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ORIGINAL PAPER

Modeling green growth and resource efficiency: new results

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Abstract Green growth is an environmental policy strategy that aims at an absolute decoupling between economic growth and resource consumption. As far as the applied policy measures focus on direct enhancements of economy-wide resource efficiency levels, their overall achievements might however be weakened by their induced rebound effects. This paper seeks to investigate the nature and significance of such trade-off interrelationships with regards to material efficiency improvements within the German economy. To this, we present the outcomes of individual policy simulations by means of the PANTA RHEI model. Taxes, information, and regulation activities are considered as policy instruments. Our overall empirical findings cannot falsify the green growth paradigm as the observed magnitude of economy-wide rebound effects appears unable to inhibit future absolute decoupling trends.

Keywords Green growth · Economic-environmental modeling · Resource policy modeling · Resource efficiency · Rebound effect · Recycling

JEL Classification C51 · C54 · C63 · C67 · Q31 · Q32 · Q38

The reported progress with regards to the modeling of material consumption in PANTA RHEI represents the most significant GWS-contribution to the MaRess (material efficiency and resource saving) project which was financed by the German Ministry for the Environment. See http://ressourcen.wupperinst.org/ for further details.

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Introduction

The question at hand

A central question of environmental policy is whether it will be possible to reach an absolute decoupling of economic growth measured in monetary terms at constant prices from the extraction of natural resources measured in physical units. Policies that improve resource efficiency might be able to achieve decoupling, but higher resource efficiency might also boost economic growth and resource consumption as it shifts the macroeconomic production frontier and increases consumer income.[1]

These so-called "rebound- effects" (see, i.a., Schipper, 2000 or Sorrell, 2007a, b, 2009) expose green growth efficiency concepts to severe criticisms: Common critics of green growth efficiency concepts (see, i.a., Jackson 2009a, b and Sorrell 2010 for recent contributions in this regard) refer to empirical evidence from industrialized countries whose past macroeconomic developments usually achieved only relative decoupling, i.e., growth rates of resource consumption being positive but lower than those of GDP. In light of these historical trends, they demand "zero growth"

[1] For the sake of completeness, we have to acknowledge that many policy measures have already been implemented which actually did induce abatement costs (instead of cost reductions). In this regard, an anonymous reviewer exemplarily referred to the case of sulfur emissions which were decoupled from economic growth by the introduction of cost-rising end- of pipe technologies. Nevertheless, as will also be laid out on the following pages, policies intended to boost resource efficiency do of course induce apparent economy-wide (positive) income and demand effects. Thus, whereas our paper focuses only on a selected subset of policy interventions, we are convinced that any discussion whether their intended decoupling effects might be blocked by their induced rebound effects warrants a sound empirical appraisal.

strategies. However, the effect of efficiency policies crucially depends on the set of instruments chosen for their implementation. Insofar, even if we did not observe any absolute decoupling over the last decades, this does not necessarily imply that it is infeasible to achieve absolute decoupling paths in the future. In what follows, we are going to argue that for a selected set of instruments, comprehensive model simulations are indeed able to indicate potential pathways to absolute decoupling.

The case of material efficiency

Rebound-effects are usually more or less exclusively discussed by *energy* economists. This is quite astonishing as managerial-economics seems to indicate that *material* costs represent up to 40% of individual firms' overall costs with the corresponding share of energy costs ranging around 2% only. Thus, microeconomic observations indicate striking rebound potentials with regards to increases in material efficiency.

It should be well understood that such microeconomic evidence cannot be directly mapped to a macroeconomic scale as economy wide rebound effects emerge from numerous price and income adjustments that have the potential to stimulate reallocations of final as well as intermediate demand. Furthermore, an initiating rise in resource productivity might be induced by substitutions of resource intensive products in the vector of final demand as well as by resource saving technological innovations and the abolition of inefficient production processes for a given vector of final demand. The overall outcome of these interdependent movements might thus only be depicted by means of a total analysis (Greening et al. 2000, Binswanger 2001, Guerra and Sancho 2010). The task of evaluating resource efficiency programs with regards to macroeconomic rebound effects therefore constitutes a natural field of application for economic-environmental models. As this topic seems to have been disregarded (at least) by most macroeconomic researchers, up to now, we intend to contribute some wanting macroeconomic insights to the wide-ranging rebound literature.

State of the art in economic-environmental modeling

Material flows are a prominent field of industrial ecology using input output models. A big literature has grown here so that a handbook on this topic is now available (Suh 2009). But macroeconomic modeling of the flow of materials which means that the integration of material flows in a complete macroeconomic framework that is in line with the just-mentioned requirements has just begun a few years ago following the van den Bergh and Janssen (2004) argument that “adding economics to industrial ecology favors increasing policy realism”.

In order to comply with this claim for policy realism, any modeling approach to resource efficiency issues should, according to our point of view, satisfy the following requirements:

- Complete endogenization of final and intermediate demand;
- Detailed representation of technology with regards to labor, capital, and intermediate product flows;
- Endogenous prices reflecting the supply side decisions in realistic market structures;
- Sufficient disaggregation into sectors and product groups combined with macroeconomic closure;
- Incorporation of the interdependencies between production and import of goods in monetary terms and the disaggregated use of resources measured in physical units.

As regards the modeling of resource efficiency effects, these requirements were (as far as known to us) first of all met by Distelkamp et al. (2005a, b, c). They derived first policy simulations with regards to German total material requirement by means of the economic-environmental model PANTA RHEI. Based on this dataset, Meyer et al. (2007) provided first rebound estimates for a rising material efficiency scenario which was also modeled within the PANTA RHEI framework. They came to the result that rising material efficiency has a strong rebound effect and is therefore only able to induce a relative decoupling. Giljum et al. (2008) consider global material extraction data in their simulations of European environmental policies (including material policy). The applied global modeling framework Global Interindustry Forecasting System (GINFORS; see, e.g., Lutz et al. 2010 for a model description) indicates similar effects of material efficiency improvements on GDP for a number of European countries. Ekins and Speck (2011) compile most recent results with regards to the impacts of an environmental tax reform on economic development and material and energy consumption in Europe. State-of-the-art approaches to the modeling of global material extraction and consumption (by means of the models E3ME and GINFORS) are also outlined by Barker et al. (2011).

Contributions of the paper

As regards the list of references given above, only Meyer et al. (2007) provided a first empirical assessment of the potential rebound-pitfalls of economy-wide increases in material efficiency. The paper at hand follows this seminal contribution as all subsequent simulation results have also been computed by means of the PANTA RHEI model. However, whereas the results of Meyer et al. (2007) were based on a model version whose reaction functions had been estimated on time series observations ending in the year 2000, our analyses have been conducted within an updated modeling framework. The historical time series database of this updated PANTA RHEI version spans until 2007. Therefore it also mirrors the historical surge in material prices after the year 2000 which (at least in many cases) enabled us to depict the price elasticities of crucial input structures more precisely.

Furthermore, as will be outlined in the following sections, our actual simulations reflect a more comprehensive policy mix which incorporates different material policies in combination with an engaged climate policy. These central extensions of the analytical framework of Meyer et al. (2007) reflect our insight that, as will be shown in light of our baseline discussion, an engaged *climate* policy cannot be the only environmental policy. It has to be complemented by a *resource* policy.

The resulting findings indicate that absolute decoupling of economic growth from total material requirement then indeed seems to be possible. These quantitative results therefore seem to weaken the theoretical skepticism against green growth efficiency concepts.

The paper is organized as follows: "Data" section features the material data of the Wuppertal Institute that allows total material requirement (TMR) modeling in deep sectoral disaggregation. "The model PANTA RHEI" section provides general summary information with regards to PANTA RHEI. Technical details of our analyzed policy scenarios are given within "The analyzed scenarios" section. Finally, section 5 discusses the results of a simulation on recycling which refers to the debate on green growth and the rebound effect and "Conclusions" section concludes.

Data

Our main concern focuses on disaggregated TMR time series which had been provided by the Wuppertal Institute for the 1995–2004 period. Table 1 provides an overview on this dataset which is available in accordance to the official 71 sector scheme of the German input–output accounting framework (see Acosta-Fernandez 2008 for further details concerning Wuppertal's TMR data work).

Apart from material categories, these data are also classified in accordance with the following accounting categories: domestic extraction used, unused domestic extraction, imports and hidden flows associated to the imports ("rucksacks"). Domestic extraction used gives the materials that have been extracted and have been used to produce goods. Unused domestic extraction consists of rubble and other extractions that cannot enter the production process. Direct imports are the imported materials and also the materials that are part of intermediate and finished imported goods. The hidden flows associated to the imports ("rucksacks") are the materials that have been used in the production of the imported goods abroad but are not directly part of the imported material or product.

The model PANTA RHEI

Some general remarks

PANTA RHEI is a macro econometric model for Germany that depicts the dependency of resource consumption and emissions from the development of the economy in deep sectoral detail. The theoretical background of the model can be addressed as evolutionary: Agents are assumed to decide under conditions of bounded rationality on imperfect markets with price setting behavior of suppliers. Path dependencies with respect to the immobility of invested capital stocks and structural rigidities as well as chronological time paths are taken into account.

Structural equations are usually modeled on the 71 sectors level (two-digit NACE classification) of the input output accounting framework of the official system of national accounts (SNA) and the corresponding macro variables are then endogenously calculated by explicit aggregation. In that sense, the model has a bottom up structure. It satisfies a self-contained and consistent integration of the SNA accounts which fully reflects the circular flow of generation, distribution, redistribution, and use of income.

The model is empirically evaluated: The parameters of the structural equations are econometrically estimated. On the time consuming model-specification stage, various sets of competing theoretical hypotheses are empirically tested. As the resulting structure (which compiles about 50,000 equations) is characterized by highly nonlinear and interdependent dynamics, the economic core of the model has furthermore been tested in dynamic ex post simulations. At this, the model is solved by an iterative Gauß Seidel algorithm year by year. The whole system has been used in many long-run forecasts until 2030 (ex ante simulations) where it had to pass many plausibility checks.

The model structure in overview

The core of PANTA RHEI is the economic module, which calculates final demand (consumption, investment, exports) and intermediate demand (domestic and imported) for goods, capital stocks, employment, wages, unit costs, and producer as well as consumer prices in deep disaggregation of 71 or 59 economic sectors. The disaggregated system also calculates taxes on goods and taxes on production. The

Table 1 The material categories of the Wuppertal data set

Domestic extraction	Imports
Biomass	
Biomass from agriculture	Products of agriculture and hunting
Biomass from forestry	Products of forestry
Biomass from fishery	Fish, products of fishery
	Other products (food, tabacco, wood, paper, etc.)
Metals	
Iron ores	Ores
	Pig iron, steel, tubes, semi-finished products mainly from pig iron/steel
	Non-ferrous metals and semi-finished products mainly from non-ferrous metals
	Metal products
	Other products (machinery, business machines, vehicles, etc.)
Nonmetallic minerals	
Peat for horticultural purposes	Nonmetallic mineral processing, n.e.c.; other products of mining
Ashlar, natural stones, n.e.c.	Glass, ceramics, machined nonmetallic mineral processing
Gravel, sand; broken natural stones	
Chemical and fertilizer minerals	
Salt and sodium chloride; seawater	
Nonmetallic mineral processing, n.e.c.; other products of mining (contains disposed excavated soil of the constructionsector)	
Energy carrier	
Hard coal	Coal and peat
Lignite	Crude oil/natural gas
Peat	Products of coke oven plant and petroleum, fissible, and fertile material
Crude oil and natural gas	Energy and services of energy supply
Other products	
	Other products (clothing, leather, chemical products, rubber, and plastics, measuring instruments, etc.)

corresponding equations are integrated into the balance equations of the input output system.

Value added of the different branches is aggregated and gives the base for the SNA system that calculates distribution and redistribution of income, use of disposable income, capital account, and financial account for financial enterprises, non financial enterprises, private households, the government, and the rest of the world. Macro variables like disposable income of private households and disposable income of the government as well as demographic variables represent important determinants of sectoral final demand for goods. Another important outcome of the macro SNA system is the variable net savings and its related stock variable governmental debt. Both are important indicators for the evaluation of policies. The demand side of the labor market is modeled in deep sectoral disaggregation. The aggregate labor supply is driven by demographic developments.

The energy module explains final energy demand in physical units in deep sectoral disaggregation as well as the conversion of primary energy into secondary energy carriers. The energy module further calculates the shares of 30 energy carriers. Emissions are calculated from primary energy inputs. The energy module is linked interdependently with the economic module, the traffic module, and the dwelling module.

The traffic module explains the demand for passenger traffic and traffic for the transport for goods in physical units for the carriers railway transport, road transport, water transport, and air transport. Further stocks of vehicles and their energy consumptions are estimated. The traffic module is linked interdependently with the economic module and the energy module.

The dwelling module depicts the dependency of the use of buildings for dwelling in physical units like housing space from economic and demographic variables. There is a link from the dwelling module to investment in buildings in the economic module and the energy demand for residential purposes in the energy module.

The material module explains in detail the domestic extraction of biomass, nonmetallic minerals, metals, and fossil fuels depending from the economic development. The domestic extraction of fossil fuels used is related to the production of fossil primary energy carriers that is calculated in the energy module. A detailed description of the material module is given in the following subsection.

The material module

The material module explains all variables of the Wuppertal data set. In the deep structure of the Wuppertal data set, material intensity of domestic extraction used is defined as the relation between the extraction of materials in physical units (tons) and gross production of the extracting sector measured in monetary terms at constant prices. The material intensity is explained by the price index of the material in relation to the price index of gross production of the extracting sector and a trend. Multiplication of the material intensity variable with gross production at constant prices of the extracting sector yields domestic extraction used of the material in question. Exceptions are fossil fuels, which are explained by the energy module as already mentioned. Domestic extraction unused is given for the different kinds of materials with their relation to domestic extraction used with constant factors.

The intensities of direct imports of materials are defined as the relation of direct material import measured in physical units (tons) and the import of the product category measured in monetary terms at constant prices that is related to the material in question. These material intensities are dependent from the relation of the price index of the materials and the price index of the import good that is related to the material in question and a time trend. The rationale behind is the assumption that producers abroad will reduce the material intensities, if world market prices for that material will rise relatively to the product price, which they can achieve. Multiplication of the material import intensities with the imports of the related goods in monetary terms at constant prices gives the direct material imports. The hidden flows are associated to the imports calculated with constant factors to the direct material imports.

This kind of modeling approach guarantees that changes in economic activity will have in deep detail consistent reactions in the economy's structure and in material inputs in physical terms. It can be expected that policy measures in the field of resource efficiency as well as price changes on international resource markets will have adequate effects on economic and material variables.

The analyzed scenarios

Scenarios are sets of assumptions for the exogenous variables, i.e., variables that are not explained in the model. For every model simulation experiment, one has therefore in the first instance to decide about the quantitative developments of the exogenous variables. The method of policy simulations then can be understood as a comparison between a model forecast with explicit exogenous policy assumptions to a model forecast in absence of the assumed policy measures (the so-called “baseline”). This comparison reveals the overall impacts of the direct and indirect effects induced by the of the policy measures under consideration.

This section summarizes our baseline assumptions as well as the policy implications of the analyzed scenarios. As regards the baseline assumptions, we focus on the most relevant drivers for German material consumption only, namely global economic development trends and the assumptions about the implied climate policy measures over the next 20 years.

The baseline

In order to reflect inherent uncertainties underlying our final baseline specification, central assumptions with regards to the aforementioned drivers have been evaluated by means of preliminary sensitivity analyses. Figure 1 reflects one central result of these preliminary sensitivity analyses. Three alternative baseline specifications have been evaluated with regards to German TMR (Fig. 2). These individual specifications might be labeled as follows

Base I: Moderate climate policy, optimistic exports, and resource prices.

Base II: Moderate climate policy, pessimistic exports, and resource prices.

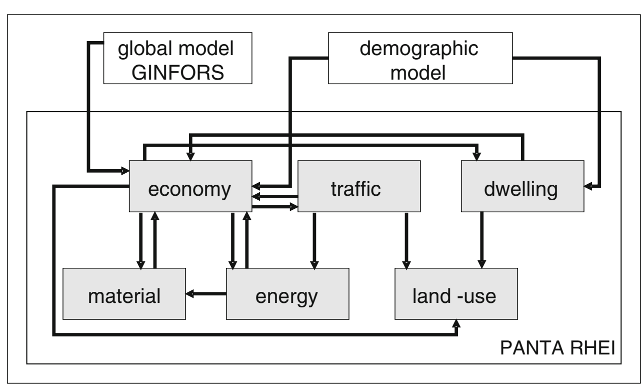

Fig. 1 The structure of the model PANTA RHEI

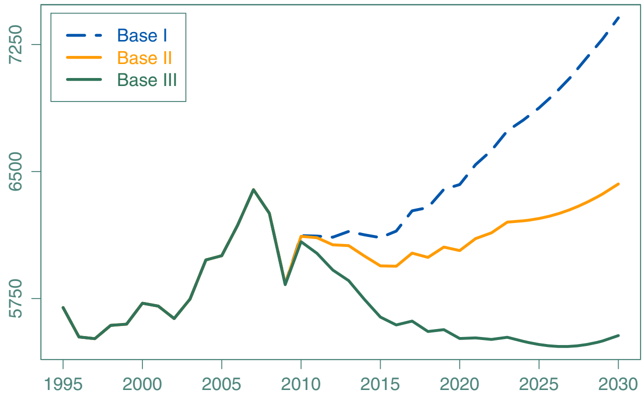

Fig. 2 The development of German total material requirement (in milliion tons) for three alternative baseline specifications. *Dashed line*: base I; *solid light line*: base II; *solid green line*: base III

Base III: Engaged climate policy, pessimistic exports, and resource prices.

Before we discuss some further details of the individual baseline runs, let us first define the individual climate policy and world economic development trends which determine these individual baseline specifications.

Global economic trends

Our assumptions concerning global economic trends have been derived by means of the GINFORS model under the assumption of a rapid recovery from the 2008–2009 subprime crisis. Oil prices as well as other resource prices (our scenarios in fact do reflect individual price paths for eight types of resources) are therefore expected to rise steadily after their dramatic slump in face of the crisis.

In the pessimistic variant, real oil prices are expected to rise by 60% from 2009 to 2030. Real prices for metals are assumed to rise by 71% and for food by 42%. The average annual growth rate of German exports (in constant prices) might then be expected to equal 3.2% from 2010 to 2030. Thus, German exports are assumed to almost double within this 20-years horizon. However, we have to respect that German exports historically figured an average annual growth rate of 6.6% in real terms between 1990 and 2006. Thus, our pessimistic variant indeed implied a reduction of future growth rates. Nevertheless, this specification implies an export ratio (relative to GDP) of 63% in 2030, which is even by far greater than the historic maximum of 46% in 2007.

In the economically more optimistic variant real oil prices are assumed to grow only by 50% until 2030 (metals, 60%; food, 30%). The average growth rate for German exports equaled 4.1% p. a. in this setting.

Climate policy actions

Our assumptions concerning climate policy are consistent with “Politikszenarien für den Klimaschutz V”, a policy study in which the Institute for Applied Ecology (Öko Institut), the Forschungszentrum Jülich, the DIW Berlin, and the ISI Fraunhofer- Institut estimated the effects of two policy scenarios in charge of the Federal Environment Agency (see Umweltbundesamt 2009 for details). Their so-called “with measures scenario” and their more ambitious “structural change scenario” do in fact represent our “moderate” or, respectively, “engaged” climate policy configurations. Most of the relevant instruments are already established in Germany but will be more or less enforced within the individual scenarios. Despite improved energy efficiency in industry and households (here especially in dwelling), a further expansion of renewable energies is assumed whereas the phase-out of nuclear energy is assumed to follow the enactments of the former red/green coalition (for more details see Distelkamp et al. 2010, pp. 19).

In the more engaged structural change scenario, the target of the present conservative administration (Lindenberger et al. 2010) to reach an 85% reduction of greenhouse gas emissions (compared with the year 1990) will be achieved as far as the pessimistic assumptions concerning exports and resource prices are effective. In this configuration, German greenhouse gas emissions will already be reduced by 55% until the year 2030.

Discussion of baseline sensitivity analyses

Base I might be understood as a plain “business as usual” scenario. Exports are growing from 2010 to 2030 with nearly the same average growth rate as they did in the two decades before and we are facing a moderate climate policy. Some years after the crisis, TMR gets the same dynamic that it has had in the decades before. This business-as-usual scenario shows only a relative decoupling between economic development and resource use: Real GDP rises from 2008 to 2030 by 29.5%, TMR grows in this period by 18.5%.

Lower exports and higher resource prices in base II will reduce the growth of TMR so that the level of 2008 will be reached not earlier than 2030 (2030 against 2008, +2.8%); but since GDP rises only by 16.3%, we have more or less the same difference in growth rates as in base I and insofar also only relative decoupling.

The engaged climate policy of the base III specification will be able to reduce TMR absolutely, so that in 2025 the levels of the year 1995 can be reached. Since GDP has nearly the same growth rate as in base II, we observe an absolute decoupling. But after 2025, a slight upward movement of TMR can be observed, which means that climate policy is not able to guarantee a

Table 2 The effects of a higher input of secondary metals (factor 3) in the production of non-ferrous metals in Germany in the year 2030

Deviations from baseline	Gross domestic product	Public debt	Employment	Energy consumption	TMR
In percentage, %	+ 0.01	−0.05	+0.024	+0.006	−3.3
Absolute	+0.33 billion€	−1.0 billion€	+7,000 persons	+534.0 TJ	−196.8 million t

Elasticity of substitution −0.4

permanent absolute decoupling of economic development and resource consumption.

These baseline considerations clearly show that an engaged climate policy cannot be the only environmental policy. It has to be complemented by a resource policy. In what follows, we are going to discuss some selected resource policy instruments. For the remainder of the text, all scenario analyses will refer to base III.

The material scenarios: an overview

Our policy scenarios exemplarily consider the most important policy approaches—information policy, economic instruments, and regulation by setting technical standards. Due to space constraints, each of the three policy approaches will be illustrated by one demonstrative scenario analysis only.

Tax simulations

The impact of economic instruments is simulated for taxes on consumption and taxes on resource inputs. Taxes on consumption are analyzed by changing the actual tax rates on value added for railway transport services and air transport services. The tax rate on railway transport services is reduced from the normal rate of 19% to the lower rate of 7% that is given for several goods. On the other side, the tax rate on the resource intensive air transport, which today still has the reduced tax rate of 7%, is raised to 19%.

The exemplary application of a material input tax (MIT) considers the case of construction minerals. It is assumed that in all European countries a tax of 2€ per ton on domestic extraction used would be introduced in 2012 rising by 5% p. a. and reaching 4.8€ in 2030. This tax is interesting since it has already been established in some European countries. Furthermore, the import problem is much less important than for other resources.

The results show that higher rates of value added taxes for material intensive and less rates for material extensive consumption goods seem to indicate steps in the right direction. However, the overall effects appear rather small. The material input tax on construction minerals is able to reduce the input of construction minerals by 16.1%, which means for TMR a reduction of 1.5% without any disturbances in the economy compared with base III. It seems that the MIT in general has a strong potential.

Information instruments

As far as market failures enable firms to operate, resource inefficient processes information instruments represent an attractive approach (Fischer et al. 2004). However, macroeconomic impact analyses of single information instruments are almost impossible due to the deficiency of necessary datasets. The solution of that problem is to try an estimation of the effects that would occur, if best information of agents was given. What are the costs of best information and which impact can be derived for resource consumption? There is data from well-known consulting firms and governmental institutions for the costs of the best information on material efficiency and the success which these firms had in material efficiency. Fischer et al. (2004) estimate that firms of the manufacturing sector in the average are able to reduce their material costs by 20%. The costs are equivalent to the savings of 1 year, two thirds of them being investment in machinery, one third additional service inputs. These are no assumptions, but experience from concrete consulting work. In this way, the potential of an information and consulting program on material efficiency for the economy and its total material requirement could be estimated.

Table 3 The effects of a higher input of secondary metals (factor 3) in the production of non-ferrous metals in Germany in the year 2030

Deviations from baseline	Gross domestic product	Public debt	Employment	Energy consumption	TMR
In percentage, %	+0.04	−0.1	+ 0.03	+0.01	−8.9
Absolute	+1.0 billion€	−2.5 billion€	+10,600 persons	+916.0 TJ	−489.8 million t

Elasticity of substitution −1.0

Table 4 Simulation results for the combined resource efficiency scenario

Deviations from baseline	Gross domestic product	Public debt	Employment	TMR
In percentage, %	+14.0	−11.0	+1.9	−20.0
Absolute	+372 billion€	−251 billion€	+680,000 persons	−993 million t

The results have shown that there is a strong rebound effect, which raises GDP by 14.2% against the baseline in 2030. But in spite of this, TMR could be reduced by 9.2% against base III. So there is absolute decoupling even in this case of a strong rebound effect. As base III already implies a lower TMR in 2030 than 2010, the addition of a material efficiency policy implies an absolute fall of TMR against historic values.

Recycling by regulation

As an example for regulation by technical standards, a mandatory share of recycled metals in final products made of non-ferrous metals has been considered. Two variants to implement such a policy are thinkable. The first is a worldwide sector agreement on the production of non-ferrous metals. The second is a domestic regulation of the production of non-ferrous metals combined with the obligation for a certificate that guarantees the standard for imported semi-finished and finished goods made to a certain amount of non-ferrous metals. In the simulation, it was assumed to raise the present share of recycled non-ferrous metals by factor 3 till 2030. Since there was no data about the input of recycled material in the production of non-ferrous metals, the input coefficient (relation between input of recycled material and the output of non-ferrous metals in monetary terms at constant prices) was taken.

Depending on the elasticity of substitution between the input of ores and of recycled material an 8.9% reduction of TMR seems possible in absence of strong economic impacts. The econometric estimation gives −0.4, which means that a rise of the input coefficient in monetary terms at constant prices of recycled material by one percent will induce a reduction of the input coefficient of ores of 0.4%. So there will be higher costs of production. On the other side, it is possible that an extension of recycling may improve the technology so that these costs reduce. This seems to be plausible because it is expected that in the future metal prices will rise much stronger than goods prices. To get an idea for the potential of such an improvement, we also ran a second simulation with an assumed elasticity of −1 (i.e., substitution without costs).

Overall, these simulations showed that in the first case, a 24% reduction of the consumption of ores measured in tons happened; in the second case, a 60% reduction of ores in the domestic production of non-ferrous metals was possible. These reductions were assumed also for the contents of ores in the imported goods.

Assuming a −0.4 elasticity the main macroeconomic outcomes might be summarized as shown in Table 2 (all figures represent deviations from base III). Rising costs in the production of non-ferrous metals will raise costs in metal production (non-ferrous metals plus steel) till 2030 by 0.1%. Demand for metal products will be 0.08% and employment 0.06% (130 persons) lower. In the recycling sector, demand and production will rise till 2030 by 18.1%. Higher capacity utilization will induce a reduction of prices in that sector by 6.3%, employment will rise by 5.1% (1,200 persons). The reduction of imported ores raises GDP by 0.34 billion€ (0.01%), which has additional positive effects on employment. Total material requirement (TMR) is reduced by 197

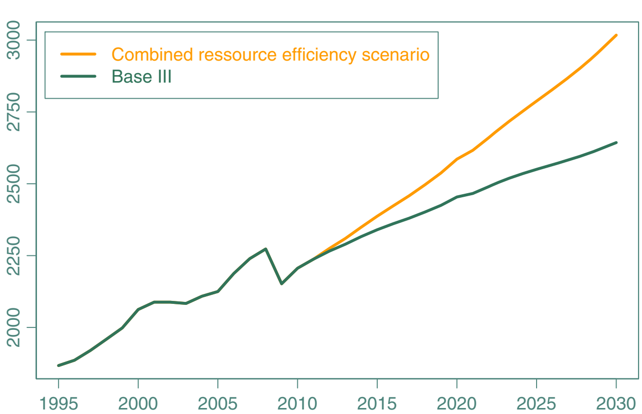

Fig. 3 German GDP in billion Euros and constant prices

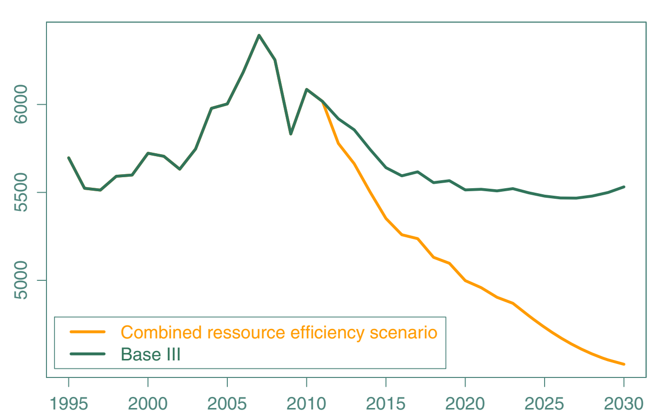

Fig. 4 German total material requirement (in million tons)

million tons (−3.3%), which of course is highly concentrated on metals.

With an assumed elasticity of −1 there will be no negative effects in metal production and the reductions of ore imports are much higher (see Table 3). The effect on TMR is now higher by a factor 2.7 which is near to the relation of the elasticities of substitution in both scenarios: TMR reduces now by 8.9%. The TMR for metals is reduced by 23.5%, which is highly concentrated on the hidden flows of imported goods (rucksacks).

The combined resource efficiency policy scenario

So far, it could be shown which impacts individually selected instruments show. We now close our presentation of results with a discussion of the findings for a total policy scenario which embraces over all of the abovementioned resource policy instruments. Thus, the results presented within Table 4 might be seen to evaluate the potentials of a forced policy strategy towards improvements in resource efficiency.

If all of the abovementioned resource policy instruments were simultaneously applied (with a substitution elasticity of −1 for the recycling case) resource productivity would be doubling from 2010 to 2030. Compared to the base III reference scenario we observe the following results for 2030: A rise of GDP in constant prices of 14% (+372 billion€; see also Fig. 3), a shrinkage of public debt by 11% (−251 billion€), an increase of employment of about 1.9% (+680,000 persons) and a reduction of total material requirement by 20% (−993 million tons, see also Fig. 4). CO_2 emissions remain at the low base III level in spite of the strong rebound effect.

Conclusions

The paper started with a discussion of the central question of environmental policy whether it is possible to reach an absolute decoupling of economic growth and resource consumption. Some discussants preferring "zero growth" policy concepts argue with a view back that absolute decoupling has never happened in the past and referring to the rebound effect they see no chance for the future to reach absolute decoupling (see Jackson 2009a, b for example). Our position was that until now, no country has really tried to reach absolute decoupling and that it depends from the concrete policy how strong the rebound effect is. Answers to that can only be given by the application of economic-environmental models that have to fulfill certain requirements in simulation studies, because the questions are too complicated to be answered after pure concentrated thinking. The paper tried to give a short report on improvements that could be achieved with he model PANTA RHEI during the MaRess project concerning the data and the model structure that is based on it. The paper further summarized the results that have been achieved in the several simulation studies. Our baseline III showed that in the case of a moderate export development for Germany and an engaged climate policy, it will be possible to reduce TMR in Germany till 2030 to the level of 1995. Each of the further discussed alternative resource policies will bring a further reduction of TMR. The reason is that there are some policies, which have very small rebound effects. This could be shown for the recycling policy, which we looked at in more detail. But even the information and consulting program, which has a strong rebound effect, induces an absolute reduction of TMR.

Further research is necessary especially in the field of material input taxes. The example of the tax on construction materials has shown the potential. The experience of a relative high price elasticity of material inputs that we made with the actual version of PANTA RHEI gives evidence for this conjecture.

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