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Quantitative Assessment of Pathways to a Resource-Efficient and Low-Carbon Europe

Martin Distelkamp

Mark Meyer

WWW.GWS-OS.COM

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AUTHORS

Martin Distelkamp,

Tel: +49 (541) 40933-160, E-Mail: distelkamp@gws-os.com

Mark Meyer

Tel: +49 (541) 40933-290, E-Mail: m.meyer@gws-os.com

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1 INTRODUCTION

Various environmental footprint concepts have been developed and applied in sustainability research during the past two decades (see, e.g., Hoekstra and Wiedmann 2014 for a literature review). However, modelling of future scenarios has, until recently, tended to focus only on individual aspects at a time with a special emphasis on emission scenarios (see, e.g., the well know mitigation scenarios for the IPCC like, inter alia, van Vuuren et al. 2011).

Though the sustainability research community as well as international decision makers seem to share the conviction that, akin to the challenges of climate policy, a great transition will also be needed in order to decouple human wellbeing from resource use over the next decades (European Commission 2011, Hoekstra and Wiedmann 2014, UNEP 2011, UNEP 2014), there exist only scarce quantitative assessments of possible transition scenarios which do also concern this matter. Our paper is intended to advance this branch of research by a presentation of key scenario insights from the global simulation model GINFORS which take account of the complex interrelations between different environmental objectives.

GINFORS is a dynamic environmental economic model which is based on a Multi-Regional Input-Output (MRIO) database. The current GINFORS version, which is based on the WIOD dataset (Dietzenbacher et al. 2013), has been re-engineered over the last couple of years and facilitates simulation studies with a detailed mapping of 38 national economies and a rest of world region until the year 2050.

Each GINFORS simulation is soundly rooted on an endogenous mapping of detailed national economic structures and international economic interrelationships due to globalized trade patterns. Income effects resulting from (i.a.) diversified investment expenditures, induced efficiency improvements or sustained shifts in consumption patterns are explicitly modelled. Hence, each simulation run accounts for potential macroeconomic rebound effects (Sorrell and Dimitropoulos 2008, Sorell et al. 2009) in a variety of ways. Concerning environmental questions, the modelling of the economic system is consistently interlinked with subsystems that explain energy use, electricity production, air emissions and material extractions in physical terms. See Meyer and Ahlert (this issue) for a systematic discussion of the methodological background of to the current model version.

Whereas a multitude of publications already applied various MRIO databases for ex post assessments of resource-related national footprint indicators (see, e.g., Bruckner et al. 2012, Wiebe et al. 2012b, Wiedmann et al. 2015 or Wood et al. 2015 for some selective recent applications in this regard), there exist only scarce ex ante assessments of possible transition scenarios concerning this matter (but, see e.g., European Commission 2014 or Schandl et al. 2016 for recent examples in this regard). The modelling framework of GINFORS also rests on a MRIO database. Thus, GINFORS is also able to map quantitative indicators of material extractions embedded in regional consumption activities over the global supply chain. Current GINFORS applications therefore feature medium to long term projections of national material footprint indicators like Raw Material Consumption

(RMC).

In this regard, we have been able to implement comprehensive scenario simulations over the course of the POLFREE project, a research project funded by the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 308371 (http://www.polfree.eu/polfree/). In this project we linked GINFORS with the vegetation model LPJmL (Beringer et al. 2011), allowing for enhancing the analysis with regard to limitations of water and land availability and their impact on crop demand, supply and prices.

In POLFREE four scenarios have been developed presenting different futures of the world economy and its pressures on the environment till 2050: The *Business-As-Usual* scenario assumes that the EU will only change the ETS system introducing an active supply side. The Non-EU countries will have no change of their climate and resource policy at all. Further three distinct resource-efficient, low-carbon scenario simulation studies are presented which reflect key response relationships of selected socio-environmental indicators for varying degrees of international policy actions and types of policy. In *Global Cooperation* all countries co-operate through international agreements and harmonized economic and regulatory policy instruments to pursue decarbonisation and a resource-efficient global economy. In *EU Goes Ahead* the EU pursues the development of a low-carbon, resource-efficient economy unilaterally, through strong EU-level economic and regulatory policy instruments instituted by Member States. The rest of the world fails to increase existing ambition. The latter is also the case in *Civil Society Leads*, but now European citizens/consumers and businesses drive resource-efficiency and decarbonisation through voluntary changes in preferences and behavior. Policies are introduced to facilitate such changes. One might interpret this future as one with a high weight of leisure time and a low weight of GDP in the welfare function.

Each of the three alternative scenarios asks for the mutual achievement of four environmental targets for the EU until 2050 (Jäger 2014): (1) reduction of CO_2 emissions to 80% of 1990 levels, (2) limitation of the consumption of virgin abiotic materials (RMC) to 5 t per capita and year, (3) reduction of the "cropland footprint" by 30% against 2005 levels and (4) limitation of water exploitation indices to under 20%.

On the following pages we provide an overview on the outcomes of these intensive modelling works. Please note that, due to space constraints, we will exclusively report about our experiences concerning the future prospects of lowering CO_2 emissions and abiotic material consumption. Further modelling details, referring (i.a.) to the other environmental targets above might be inferred from Meyer et al. (2015). Our presentation of results evolves as follows: Section 2 discusses the assumptions of the scenarios and Section 3 summarizes key results and completes these findings by a deeper discussion of the main drivers for the aforementioned scenarios. Section 4 concludes.

2 EXOGENOUS PREDETERMINATIONS AND POLICY ASSUMPTIONS

2.1 EXOGENOUS PREDETERMINATIONS

GINFORS is characterized by a very high degree of endogeneity. This does not only hold for the variables but also for the parameters (e.g. price elasticities) of the model. Exemptions are population, world market prices for coal, oil, gas and metal ores and tax rates.

All scenarios use the medium variant of the UN World Population Prospects: The 2012 Revision (United Nations 2013) as exogenous specification for the demographic development for three age groups (0-14 years, 14 to 65 years, over 65 years) in the different countries/regions of the world. This means that world population will grow up to 9.5 billion people in 2050 and not only industrialized countries are facing ageing societies.

Exogenous specifications for the development of fossil fuel prices have been taken from the IEA Energy Technology Perspectives 2012 that give price developments for coal, oil and gas up to 2050 for, respectively, 2ºC, 4ºC and 6ºC average global temperature increase. As the GINFORS simulation results for global CO_2 emissions (and demand for fossils) in the *Business-As-Usual* scenario more or less fit to a 6ºC pathway, those for the *EU Goes Ahead* and the *Civil Society Leads* scenarios approximately fit to a 4ºC pathway and those for the *Global Cooperation* scenario roughly fit to a 2ºC pathway the respective price trajectories are applied.

A reference for long run developments of world market prices for metal ores till 2050 could not be found. During the last 20 years these prices (in constant US-Dollars) featured an average increase by 2.4% per year. Based on this information, the expectation that ore contents in the deposits will further diminish and demand for virgin metal ores will further increase, an annual growth rate of the real price for metal ores of 4% p.a. is assumed. As the global demand for virgin ores in the scenario *Global Cooperation* is performing considerably slower this assumption is modified in that scenario in the following way: the growth rate of the real price linearly declines from 4% to 0% p.a.

Usually all tax rates on income and wealth, on goods and services and on production as well as the rates for the contributions to social security as key fiscal policy parameters are assumed to stay constant in time. However, in case of severe public budget deficits, some automatic stabilization procedures were applied in order to mimic internationally applied fiscal policy rules.

2.2 ENVIRONMENTAL POLICY ASSUMPTIONS

Based on the vision of a resource efficient economy (Jäger 2014), the narratives and scenario formulation (Jäger, Schanes 2014) and the comprehensive analysis of policy mixes for resource efficiency (Wilts et al. 2014) the main challenges in modelling and quantifying the environmental and economic impacts were:

- Identification of key policy instruments (and voluntary behavioral changes) that fit to the respective narrative/scenario.

- Translation of narratives on global governance schemes (which countries start? which countries follow how fast?) into quantitative model assumptions.

Table 1: Policy Mixes in the target scenarios (main instruments).

	Global Cooperation	EU Goes Ahead	Civil Society Leads
Climate policy	upstream carbon tax, regulation of the share of renewables, regulations and economic instruments favouring e-mobility & investment in energy efficiency of buildings	**Difference to Global Cooperation:** In EU: Economic instruments are designed, so that they do not endanger international competitiveness • e.g. taxes on final demand instead of upstream taxes • or direct compensation of taxes In Non-EU: • Moderate climate policy that allows to stay at 4 degree warming pathway • No resource policy action	**Difference to EU Goes Ahead:** In EU: • Resource policy instruments : Instead of top down bottom up, changes driven by intrinsic motivation of consumers • more leisure time, less total consumption In Non-EU: The same as in EU Goes Ahead
Decoupling of economic development and the use of minerals	regulation for recycling, upstream tax, public innovation fund for the material efficiency		
Sustainable agricultural land and water use	regulation for water abstraction of agriculture, information programs to avoid food waste & to reduce yield gaps, tax on meat consumption		
ETR	tax revenues are used for a reduction of taxes on goods and services with low carbon and resource contents		

Source: Own table

- Where necessary, translation of research results on direct impacts (e.g. costs, investment needs) and on prospects on success (e.g. for information-based instruments) into quantitative model assumptions.
- Assigning to each of the three target scenarios a degree of intervention for the identified and quantified policy instruments that on the one hand does not exceed plausible levels and on the other hand allows mutual target achievement.

For each of the three target scenarios a set of 20 to 30 single policy instruments (and voluntary behavioral changes) could be identified and quantified. Table 1 summarizes the key elements for the three different scenario settings. More details can be found in Meyer et al. (2015).

3 RESULTS AND DISCUSSION OF RELEVANT RESPONSE RELATIONSHIPS

In this section the core simulation results of the model GINFORS for three macro-indicators (GDP, CO_2 emissions and use/extraction of abiotic raw materials) are discussed. In addition the impacts of a big transition on different economic sectors in the EU are presented. Readers that are interested in more detailed simulation results – especially on land, water and crop use – are referred to Meyer et al. (2015).

3.1 BUSINESS-AS-USUAL

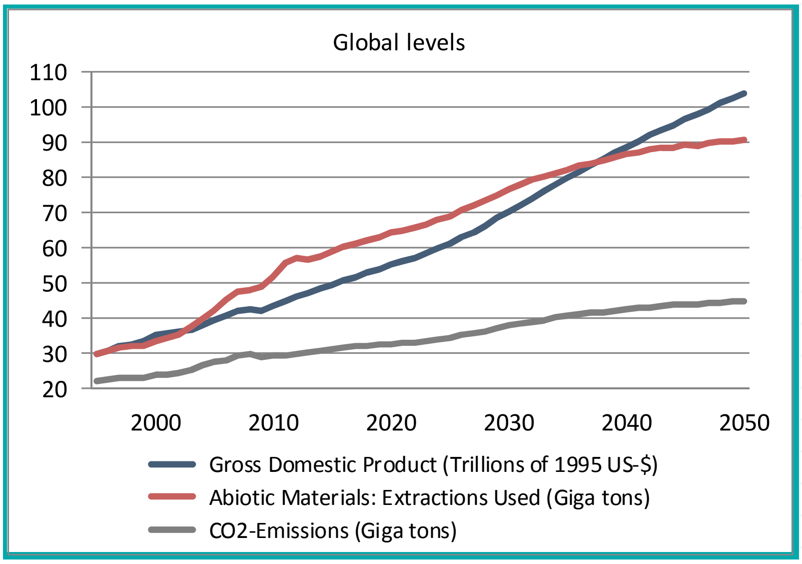
General indications of the long-run development trends emerging within the *Business-As-Usual* scenario can be identified with a view on Figure 1. Figure 1 displays the projected trajectories for global GDP (in US-$, based on 1995 prices and exchange rates), global CO_2 emissions and global used abiotic material extractions. As can be seen, global GDP (dark grey line) is expected to grow continuously over the simulation period, with implied average annual growth rates comparable to, but slightly less than historically observed: For the 2015-2050 period, global GDP is expected to grow on average by about 2.2% per annum.

The implied average annual growth rate for the historical 1995-2015 period ranged around 2.6%. Thus, whereas economic development is projected to follow a robust growth path, the *Business-as-Usual* scenario might, at least with regards to other scenarios like, e.g., the publicly available Shared Socioeconomic Pathways (SSPs, see Kriegler et al., 2012 for an introduction) projections, be classified as implying a rather moderate growth regime (see also Figure 10 in the appendix).

Whereas we are not intending to initiate a continuative methodological discussion on this topic, we would like to annotate that, according to our understanding, this feature might essentially be attributed to the empirical grounding of the GINFORS model: Based on econometrically evaluated reaction functions, our modelling approach does not incorporate formative normative hypotheses like, e. g, a global convergence assumptions among countries' welfare.[1] Furthermore, economic growth is dampened by globally implied stabilization policies with regards to public debt. A rise of income taxes and/or a reduction of public spending may avoid a financial crisis, but it reduces economic growth.

[1] The incorporation of a global convergence assumption would certainly boost global GDP growth projections. However, as long as we cannot identify strong empirical support in favor of such a hypothesis, we decided to refrain from such (rather normative) building blocks in our modelling approach. See also Romero Lankao et al. (2008) for a critical empirical assessment of the global convergence hypothesis.

Figure 1: Key Developments within the *Business-As-Usual* Scenario.



Source: GINFORS3, Business-As-Usual Scenario 9/2015 (GWS).

The moderate economic growth dynamics are accompanied by rising global extraction activities (green line) as well as soaring CO_2 emissions: Over the last 20 years, the growth rates of global abiotic material extractions equaled an annual average of about 3.5%. The recent historical developments were (at least to large extends) triggered by surging extractions of construction minerals which have especially been driven by Chinese investments in infrastructure. Currently, China's domestic extractions of construction minerals represent about 50% of the globally used construction minerals. However, as it seems doubtful to extrapolate the fast-increasing demands for construction minerals of currently urbanizing world regions into further accelerating demand patterns over the next decades, the *Business-As-Usual* scenario assumes that the construction minerals accumulation patterns of currently urbanizing countries converge to those of developed countries once sufficient levels of buildings and infrastructure stocks have been established. (See also Fishman et al. 2016 for a recent analysis of stochastic trends in international construction material extractions in this regard.) Therefore, we expect that also China's demand for construction minerals will peak over the projection period, followed by a reduction due to national population developments.

Overall the scenario thus expects an ongoing increase of global resource extractions with slowly diminishing growth rates. However, with the total sum of globally used domestic abiotic material extractions levelling slightly above 90 billion tons in 2050, our projection is characterized by attenuating growth dynamics. See, e.g., Dittrich et al. (2012) in this regard who illustrate that a static extrapolation assuming (on average) all countries to equal current per capita material consumption levels of OECD countries from 2030 on, might end up with global total extractions levelling around 180 billion tons (including ca. 145 billion tons of abiotic materials) in the year 2050. Interestingly, Schandl et al. (2016), claiming to provide "for the first time, scenarios of future material, and energy and carbon footprints for the four decades to 2050, taking into account economic drivers and biophysical pressures" (Schandl et al., 2016, p. 46), do also project total global material extractions to achieve a level of more than 180 billion tons by 2050. Following their explanations, only a "global carbon price in concert with technological change resulting in a doubling of material efficiency would allow stabilization of material extraction at 95.2 billion tons by 2050" (Schandl et al., 2016, p. 46). However, at least with regards to the following two issues, the assessments of Schandl et al. (2016) have to be interpreted with care: In their analysis, economic dynamics are also not interrelated with technological developments. Furthermore, their applied GDP projections incorporate very strong growth assumptions.[2]

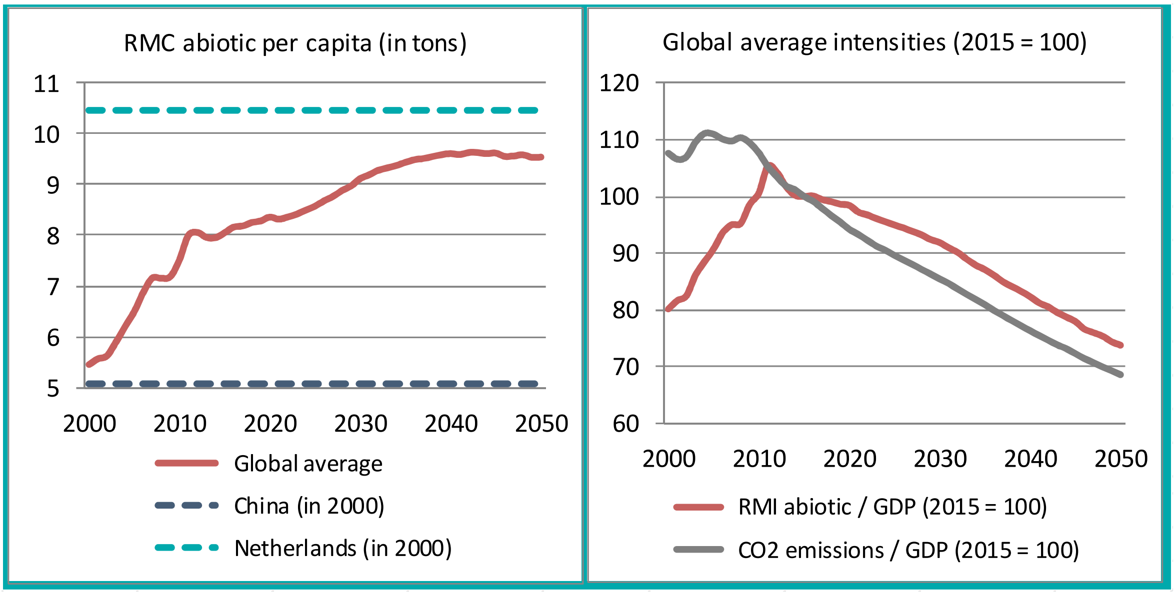
In light of the above mentioned studies, our *Business-As-Usual* scenario thus seems to imply somewhat moderate increases in global extraction activities. This might also indicate implied decisive upward-biases for the applied (more or less) static extrapolation procedures of other research teams. However, due to space constraints, we do not aspire to initiate a deeper methodological examination of these issues within this article. But our readers should be aware of the fact, that our *Business-As-Usual* scenario has been endogenously generated by a simulation model with econometrically estimated reaction elasticities which is able to map explicitly the complex interactions between economic dynamics, CO_2 emissions and material extractions.

In any case, our projections do also indicate lasting increases of the environmental and social pressures resulting from raising global extraction activities. In this regard, we might, e.g., refer again to Dittrich et al. (2012) who did also present some rough "best practice" extrapolations. Although their applied rule of proportion calculus does (i. a.) not facilitate an endogenous mapping of technological progress as well as resulting income and rebound effects, their static estimate of about 76 billion tons abiotic global material consumption in 2050 is sometimes referred as provisional upper target for future material consumption.

As already mentioned, our simulation studies have (i.a.) been analyzing whether it seems obtainable to reduce the consumption of virgin abiotic materials (RMC) to 5 t per capita and year. As it is not straightforward to derive distinct target values for global extraction activities, some scholars also refer to historical benchmark figures (like global extraction activities of the year 2000) and stress the imperative of international fairness (see, e.g., Jacob et al., 2015) in this regard. As indicated by the left panel of Figure 2 this line of reasoning seems to favor much lower targets for global extraction activities. The solid dark time series in the left panel reproduces historical developments together with our *Business-As-Usual* projection of globally used abiotic material extractions for the 2000-2050 time period. In contrast to Figure 1, global extraction volumes are now represented by per capita figures.

[2] Concerning global per capita GDP, Schandl et al. rely on an implicit growth factor of almost 2.5 for the 2010-2050 period. Over the same time period, our *Business-As-Usual* scenario implies an (endogenously derived) growth factor slightly above 1.7 for global per capita GDP. Referring again to historical growth rates (as well as Figure 10 in the appendix), the analysis of Schandl et al. thus seems to rest on relatively strong economic growth paths.

Figure 2: Global averages for RMC abiotic per capita and environmental intensities in the *Business-As-Usual* scenario.



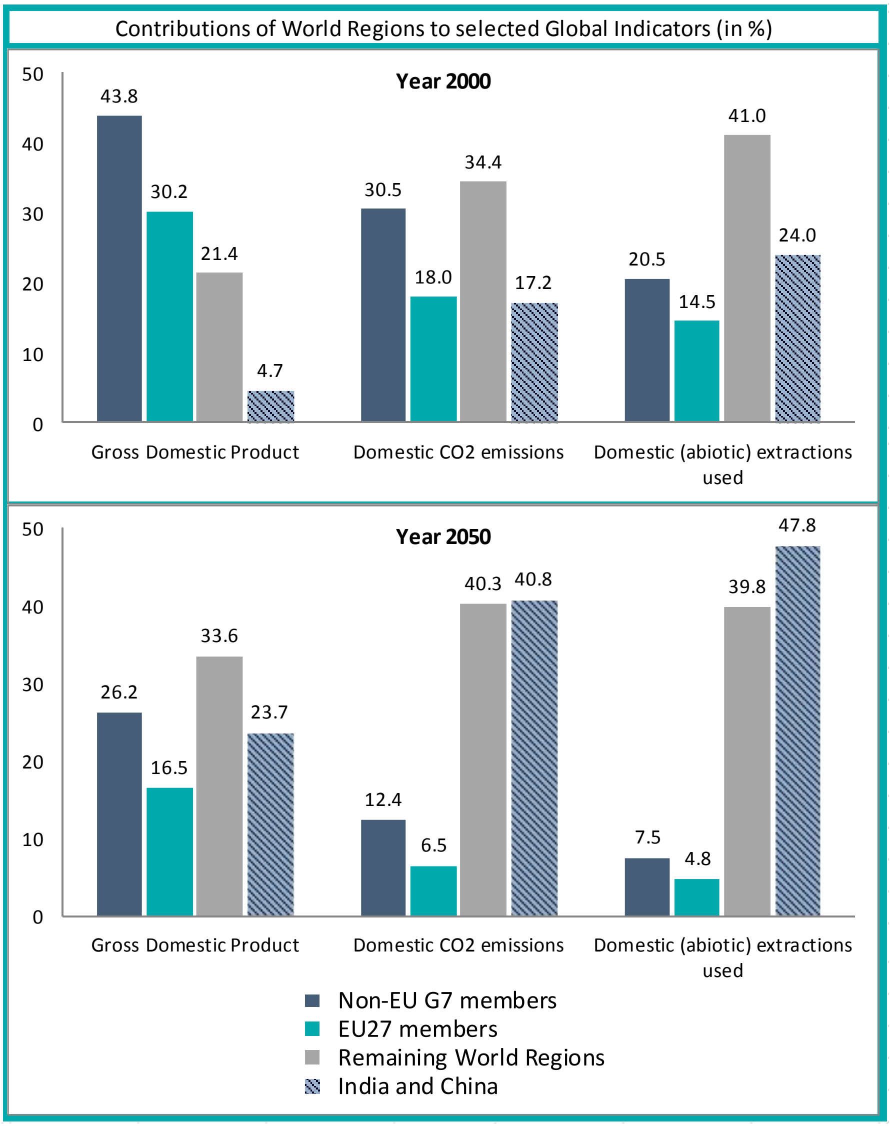
Source: GINFORS3, Business-As-Usual Scenario 9/2015 (GWS).

These per capita relations are projected to almost double within the observed time span: Starting from an average per capita relation slightly above Chinese abiotic RMC per capita values of the year 2000 (indicated by the lower dotted line), the rise in global per capita extractions can be interpreted as an asymptotic convergence to corresponding Dutch RMC values of the year 2000 (indicated by the upper dotted line). According to the proponents of historical benchmark targets, our *Business-As-Usual* scenario therefore implies clear indications of remaining needs for policy action.

The right panel of Figure 2 illustrates that these needs for policy action emerge although our simulations do also indicate significant technological progress over the next decades. Shown are the simulated intensities for used abiotic material extractions (i.e., global extractions used in relation to global real GDP) as well as CO_2 emissions in the *Business-As-Usual*. Apparently, both intensities are assumed to decrease by roughly 30% until 2050 (compared to 2015 levels). Therefore, from a resource perspective as well as from a climate policy perspective, the *Business-As-Usual* scenario features relative decoupling of economic growth from environmental pressures. But neither material extractions nor CO_2 emissions will experience an absolute decoupling from economic growth.

This issue is especially notable in light of the *Business-As-Usual* projections for global CO_2 emissions (light grey line in Figure 1), which are projected to increase steadily until 2050.

Figure 3: Global Structural Shifts in the *Business-As-Usual* Scenario.



Source: GINFORS3, Business-As-Usual Scenario 9/2015 (GWS).

Accordingly, the current emission levels will be exceeded by more than 40% in 2050 and global CO_2 emissions will accumulate over the 2000-2050 period to roughly 1,800 Gt. This is of course far above any reference value for limiting global warming to 2° or less (Meinshausen et al. 2009). Some regional indications of the long-run development trends emerging within the *Business-As-Usual* scenario can be identified with a view on Figure 3 which displays overall contributions of selected world regions to global GDP, global CO_2 emissions and global used abiotic material extractions. The upper panel of Figure 3 reproduces historical findings for the year 2000. As indicated by the left cluster of bars, EU27 Member States (green bar) and the remaining G7 members (Canada, Japan and USA, dark bar) together produced roughly three fourth of global GDP. But, as can be inferred from the lower panel of Figure 3 this common share of industrialized countries contributions to global GDP is projected to decline significantly over the next decades: Until 2050, the *Business-As-Usual* results indicate a reduction of the Non-European G7-contributions to global GDP from almost 44% to roughly 26%. In case of the EU27 Member States, this share is projected to decline from more than 30% in the year 2000 to less than 17% in 2050. Simultaneously, India and China (illustrated by hatched bars within Figure 3) are projected to experience an impressive transition with aggregated shares in global GDP more than quintupling between 2000 (4.7) and 2050 (23.7%). Accordingly, for 2050 both countries are indicated to represent almost similar contributions to World GDP than the Non-EU G7 aggregate (representing Canada, Japan and the USA). As the remaining World regions (light grey bars) will also augment their shares in global GDP, essentially the EU27 Member States are expected to lose global economic importance: Having been ranked at position two in the year 2000, their year 2050 share in Global GDP does only imply the last position in this overview of global regional economic developments.

One reason for the weakness in EU growth is the rise of prices for resources. In the case of abiotic resources the rise of prices is given by assumption (see above). Since abiotic resources have nearly totally to be imported by the EU this has a negative effect on its growth. In the case of prices for biotic resources we are facing an endogenous result: Global economic growth and a trend in developing countries to more meat consumption push the demand for biotic resources, whereas supply can only partly adjusted because agricultural land use and especially that of cropland can only slightly be raised. Further the productivity of cropland can't be raised as it did in the past. In the average over all 13 kinds of crops and all years the global real crop price will rise with 2.1% per year. This means that food becomes very expensive globally, which induces severe social problems inside and between the countries. Since price elasticities for food are low, the nominal share of food in total consumption rises reducing the shares of other goods. In India for example the share of food in consumption has been 47.4% in 1995, fell to 39.7% in 2015 and will rise up to 46.8% in 2050. Especially in developing and newly industrialized countries such effects will be observed reducing the demand for manufactured goods and insofar the exports of the EU.

The development of the labour market in the EU is characterized by two impacts. On the one side labour demand will be falling from 2015 to 2050 (-31 million jobs) since the growth of labour productivity will be higher than GDP growth. On the other side labour supply is also reducing in most countries since the number of persons of the age group of 15 to 65 is shrinking. Only in Austria, Luxembourg, Denmark, Sweden, France and the UK the opposite is the case. The situation will be very different in the countries. Some countries like Germany will have over-employment others like France will suffer from ongoing unemployment. This may induce more migration inside the EU and is not depicted in the (exogenous) population prospects. The average employment quota (employed persons/persons in the age group 15 to 65) in the EU will slightly fall from 65.5 % in 2015 to 64.7% in 2050.

The outstanding economic performance of Non-G7 countries intensifies accompanying environmental pressures. It seems obvious that, if these countries do not introduce ambitious climate policies, there will be no chance for reaching the global 2 degrees warming target: In absence of such measures, the *Business-As-Usual* scenario expects more than 80% of overall year 2050 CO_2 emissions to be emitted within their territories (mid cluster of bars).

In case of abiotic resource extractions these regional disparities are projected to become even more intensified. As illustrated by the right cluster of bars, the *Business-As-Usual* simulation indicates that in the year 2050 nearly 88% of all used extractions will be taking place within the territories of Non-G7 countries. Apart from environmental pressures stemming from increased global extraction rates (see Figure 1), this feature might also rise concerns about the security of material supplies in traditional industrialized countries. At least, it seems to plea for enduring efforts within G7 countries to advance towards a green economy.

3.2 COMPARISON OF BUSINESS-AS-USUAL PROJECTIONS WITH ALTERNATIVE SCENARIO SIMULATIONS

3.2.1 GLOBAL RESULTS

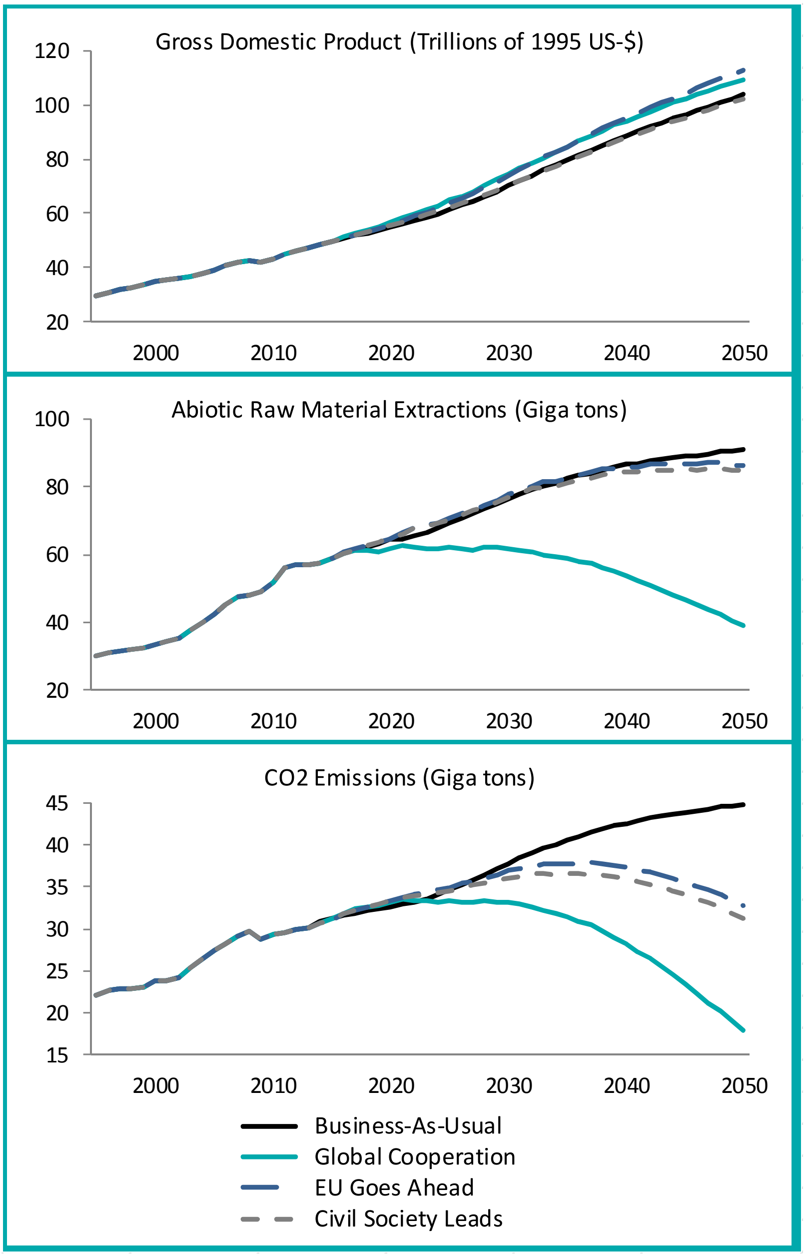
Figure 4 merges global simulation results for real GDP, abiotic material extractions and CO_2 emissions in the baseline as well as in alternative scenario simulations which integrate the policy assumptions summarized within Table 1. The upper panel of Figure 4 illustrates that an incorporation of the simulated policy assumptions might essentially be costless at the global level. Only in case of the *Civil Society Leads* scenario (light dotted line) a slight weakening of global GDP growth can be identified. However, in this scenario, where the intrinsic motivation of European consumers, employees and firms is assumed to induce an all-embracing transition towards a sufficiency-oriented EU27-economy, GDP definitely should not be interpreted as an indicator of welfare. Accordingly, in this scenario all monetary valued outcomes have to be interpreted with great care. Apart from that, both alternative simulations, the global cooperation scenario (solid light line) as well as the *EU Goes Ahead* scenario, indicate significant medium - to long-term gains in global GDP.

In the *Global Cooperation* scenario these developments are mainly driven by the following two impacts: The investment in new technologies for renewable energies, grids and the energy efficiency of buildings and recycling pushes the circular flow of income and thus raises growth. The long run rise of the capital stocks means higher capital costs and insofar higher prices. This has negative effects on GDP in later years. But coincidentally, a lowered material intensity of the global economy reduces costs and dampens price dynamics in manufacturing. For the global economy the overall resulting effects are clearly positive as Figure 4 shows: The deviation of global GDP in the scenario *Global Cooperation* from the reference is positive and represents about 5.2% of its *Business-As-Usual* value in 2050.

In the *EU Goes Ahead* scenario, the corresponding gains in global GDP are even remarkable higher (GINFORS indicates an increase of global GDP of about 8.6% compared to its *Business-As-Usual* value of the year 2050). In this scenario, the EU represents the only world region which improves its resource efficiency rigorously. Thus, due to domestic cost advantages, EU exports are boosted whereas European import demand evolves rather weak. Accordingly, EU Member States realize first-mover advantages: Extra-EU trade surplus increases by roughly 22% compared to the *Business-As-Usual* scenario.

As regards global abiotic material demand (mid panel of Figure 4), only the *Global Cooperation* scenario lends itself to an absolute decoupling from global economic growth. The observed reduction in global material extractions is mainly driven by regulations concerning the recycling of metals and non-metallic mineral products and the taxes on the use of metals and non-metallic minerals. Simultaneously, the global application of ambitious climate policy instruments reduces fossil fuel extractions. Overall, the implied average per capita extraction level of abiotic resources can thus be reduced to approximately 4.1 tons per capita in 2050. In other words: The simulated per capita figures do even fall below their aspired target value by about 18%. However, as might already have been sensed from the discussion of key *Business-As-Usual* results illustrated within Figure 3 isolated variations in European scenario parameters do not suffice to reduce global material extractions significantly: Whereas both dotted lines in the mid-panel of Figure 4 do indicate some reductions in global extraction activities, the illustrated deviations might indicate a stagnation of global abiotic material extractions around the year 2050 (in the *Civil Society Leads* scenario). But both simulations do not give any indications of absolute reductions of global extraction activities.

Figure 4: Selected Global Results of the POLFREE Simulation Studies.



Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

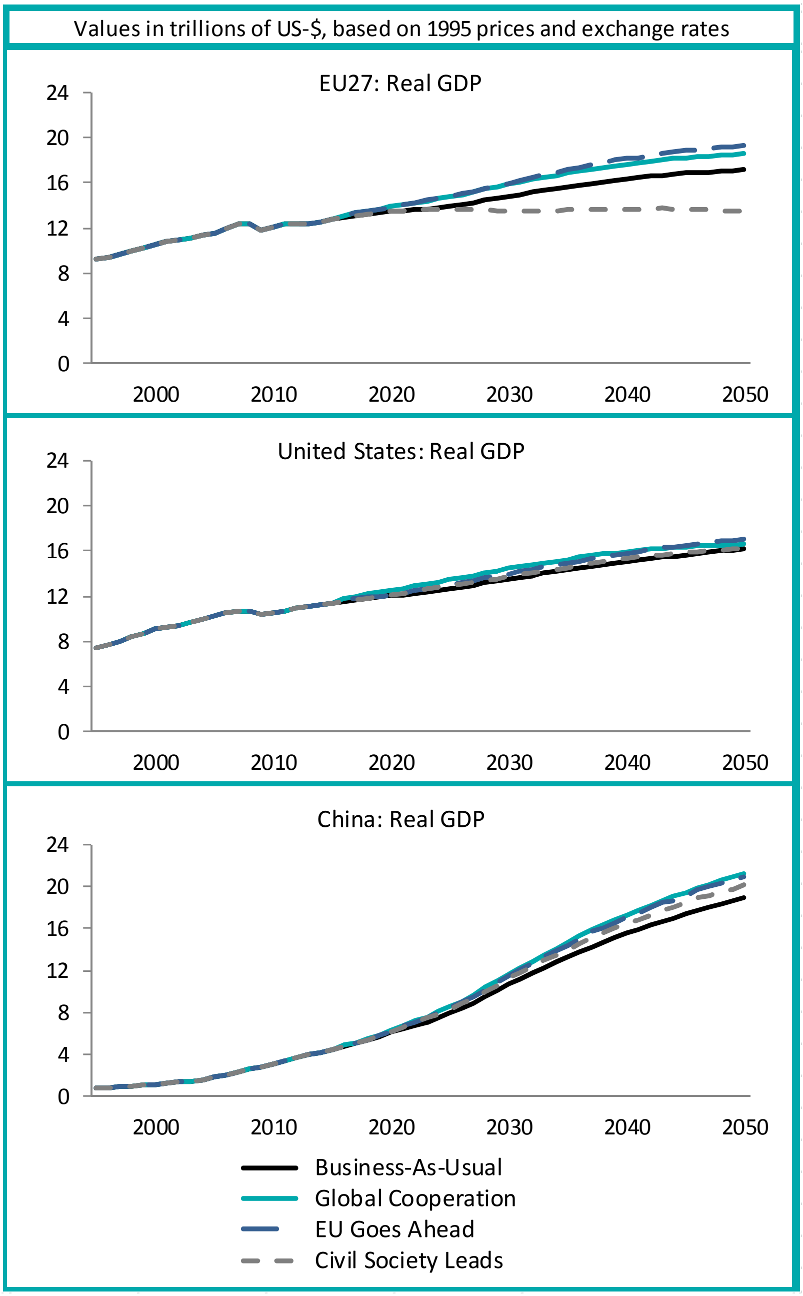
With regards to CO_2 emissions (lower panel of Figure 4) we do also observe significant global reductions in the scenarios *EU Goes Ahead* as well as *Civil Society Leads* (dotted lines). This observation points to the fact that, contrary to our implied resource policy assumptions, the scenarios *EU Goes Ahead* as well as *Civil Society Leads* do also imply (only moderate) global climate policy actions. Nevertheless, the resulting figures clearly demand for ambitious global climate policy actions as the global RCP 2.6 target values for 2050 can only (nearly) be met by the *Global Cooperation* simulation.

In the alternative scenarios the Non-EU countries increase their share of renewables in electricity production only to 70%, which reduces the impacts of e-mobility on global CO_2 emissions drastically. Further in the Non-EU countries there are no improvements of the energy efficiency of buildings and the carbon price does now not exist. Also the lack of material efficiency instruments in the Non-EU countries, which allows for higher demand and production in the carbon intensive basic industries, is responsible for the rather low reduction of global CO_2 emissions. Overall, global CO_2 emissions reaching about 33 Gt in 2050 thus seem to refer to a 4°C world warming trajectory.

3.2.2 INTERNATIONAL COMPARISON

This subsection is intended to illustrate the underlying dynamics of the just discussed global results by a complementary presentation of selected national simulation outcomes. With regards to national economic developments Figure 5 merges time series plots of real GDP for the EU27 Member States, the United States and China. In order to ease comparison, all subfigures have been arranged on identical scales.

Figure 5: GDP developments in EU27, USA and China in Alternative Scenario Simulations.



Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

Generally, a substitution of raw materials like fossil fuels, ores and non-metallic minerals reduces costs in manufacturing and therefore induces positive impacts on GDP. As mining and quarrying as well as other basic industries have a less weight in the EU than in the global average, EU Member States can realize strong economic benefits in the *Global Cooperation* as well as in the *EU Goes Ahead* scenario. In 2050, EU27 real GDP is projected to exceed its *Business-As-Usual* reference value by 8.0% in the Global Cooperation case and by 12.3% in the *EU Goes Ahead* scenario (upper panel of Figure 5).

Compared to these scenarios, the *Civil Society Leads* scenario assumes that intrinsic motivation of consumers, employees and firms induces structural change of the economy to such a degree that the ambitious environmental targets are achieved. Several activities change the structure and volume of consumption, reducing environmentally harmful commodities like consumer durables, high-carbon, material-intensive transport and meat consumption. Further, employees seek to reduce hours worked in the formal economy, inducing an increased share of part-time employment in order to have more time for the family, engagement in society, volunteering and leisure.

The increased share of part time employment – hours worked per person are reduced by 20% - implies of course a reduction of total consumption. The households reduce its average propensity to consume till 2050 by 10%. This induces a negative multiplier /accelerator effect: A reduction of consumption demand diminishes production and income and this further reduces consumption and so forth. This process is supported by investment which reacts on lower production. International trade is stabilizing the fall of GDP driven by domestic demand. Imports fall together with domestic demand, and exports are not changing compared with *Business-As-Usual*: The supply side of the EU economies is not affected by instruments which keeps the competitiveness relatively stable. The trade surplus of the EU is 30% higher than in *Business-As-Usual*. The EU finances growth abroad. The total effect on GDP is a reduction of -22% compared with *Business-As-Usual*, which means zero growth – the level of GDP in 2050 will be more or less the same as in 2015. The level of total consumption equals that of 1995.

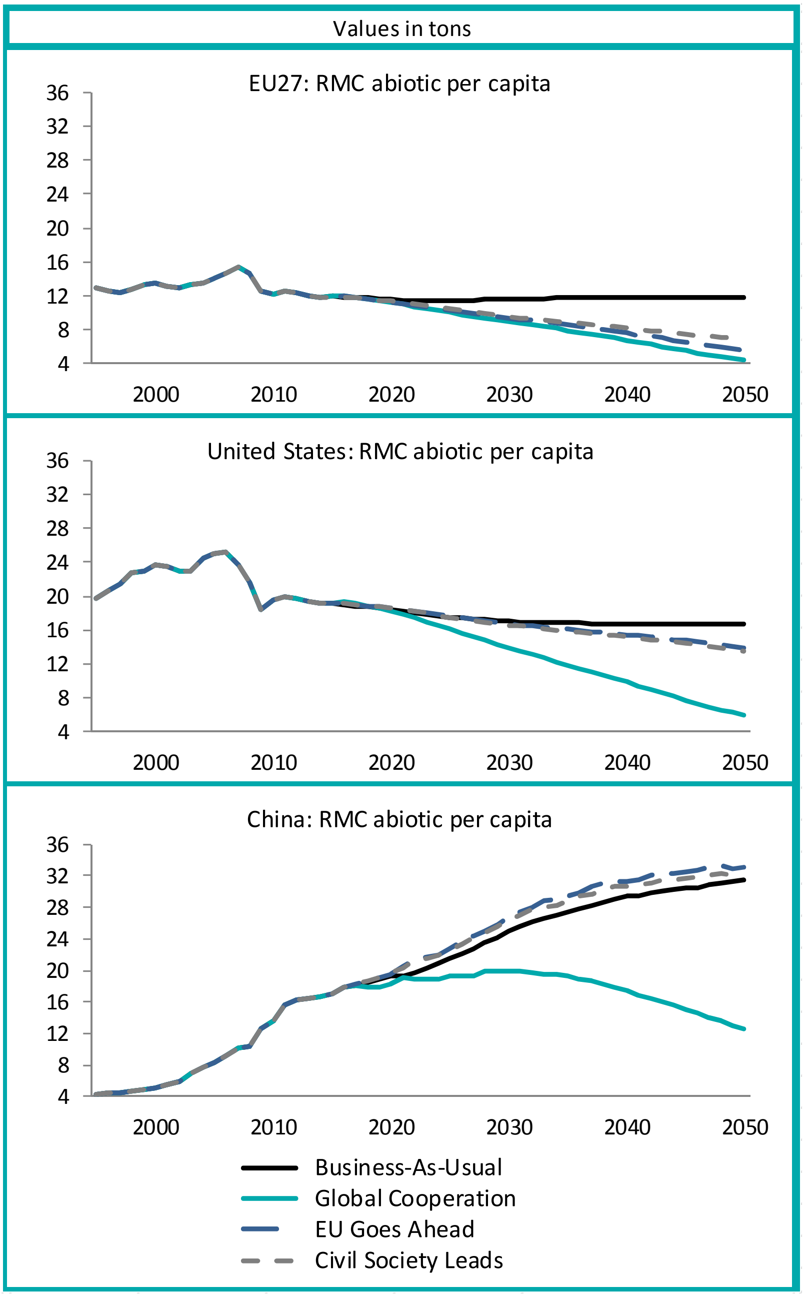
For the United States as well as China, all scenarios are overall beneficial. In case of the just discussed *Civil Society Leads* scenario this might straightforwardly reflect the fact that EU countries do finance growth abroad. Mining and quarrying sectors and the directly following stages of production do of course suffer from direct demand reductions. However, for any country under consideration the overall GDP effects of material efficiency are directly related to its position in the international supply chain. Those countries that are importing materials are winners and those that are exporting materials are losers.

The responsibility of the EU for total abiotic material extractions can be traced by the indicator RMC, which represents direct extractions plus those that are done abroad and embedded in the imports of goods and services minus those that are part of the exports of goods and services. In the *Global Cooperation* scenario this indicator is reduced to 4.6 tons per capita in 2050 for EU27 Member States (upper panel of Figure 6). In case of the *EU Goes Ahead* scenario, this indicator tends to fall to a level of 5.8 tons per capita. The main reason behind these simulation results is the lack of significant resource-efficiency improvements outside the EU. As substantial shares of domestic final demand are imported from non-EU countries this hampers the opportunities of unilateral policies (i.e. taxes on final demand for RMC intensive products) that try to limit RMC. The same applies in case of the *Civil Society Leads* scenario which features the relative highest European raw material demand (7.0 tons in 2050). This relative high RMC value refers to the fact that the assumed changes in domestic demand do not induce significant effects on the supply side in favor of additional resource efficiency achievements.

With regards to China and the USA we can identify that the assumed international policy measures of the *Global Cooperation* scenario are indeed able to induce an absolute decoupling from economic growth in both countries (see the light lines in the upper as well as the lower panel). Only in case of the Chinese developments the resulting year 2050

RMC figures do however miss the 5 tons per capita target significantly.

Figure 6: RMC developments in EU27, USA and China in Alternative Scenario Simulations.

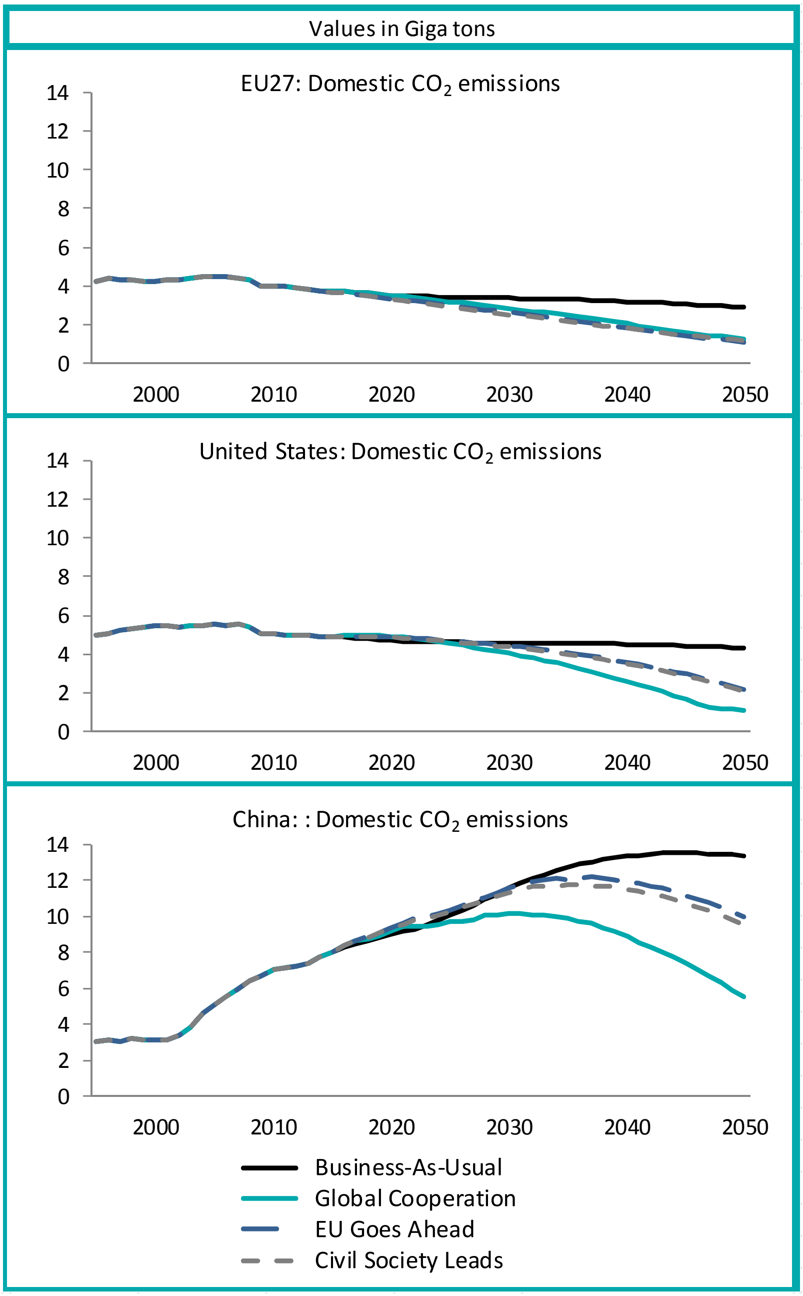


Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

With regards to the remaining scenarios where extensive resource policy measures remain restricted to EU countries only, we observe diverse international reaction patterns. In China income effects seem to dominate the overall effects on its resource consumption: In the scenario *EU Goes Ahead* as well as in the *Civil Society Leads* scenario the observed GDP increases of Figure 5 are accompanied by rising RMC figures. This does not apply in case of the US economy. This might be explained by the fact that for the USA, considerably lower income effects are observed (e.g., China's real GDP is expected to outmatch its year 2050 reference value by about 11% in the *EU Goes Ahead* scenario whereas the corresponding increase in US GDP equals about 5.1%). Therefore, these triggering income effects do not over-compensate initial reduction effects which are directly released by Europe's modernization of its production technologies.

Aspiring an 80% reduction of domestic CO_2 emissions in relation to historical year 1990 values, the overall target for EU CO_2 emissions equals about 1 Gt. In the scenario *Global Cooperation* a reduction of 74 % against the level of 1990 is achieved. So, the EU target is almost met in this scenario (see the upper panel of Figure 7). In the *EU Goes Ahead* scenario, these figures are further reduced to about 1.1 Gt in 2050. Referring to the higher GDP growth rates of this scenario this is quite remarkable. Especially as the main drivers of emissions reductions – renewables in electricity production, e-mobility and investment in energy efficiency in buildings – are driven by identical assumptions in both scenarios. However, the assumed world market price trajectories for fossil fuels feature stronger price dynamics in the *EU Goes Ahead* scenario. The higher pressure in taxation in Global Cooperation can't overcompensate this effect, so that purchasers' prices for fossil fuels in *EU Goes Ahead* are a bit higher than in *Global Cooperation*. Hence, stronger cost pressures do induce stronger global incentives to reduce CO_2 emissions in this scenario.

Figure 7: CO_2 emission developments in EU27, USA and China in Alternative Scenario Simulations.



Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

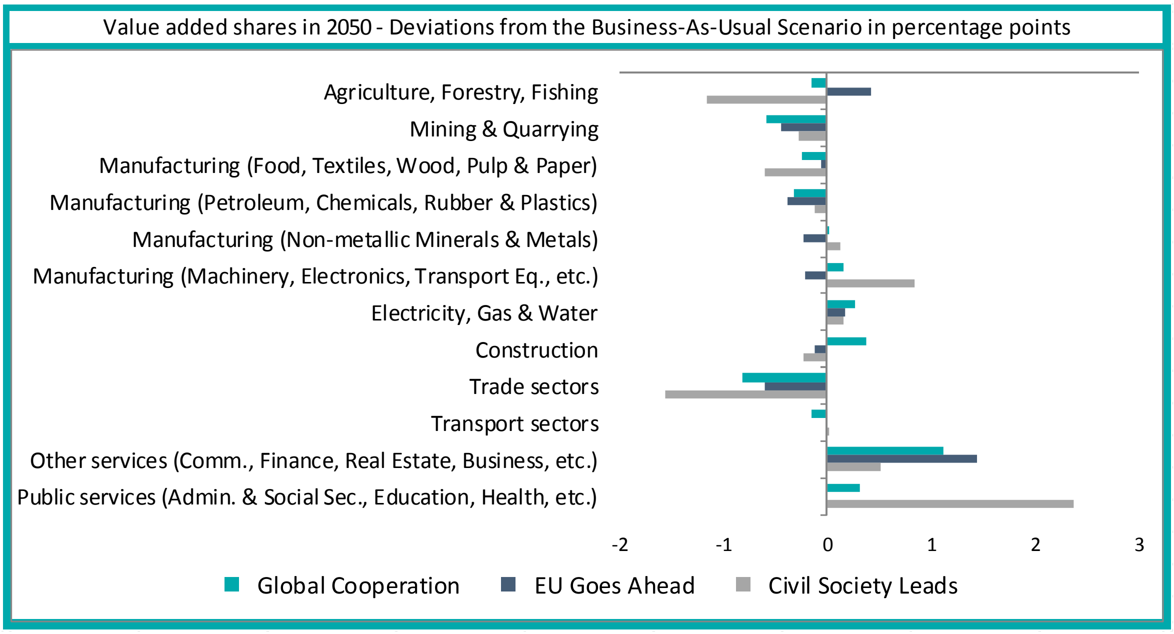
In case of China and the USA, the resulting time series more or less represent the direct effects of varying international measures in order to prevent climate change. Please remember that, compared to resource policy actions, also the scenarios *EU Goes Ahead* and *Global Cooperation* do incorporate continued global efforts in climate policy. However, as only moderate international progress is assumed within these scenarios, both extra-EU countries do not feature sufficient (i.e., suitable for a 2° target) decoupling of CO_2 emissions from economic growth in both scenarios. Much stronger progress is observed within the *Global Cooperation* scenario with US emissions slumping to a level of about 1.1 Gt in 2050 and Chinese emissions being reduced to about 5.5 Gt.

3.2.3 SECTORAL RESULTS FOR EU27

This subsection provides deeper insights into sectoral developments within the European economy across the simulated scenarios. For the sake of clarity, the original model results (which rest on a detailed mapping of 35 industries) have been aggregated to a 12 sector-scheme.[3]

Figure 8 illustrates the observed variations in EU27 industries' value added for this aggregated presentation scheme. Shown are year 2050 deviations of the relative contributions of the indicated sectors to overall macroeconomic value added. Apparently, the mining and quarrying industry as well as basic industries (like the food and beverages, refineries or the pulp and paper industry) are indicated to suffer in all simulation runs. These industries are suffering from a diminished demand for their products in a resource efficient economy, which might also be causative for the observed decrease of trade services' (including the sales of motor vehicles) margins in all simulation run. The same tends to apply in case of the agricultural sector (which, nevertheless, is projected to increase its relative share in overall value added within the *EU Goes Ahead* scenario) as well as in case of the non-metallic minerals and basic metals industries.

Figure 8: EU27 Sectoral Results for Value Added impacts.



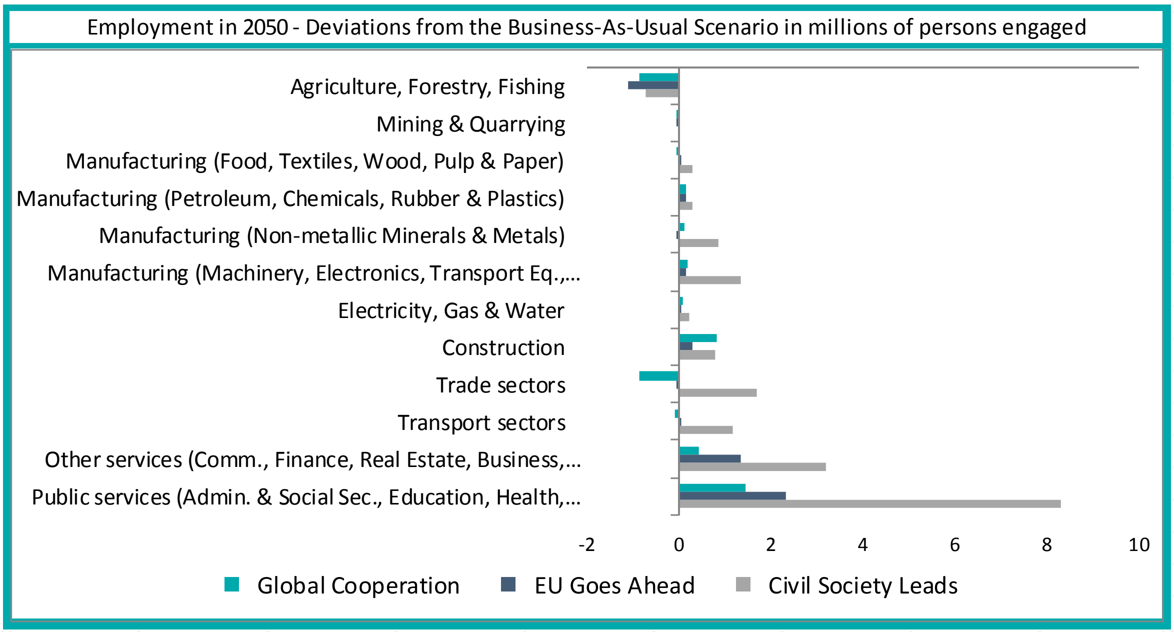
Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

As outstanding profiteers we can identify the energy and heat suppliers (sectors electricity, gas and water) as well as service sectors. As regards energy supply, these findings are especially triggered by strong increases in electricity production which are mainly driven by the assumed diffusion of e- mobility technologies. The service sectors do of course benefit from relative cost advantages as rigorous measures to improves European resource efficiency do essentially trigger production costs in the non-service industries.

[3] Additional details are of course available upon request by the authors. See, e.g., Meyer at al. (2013) for a detailed overview of the applied sector classifications.

But overall, we would also like to point out that no simulation run provides any indications of disruptive distortions of traditional economic structures. One important element which satisfies these characteristics seems to be given by the assumed recycling scheme with regards to environmental taxes: As all additional environmental tax revenues are given back to the economy, even remarkable high tax revenues do not cause strong structural side effects. This might be identified as a crucial issue promoting the feasibility of real world policy implementations.

Figure 9: EU27 Sectoral Results for Employment impacts.



Source: GINFORS3, Business-As-Usual and target scenarios 9/2015 (GWS).

At the same time, all three scenarios feature distinctive positive employment effects for the EU27 aggregate. The European economy is reducing its material intensity and raising the capital intensity of labour accompanied by gains in employment and economic growth. See Figure 9 in this regard, which merges the total difference of employed persons per sector for the year 2050. In the *Global Cooperation* scenario, these differences amount to an overall employment increase of about 1.4 million people in the year 2050.

Notably, the positive labour market effects emerge considerably stronger in both remaining scenarios. Compared to the *Business-As-Usual* Reference, the *EU Goes Ahead* Scenario rises overall EU27 employment roughly by 3.5 million jobs in 2050. As such, if global cooperation to achieve a resource-efficient, low-carbon economy is not forthcoming, unilateral action at the EU level to pursue these goals is clearly an economically attractive position.

Furthermore, in the *Civil Society Leads* scenario where employees are assumed to reduce hours worked in the formal economy, inducing an increased share of part-time employment in in favor of enhanced time budgets for family issues, engagement in society, volunteering or leisure time, hours worked per person are reduced by 20%. About 17 million new (part time) jobs will be created compared with *Business-As-Usual*, which represents a rise by more than 9%. This feature is caused by a reduction of labour productivity which dampens wage dynamics, so that the overall effect on jobs in the EU is larger than expected by simple ceteris paribus assessments.

4 CONCLUSIONS AND OUTLOOK ON FURTHER RESEARCH

The modelling results with GINFORS/LPJmL – that are not rooted in exogenous assumptions for factor productivity advancements but are endogenously explained based on historical observations for changes in the economic systems (and their interrelation with the environment) – emphasis that if we will not be successful in realizing an ambitious global climate and resource policy, the planetary boundaries will be offended by far. This very risky development will in the EU be accompanied with a weakening of economic growth, less acceptable social conditions and growing risks on financial markets.

The further policy lessons coming out of the simulations results with the model GINFORS in the POLFREE project are rather favorable:

- Ambitious global environmental targets can be reached and simultaneously positive effects on income, employment and public debt can be reached. But this needs an international agreement on a comprehensive policy mix, which contains information instruments, economic instruments and regulations.
- If global agreements cannot be realized there remains the option *EU Goes Ahead*. The EU would be able to meet ambitious environmental targets even though the corresponding global targets will not be reached, because the EU is simply too small. But the EU would economically benefit, which will earlier or later initiate the other countries to follow. International competition will help that ambitious global targets can be met, but this requires that at least one bigger country or region goes ahead.
- It could be shown that reductions of total consumption and structural change of consumption based on intrinsic motivation of consumers can have substantial impact on resource use. If this is accompanied by a rise of part time working the zero growth economy would generate much more jobs. Of course in this “Beyond GDP” world the weights of GDP, employment and leisure in the welfare function are different from that in the other scenarios.
- If consumers are not willing to reduce their average propensity to consume, structural change of consumption – however it is induced by intrinsic motivation of consumers, economic instruments or regulations – has to be accompanied by instruments applied on the supply side of the economy. The change of the input structure of production is more efficient.

Besides these policy lessons that can be learned from the modelling exercise we would like to conclude with some hints at further research needs:

- Although the availability and quality of historical data that enables global environmentally extended multiregional Input-Output modelling improved significantly in the recent past, we are still far away from a perfectly standardized global MRIO dataset that is steadily updated. As a matter of principle, any serious modelling attempt to the international resource-climate nexus essentially requires up-to-date data sets which map historical developments in a reliable and globally comparable manner. Therefore, we call for sustained international efforts in favor of regular advancements with regards to publicly available MRIO datasets.

- This article demonstrates (i.a.) our abilities to assess historical as well as future global material demand of individual economies by means of the indicator RMC. Our discussion of the *Business-As-Usual* results already indicated that this feature exceeds usual state of the art assessments of national material consumption developments. Indeed, national statistical offices usually do not provide regular RMC-reports. But this would be certainly desirable in order to provide national governments with a reliable information base for monitoring and further developments of their resource policy measures.
- The discussion of our *Business-As-Usual* results also indicated apparent challenges and uncertainties concerning the expectable amounts of future global extraction activities. This finding certainly calls for intensified communications between the globally active modelling teams.
- Whereas our discussion of the developments in international resource use focused on the RMC indicator, we do doubt that the analysis of a single headline indicator might already afford the thorough monitoring of resource policy advancements. To this, indicators for Raw Material Use should also be accompanied by indicators for Raw Material Inputs. Furthermore, other resource categories also have to be assessed by indicators that monitor, i.a., land and water use issues.
- One constraint in the presented modelling exercise was the exogeneity of world market prices for abiotic raw materials. In an ongoing national research project (SimRess) we are currently investigating the potentials of a soft-link approach in order to map these price dynamics by the interplay of GINFORS with supply side projections of international material availabilities.

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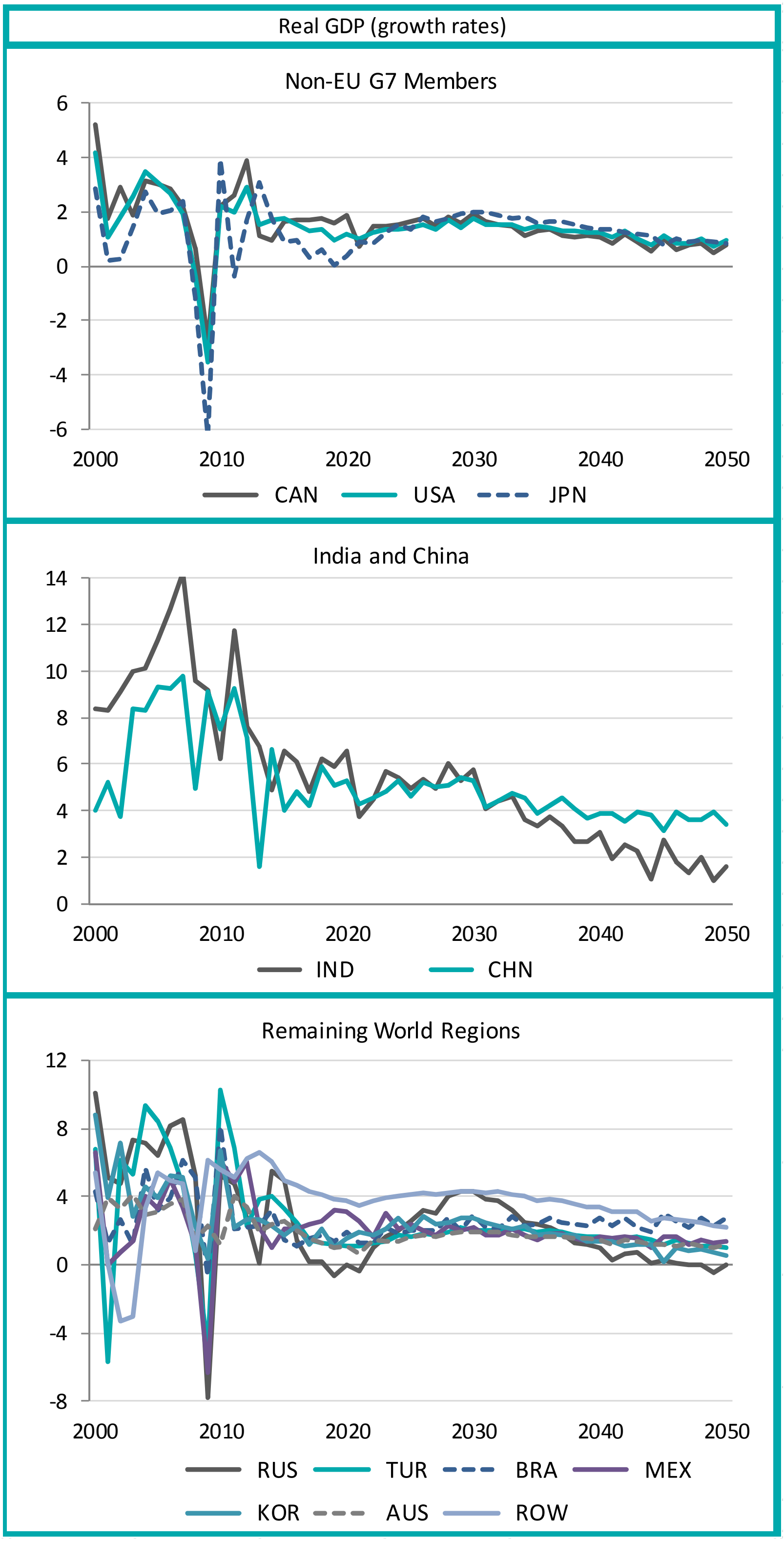
APPENDIX

Figure 10: Real GDP growth rates in the *Business-As-Usual* scenario.



Source: GINFORS3, Business-As-Usual Scenario 9/2015 (GWS).