out of 30 of the most important input-coefficient deal with either the construction industry or the product group “other mining and quarrying products”. If we compare the findings for global resource savings with those for the reductions of resource extractions within the EU27 territory (lower half of the figure) we can see that, although the main reduction of construction mineral extractions happens domestically, a remarkable decline of almost 100 million tons occurs somewhere else.

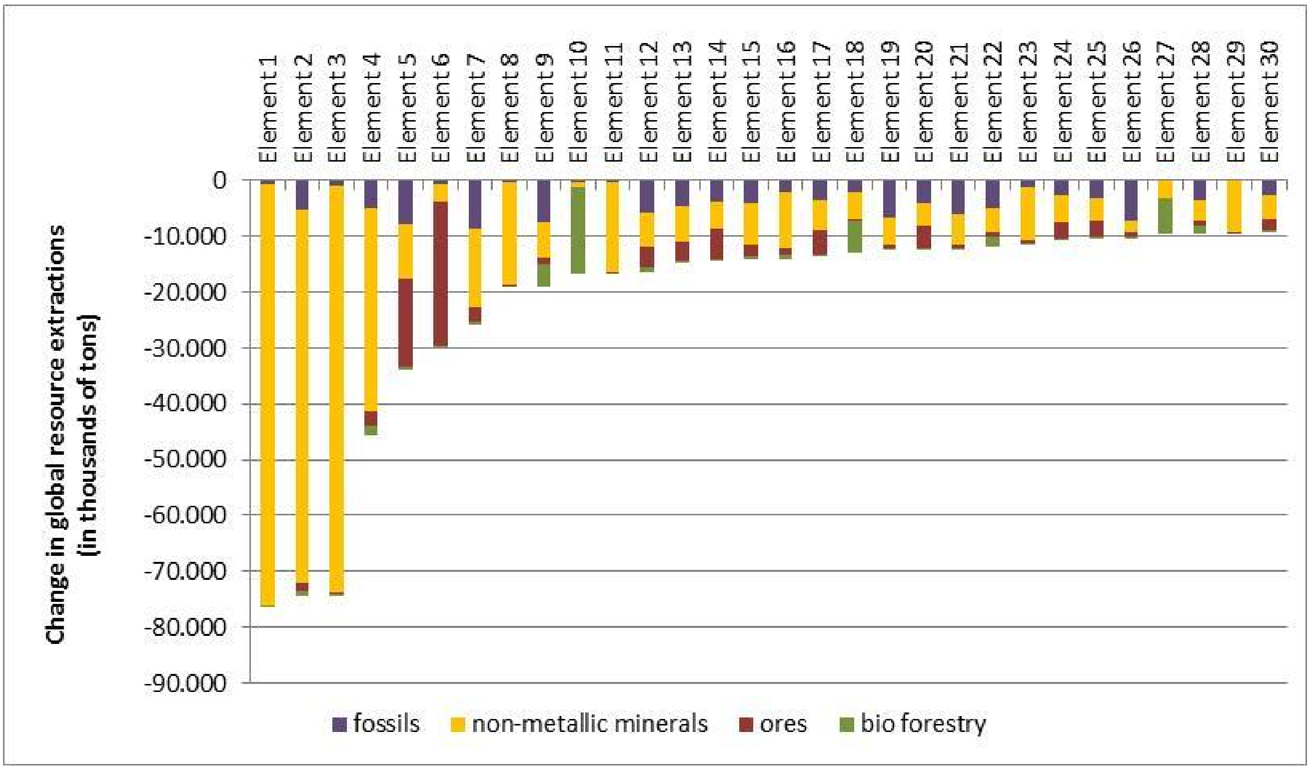
Figure 3: Simulation experiment 1 - The effects on global and domestic (EU 27) resource extractions



The second biggest resource saving can be observed with regard to ores (-82.900 thousand tons). But in contrary to the construction minerals the reduction of resource extractions in the case of ores predominantly occurs outside the EU27. With other words: If the 30 most important input-coefficients in all EU27 countries would be 10% lower, the direct and indirect imports of ores by the EU would diminish by more than 70 million tons.

In figure 4 in addition to the simulation experiment for all 30 input coefficients together the effects on global resource extractions for 30 individual simulations are presented. This figure does without a complete labelling of the respective simulation experiment (input coefficient) at full length. Instead the notation of "element 1 to 30" refers to list of 30 most important input coefficients (see table 1).

Figure 4: Simulation experiment 1 - The effects of single simulations (input coefficients) on global resource extractions



Some interesting findings can be observed:

In some simulation runs (i.e. the input of "other mining & quarrying products" in the industry "other non-metallic mineral" [list element 1] or the input of the same product group in the chemical industry [list element 8]) the resource reduction is highly concentrated in the directly affected resource category (non-metallic minerals) and shows only minor indirect effects on other resource categories.

In other simulation runs (i.e. the input agricultural products in the food and beverage industry [list element 9] or the input of “wood and products of wood” in the construction sector [list element 18]) the resource reductions occur widespread over all resource categories.

Although almost 50% of resource reductions in ores are induced by only two input-coefficients of the basic metal industry also some input-coefficients on later stages of production (i.e. the input of “fabricated metal products” in the “construction sector” [list element 17] or the input of “Radio, TV & Comm. Equipment” in the industry “Electrical and Optical equipment” [list element 13] show remarkable potentials for a reduction in ore extractions.

Although we did not include the extractions of biomass food and feed into our term “global total resource extractions” the inputs of “agricultural products” as well as the inputs of “food products and beverages” are three times listed in the 30 most important input-coefficients [list elements 9, 22 and 28]. If we look at the resource reduction impacts of these three simulation experiments, they show widespread reductions over all resource categories.

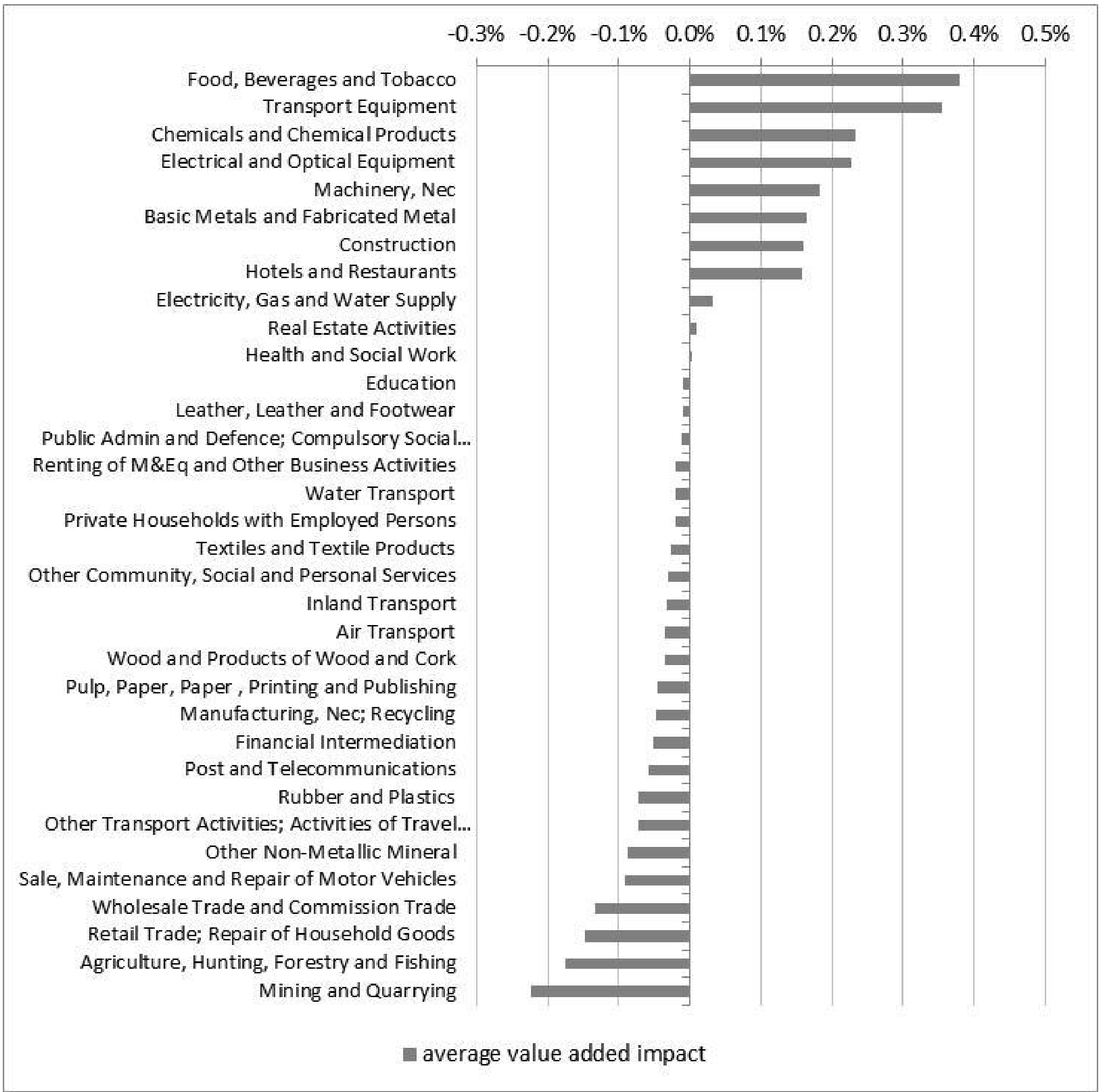
4.1.4. The effects on the different industries

To analyse the effects on the different industries we look again at the results of the simulation experiment in which the 30 most important input coefficients are lowered *simultaneously* by 10% in each Member State. In this case the immediately induced GDP-effect amounts to +0.48%. But does this mean that all industries can gain? Or are there winners and losers?

Figure 5 visualises the observed simulation results with regards to real value added.[13] Shown are the observed industry results averaged over all EU27 economies. We identify significant positive effects for those industries that benefit directly from increased profit margins due to lower cost dynamics. Economically speaking a reduction of an input-coefficient means an increase of productivity and the higher the reduction of intermediate inputs in relation to the industry output is, the higher is also the potential of an increase in value added. Last but not least these results confirm the findings of a recent bottom-up study on the potential benefits from improving resource efficiency for three example sectors (AMEC Environment & Infrastructure & BIO Intelligence Service, 2013). But the interaction between productivity increases and value added reaction by far is not a linear and simple connection. It is also influenced by international competition as well as by individual price elasticities of different markets.

[13] To derive these figures we deflate the value added at current prices with production prices of industry concerned.

Figure 5: Simulation experiment 1 - Industry-specific immediate effects



On the loser side we observe mainly industries (i.e. agriculture, mining & quarrying, other non-metallic mineral) that face a decline of demand as they produce the intermediate goods that are used less. However, also the trade sectors appear negatively affected.

4.1.5. The effects on country level

The different economies within the EU show a big diversity with regard to their structures. Therefore a simulation experiment that leads to quite different adaptations in the different industries that are directly and indirectly affected also might shift the relative (economic) strength within the EU. To gain insights into the potential impacts of increased resource productivity on individual EU Member States GDP we look again at the simulation where all 30 input coefficients are changed simultaneously in all EU27 Member States.

Figure 6: Simulation experiment 1 - The effects on GDP at national level

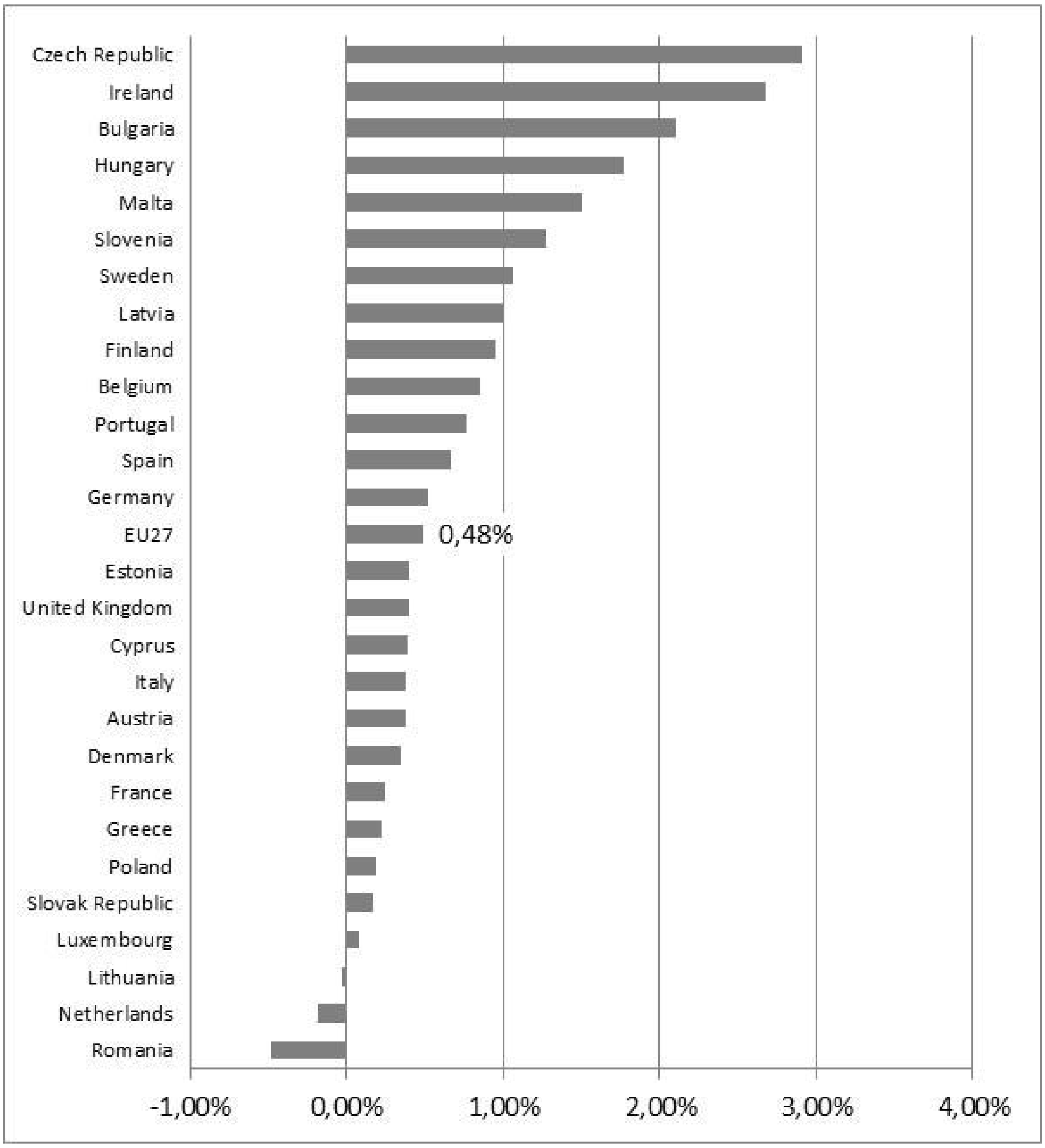


Figure 6 visualises the impacts on GDP (in%) for each individual Member State. The overall impact on EU27 GDP of this simulation experiment is 0.48%. But some countries are affected quite different from this average figure. On the one hand countries like the Czech Republic, Ireland, Bulgaria, Hungary, Malta, Slovenia and Sweden show a GDP impact that is remarkably higher. These economies would gain market shares within the common market. On the other hand countries like Lithuania, the Netherlands and Romania feature negative GDP impacts. One explanation for these differences among Member States is the relevance of industries that are benefitting or suffering (in relative terms) directly and indirectly from resource productivity increases within the different economies.

Whereas these partly observed negative GDP effects do indicate challenges to deal with distribution effects among Member States, they certainly do not suggest a non-ambiguous interpretation. In other words: Increases in industrial resource productivity cannot be claimed to bet generally harmful to the national economies of Lithuania, the Netherlands and Romania.

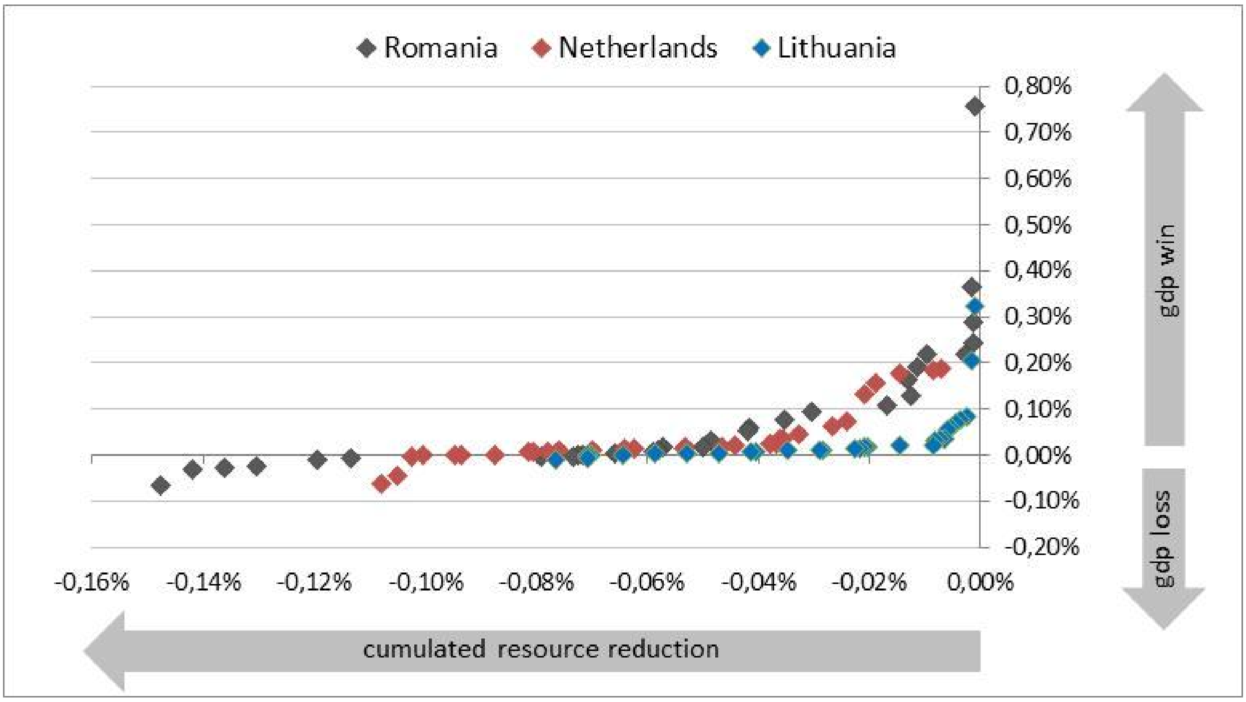
To illustrate the general potentials of resource productivity measures in the just mentioned countries we ran three further sets of simulation studies, each of them intended to derive national MAC curves: 30 individual simulations were run, each assuming a 10% change in one of the input coefficients of Table 1 for Lithuania only, then the same exercise was undertaken for the Dutch economy only and for Romania only. Re-arranging these findings according to the previously described procedure (see section 4.1.2), these studies ended up with national benefit curve estimates for these three countries as presented within Figure 7.

These national benefit curves show that,

- The cumulated GDP impacts for all three countries are significantly positive (+2.9% for Romania, +1.2% for the Netherlands and +1.1% for Romania). This finding clearly demonstrates that the negative GDP impacts for these three countries resulting from an simultaneous resource efficiency increase in *all* EU27 member states (see figure 5) are not caused by the resource efficiency increase in Lithuania, the Netherlands or Romania itself. Rather the economies of these countries tend to suffer from indirect effects on the intra EU-trade induced by resource efficiency increases in other member states.

- Although the Romanian and Lithuanian economies are much smaller than the Dutch one the cumulated impact on global resource extraction for an isolated resource efficiency increase in Romania is bigger than in the Netherlands. And even Lithuania with its more than 20 times smaller economy shows a potential for reductions in global resource extractions that is only slightly smaller than in the Netherlands (-0.11% for the Netherlands vs. -0.08% for Lithuania).

Figure 7: Simulation experiment 1 – National benefit curves for Lithuania, Netherlands and Romania



Before we leave the topic of the impacts on country level in a last step we would like to take a look at the results if we execute the previously described simulation exercise not only for three selected countries but for all 27 EU member states. But to present the results of these 810 simulation runs by illustrating 27 different benefit curves would definitely overload the paper at hand with too many details. To condense the main findings of the simulation experiments for single EU27 countries the following figure 8 shows the cumulated impacts of all 30 simulation runs.

On the left side of the figure the simulation results for cumulated impacts on global resource extractions determines the position on the x-axis and the resource productivity (as reported by Eurostat for the year 2012) determines the position on the y-axis. Each dot represents one EU27 country and the labelling on the right side of the figure might help with regard to this relation.[14] On the right side of the figure the position on the x-axis is determined by the simulation results for cumulated impacts on national GDP while the position on the y-axis remains the same as in the left part.

The results can be outlined as follows:

- The lower the resource productivity is in a country, the higher are the potentials for savings in global resource extractions that can be achieved through resource efficiency measures focusing on some important production processes in the country. A simple

[14] The figure abstains from presenting results for the two EU27 countries Luxembourg and Malta, due to small number problems that might occur in simulation experiments for them.

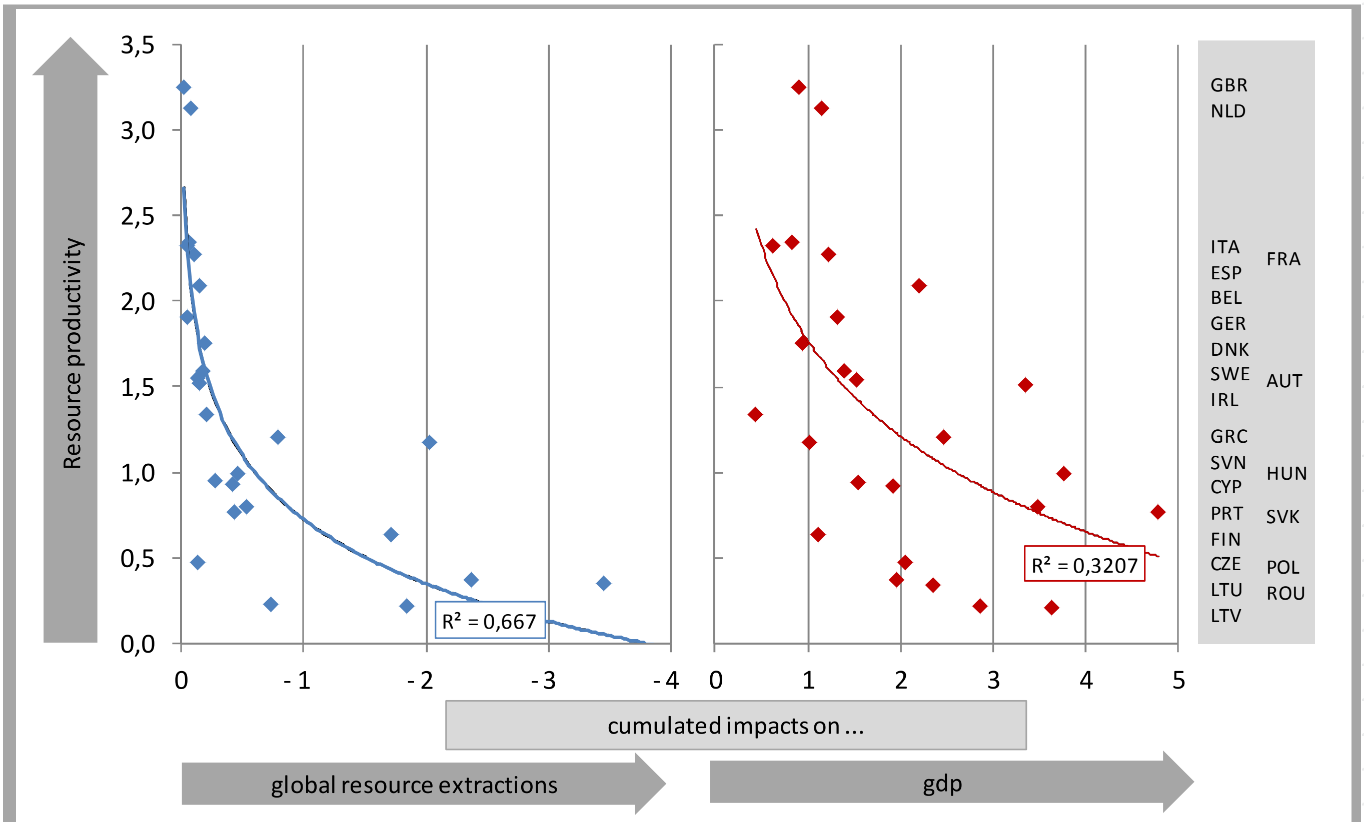
correlation analysis between the simulation results for impacts on global resource extractions and the resource productivity of the respective country shows a coefficient of determination of 67%. Although, this connectivity is far from a simple linear interrelation.

- Although the potentials for savings in global resource extractions in countries with already high or above average resource productivity are far from negligable. This can be illustrated by looking at the figures for the United Kingdom, the country with the second highest resource productivity in EU27. The cumulated global resource savings for this country amount for around 53 thousands of tons. This equates to around 8% of the savings that are expected if the simulation experiments are carried out for the whole EU27, as documented in the precedent chapters. If we bear in mind that the Britisch economy accounts for about 16% of EU27 GDP the resource savings that can be expected by advances in national resource efficiency are indeed notably lower for this already relative resource productive economy but still far from negligable.

- The cumulated GDP impacts for *all* single country simulations are clearly positive. And besides Greece they are throughout higher than the comparable result for the EU27 simulation (+0.5%). This result clearly indicates that from an economic perspective forerunner countries are gaining most from resource efficiency improvements.

- To infer from the current status of resource productivity to the potentials of GDP gains appears much less stringent. Nevertheless the highest potentials for GDP gains predominantly are given in eastern European countries with relative low resource productivities.

Figure 8: Simulation experiment 1 – Cumulated impacts for single country simulations



Units: Resource productivity = in Euro per kilogram DMC, chain linked volumes (2005) in 2012; source: Eurostat
GDP = cumulated impacts on national gdp at 2005 prices in %
Global resource extractions = cumulated impacts on global resource extractions in kg per Euro of national gdp at 2005 prices

The last question with regard to the results of simulation experiments for single EU27 countries is the one about the relevance of the single input-coefficients for global resource uses. Therefore in table 3 for all countries the five most important input-coefficients are identified.

For example in Austria a reduction of inputs of “Other mining and quarrying products” in the “Construction” sector shows the biggest potentials for a reduction of global resource extractions (rank 1). In the simulation experiment for the whole EU27 this input-coefficient was only the third most important one (rank 3), as indicated in the first row of the table.

To summarise, the simulation experiments for single EU27 countries clearly indicate that the importance of single input-coefficients for global resource uses varies a lot between countries. Although in nearly all member states some input-coefficients that directly or indirectly refer to building activities show up among the five most important input-coefficients. The same holds for input-coefficients that refer to inputs of processed or unprocessed metal products.

Table 3: Simulation experiment 1 – The most important input coefficients with regard to global resource extractions in the different EU27 member states

EU27		Austria	Belgium	Cyprus	Estonia	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Slovak Republic	Slovenia	Spain	Bulgaria	Czech Republic	Denmark	Hungary	Latvia	Lithuania	Poland	Romania	Sweden	United Kingdom
1	Input of "Other mining and quarrying prod." in industy "Other Non-Metallic Mineral"				3		3	3			1		1			4								1		2
2	Input of "Other non-metallic mineral prod." in industy "Construction"	3					2	1			2					3				1			2	2		
3	Input of "Other mining and quarrying prod." in industy "Construction"	1	4		1	1	1	2	3		3		5		1	2		1				1		3	4	4
4	Input of "Construction work" in industy "Construction"												2		4	1		2			1		1	5		3
5	Input of "Basic metals" in industy "Basic Metals and Fabricated Metal"	2			5	4		5		3	4		3													
6	Input of "Metal ores" in industy "Basic Metals and Fabricated Metal"		3					4				1			3							5		4	3	
7	Input of "Chemicals, chemical prod. " in industy "Chemicals and Chemical Products"		1				4													4						
8	Input of "Other mining and quarrying prod." in industy "Chemicals and Chemical Prod."														5	5										
9	Input of "Prod. of agriculture, hunting" in industy "Food, Beverages and Tobacco"			3			5		1								4		1		4		3			
10	Input of "Prod. of forestry, logging " in industy "Wood and Prod. of Wood and Cork"			4	2	2				1							5								1	
11	Input of "Other mining and quarrying prod." in industy "Mining and Quarrying"		5			3									2		3				5					
12	Input of "Motor vehicles" in industy "Transport Equipment"	5																5		2						
13	Input of "Radio, TV & Comm. Eq." in industy "Electrical and Optical Equipment"																	4								
14	Input of "Fabricated metal products" in industy "Basic Metals and Fabr. Metal"																									
15	Input of "Other business services" in industy "Rent. of M&Eq and Other Business Act."	4	2						2			2								5		2				1
16	Input of "Construction work" in industy "Real Estate Activities"																		2		2					
17	Input of "Fabricated metal products" in industy "Construction"			2													2		5			3				
18	Input of "Wood and products of wood" in industy "Construction"				4	5				2													4		5	5
19	Input of "Electricity" in industy "Basic Metals and Fabricated Metal"									4				1									5			
20	Input of "Fabricated metal products" in industy "Machinery, Nec"			5								4		4												
21	Input of "Electricity" in industy "Chemicals and Chemical Products"								4					5												
22	Input of "Food products and beverages" in industy "Food, Beverages and Tobacco"										5								3							
23	Input of "Other non-metallic mineral prod." in industy "Other Non-Metallic Mineral"			1								5		2			1			3	3					
24	Input of "Basic metals" in industy "Transport Equipment"								5																	
25	Input of "Machinery and equipment" in industy "Machinery, Nec"																									
26	Input of "Diesel oil for road transport" in industy "Inland Transport"									5		3							4							
27	Input of "Prod. of forestry, logging" in industy "Pulp, Paper, Printing and Publ."																									
28	Input of "Food products and beverages" in industy "Hotels and Restaurants"												4													
29	Input of "Other mining and quarrying prod." in industy "Basic Metals and Fabr. Metal"													3								4			2	
30	Input of "Office machinery and computers" in industy "Electrical and Optical Equip."																	3								

4.2 Simulation experiment 2: The effects with consideration of inter-temporal effects

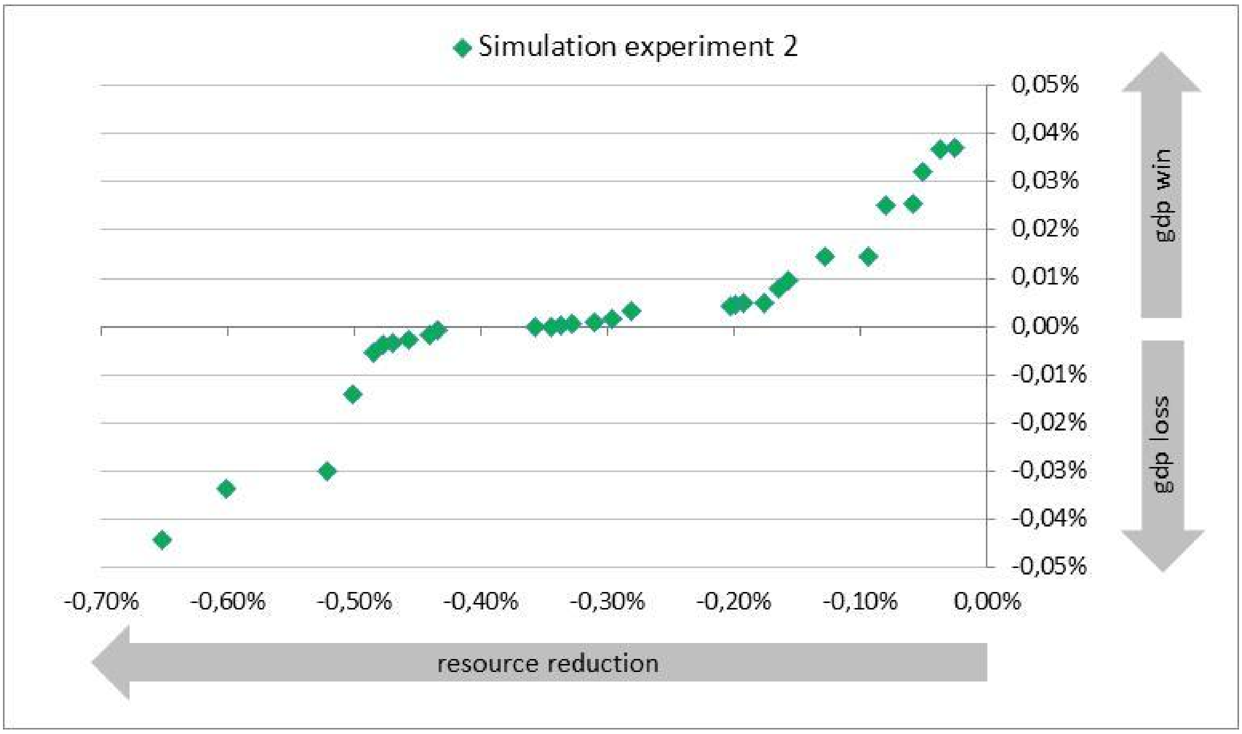
4.2.1. The setting

This subsection complements our presentation of results by a sensitivity analysis with regards to inter-temporal rebound effects. We re-structured our thought experiments as follows: Instead of assuming an immediate decrease of selected intermediate inputs by 10%, we now conducted simulation runs which considered a steady decline of selected intermediate inputs (as given by Table 1) by 2% p.a. over a 5 years horizon in any Member State. To distinguish the resulting findings from the ones presented before, this simulation setting will be labelled simulation experiment 2 in all subsequent annotations. Consequently, the previously presented immediate short run results will be referred as simulation experiment 1.

4.2.2. The benefit curve

In contrary to simulation experiment 1, the medium term benefit curve for EU27 presented within Figure 9 no longer provides a clear indication in favour of win-win situations. 19 out 30 simulations still show positive GDP variations but the number of simulations with (slightly) negative GDP impacts increased from 5 to 11.

Figure 9: Simulation experiment 2 – The benefit curve for the EU27



Before we take a look at the table with the corresponding data background (Table 4) the range of values should be classified. In all result presentations for simulation experiment 2 we look at the average or cumulated effects of a five year period. If we compare the settings/assumptions of the first and the second simulation experiment the average decrease of the input coefficients over the five year period represents about 60% of the decrease in the one year simulation. With other words: In absence of any rebound effects we would expect the values of Figure 9 to range about 40% below the corresponding ones of Figure 2. Accordingly, in order to ease comparisons, Table 4 displays re-scaled figures with regards to the simulation experiment 1 results (figures are composed in the two columns right of the results for simulation experiment 2).

If the impact on GDP in simulation experiment 2 for a certain input coefficient change is bigger than the respective converted value for simulation experiment 1 the simulation experiment comes to the conclusion that the inter-temporal rebound effects on the economy tend to be positive. But this holds only for 7 out 30 simulations (input coefficient changes). In 5 cases the GDP impact is more or less the same as in the short run and in 18 simulations the inter-temporal effects lead to a diminished impact on GDP. Therefore one of the central findings of the simulation experiments is that macro-economic gains from resource productivity increases are by no means a sure-fire success. But they are possible.

On the other hand the inter-temporal view also gives new insights in the potentials for reductions in global resource uses. Although inter-temporal rebound effects here, too, lead to a diminished optimism. But if we compare the cumulated figure for our five years simulation experiment (-0.65%) with the converted cumulated figure for the one-year simulation (-0.75%) we can conclude that inter-temporal rebound effect tend to diminish the potentials of resource reductions only slightly. This can also be approved by looking at the single simulation results. In the majority of cases the consideration of inter-temporal effects does not change the findings for impacts on global resource extractions significantly. In 9 out of 30 cases the potentials for resource reductions are lower but still meaningful and in one case (the inputs of “Radio, TV & Communication Equipment” in the industry “Electrical and optical equipment”) inter-temporal rebound effects tend to increase the potentials for resource reductions.

Table 4: Simulation experiment 2 – Data background of the benefit curve and the influence of inter-temporal rebound effects on GDP and resource use impacts

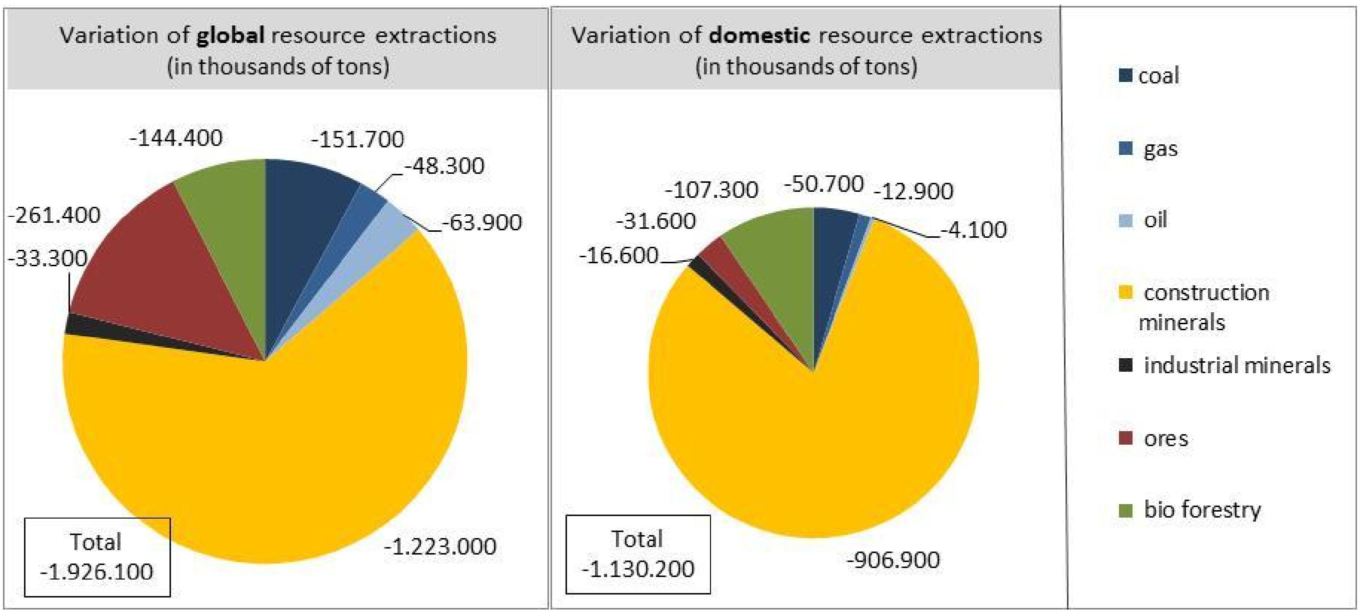
Data background			Simulation exp. 2		For comparison: Simulation exp. 1 60 % of		Inter-temporal rebound effects	
List element	Input of …	in industry …	Variation gdp in %	Variation global resource use in %	Variation gdp in %	Variation global resource use in %	gdp	res.
7	Chemicals, chemical prod.	Chemicals and Chemical Products	0,037%	-0,025%	0,029%	-0,029%	pos.	neut.
16	Construction work	Real Estate Activities	0,037%	-0,011%	0,025%	-0,016%	pos.	neut.
9	Prod. of agriculture, hunting	Food, Beverages and Tobacco	0,032%	-0,014%	0,044%	-0,022%	neg.	neg.
22	Food products and beverages	Food, Beverages and Tobacco	0,026%	-0,008%	0,043%	-0,014%	neg.	neg.
13	Radio, TV & Comm. Eq.	Electrical and Optical Equipment	0,025%	-0,022%	0,019%	-0,017%	pos.	pos.
30	Office machinery and computers	Electrical and Optical Equipment	0,014%	-0,013%	0,014%	-0,010%	neut.	neut.
5	Basic metals	Basic Metals and Fabricated Metal	0,014%	-0,035%	0,026%	-0,039%	neg.	neut.
6	Metal ores	Basic Metals and Fabricated Metal	0,010%	-0,029%	0,007%	-0,034%	pos.	neut.
26	Diesel oil for road transport	Inland Transport	0,008%	-0,007%	0,008%	-0,012%	neut.	neut.
25	Machinery and equipment	Machinery, Nec	0,005%	-0,011%	0,015%	-0,012%	neg.	neut.
12	Motor vehicles	Transport Equipment	0,005%	-0,016%	0,030%	-0,019%	neg.	neut.
28	Food products and beverages	Hotels and Restaurants	0,004%	-0,006%	0,015%	-0,011%	neg.	neut.
24	Basic metals	Transport Equipment	0,004%	-0,003%	0,001%	-0,012%	pos.	neg.
1	Other mining and quarrying prod.	Other Non-Metallic Mineral	0,003%	-0,079%	0,001%	-0,087%	pos.	neg.
10	Prod. of forestry, logging	Wood and Prod. of Wood and Cork	0,002%	-0,015%	0,001%	-0,019%	neut.	neut.
14	Fabricated metal products	Basic Metals and Fabricated Metal	0,001%	-0,014%	0,003%	-0,016%	neg.	neut.
8	Other mining and quarrying prod.	Chemicals and Chemical Products	0,001%	-0,017%	0,001%	-0,022%	neut.	neut.
29	Other mining and quarrying prod.	Basic Metals and Fabricated Metal	0,000%	-0,010%	0,000%	-0,011%	neut.	neut.
21	Electricity	Chemicals and Chemical Products	0,000%	-0,007%	-0,006%	-0,014%	pos.	neg.
23	Other non-metallic mineral prod.	Other Non-Metallic Mineral	0,000%	-0,012%	0,001%	-0,013%	neg.	neut.
3	Other mining and quarrying prod.	Construction	-0,001%	-0,078%	0,001%	-0,085%	neg.	neg.
27	Prod. of forestry, logging	Pulp, Paper, Printing and Publishing	-0,002%	-0,006%	0,000%	-0,011%	neg.	neut.
11	Other mining and quarrying prod.	Mining and Quarrying	-0,003%	-0,016%	0,000%	-0,019%	neg.	neut.
20	Fabricated metal products	Machinery, Nec	-0,004%	-0,012%	0,004%	-0,014%	neg.	neut.
19	Electricity	Basic Metals and Fabricated Metal	-0,004%	-0,008%	-0,001%	-0,014%	neg.	neg.
18	Wood and products of wood	Construction	-0,005%	-0,007%	-0,003%	-0,015%	neg.	neg.
17	Fabricated metal products	Construction	-0,014%	-0,017%	0,000%	-0,016%	neg.	neut.
15	Other business services	Rent. of M&Eq and Other Business Act.	-0,030%	-0,020%	0,031%	-0,016%	neg.	neut.
2	Other non-metallic mineral prod.	Construction	-0,034%	-0,080%	-0,005%	-0,085%	neg.	neg.
4	Construction work	Construction	-0,044%	-0,051%	-0,005%	-0,052%	neg.	neut.

4.2.3. The effects on resource extractions in detail

As regards the detailed view on variations in resource extractions, Figure 10 presents cumulated results for simulation experiment 2.[15] Although the levels, due to the five years perspective, differ a lot from those given in Section 4.1, the conclusions with regards to the structural composition of the mapped resource categories appear relatively stable.

[15] In case of this detailed presentation of results per resource category as well as for the subsequent presentations of further economic details we again base our report on a simulation experiment which considers a joint variation of all 30 input-coefficients simultaneously.

Figure 10: Simulation experiment 2 - The effects on global and domestic (EU27) resource extractions



The central findings of the simulation experiment 2 with regard to global resource uses therefore can be summed up as:

- If a limited decrease of 2% per annum of the 30 most important intermediate inputs in industrial processes across the EU27 can be achieved within 5 years the global resource extractions of fossils, minerals and forestry can be diminished by nearly 2 billion tons.
- This imposes not only a numeral reduction of resource extractions within the EU27 territory of 1.1 billion tons (mainly constructions minerals and biomass forestry) but also a significant decline of resource extractions somewhere else in the world (mainly ores, coal, gas and oil).
- Besides the environmental rational of resource savings the simulation results for ores, gas and oil stress the potentials of resource productivity increases for a diminishing import dependency (and vulnerability) of the EU with regard to materials with a high geopolitical conflict potential.

4.2.4. The effects on the different industries

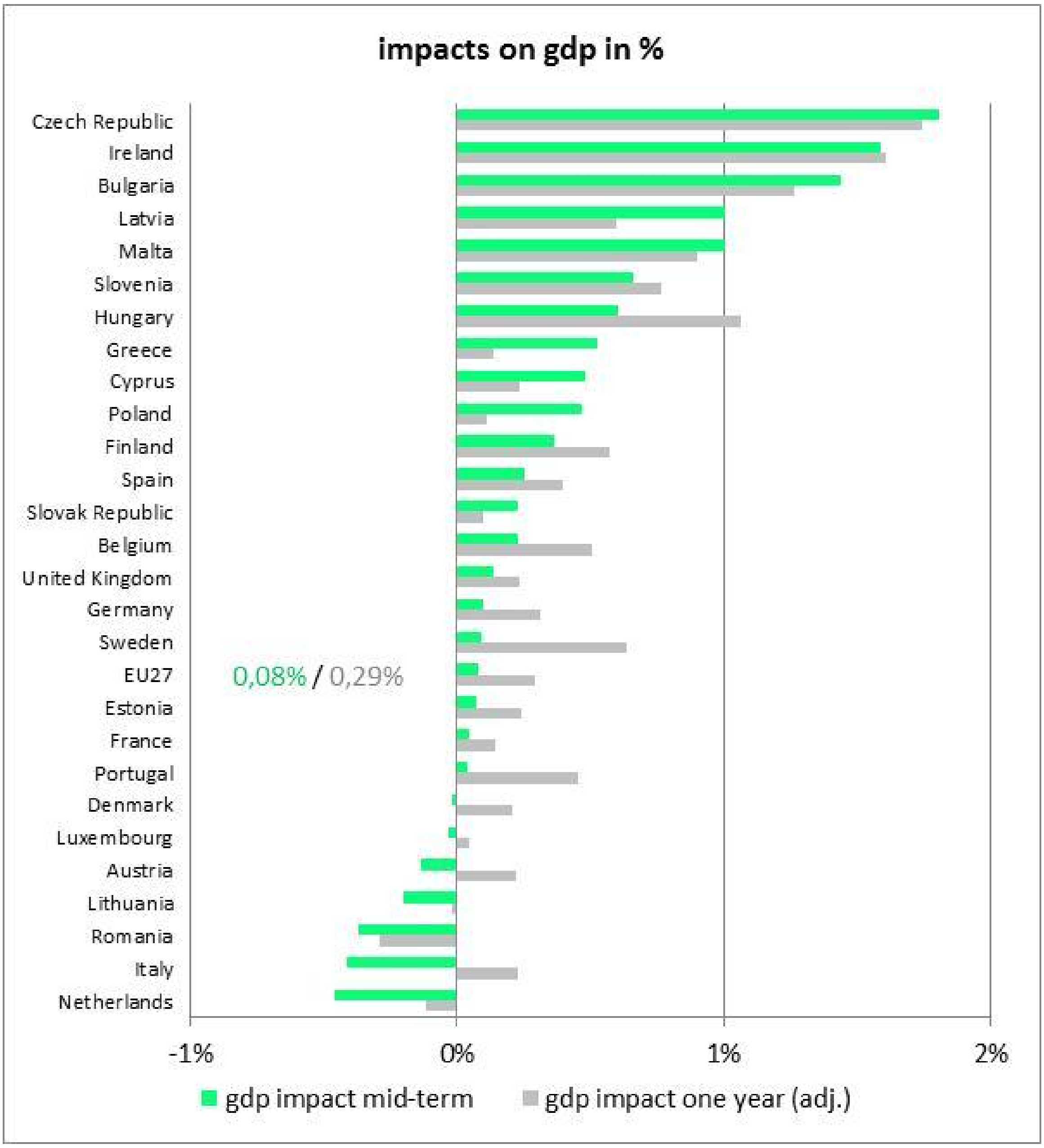
The overall evidence with regards to industry-specific outcomes also appears more or less unaltered by the inter-temporal perspective of simulation 2 (see Figure 11). Therefore, we waive a detailed presentation of effects on different industries for simulation experiment 2.

Figure 11: Industry-specific inter-temporal effects

4.2.5. The effects on country level

This subsection summarises the impacts on Member States' economic growth over the five years simulation horizon. National GDP results of the medium-term simulation are represented by the green bars of figure 12. To ease comparisons with respective findings from the one year simulation, these immediate results (grey bars) have again been re-scaled to compensate for differing strengths of intervention.

Figure 12: Simulation experiment 2 - The effects of a joint resource productivity increase in EU27 on GDP and the role of inter-temporal rebound effects



This subsection summarises the impacts on Member States' economic growth over the five years simulation horizon. National GDP results of the medium-term simulation are represented by the green bars of figure 12. To ease comparisons with respective findings from the one year simulation, these immediate results (grey bars) have again been re-scaled to compensate for differing strengths of intervention.

Figure 12 indicates, for most countries as well as for the overall EU27 aggregate, that inter-temporal rebound effects tends to reduce the economic benefits of resource productivity increases significantly. In this regard, most severe rebound effects are indicated for Italy, Sweden, Hungary and Portugal. On the other hand, we observe few countries where immediate positive GDP effects tend to increase over time. The highest positive deviations of GDP impacts between the two simulation experiments can be observed for Latvia, Greece and Poland.

5. Sensitivity analysis

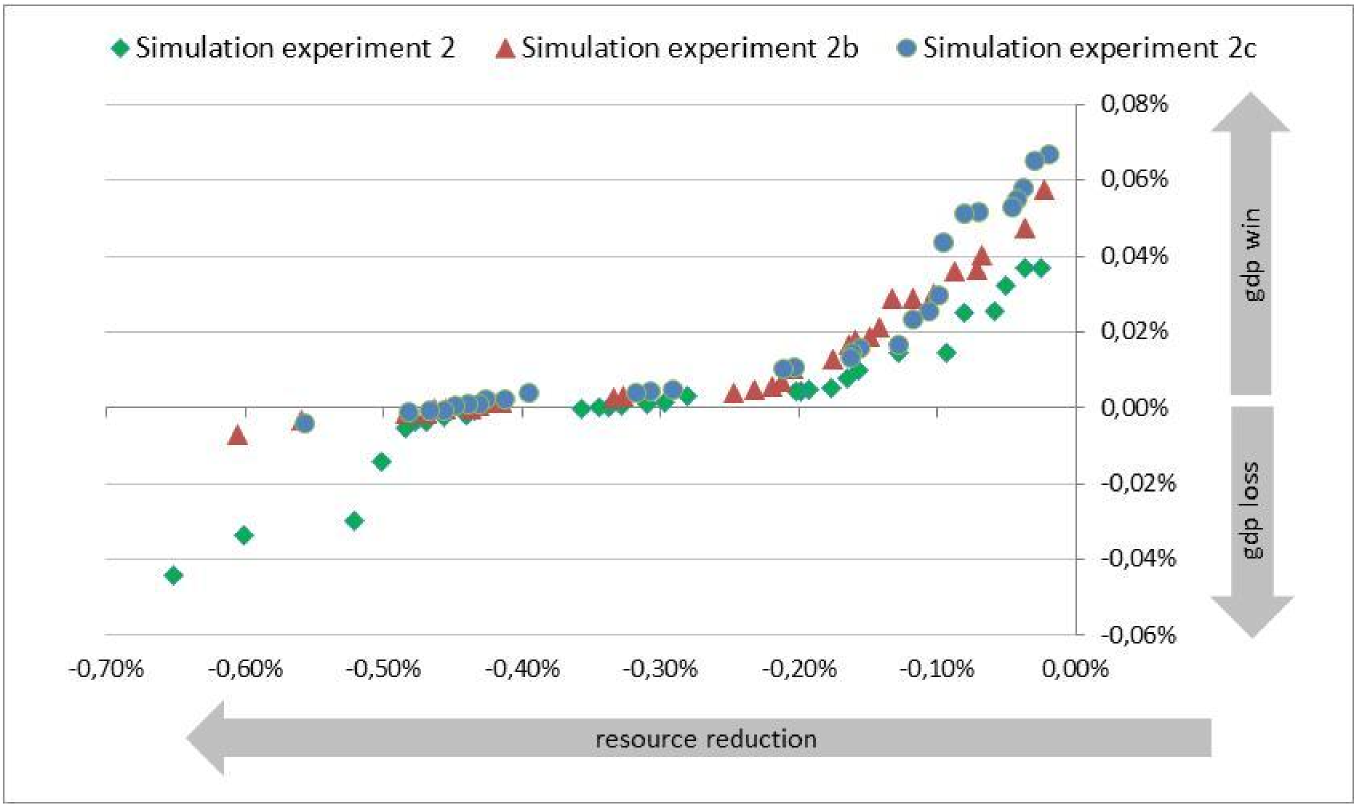
So far, we have always been assuming increases in resource efficiency (reductions in input coefficients) without any further assumptions about the causes. One can say that these two simulation experiments simply assume that the web of constraints (see Bastein et al., 2014 that hampers resource efficiency improvements becomes more perforated. This approach is justified as our contribution is only intended to illuminate general potentials and initial challenges of industry-specific resource efficiency measures with regards to global resource demand. In contrast to this, concrete scenario analyses which evaluate individual dematerialization instruments and make allowances for their specific implementation costs will be carried out by later studies of the POLFREE project.

Nevertheless, we have to assure that our findings presented so far do not exhibit significant sensitivities. This subsection therefore completes our paper by two sensitivity analyses. To this, we considered the following modifications of simulation experiment 2: In variant 2b ("RE improvements by taxation"), the reduction of input coefficients does not happen by itself but is induced by a taxation of the respective industrial production. Assuming revenue neutrality, increases in tax revenues are compensated by corresponding tax reductions for service industries. In variant 2c ("RE improvements by information programme") we fell back on own previous research Meyer et al., 2007, Giljum et al., 2008, Meyer, 2012 and implied the cost assumptions of an information and consulting program.

Whereas a detailed representation of the underlying settings of these sensitivity analyses might be omitted at this place,[16] the resulting benefit curves indicate a high degree of reliability for our overall findings (see Figure 13): The SE 2c ("RE improvements by information programme") shows more positive and higher GDP benefits, whilst the SE 2 ("RE improvements just happen") shows the lowest economic benefits. The SE 2b ("RE improvements by taxation") lies somewhere in-between. With regard to potentials for resource reductions the findings are reverse. The highest potentials are observed for SE 2, than comes SE 2b and the simulation experiment with the lowest reductions in global resource extractions is the SE 2c. But all in all the changes that are induced by the different settings are much lower if we look at the environmental figures than for the economic performance.

[16] Corresponding details are of course available upon request by the authors.

Figure 13: Sensitivity analysis – The benefit curves for the EU27



As most of the results that have already been presented in section 4.2 for SE 2 do not differ significantly in SE 2b and SE 2c besides the already mentioned tendencies for impacts on economic growth and global resource uses we don‘t want to bother the reader with too many details but rather stress some central findings.

- The implementation of different causes of resource productivity increases affects the magnitude of resource reductions (-4% SE 2b compared to SE 2 and -17% SE 2c compared to SE 2) but neither influences significantly the mixture of resources that are reduced nor the findings with regard to the segmentation into domestic extractions and extractions abroad.

- With only a very few exemptions also the findings about the potential winners and losers from a sectoral perspective do not change in the sensitivity analysis.

- In SE 2c the economic benefits are significantly higher than in SE 2. SE 2b shows GDP gains in-between these two simulation results. These observations do not only hold for the EU27 (+0,6% in SE 2c, +0,3% in SE 2b and +0,1% in SE2) but also for the different simulation experiments that show GDP impacts on the national level.

6. Conclusions and outlook

This paper outlined the results of extensive applications of the GINFORS model in order to illuminate prospects and challenges of industry-specific resource efficiency measures. In this regard, we identified a set of 30 input coefficients which represents a substantial potential for reductions in global resource demand. A detailed comparison of our top-down findings with results from related bottom-up studies has been omitted in order to keep this paper self-contained. Thus, such a comparison remains for future research.

However, our findings do apparently fit to the results of most recent related studies. See, e.g., “other mining and quarrying products” (like sand, stones, gravel, lime etc.), which have been identified as most important inputs of our pre-analysis. They are used in “other non-metallic mineral” industries to produce ceramics, tiles, cement, plaster, glass and glass products, etc. These products are to a high degree inputs in “construction”, where also the “other mining and quarrying products” are directly used. Furthermore, rank 4 has been given to “construction work” as input to the sector “construction”. Overall, these findings reflect the fact that non-metallic minerals represent a predominant share of European resource consumption (see, e.g., also European Commission, 2014 in this regard) and do closely correspond to the outstanding significance of the construction sector with regards to European material use (see Sectoral Resource Maps, Information Hub, European Commission, DG Environment, March 2013) .

Based on consequent modelling studies, we further identified significant and reliable indications in favor of resource efficiency measures: Whereas rebound effects tend to diminish initial reductions in global resource demand, environmental burdens might nevertheless be reduced over medium-term horizons by European increases in industrial resource efficiency. Domestically, the demand for construction minerals seems to be affected most by the studied input variations. However, we also observed significant potentials for resource extractions outside the EU (mainly ores, coal, gas and oil). Besides the environmental rational of resource savings the simulation results for ores, gas and oil stress the potentials of resource productivity increases for a diminishing import dependency (and vulnerability) of the EU with regard to materials with a high geopolitical conflict potential.

From an industry perspective we identified significant positive effects in case of industries benefitting directly from increased profit margins due to lower cost dynamics. On the loser side we observed mainly industries (i.e. agriculture, mining & quarrying, other non-metallic mineral) that face a decline of demand as they produce the intermediate goods that are used less.

Overall, our simulations indicate noteworthy potentials for aggregated win-win outcomes of resource efficiency increases: The estimates of section 4 and 5 indicate that limited and manageable reductions of the most resource relevant intermediate inputs in industrial processes across EU27 Member States within only five years can reduce global resource extractions by 1.5 to 2.0 billion of tons. And even more. These resource reductions would be accompanied by positive impacts on GDP of 0.1 to 0.6% per year.

However, our findings also illustrate the challenges to deal with distribution effects among Member States. Our simulation setup indicated notable macroeconomic costs of simultaneous increases in European resource efficiency in case of Italy, Lithuania, Netherlands and Romania. This is not to say that these countries would have to suffer from applied European resource efficiency measures: We refrained from any attempts to map concrete policy instruments in our simulations. Neither did we attempt to conduct full-fledged scenario simulations. Thus, our results so far have to be understood as outcomes of basic thought experiments. By highlighting the just mentioned challenges, they hopefully provide a helpful policy-advice: As the 27 national economies of the EU feature individual characteristics, they also feature individual reactions to uniform policy measures. Thus, uniform European resource efficiency measures will have to be accompanied by balancing economic instruments. Alternatively, they should rather be replaced by national policy approaches.

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8. Annex

Table 5: List of Products

Running number	CPA Category	Running number	CPA Category
1	Products of agriculture, hunting and related services	31	Secondary raw materials
2	Products of forestry, logging and related services	32	Electrical energy, gas, steam and hot water
3	Fish and other fishing products; services incidental of fishing	33	Collected and purified water, distribution services of water
4	Coal and lignite; peat	34	Construction work
5	Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	35	Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel
6	Uranium and thorium ores	36	Wholesale trade and commission trade services, except of motor vehicles and motorcycles
7	Metal ores	37	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods
8	Other mining and quarrying products	38	Hotel and restaurant services
9	Food products and beverages	39	Land transport; transport via pipeline services
10	Tobacco products	40	Water transport services
11	Textiles	41	Air transport services
12	Wearing apparel; furs	42	Supporting and auxiliary transport services; travel agency services
13	Leather and leather products	43	Post and telecommunication services
14	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	44	Financial intermediation services, except insurance and pension funding services
15	Pulp, paper and paper products	45	Insurance and pension funding services, except compulsory social security services
16	Printed matter and recorded media	46	Services auxiliary to financial intermediation
17	Coke, refined petroleum products and nuclear fuels	47	Real estate services
18	Chemicals, chemical products and man-made fibres	48	Renting services of machinery and equipment without operator and of personal and household goods
19	Rubber and plastic products	49	Computer and related services
20	Other non-metallic mineral products	50	Research and development services

Running number	CPA Category	Running number	CPA Category
21	Basic metals	51	Other business services
22	Fabricated metal products, except machinery and equipment	52	Public administration and defence services; compulsory social security services
23	Machinery and equipment n.e.c.	53	Education services
24	Office machinery and computers	54	Health and social work services
25	Electrical machinery and apparatus n.e.c.	55	Sewage and refuse disposal services, sanitation and similar services
26	Radio, television and communication equipment and apparatus	56	Membership organisation services n.e.c.
27	Medical, precision and optical instruments, watches and clocks	57	Recreational, cultural and sporting services
28	Motor vehicles, trailers and semi-trailers	58	Other services
29	Other transport equipment	59	Private households with employed persons
30	Furniture; other manufactured goods n.e.c.		

(List of Products continued)

Table 6: List of Energy Carriers

Running number	NACE Category
1	Hard coal and derivatives
2	Lignite and derivatives
3	Coke
4	Crude oil, NGL and feedstocks
5	Diesel oil for road transport
6	Motor gasoline
7	Jet fuel (kerosene and gasoline)
8	Light Fuel oil
9	Heavy fuel oil
10	Naphta
11	Other petroleum products
12	Natural gas
13	Derived gas
14	Industrial and municipal waste
15	Biogasoline also including hydrated ethanol
16	Biodiesel
17	Other combustible renewables
18	Electricity
19	Heat

Table 7: List of Resource Categories

Abiotic resources	Biotic resources
Fossil coal	Biomass animals
Fossil oil	Biomass forestry
Fossil gas	
Other fossils	
Construction minerals	
Industrial minerals	
Ores	