Developing Resource use Scenarios for Europe

Working Paper no 25

Authors: Marina Fischer-Kowalski (UNI-KLU),
Dominik Wiedenhofer (UNI-KLU), Willi Haas (UNI-KLU),
Irene Pallua (UNI-KLU), Daniel Hausknost (UNI-KLU)

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Authors: Marina Fischer-Kowalski (UNI-KLU), Dominik Wiedenhofer (UNI-KLU), Willi Haas (UNI-KLU), Irene Pallua (UNI-KLU), Daniel Hausknost (UNI-KLU)

Reviewed by: Miklós Antal (UAB), Julia Steinberger (University of Leeds)

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Developing Resource use Scenarios for Europe

Marina Fischer-Kowalski (UNI-KLU), Dominik Wiedenhofer (UNI-KLU), Willi Haas (UNI-KLU), Irene Pallua (UNI-KLU), Daniel Hausknost (UNI-KLU)

Contribution to the Project

Work package 204 will generate biophysical scenarios for resource constraints to the supply side of economic activity in Europe. Scenarios will be both oriented at natural constraints (resource scarcity) and at politically targeted constraints (European climate policies, resource use reduction goals, UNEP global contraction and convergence scenarios) and thus establish material boundaries to serve as input to the macroeconomic models developed in work package 205 and to constitute the biophysical frame for the analyses of other work packages. A particular challenge for this work package is the strong empirical interlinkage between the use of various resources (energy-materials, biomass use - land use - water use, energy - metals etc.). It does not make sense to formulate constraints independently from one another. These interlinkages may then in turn be a challenge for the economic models. There will be an internal workshop to clarify the needs and potentials of the respective economic models in terms of the specification of constraints.

Keywords: Biophysical constraints, CGE models, economic growth path, economic strategy, industrial innovation, industrial policy, innovation policy, socio-ecological transition

Jel codes: Q3, Q4, Q5

Tables and Figures

Executive Summary

Chapter 1 of this report reviews a number of approaches to conceptualize and operationalize biophysical constraints for economic performance. The starting point is a scoping study by Cambridge Econometrics and Sustainable Europe Research Institute (SERI) that reviews a large number of macroeconomic models investigating their ability to provide information on the interlinkages between the economy and the environment required from a sustainability viewpoint. This scoping study yields two key recommendations for macroeconomic modelling: to incorporate resource use in the explanation of economic development, and to allow for non-linear relationships, thresholds and limits (Serice 2010). The report then turns to another useful approach from OECD that makes an effort to conceptualize causal pathways linking global environmental change (originally: climate change) to economic development via policy regulations, direct biophysical impacts and price effects on global markets (OECD/Martinez-Fernandez et al. 2010). The three types of effects are discussed. In a next section, insights from a report from the FP7-NEUjobs project are presented. In this project, a wide array of (mainly) natural science literature had been screened to identify "global megatrends" that would impact European economies and policy-making. Given far-reaching uncertainties and complex interrelations, the megatrends identified (i.e. energy transitions, rising challenges to resource security and increasing climate change impacts) are grouped to envision two future world contexts for Europe, a "tough" and a more "friendly" world. For the year 2025, the features of these worlds are sketched on the basis of a literature review (NEUjobs 2012). The chapter concludes that indeed the availability and use of natural resources provides a key link between economies and the environment, but that it is advisable to deal with them not one by one, but in a systemic fashion that takes into account their strong interrelationships on the one hand, and the high uncertainty of constraints of particular resources on the other. It concludes that the future of European resource supply may be expected to be fairly different from the past, and should be expected to change to the worse, both for environmental reasons and for reasons of strongly increasing international demand and competition.

Chapter 2 is devoted to a descriptive analysis of the changes in global and European resource use in the past and emphasises the non-linearities that can be observed. It focuses on long-term structural changes in the energetic base of socio-economic systems, leading to fundamental transformations in the scale and quality of society-nature interactions. Similar fundamental transformations should be expected for the (inevitable) transition from fossil to renewable energy sources. Based on a set of case studies of industrial countries for which long term data series for resource use (material and energy use) are available, it discusses the transition from the agrarian to the industrial metabolic regime and seeks to identify structural breaks in the development of energy use in the second half of the 20th century. The main finding is that a stabilization of per capita energy and resource use in most high-income countries was reached in the early 1970ies that is still lasting, after a period of accelerated growth of resource use since the end of World War II. During this time the so-called 'decoupling' of energy and materials use from economic growth became much more pronounced, a phenomenon we describe as the "1970s syndrome". An explanation of this common and marked turn in the upward trend of energy and materials consumption needs more research and will be further pursued in work package 201.

Finally, Chapter 3 suggests four scenarios for European resource use up to the year 2050, aligning with the global resource use scenarios developed by UNEP's International Resource Panel (2011). A "trend scenario" prolonging Europe's resource use into the future proves to be very close to the "freezing" scenario proposed by UNEP for high income industrial countries, and leads to an average per-capita resource use in Europe on the same level as in the early 2000s. A "best practice scenario" generalizes the past success of some European countries in downsizing their resource use to all European countries up to 2050. The fourth scenario, the “radical transformation scenario”, follows UNEP’s “moderate contraction and convergence” scenario in halving the per capita annual resource use of European countries, leading to what is commonly called “absolute decoupling”. The last part of the chapter is devoted to the feasibility of such a scenario, on the one hand, and the consequences this might have for the European economies.

The concluding remarks emphasize that a successful scenario exercise requires an intimate collaboration between macroeconomic modellers and scientists contributing from the environmental and socio-ecological angle. There will be place for such collaboration in the further course of the WWWforEurope project.

Introduction

It was a trial-and-error process that led to the scenario decisions incorporated into this report, across a number of intensive discussions between our team of socio-ecologists and macroeconomic modellers. Stepping stones of this process can be described as follows.

1) In October 2012, the Institute for Social Ecology (SEC) organized a workshop in Vienna to explore the interests of macroeconomic modellers in WWW to incorporate scenarios of biophysical constraints into their modelling exercises, and to gain mutual understanding of expectations and possibilities. Agreement was reached that SEC and WIFO would prepare presentations for the WWW Workshop on macroeconomic modelling planned by WIFO for which, on the one hand, possibilities to operationalize biophysical constraints, on the other hand, links from the macroeconomic model under development to biophysical constraints would be explored.
2) In March 2013, the respective presentations were made and contributed to a shared understanding of the structure of the tasks in WP 2.4 and 2.5. In particular, it was agreed that the macroeconomic model in preparation would cover EU 27 (and not, as originally envisioned, only some particular European countries), and that the scenario work should therefore also refer to EU 27. It was also agreed that there should be at least one scenario implying a radical European change towards a biophysically more sustainable state; as an adequate time frame for this we agreed on 2050.
3) These agreements had certain implications for resources and timing. It became clear that this task required an intensive and continued interaction process between the teams involved – in contrast to the project plan asking for finalization of scenarios now, ahead of the macroeconomic modelling. The SEC team therefore decided to reserve some labour power for the joint development of the scenarios with the macroeconomic model in the following months. This could be achieved more easily as we could build upon previous work within the framework of the EU-FP7 NEUjobs project, as will be acknowledged wherever applicable.

In effect, this milestone report comes a little prematurely: it will develop resource use scenarios for Europe, but it cannot yet create an interface with the macroeconomic models (as they are not mature enough yet), and it cannot yet analyse and interpret model results, as they do not yet exist.

In this report, we make an effort to bridge the gap between natural science based insights about environmental impacts and macroeconomic functioning. This gap is fairly wide: If we consider for example the widely received analysis of Rockström et al. (2009) about planetary boundaries and both the time frame and the variables included in typical macroeconomic analyses, the required bridge would have to span a distance that needs additional scientific pillars in between. The IPCC, for issues of climate change and energy use, has been able to build such a bridge, with the help of a large interdisciplinary research community, at least to a certain extent. For the much wider issue of natural resources and their limitations, and the impacts of these limitations upon the economy, such a bridge does not exist yet. What we are trying to do in this report is building some pillars of such a bridge based on socio-ecological analytical work of the past decade.

The structure of this report is the following. In chapter 1, we review a number of approaches we consider useful to relating biophysical constraints with macroeconomic models. In chapter 2, we discuss the long-term variability of socioeconomic resource use (and concomitant wastes and emissions) as an issue of non-linear change. Chapter 3, finally, will provide scenario calculations for EU 27 with a time frame to 2050 that lean upon UNEP's (2011) "contraction and convergence" scenarios and break them down from a global to a European level.

With regard to the overall goals of the project WWWforEurope, each chapter serves a different purpose. Chapter 1 explores the framework conditions for linking European wealth and welfare (less so: work) with changing global framework conditions, reviewing existing efforts to relate economic to biophysical change and explores the pathways of possible interlinkages. Chapter 2 makes a strong empirical claim for on-going structural change, both within high income industrial economies and globally. It warns against simple extrapolations of past trends into the future, and it bears a positive message: that the strong bond between economic growth and the use of environmental resources has been lessening in the past decades, even that Europe could be at the verge of a new transition (that it might not yet be willing to recognise). Chapter 3 then makes an effort at preparing biophysical scenarios for an on-going modelling effort in collaboration with economists (WP 205). What is clear is that this will require substantial additional efforts to provide adequate input into economic models: but there is a good chance for moving along non-conventional pathways.

1. How to introduce biophysical constraints into macroeconomic models

At WWW's macroeconomic modelling conference in 2013 we presented the following considerations from literature for discussion, in order to create a shared understanding of possible (and impossible) ways to incorporate biophysical constraints in macroeconomic models.

1.1 Diagnosis and advice from the SERICE scoping study (2010)

In a 2010 report to DG environment, Cambridge Econometrics in collaboration with the Sustainable Europe Research Institute SERI examined the links between macroeconomic perspectives and sustainable development. It considered how these links are represented in economic theory and asks if the macroeconomic modelling used today is up to the task of evaluating policy from a sustainable development viewpoint. If not, then models risk missing out on the analytic requirements for sustainable development: the strong (two-way) linkages between the economy and the environment, the importance of the long term, the necessity of an integrated approach and the danger of thresholds.

“If these issues are missed by our models, then they risk giving us the wrong answers and leading us in the wrong direction”, the report states, and continues with the following diagnosis.

“In the neoclassical model of the economy the environment and its natural resources have never found a strong footing.

- The ecosystem is treated as a subsystem of the economy whose main functions are the limitless extraction of resources and the free disposal of waste.
- The environment mainly features in microeconomics, where it is assumed that the internalisation of negative externalities through the price mechanism can solve all ecological problems.
- Mainstream macroeconomic theory is profoundly oriented towards the goal of continuous and exponential economic growth. It is assumed that economic growth can increase innovation and efficiency and lead to decoupling of economic growth from negative environmental impacts.
- The welfare of future generations is safe because there is full substitutability of natural capital so the depletion of natural resources can be compensated via investments in other forms of capital (a concept known as ‘weak sustainability’). From a neoclassical economics perspective, there is no need for a new macroeconomic framework for sustainability.

The possibility of not being able to substitute between input factors, or of the depletion of stocks of resources, is largely ignored. Where external factors, such as environmental emissions or human health effects, are included in the modelling framework they are often assigned monetary values.

An alternative macroeconomic framework is being developed by ecological economists by extending the neoclassical framework to explicitly include the environment and its services to the economy. In ecological economics:

- The economic system is not only embedded in the larger environmental system but is also completely dependent on it as both a source of inputs and as a sink for the matter or energy transformations required by economic activity.
- The assumption that capital can substitute for resources is rejected on the basis that certain functions that the environment performs cannot be duplicated by humans (known as 'strong sustainability').
- Environmental constraints imply limits on economic scale and thus limits to growth.
- Ecological economists are sceptical about the possibility to dramatically change technologies, investment and consumption patterns in a way that decouples economic growth from environmental impacts.

In effect, ecological economists argue for a serious rethinking of standard economic assumptions and theories. At the same time, the report has to admit that "a complete macroeconomic model in tune with ecological economists' thinking does not yet exist"." (SERICE 2010, executive summary, p. iii)

In tune with its analysis, the SERICE report issues the following recommendations for improving the representation of ecological sustainability issues in macroeconomic models.

Recommendation 1: Incorporating resource use into the explanation of economic development

They find that "it would be possible to integrate demand equations for the physical consumption of materials (minerals and biomass) and water into existing macroeconomic frameworks (including feedback to economic sectors such as agriculture, mining and water supply). Eurostat provides relatively detailed data sets on which such an analysis could be based. However, this is only one step in setting up a system that is capable of carrying out a comprehensive analysis. A more complete list of steps is:

- Identify and define the most important groups of resources.
- Measure the available stocks (e.g. fossil fuels) or maximum carrying capacities (e.g. annual fresh water supply).

- Include the demands for these resources and, where possible, available stocks or carrying capacities in macroeconomic models.
- Allow supplies to influence behaviour, for example (but not limited to) in price formation in the model structures."

The authors think that the last of these steps requires a much larger research input as the behavioural responses to extreme outcomes are unpredictable. However, the other steps they consider all possible with given model frameworks and supplementary analysis, and the modelling approach required is close to that already applied for energy use. (SERICE 2010, p. vii)

Recommendation 2: Nonlinear Relationships, thresholds, limits

"The standard modelling approach is based on linear (or log-linear) elasticities, for example an elasticity of -0.5 would mean a 10% increase in price leads to a 5% decrease in demand. Although there are cases where this assumption is relaxed, our view is that this type of relationship is often forced on model parameters. This potentially negates several important features and leads to the following issues and potential developments:

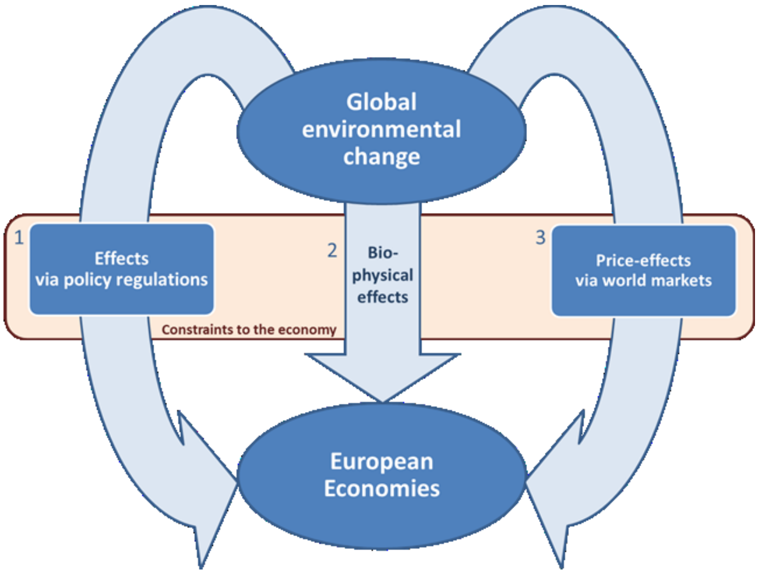
- Linear approximations of curved relationships may be reasonably accurate for small changes, but will become less accurate as the model moves further from base.
- Threshold effects and physical limits should be taken into account. However, problems arise in defining thresholds that have not previously been reached (e.g. mineral resources becoming scarce), or where thresholds vary over time (e.g. annual rainfall).
- A proper treatment of asymmetrical relationships could be a relatively easy improvement to make, with separate parameters for positive and negative relationships. For example, if high commodity prices lead to investment in new equipment, this equipment will still be used if prices fall again.
- The assumption that model elasticities do not change over time should be examined more closely." (p.viii)

While SERICE issues a number of further recommendations, our presentation below will place particular emphasis, analytically and empirically, on the validity of the above two key recommendations.

1.2 Adopting OECD's impact model for resource use

While it is fairly common to describe impacts upon the environment in terms of overstretched sinks due to increasing amounts of wastes and emissions, these adverse effects usually only feedback upon economies through political regulation. With increasingly limited natural resources, though, one may expect a more immediate impact upon economies. In our analysis of causal pathways that might render themselves for macroeconomic modelling we borrow a scheme from recent work on green jobs and skills in relation to climate change (OECD/Fernandez et al. 2010) and modify it for our own context:

Figure 1 **Conceptualizing general pathways how potential biophysical constraints may affect economies**



adapted from OECD/Martinez-Fernandez et al. 2010

There are three types of causal pathways that may connect environmental changes / impacts (biophysical constraints) to European economies.

Effects via policy regulations (1) occur when governments intervene by legal measures to mitigate adverse pressures on nature. This can take the form of prohibiting the use of certain materials, by mandatory standards on energy efficiency and building codes, by taxation and pricing emissions, or more softly by self-binding goals, like the Kyoto agreements or the R2020 goals.

Methodologically, relying on policy regulations has a number of advantages. On the one hand, the existence of such regulation already proves that there is a consensus that one may expect severe environmental impacts: if there were no consensus on unwelcome adverse impacts, there would be no regulation (The inverse, of course, cannot be claimed!). Additionally, these regulations are usually quantitatively specific, so that the constraining limit can be clearly defined. Finally, in most cases the causal link between regulation and economic activity is not very specific: there are usually a number of ways to comply.

Biophysical effects (2) occur when changes in the environment directly impact the economy. This includes **singular events** like disasters damaging infrastructures or major accidents cutting off energy and water supply, or epidemics threatening lives and temporarily reducing the labour force. Droughts and pests may reduce regional harvests or cause disruptions of water supply to households and industry. As long as this is about singular local or regional events, research has shown that there may be a short term economic impact (e.g. earthquake effecting Port of Kobe, see Toya and Skidmore 2007; economic effects of the floods in 2002, see Kletzan et al. 2003; droughts and harvest losses, see Okuyama 2007), but in the medium and long term the economy recovers and returns to business as usual.

What is not so clear is the impact of a rise in the **frequency and extent of such events**, including more and more numerous supply disruptions of materials and energy. We would assume that economic players will employ the following adaptation strategies, such as:

- Building up emergency supply systems by investments in infrastructure and increased stock-keeping (such as multi fuel burners, fuel and water tanks, electricity generators, changes to production systems with reduced just-in-time deliveries)
- Diversification of product portfolios, including the phasing out of highly vulnerable production processes to increase economic robustness (e.g. selection of crops)
- Fortification of existing infrastructures to make them less vulnerable (flood protection, strengthened roof construction to deal with increasing snow loads, etc.)

The common economic denominator of these strategies is probably a rise in factor costs (investments) and decreasing efficiency of production (c.f. Randers 2012 and his assumption on declining productivity increases). Methodologically it seems difficult to parameterize these impacts.

On top of this, incremental **systematic environmental trends** are also to be expected, for example rising sea levels and increasing aridity in Southern Europe. These impacts on natural conditions for production might promote a structural shift in national economies and a change in geographic economic patterns. For example the agricultural production of Southern Europe might be faced with water scarcity. Summer tourism in Southern Europe and winter tourism in the Alps might be faced with unfavourable temperature changes.

Price-effects on world markets (3) occur where markets perceive tightening biophysical constraints. So expected shortages of supply due to scarcity of energy sources or specific materials lead to an increase in prices and may lead to increases in price volatility. In the case of metals, declining ore grades in major mining sites trigger price effects. Or the oil price amongst other factors might change due to new knowledge about size and accessibility of available resources and reserves. The so called EROI, the ratio of how much energy is gained to how much energy is required to explore or grow, extract, produce and deliver it at the point of use, may play an increasing role, since fossil fuels show declining EROIs and renewable energy carriers show lower EROIs than the fossil fuels in the past decades (see Hall 2008).

Whether the increase in price volatility is mainly caused by changes in the physical fundamentals or by changes in the financial fundamentals is subject to discussion. In the past for example speculation has amplified the volatility of commodity prices (Chevalier 2010). Similarly, it is likely that the physical fundamentals will play an increasing role in price rises by the end of the decade, adding to increasing volatility.

In addition to growing information on biophysical constraints and related environmental impacts, as a fourth effect not included in the OECD model, also consumer preferences may be affected, with some segments of the population adopting more sustainable consumption practices. NEUjob's Global Challenges Model

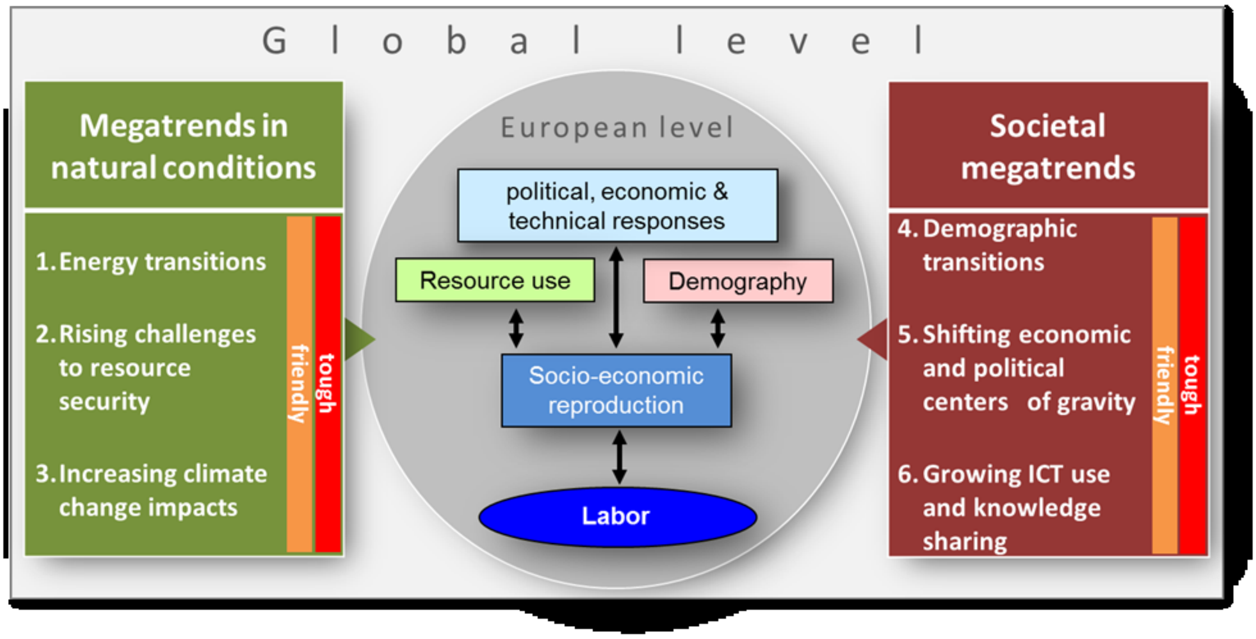
The historical socio-ecological transitions, such as the fossil fuel based industrialization of Europe and beyond, led to a new type of society with unprecedented levels of natural resource extractions and energy and material consumption for approximately 15% of the world population, with equally unprecedented scientific and technical knowledge and with democracy. However, this transition is not only historical but still on-going, as 60% of the world's population in the emerging economies are in a take-off or an acceleration phase towards a fossil fuels based system (see chapter 2). Also a further socio-ecological transition away from fossil fuels can be expected to have similar far-reaching implications as this still on-going transition into fossil fuels, not only for production and consumption patterns, but also for many other features of society.

There is ample evidence provided by global change research that human activity caused and causes major changes in the functioning of natural systems on every spatial scale, from local to global, and is transforming the earth system at an increasing pace (IPCC 2007, Karl and Trenberth 2003, Rockström et al. 2009a, Schellnhuber 1999, UNEP 2007, Turner et al. 1990, Vörösmarty et al. 2004, WBGU 2011). Such changes are now being accelerated by the on-going process of industrialization in the very populous emerging economies. Thus, imagining the further expansive continuation of the industrial sociometabolic regime for a majority of the world, 2025 or even more so 2050, seems biophysically not feasible and threatens to further erode humanity's natural base. It is very hard to know how fast this will happen, and this is subject to debate. It is not so hard to know that some of this will happen, such as the exhaustion of cheap fossil fuels and a number of other natural resources, and – to say the least – an increasing volatility of the climate system. Still, these changes occur in response to, or as a consequence of, the continuing socio-ecological transition towards fossil fuel based industrial societies and inevitably – sooner or later – will impose a new socio-ecological transition away from fossil fuels on societies.

Under the "global megatrends in natural conditions" the NEUjobs report subsumes energy transitions (into and away from fossil fuels), rising challenges to resource security and increasing climate change impacts. On the other side, NEUjobs sees elements of the social part of the socio-ecological transition happening, related to social and technical achievements generated by the last transition, and terms them global "societal megatrends". The three most important elements of the global societal megatrends identified are the continuation of the global demographic transition, the on-going shifts in the economic and political centres of gravity worldwide, and the growing use of information and communication technologies plus related new forms of knowledge sharing. These megatrends, so NEUjobs argues, fundamentally reshape the global framework conditions for Europe. As stated above, it is an open question how fast and how radical these megatrends will evolve. Therefore they draw a distinction, for each megatrend, based on existing literature, between “friendly” and “tough” variants by 2025 and by 2050, and use these as global framework scenarios for the European option space.

Figure 2 pictures the European option space in this (dynamic) global framework. In the centre of the picture, there is the socio-economic reproduction of the European population at a certain level of welfare. The population is subject to demographic change (depending on global and internal conditions). Its reproduction, depending on the mode of production and consumption, requires the use of natural resources the supply of which is subject to global (and internal) conditions. It also requires a certain amount and quality of human labour, again depending on global and internal conditions. At the top of the picture, there is the European policy process, political, economic and technical response strategies in a changing world.

Figure 2 **Global megatrends impacting upon Europe’s future by 2050**



Source: NEUjobs 2012, p, 77, http:// http://www.neujobs.eu/publications/socio-ecological-transition-and-employment-implications/socio-ecological-transitions-de

While global scenarios and key assumptions are based on an extensive review of literature, NEUjobs makes an effort at simplifying and aggregating the options to generate two variants of a global future world, a “friendly” and a “tough” one. The goal of this exercise is to find those key assumptions necessary for formal modelling as well as for creating self-consistent story lines of two possible futures. These possible futures map out the range of the possible global conditions for 2025 and 2050. For defining “friendly” and "tough”, NEUjobs draws a distinction between a slow rate of change that is less challenging for Europe, and a more radical or rapid version.

Friendly: A friendly future includes rather moderate changes which are less challenging for European policy making. It focuses on incremental global changes in the lower ranges of change found in the literature.

Tough: The sketch of a tough global future is based on still quite likely but rather severe changes which would be highly challenging for European policy making, using the higher ranges of change found in literature, including possible abrupt changes.

The cutting point between "friendly" and "tough" is chosen in a way that each has a similar likelihood. As in many areas quantification of trends is difficult and there are no broadly accepted and reliable likelihood estimates, these choices are based on own expert judgement.

The literature review was organized according to the six areas identified as directly related to past, on-going and future socio-ecological transitions (see Figure 2). In each area, the latest global forecasts or scenario analyses from international organizations (such as IPCC, World Bank, UN, UNDP, UNEP, FAO, IMF, IEA, OECD and others) were screened and complemented where appropriate with similar efforts from international NGOs. On top of this, there was an effort to capture relevant journal articles or books that deal with socio-ecological transitions in one of these fields. European project reports were included as far as they dealt with these global issues. The literature thus covered is vast and highly heterogeneous. Economic literature was not covered as much as other fields, as economic forecasts tend to extend over much shorter timespans than required. Nevertheless, all recent World Bank or OECD reports were screened. Political science literature also tends to have a different format in dealing with the future: there are hardly any quantitative estimates, but rather verbal analyses of on-going trends. More natural science oriented assessments (as for resources, climate or demography) in many cases offered the most appropriate format: they tend to cover a longer time period and offer quantitative descriptions, often with estimates of uncertainty attached (see NEUjobs 2012).

Table 1 **Alternative futures by 2025 concerning the global megatrend "resource security"**

	friendly	tough
	Energy transition	
Demand	Roughly at today's levels[1] *(EREC 2010, EREC/Greenpeace Energy [R]evolution Scenarios)*	Increases by up to 40%[2, 3] *(EIA 2011, EIA High Oil Price Case)*
Supply	**Oil:** Can keep up with demand due to new discoveries of conventional and unconventional oil, increased recovery rates **Nuclear energy** stagnating **Biofuels:** Progress in second generation biofuels lessens conflicts over land for food production	**Oil:** Shortages due to peak oil and delayed investment in new production *(Alekett et al. 2010)* **Nuclear energy** slowly phasing out due to increased risks **Biofuels:** no progress in second generation biofuels, first generation biofuels require substantial share of agricultural land competing with food production over land
Prices	**Oil price** at around USD100 *(IEA 2011, IEA 450 Scenario)* Due to improved price finding mechanisms and management of stocks reduced **oil price volatility** **CO_2 price** of around USD70 *(estimation based on WEO, IEA 450 Scenario)*	**Oil price** approaching USD200 *(EIA 2011, EIA High Oil Price Case)* **Oil price volatility** remains high and negatively affects investment and economic activity No or low **CO_2 price** of USD35
EROI[4]	of global oil and gas production decreases to 20:1 *(Gagnon et al. 2009)*	of global oil and gas production decreases to 10:1 *(Gagnon et al. 2009)*
CCS[5]	very limited in scale[6]	failing

[1] Share of fossil fuels drops to 70% *(estimation based on IEA 450 Scenario)*

[2] Share of fossil fuels remains at 80% *(see IEA New Policies Scenario, EIA scenarios and industry scenarios)*

[3] Share of biomass constant at about 10% *(IEA New Policies Scenario)*

[4] Energy return on investment

[5] Carbon capture and storage

[6] Up to now CCS technologies have not been proven on a commercial scale. To the contrary: Several factors like investment and operation costs (Hirschhausen et al. 2010), efficiency losses (IPCC 2005, IEA 2011), publicly acceptable storage potentials (Gerling et al. 2010, Höller 2010), storage leakages and environmental risks raise serious doubts on the timely feasibility of this technology.

Source: NEUjobs 2012, p.85

Table 2 **Alternative futures by 2025 concerning the global megatrend "resource security".**

Resource security		
Demand	**Critical metals:** +20 % increase of total demand over 2007 *(Buchert et al. 2009)* **Rare Earth Elements (REE):** +120% increase over 2007[7] **Phosporus:** +10%increase over 2000[8] *(Van Vuuren et al. 2010)* **Food:** Moderate demand growth due to low population growth (low fertility variant) and dietary changes towards less meat in mature economies and less food waste	**Critical metals:** +50% compared to 2007 (Buchert et al. 2009) **Rare Earth Elements (REE):** +370% increase over 2007[9] (Schüler et al. 2011) and criticality of some REE severe **Phosporus:** +60% increase over 2000[10] (Van Vuuren et al. 2010) **Food:** High demand growth due to high population growth (high fertility variant) and dietary changes of emerging economies towards the level and diet of today's mature economies
Supply	**Critical metals:** supply increases are mitigated by efficient recycling systems and high recovery rates, relevant substitutions are realised, no further export restriction from producing countries, new mining projects, new discoveries **Bulk metals:** declining ore grades *(Giurco et al., 2010)* leading to slow but steady price increases **Phosphorus:** Peak 2030 *(Cordell et al., 2010, Rosemarin 2010, Zittel 2010)* **Food:** Progress towards key food security and environmental sustainability goals *(Foley et al. 2011)*	**Critical metals:** severe supply shortages due to low recycling rates, low/unknown substitutability, > 90% share of global mining within few countries and further export restrictions **Bulk metals:** declining ore grades *(Giurco et al. 2010)* leading to significant price increases **Phosphorus:** Peak 2020 *(Zittel 2010, lower range of estimate)* **Food:** Food security situation problematic, environmental impacts large

[7] REE: annual growth rate of 4.5% based on literature equals +120%

[8] Phosphorus: 44,5 Mt P_2O_5 in 2000 and 49 Mt P_2O_5 in 2030

[9] REE 9.0% per year based on literature equals +370% and criticality of some REE more severe than projected

[10] Phosphorus: 44,5 Mt P_2O_5 in 2000 and 78 Mt P_2O_5 in 2030

Prices	**Phosphorus:** Steady price increases, no price shocks	**Phosphorus:** Sharp price increases and price shocks, high volatility
	Food prices increase steadily and volatility is under control *(World Bank and IMF 2011)*	**Food price volatility** high, supply cannot keep up with demand

Source: NEUjobs 2012, p.85

Table 3 **Alternative futures by 2025 concerning the global megatrends "climate change" and "population dynamics"**

Climate change impacts		
Tempera-ture	Temperature rise +0.4 °C (compared to 2005)	Temperature rise +0.6 °C (compared to 2005)
Weather extremes	Increases in precipitation extremes: 5 % per °C of warming, and other weather extremes: heat waves, droughts….	Increases in precipitation extremes: 10 % per °C of warming, and other weather extremes: heat waves, droughts…
Glaciers, ice sheet, sea level rise	Accelerating trend: melting of glaciers, Arctic sea ice decline, sea level rise faster than in the 20th c. (> 3.4mm/yr)	Accelerating trend: melting of glaciers, Arctic sea ice decline, sea level rise (much) faster than in the 20th c. (>> 3.4mm/yr)
Population dynamics		
Popula-tion	7.6 billion in 2025 8.1 billion in 2050 *(UNPD 2011, low fertility variant)*	8.3 billion in 2025 10.6 billion in 2050 *(UNPD 2011, high fertility variant)*
Ageing	Age group 65+ has an increasing share of world population. Highest percentages in mature industrial economies starting from 20% in 2010 to 26% in 2025 and to 33% in 2050 *(UNPD, 2011)*[11].	
Migration	Stagnating net migration into Europe at less than 1 million per year *(UNPD 2011).*	Net migration less than 1 million per year, but with higher migration pressure due to climate change impacts; contributing to a polarisation in European societies
Displace-ments	Risk of floods and droughts leading to short term migration and relocation	High risk of floods and droughts leading to short term migration and relocation

[11] The difference re age group 65+ between low and high fertility variant is very low in mature industrial economies due to the small differences between the variants in these countries

	movements within Europe. For 2050 inland migration from Europe's low laying coasts (e.g. Netherlands: 5.000 persons) *(IPCC 2007; Mc Leman and Hunter 2011).*	movements within Europe. For 2050 inland migration from Europe's low laying coasts (e.g. Netherlands: 50.000 persons) *(IPCC 2007; Mc Leman and Hunter 2011).*

Source: NEUjobs 2012, p.86

Table 4 **Alternative futures by 2025 concerning the global megatrends "shifting centres of political and economic gravity" and "ICT use and knowledge sharing"**

Shifting Economic and Political Centres of Gravity		
Economic shift	**Mature industrial economies'** share in world GDP declines from 50% in 2011 to 45% in 2025 **EU15** declines from 18% to 15% **Emerging economies'** share in world GDP increases from 30% to 37% **China** increases from 16% to 20% **India** increases from 6% to 8% *(own calculations[12] based on The Conference Board 2012, base scenario)*	**Mature industrial economies'** share in world GDP declines from 50% in 2011 to 40% in 2025 **EU15** declines from 18% to 13% **Emerging economies'** share in world GDP increases from 30% to 43% **China** increases from 16% to 25% **India** increases from 6% to 9% *(own calculations[13] based on The Conference Board 2012, pessimistic for mature and optimistic scenario for emerging)*
World econo-mic growth	**Mature economies:** 1,9% for 2012-2016 and 1,9% for 2017-2025 **EU15:** 1,5% for 2012-2016 and 1,7% for 2017-2025 **Emerging:** 6,0% for 2012-2016 and 3,4% for 2017-2025 *(own calculation based on The Conference Board 2012, base scenario)*	**Mature economies:** 1,1% for 2012-2016 and 1,3% for 2017-2025 **EU15:** 0,4% for 2012-2016 and 1,0% for 2017-2025 **Emerging:** 7,9% for 2012-2016 and 4,6% for 2017-2025 *(own calculation based on The Conference Board 2012, pessimistic for mature and optimistic scenario for emerging)*

[12] Friendly assumes slow but steady growth in Europe that allows for adequate responses to challenges ahead and relatively moderate growth in emerging countries so that demand for resources grows moderate as well (meaning less challenging to European resource security).

[13] Tough assumes very low growth rates for Europe that challenge stability (financially and politically through high unemployment rates and polarization in society) and quite high growth rates in emerging economies due to growing domestic markets and increasing trade between emerging economies themselves and with developing countries.

Volatility	no upward or downward trend in **commodity price volatility** over time compared to recent decades *(Calvo-Gonzales et al. 2010)* **Food and agricultural prices:** Lessons learnt from previous periods of high volatility lead to successful implementation of measures to reduce price volatility and to better deal with consequences *(FAO et al. 2011)* **Oil price:** due to improved price finding mechanisms and management of stocks reduced oil price volatility	Continued uptick in **price volatility** in a number of commodities **Food and agricultural prices:** Higher and more volatile agricultural commodity prices persist, largely due to continuing uncertainty on the supply side, against projected rising demand *(FAO et al. 2011)* **Oil price:** volatility remains high and negatively affects willingness to invest and to engage in new economic activities
Inter-national relations	**Shift in political power** from mature to emerging economies due to increased economic importance (see economic shift) leads to **reformed cooperative international relations** Common challenges dealt by weak international cooperation Little reform of existing international institutions Summit diplomacy *(see NIC and EUISS 2010, Scenario I: "Barely Keeping Afloat" and Scenario III: "Concert of Europe Redux")*	**Shift in political power** from mature to emerging economies due to increased economic importance (see economic shift) leads to **confrontational international relations** Resolving common challenges dominated by self-interested actors Attempts to resolve challenges by military, economic and resource/ energy competition Increased military conflicts and armament *(see NIC and EUISS 2010, Scenario II: "Fragmentation" and Scenario IV: "Gaming Reality: Conflict Trumps Cooperation")*
ICT use and knowledge sharing		
Societal Level	**Open governance:** increased transparency, participatory policy intelligence Improved **management of complex systems** (smart grids, modelling global dynamics, smart energy production and consumption)	**Governance by surveillance:** use of ICT tools for increasing control over population, low openness and transparency, low integration and participation Increased **management of complex systems** by ICT solutions leads to dependency on highly vulnerable systems

	Information and knowledge sharing: open collaboration, learning management systems, civil services	**Information and knowledge denial:** high and successful efforts in securing information monopolies
Individual Level	**Protection of privacy** **Ambient intelligence/ ubiquitous computing** supports daily living **Social inclusion** (right to internet and digital inclusion) **New literacy** (technology literacy, customized information services, personalized education)	**Surveillance:** disclosure of personal information, threat of social pressure) **Ambient intelligence/ ubiquitous computing** creates dependency and better enables surveillance **Social exclusion** (limited access and digital divide) **New illiteracy** (financial dependence, fragmentation of education)

Source: NEUjobs 2012, p.87f

1.3 Preliminary conclusions from Chapter 1

The following insights from the material presented in chapter 1 will carry us through the tasks ahead.

- We agree with the SERICE 2010 analysis concerning the key role of natural resources. Natural resources are a key link between the environment and the economy. Economic activities are based upon natural resources, and the input (amounts and qualities) of resources used have clear implications for the "output" of the economy (i.e. wastes and emissions) to the environment. The sustainability of economic activity is directly related to the availability of resources. Beyond these conceptual reasons, natural resources – in contrast to most wastes and emissions, except for CO2 - have the advantage of statistical data availability for Europe (Eurostat) and globally. Data for material resources are available for sufficiently long time series to render themselves useful for statistical analysis of the interrelation between economies in monetary and in physical terms, similar to the long tradition of economy-energy analyses.
- As the assessment done for NEUjobs (2012) has shown, abundance and scarcity of specific resources (such as certain metals, phosphorus or fossil fuels) are highly contested issues. For all economic actors involved, estimates of available reserves involve substantial risks of capital devaluation, and therefore tend not to be very transparent. They are further complicated by technology assumptions, assumptions about future energy availability and price, and of course assumptions about future demand and substitutability. In the endeavour of finding realistic ranges it is not wise therefore to align with certain estimates and root scenarios in specific assumptions of future resource availability or constraints. Furthermore, the use of different resources is highly interlinked: energy and non-energy material resources are strongly correlated,

the extraction and use of various metals is functionally interrelated, food and feed availability is linked to mineral resources…

- It seems advisable, therefore, to treat natural resources in a systemic, holistic fashion, looking at the sum total of material and energy resources used by societies, as accounted for by the MEFA framework (see Matthews et al. 2000, Haberl et al. 2004, Fischer-Kowalski et al. 2011) and analyse the relations between these "biophysical" features economies with their monetary features in order to create one of the pillars supporting the bridge of understanding the interrelation between environment and the economy.
- The future context for European resource supply may be expected to be fairly different from the past, and should be expected to change to the worse, both for environmental reasons and for reasons of strongly increasing international demand and competition.

2. Non-linearities in historical and contemporary resource use[14]

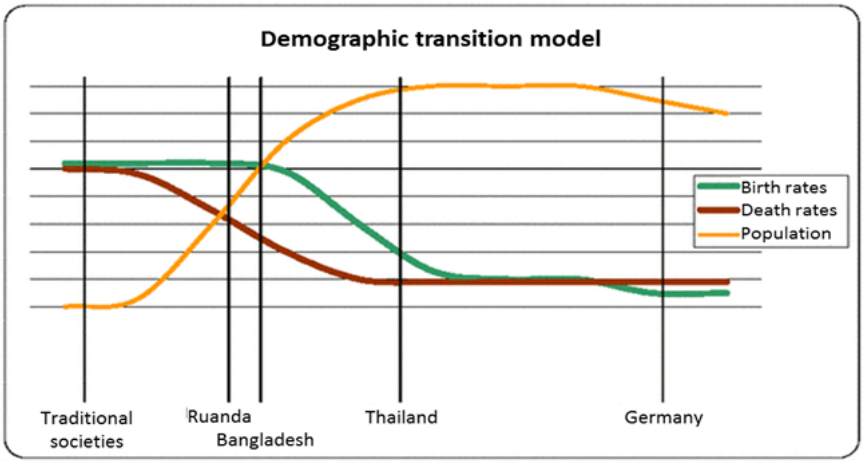
2.1 Incremental change versus transition / transformation

Several disciplines use the notion of transition in a variety of different contexts and in different meanings. In thermodynamics, the term transition is used to describe the ‘phase transitions’ of substances when transforming between solid, liquid and gaseous aggregate states (Stanley 1971).

The economic historian Karl Polanyi uses transition and transformation synonymously in his seminal book “Origins of our time: the great transformation” published in 1944. His investigation was concerned with the transformation of society into a market economy focusing on the political and economic dimensions of this process (Polanyi 1944).

Another use of the notion stems from demography. In 1945, Notestein (1945) wrote his classic elaboration of transition theory, "Population: the long view." Populations with high growth rates would become "transition growth" ones as modernization began to affect their fertility. When industrialization and urbanization become common place, fertility would reach low levels and the population would enter into the stage of "incipient decline."

Figure 3 **Demographic transition**



Source: own translation from Münz and Ullrich 2006

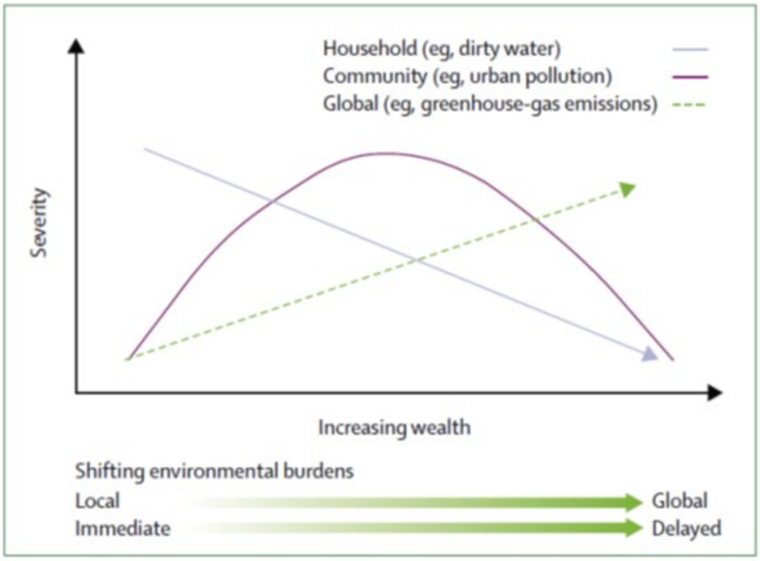
In environmental health[15], the notion of risk transition has been used by Smith to describe the tendency of the last century’s societal developments to shift environmental problems from

[14] The following chapter is an abbreviated and slightly modified version of our report for the NEUjobs project (NEUjobs 2012).

[15] The WHO (2013) defines environmental health as a topic that addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments (see http://www.who.int/topics/environmental_health/en/)

smaller to larger scales (Smith 1990, Smith and Ezzati 2005). In the poorest parts of the world fuel use in households and dirty water dominate the environmental hazards (indoor pollution), and in middle income cities fuel use for industry and vehicles dominate environmental impacts (outdoor pollution). In the richest countries, local environmental risks were reduced significantly. However, these countries shifted the problem to the global level by causing climate change and a number of other global problems such as biodiversity loss, ozone depletion and a number of other problems. This shift of environmental burdens from local to global goes hand in hand with a shift from immediate to delayed impacts.

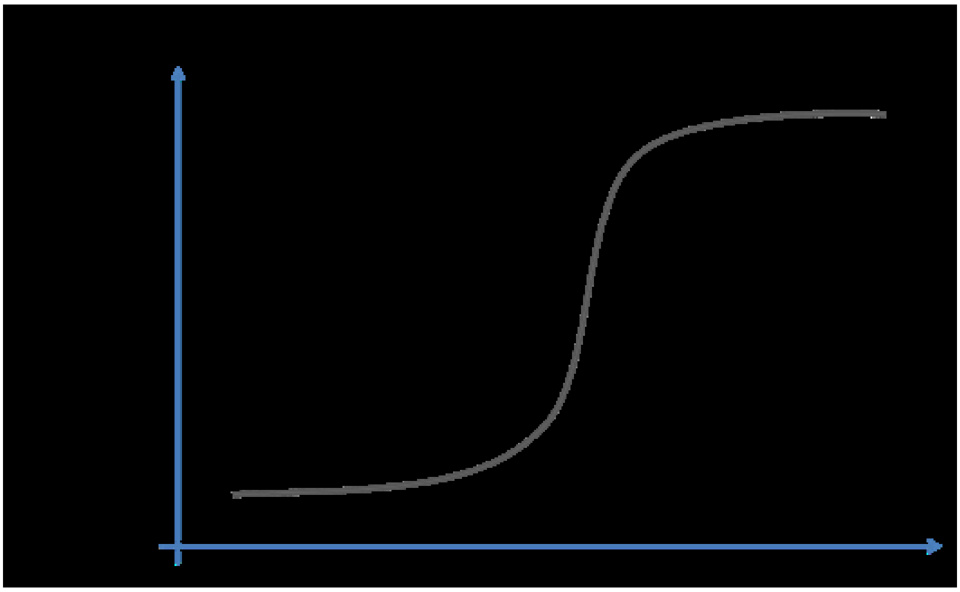
Figure 4 **Environmental risk transition**



Source: Wilkinson et al. 2007, 965-78, based on Smith 1990

Under the name of transition theory more recently a whole stock of literature concerned with societal change towards sustainability has been accumulated (sometimes called the Dutch school(s) of transitions research, see Swilling 2013, van den Bergh et al 2011). Rooted in social theory and technology systems studies, this transitions research strives for an understanding of social transformations (Rotmans et al. 2001; Foxon 2007; Grin et al. 2010; Geels 2011). It focuses on technological, social and economic change that entails profound alterations in structures, institutions and social relations and as a result, society, or a subsystem thereof, starts operating according to new assumptions, rules and practices. Transition research rests on three important components, the multilevel heuristic (landscape, regime, niches), the multiphase scheme (predevelopment, take-off, acceleration, stabilisation), and transition management. The multilevel heuristic deals with structural arrangements and interactions in transition problems and processes, while the multiphase scheme deals with the sequencing and temporal aspects in transition processes. Transition management refers to how actors obstruct or promote change and how they adapt to and learn from transition processes (Loorbach et al. 2010).

Figure 5 **Phases of a transition**



Source: Martens and Rotmans 2002

Transition thus implies that no linear, incremental path leads from one state or phase to the other, but rather a possibly chaotic and dynamic intermediate process, or a discrete “jump”. One has to be aware, though, that these distinctions are extremely sensitive to the observer’s choice of scale. From a wider perspective something may appear as a continuous process, progressing steadily. But from a closer perspective the same process may appear as whimsical, sharply fluctuating. Thus descriptions of processes as transitions or as gradual change do not necessarily exclude each other. One type of process may well be nested into the other.

Another consideration relates to the order of phases or stages, in other words, the understanding of directionality of time. The process of transition can be either conceived as reversible or as irreversible. In the case of thermodynamic states, there is complete re versibility: water can freeze, and melt again. For more complex systems, transition processes rather tend to be irreversible. There is directionality of time, and it can either imply consecutive stages of a developmental type (like Herbert Spencer’s notion of evolution, or Marxist historical materialism, or Rostow’s stages of economic growth), or it may follow a Darwinian type of evolutionary theory by assuming the future to be contingent upon the past but an open process into the future: you know the mechanisms driving it but not where it will lead to. In the first case, when a developmental model is employed, each consecutive stage follows with a certain necessity from the previous stage, and it is, as a rule, considered superior, more mature. The progress to this more mature stage can be accelerated or delayed. In the second, “Darwinian” case, the direction of change is principally unknown (Gould 2002). Many people believe earlier transitions (such as the industrial revolution) to have been of a developmental type, simply human progress. In the socio-ecological transition approach regime transitions are rather conceptualized emergent phenomena without an implicit or explicit directionality of history (for further discussion Fischer-Kowalski and Rotmans 2009).

2.2 Socio-ecological transitions as transitions between sociometabolic regimes (the Vienna social ecological approach)

The sociometabolic approach to transitions makes certain choices with regard to the above mentioned distinctions. It says the appropriate unit of analysis to investigate socio-ecological transitions is society, interpreted as a sociometabolic system (Fischer-Kowalski and Weisz 1999) that interacts with systems in the natural environment. Particular patterns of interaction are called "sociometabolic regime". Socio-ecological transitions, then, are transitions between sociometabolic regimes.

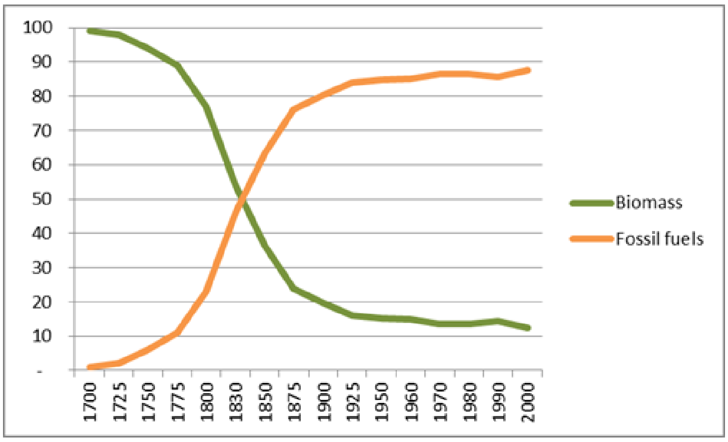
According to the sociometabolic approach, a regime, sociometabolic, is rooted in the energy system a society depends upon, that is the sources and dominant conversion technologies of energy. The theory of sociometabolic regimes has been developed by Sieferle (1982; 2001) and elaborated by Fischer-Kowalski and Haberl (2007). Depending on the reasons for and the speed of an energy transition, parts of the system may at a certain point in time be under different energy regimes: urban industrialized centres, for instance, may coexist with traditional agricultural communities, or industrialized countries with agrarian colonies. Such a "synchronicity of the asynchronic" (Füllsack 2011) influences the overall course of transitions. How these processes evolve is contingent upon specific conditions. The sociometabolic approach shares with complex systems theory the notion of emergence: neither can one state be deliberately transformed into the other, nor can the process be fully controlled. One is confronted with self-organizing dynamics (Maturana and Varela 1975) to which orderly governance or steering cannot be applied.

In the past decades, the material and energy flow accounting (MEFA) framework was developed and is now widely used to give an operational description of sociometabolic regimes in terms of societal resource use. MEFA allows calculating the resource use indicators domestic material consumption (DMC) and domestic energy consumption (DEC) which measure consumption defined as domestic resource extraction + imports – exports. DMC measures the socio-economic use of all materials in tons (except for water and air), typically distinguishing four main material groups: biomass, fossil energy carriers, non-metallic minerals and ores and metals. Accounting principles and estimation procedures are highly standardized and summarized for example in Eurostat (2009) and Fischer-Kowalski et al. (2011). DMC for European countries is regularly reported by Eurostat. The measure for domestic energy consumption, DEC, measured in Joule, is a comprehensive indicator for primary energy consumption. Beyond conventional measures (such as Total Primary Energy Supply, TPES), it does not only account for technical or commercial energy carriers, but also includes all primary biomass used by society: all feed for livestock and plant based food for humans that is, the primary energy sources for the provision of human work and draught power (Haberl 2001). DEC also accounts for electricity from hydro- and nuclear power as primary energy in the form of hydropower and nuclear heat. That is, it takes the conversion efficiency of hydro and nuclear power plants into account (Haberl 2001). DEC much better allows for a comparison across longer phases of history.

Based upon distinctions made by Sieferle (and others), the Viennese approach distinguishes the following sociometabolic regimes (most recently in Krausmann and Fischer-Kowalski 2013):

The agrarian regime. It is based upon active (as opposed to passive, as with hunters & gatherers) solar energy utilization. The active element consists in deliberately colonizing terrestrial ecosystems, trying to concentrate solar energy conversion in plants useful for human reproduction (as food and feed). Practically all energy depends on land use and the availability of land (in some cases also fishing grounds). This allows a lifestyle at an energy consumption level of up to 40 GJ/person and year and requires a large fraction of human labour (about 80%-100% of the labour power of a population).

Figure 6 **UK's historical transition from an agrarian to an industrial regime: a transition from biomass to fossil fuels as percentage of domestic energy consumption (DEC)**



Source: Krausmann et al. 2008b

The coal based industrial regime. Key feature of this regime is its ability to gain substantial amounts of additional energy from fossil sources. This additional energy is technologically translated into heat (for cooking and housing in urban centres) and later into mechanical power such as the steam engine, railways and steamships, and steel production, thus creating a new dimension of production, transportation and capital investment. The share of biomass in domestic energy consumption (DEC) gradually declines to 20% or less, and the overall energy level at this stage is at 50-150 GJ per person and year much higher than ever before in history. The generation of mechanical power has at least partially become independent from humans and animals. While agrarian societies can only count on a relatively low annual turnover of primary energy per unit of land area (average 40-70 GJ/ha); energy is more or less evenly spread across space. In contrast, coal and later petroleum can be extracted from concentrated large stocks and therefore, compared to agricultural energy regimes, need only minuscule space for extraction and production. This decoupling of energy provision from land area removed basic limits for biophysical growth inherent to agrarian societies.

The oil based industrial regime. This uses, on top of and in substitution of coal, petroleum, technologically translated into car based mobility, and later aeroplanes. Electricity provides a universally applicable and locally available form of energy; electric motors allow for the mechanization of a wide variety of decentralized technical processes. Petroleum is also key to the industrialization of agriculture ("green revolution"), providing tractors, mineral fertilizers and pesticides, and creating the opportunity to substantially raise both land and labour productivity.

Compared to any other energy carrier known before, fossil fuels offer very favourable features. One of the most important features is their very high energy density. While transport of biomass as energy carrier is quite limited since the energy necessary for transportation exceeds the energy contained in transported biomass already after short distances, fossil fuels contain a high calorific value in relatively low weight. Thus fossil energy regimes enabled unprecedented economic, but also physical growth. Growth in agrarian regimes is mainly population driven, with the consequence that it generally leads to a decline in energy use per capita. In comparison, industrial growth is based on both population growth and a surge in per capita use of natural resources (Krausmann et al. 2008a).

Based on a number of historical and contemporary case studies, typical metabolic patterns for agrarian and industrial regimes have been reconstructed. As apparent in Table 5, the socio-ecological transition between the agrarian and the industrial regime implies an increase of per capita DEC and domestic material consumption (DMC) by a factor of 3 – 5. During that process the importance of biomass as energy source decreases from over 95% to around 10 - 30%, with increasingly more fossil fuels being used. Absolute biomass consumption, though, does not decrease, as it is directly linked to population size in the form of food demand (Steinberger et al. 2010), and the regime transition is associated with a demographic transition triggering strong population growth and urbanization. Population densities increase by a factor of up to 10, while the share of agricultural population decreases sharply, from over 90% to below 10% (see Table 5).

Table 5 **Typical metabolic profiles of agrarian and industrial sociometabolic regimes**

Parameter	*Unit*	*Agrarian regime*	*Industrial regime*	*Factor*
Energy use (DEC) per capita	[GJ/cap/yr]	40 – 70	150 – 400	3 – 5
Material use (DMC) per capita	[t/cap/yr]	3 – 6	15 – 25	3 – 5
Biomass (share of DEC)	[%]	>95%	10 – 30 %	0.1 – 0.3
Agricultural population (share of total population)	[%]	>90%	<10%	0.1
Population density	[cap/km²]	<40	<400	3 - 10

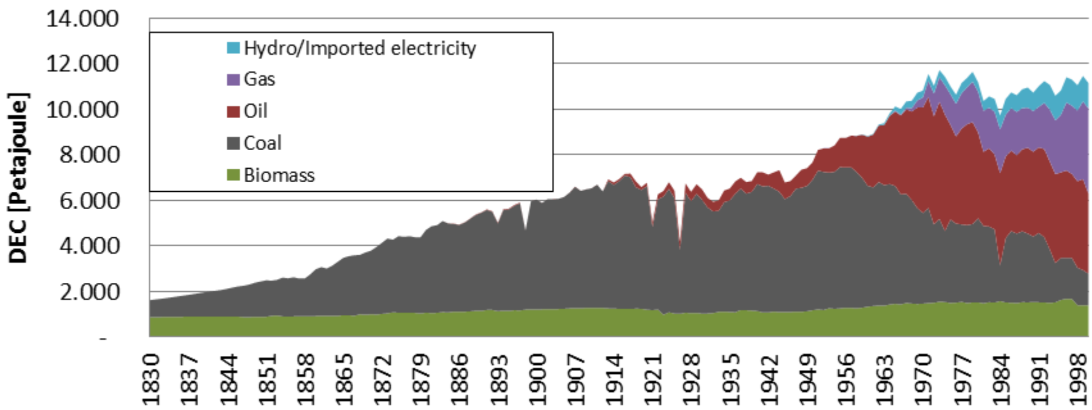
Source: Krausmann et al. 2008a; Krausmann et al. 2008b

2.3 Historical socio-ecological transitions as experienced in the UK, Austria, the USA and Japan

The primary example for the transition from the agrarian to the industrial regime is of course the United Kingdom (Wrigley 1988, Sieferle 2003; Krausmann et al. 2008b). The use of coal started already during the 17th century, when it gradually substituted for dwindling wood supplies due to widespread deforestation and allowed for textile manufacturing in growing urban centres. Much later, with the diffusion of the iron-steam engine-railroad complex (Grübler 1998), industrialization in the more common sense of the word took off (see Figure 7). From the mid-19th century onward, the use of coal increased rapidly and led to the first take-off of biophysical and economic growth (Table 5, (Krausmann et al., 2008b). The next pattern established itself after WW2. This pattern had started from the United States and was marked by the expansion of the petroleum-steel-auto cluster combined with electricity (Ayres 1990a; Ayres 1990b; Grübler 1998). This phase of increasing mass production and consumption can be looked upon as the "acceleration phase" of the industrial transition, with rapid biophysical (and even more so economic) growth (Table 5). In the UK, as well as in most "first generation" industrial economies (see further down), this acceleration phase driven by cheap oil (Pfister 2003; Smil 2003) ended with the oil price shocks in the early 1970's and gave way to a relative stabilization at high levels (Figure 7).

Due to its pioneering role, it had taken the UK 350 years to go through this socio-ecological transition process from a pre-development phase, through a take-off, an acceleration phase and an eventual stabilization of its socio-economic metabolism (Krausmann et al. 2008b).

Figure 7 **The energy transition in the UK, from 1830 – 2000**[16]



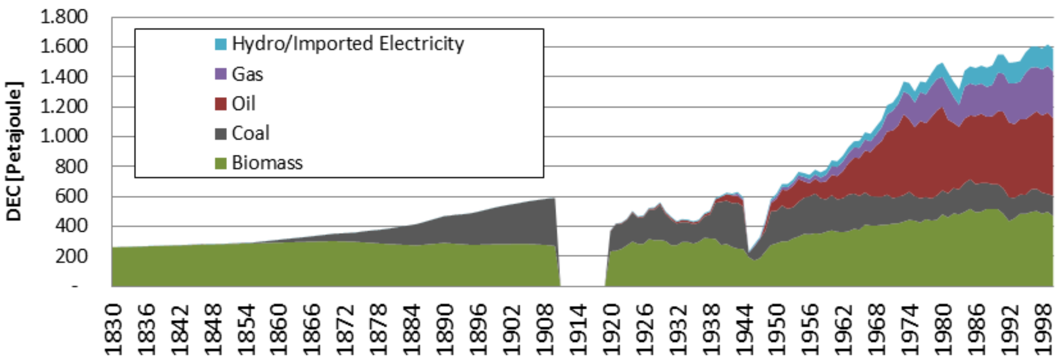
Source: Krausmann et al. 2008b, 1 Petajoule = 1.000.000 Gigajoule

The socio-ecological transition from an agrarian to an industrial regime in Austria started to take-off in the second half of the 19th century and followed a similar pattern as in the UK (Krausmann et al. 2008b, Figure 8). Because of the availability of wood in rural and iron

[16] Figures in this report use a dot as thousands separator

producing regions, biomass continued to play an important role as heat source until the acceleration phase of the post war period, when oil based industrialization, post-war reconstruction and the take-off of mass consumption led to an exponential increase of materials and energy use. As in the other mature economies, the 1970s proved to be a turning point, where resource use slowed down considerably (Figure 8). During the observed time period, domestic energy consumption increased by a factor of 6 and per capita consumption increase from approximately 73 GJ in 1830 to 197 GJ in the year 2000 (Krausmann et al. 2008b).

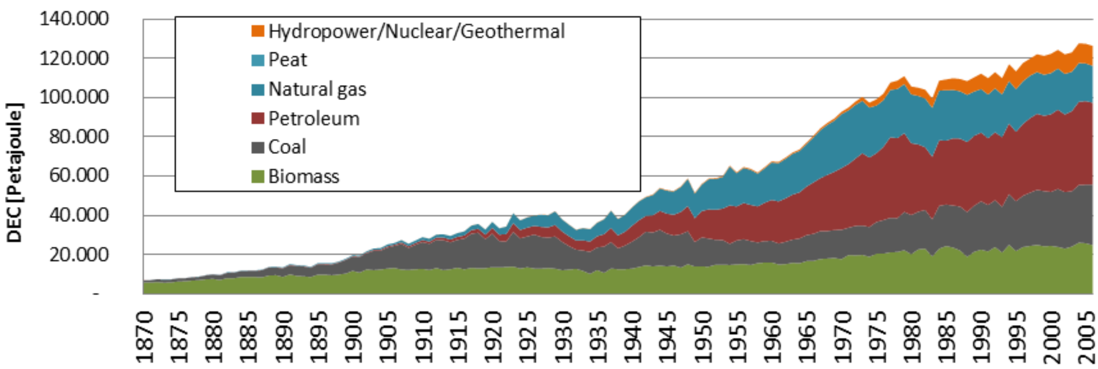
Figure 8 **Domestic energy consumption in Austria, from 1830 - 2000**



Source: Krausmann et al. 2008b

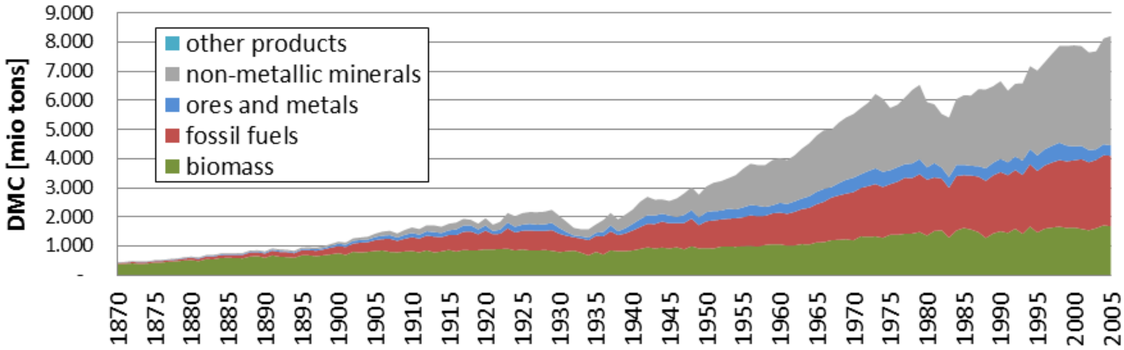
The socio-ecological transition in the USA started to take-off shortly after the civil war (1861-1865), with coal, steam and steel based industrialization and the expansion of the railway system (Gierlinger and Krausmann 2012, Figures 9 and 10). The period between the Great Depression and Roosevelt's "New Deal" in combination with preparations for WW2 marked the beginning of the acceleration phase, which lasted until the oil price shocks in the 1970's. During that period DMC grew by 3.3% annually and DMC per capita more than doubled, from 13t/cap/year in 1932 to 29t/cap/year in 1970. Also during that time per capita DEC increased by a factor of 1.8, from 260 GJ in 1970 to the peak of 484GJ in 1979. After the oil price shocks energy and materials consumption per capita stabilized and even started to decline slightly and the increases of total DMC and DEC since then only scale with population growth (Figures 9 and 10, (Gierlinger and Krausmann 2012).

Figure 9 **Domestic energy consumption in the USA, from 1870 – 2005**



Source: Gierlinger and Krausmann 2012

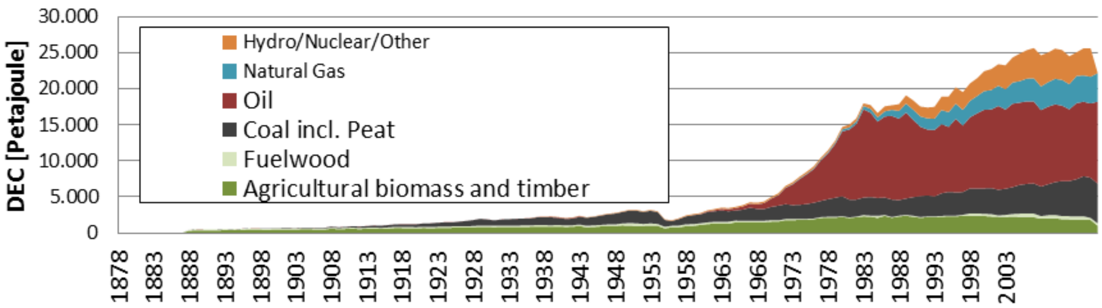
Figure 10 **Domestic material consumption in the USA, from 1870 - 2005**



Source: Gierlinger and Krausmann 2012

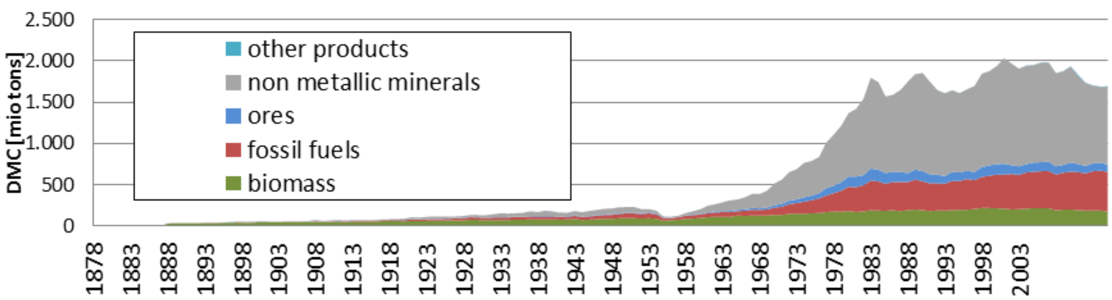
Another very interesting and surprisingly fast case is Japan, one of the few countries where absolute dematerialization has been achieved since the mid 1990's (Krausmann et al. 2011a). Japan never experienced a strong coal-driven expansion of its metabolism, but started the steep acceleration of its metabolism in the oil-age of the 1960s (Figure 11 and 12). In the observed time period from 1878 – 2005 population grew fourfold, material use (DMC) by a factor of 14 and domestic energy consumption by a factor of 50, but most of this increase took place within only a few decades. From the mid-1970's onward fluctuations and then an eventual stabilization and dematerialization set in.

Figure 11 **Domestic energy consumption in Japan, from 1878 - 2006**



Source: Krausmann et al. 2011a

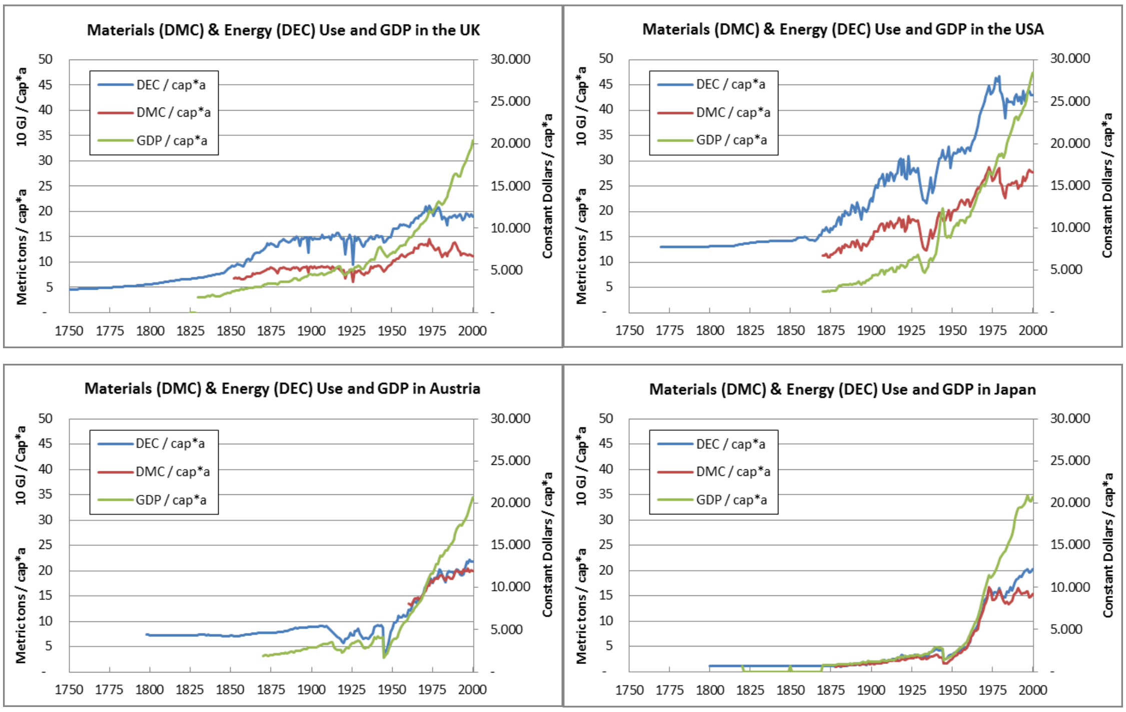
Figure 12 **Domestic material consumption in Japan, from 1878 – 2005**



Source: Krausmann et al. 2011a

The “historical” transition from an agrarian to an industrial regime as exemplified in these case studies has led to a certain metabolic saturation in most high income OECD countries, at very high per capita levels of energy and materials use, or just slow increases due to on-going population growth. Some selected countries like Japan, Germany and the UK even exhibit slightly declining levels of resource use (Gierlinger and Krausmann2012; Krausmann et al., 2011a; Weisz et al. 2006).[17] In chapter 2.5 we will make an attempt to more clearly identify the point in time when this saturation (or even decline) in resource use set in, as a first approximation to understanding its causes.

Figure 13 **Overview: The sociometabolic transition in the UK, USA, Austria and Japan, from 1750 – 2000, in relation to changes in GDP**

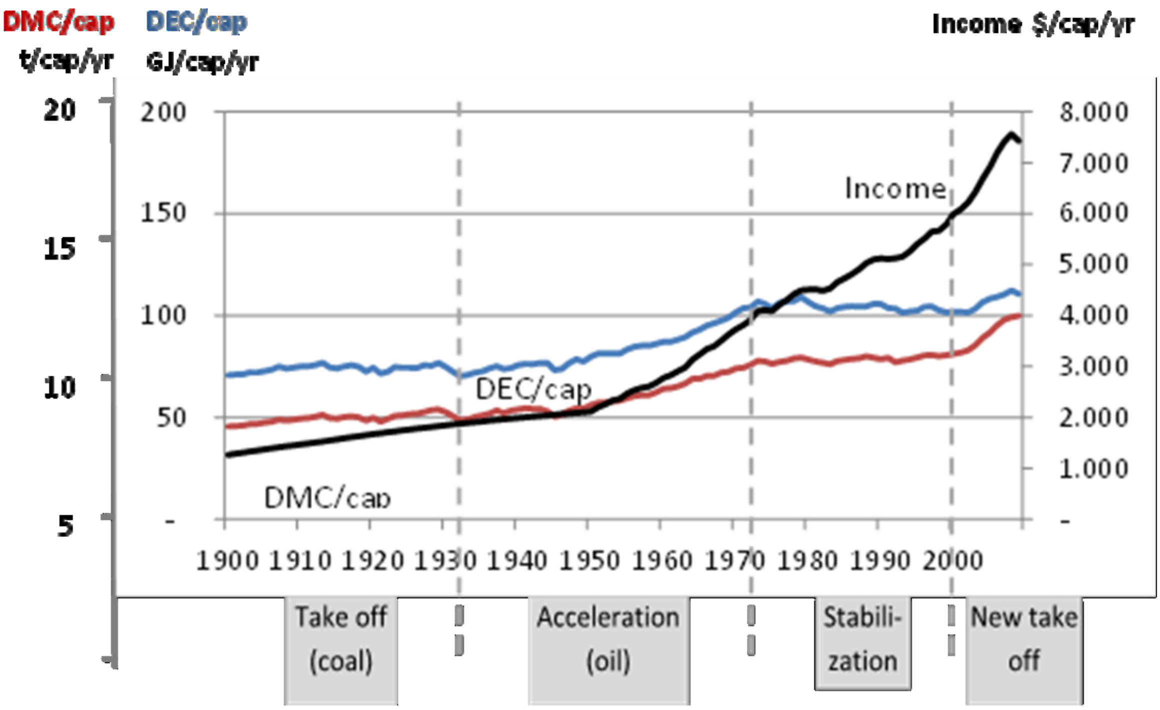


Sources: Krausmann et al. 2008b;; Gierlinger and Krausmann 2012; Krausmann et al. 2011a Pallua 2013 and Maddison 2008 for GDP and population estimates

As demonstrated in Figure 13 on a per capita base (in order to eliminate the population growth effect), in all four case studies of high income countries the apparent saturation in resource use occurs irrespective of a further steep increase in income. From the 1970s onward, there is substantial “decoupling” between income and domestic materials and energy use. As this holds not just for the four case studies for which we have long term data, but for a large majority of high income countries (see chapter 2.4), this per capita saturation of resource consumption even shows on the global level, for the period 1970-2000 (see figure 14).

[17] For the potential role of outsourcing and international trade in allowing for a reduction in domestic resource use per person, see chapter 3.

Figure 14 **Phases of global per capita materials and energy use during the 20th century.**



Source: after Krausmann et al. 2009

While we can identify, for high income industrial countries, a "1970s syndrome" that still holds[18], the global resource consumption from the year 2000 onward is again marked by a steep incline. This incline, as we will show in the next chapter, is due to the rest of the world, in particular large "emerging" economies.

2.4 Ongoing transitions from the agrarian to the industrial regime: the "insurrection of the South" (UNDP)

During the same period, a number of developing countries turn into "emerging economies" and choose the same materially and energetically intensive fossil fuels based pathway as the "old" industrial economies had (see for example the recent report on Asia and the Pacific by UNEP 2011b).

Thus in effect this was not a "historical" socio-ecological transition. Currently, a substantial number of countries comprising more than half of the world's population are following the same transitional pathway at an accelerating pace.

From a global perspective, those countries are of special interest which are either in the acceleration phase of the agrarian-industrial transition or do show clear signs of a take-off into it.

[18] In a next contribution to the WWW project (WP 201), we will analyse the "1970s syndrome" more deeply.

For an illustration, we pick the countries that the economists of Goldman Sachs in their Global Economic Outlooks identified as BRIC and Next-11 countries and attributed them the potential to match or even overtake the G7 economies (USA, Germany, UK, Canada, France, Italy, Japan) in terms of absolute economic activity (GDP) and create an overall impact on the world economy. These countries have been identified based on a “Growth Environment Score”, consisting of 13 sub-indices grouped into indicators covering 1) macroeconomic stability (inflation, government deficit, external debt), 2) macroeconomic conditions (investment rates, openness of the economy), 3) technological capabilities (penetration of PCs, phones, internet), 4) human capital (education, life expectancy) and 5) political conditions (political stability, rule of law, corruption) (O'Neill et al. 2005).

The BRICs are chosen because of their relative share of world GDP making them the largest economies next to the G7 already (especially when PPP standards are used, see (Wilson and Purushothaman 2003). In combination with optimistic prospects for a continuation of their relatively high growth rates, the BRIC countries are expected to overtake the G7 in terms of world GDP shares over the next decades (O'Neill et al. 2005; Wilson and Purushothaman 2003).

The so called Next-11 countries have also been identified as having large economic growth potential, again depending on large populations and labour force dynamics. The Next-11’s contribution to global economic growth is increasing slowly across the whole group (Wilson and Stupnytska 2007). All of the N11 have the capacity to grow at about 4% or more over the next 20 years (ibid. 2007, p. 4) and show potential to rival or even overtake some of the G7 countries until 2050 (ibid. 2007, p. 10).

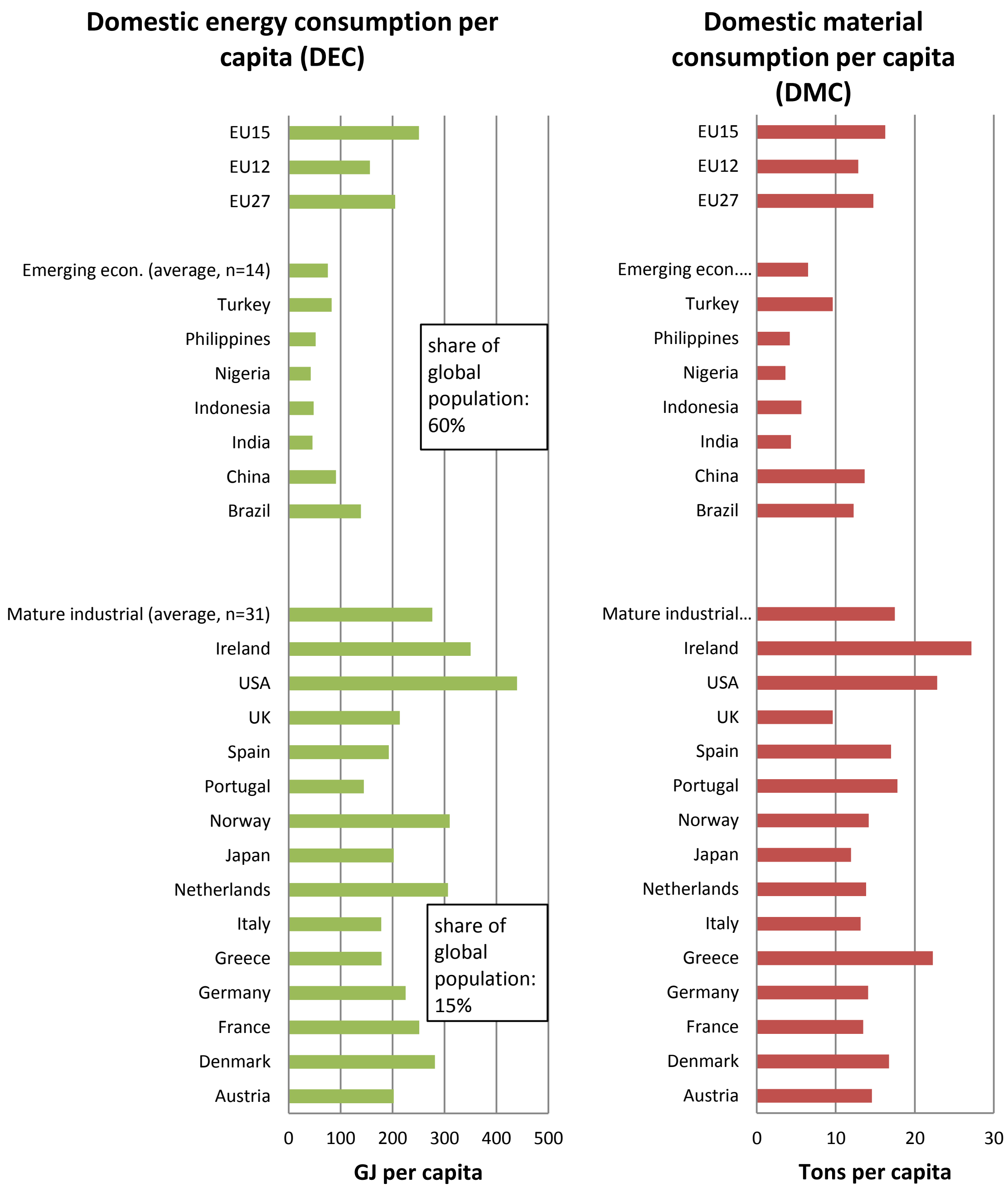
If we accept the Goldman-Sachs classification of economic dynamics and group the BRIC and the Next-11 countries together as “emerging economies”, we can compare their sociometabolic profiles with the mature industrial countries. All countries not covered as mature industrial or emerging economies are for the purpose of this report subsumed as “rest of the world” (RoW).

The group of mature industrial countries as a whole has on average a per capita DEC of 277 GJ and per capita DMC of 17 tons, while for all the emerging economies a per capita DEC of on average 79 GJ and per capita DMC of 7 tons has been calculated (Table 6). According to a sociometabolic regime classification, India, Indonesia, Bangladesh and Nigeria are still very close to the agrarian pattern. India and Indonesia, according to a recent report on Asian and the Pacific countries (UNEP 2011b) display signs of take-off not only in economic, but also in biophysical terms. If all these “emerging economies” (that comprise almost 60% of the world population) adjust their metabolic rates to the pattern of mature industrial economies, it would mean a tripling of their annual per capita energy and material resource consumption. This would imply an unprecedented explosion of anthropogenic global resource use, by far surpassing all impacts demonstrated for the “historical” sociometabolic transition of the already mature industrial countries.

Exactly such a process is already under way, as we will demonstrate in the following section for a few selected cases, namely China, India and Brazil.

China is one of the most interesting cases of an on-going sociometabolic transition, because of its population size and its economic dynamics. During the time period of 1970 - 2005, annual DMC per capita in China increased by a factor of 7, from approximately 2 to 14 tons (UNEP 2011b, 42). In the same period, total DMC grew by a factor of 11 (Figure 15). Domestic energy consumption (DEC) increased per capita by a factor of 3, from 31 to 91 GJ and overall by a factor of 5 (Figure 16). During that time period the share of biomass in DEC decreased from 60% in 1970 to 42% in 2005, on a par with fossil fuels. In the light of these rapid increases in materials and energy use, combined with high economic growth rates observed and projected, it seems plausible that China is currently in the midst of the acceleration phase of its transition from an agrarian to an industrial regime. For the validity of this diagnosis it does not matter that China has become a manufacturing centre for consumers in high income countries rather than at home; the economic take off of many now mature industrial countries in history had at first in a very similar way been achieved by success in exporting rather than by serving the consumption of their domestic populations.

Table 6 **Metabolic profiles of the country groups and selected cases (2005)**



Sources: Data compiled from Krausmann et al. 2009; Steinberger et al. 2010; Krausmann et al. 2011a; Gierlinger and Krausmann 2011; Schandl et al. 2008; Gonzalez-Martinez and Schandl 2008; Maddison 2008; CSIRO 2011; Mayer 2010; Singh et al. 2012

Figure 15 **Domestic material consumption in China, from 1970-2005**

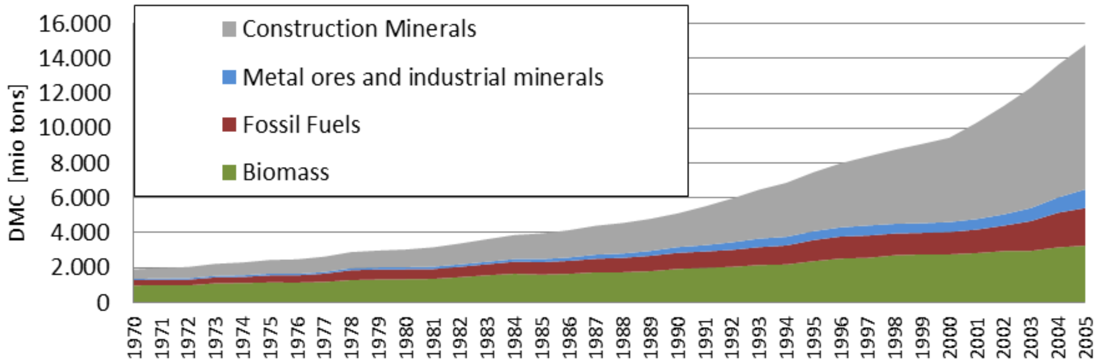
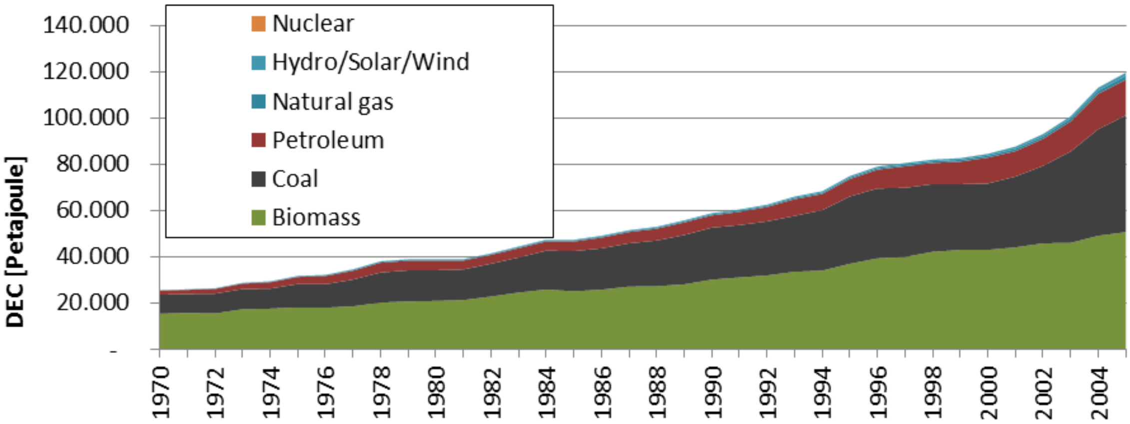


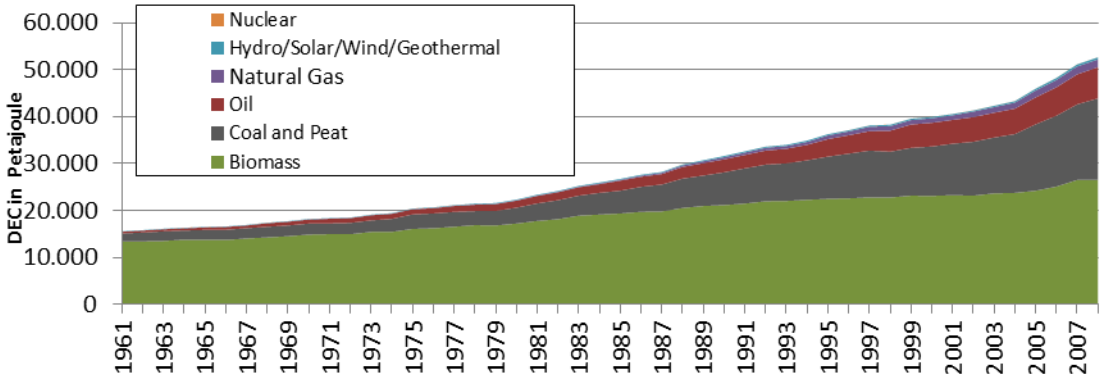
Figure 16 **Total primary energy supply of China, 1970 - 2005**



Sources: own calculations based on CSIRO 2011 and IEA 2010

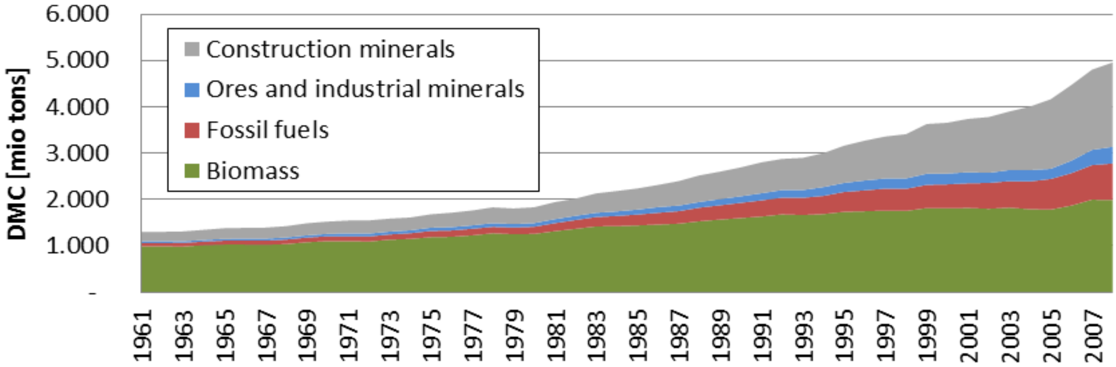
India, as the second most populous country of the world and part of the BRICs group, is also of special interest. Material and energy use in the year 2008 have been estimated at 46GJ and 4 tons per capita (Singh et al. 2012). These per capita values by themselves resemble rather an agrarian regime, but in the light of the dynamics of the Indian economy, they should rather be interpreted as a snapshot from the take-off phase (Singh et al. 2012). Between 1961 and 2008, total DEC has increased by a factor of 3.4. Although the energetic metabolism of India is still dominated by biomass, the share of fossil fuels, especially coal, is increasing rapidly, with coal at 33%, oil at 13%, natural gas at 3%, and biomass at 50% of total DEC in the year 2008 (Figure 18, Singh et al. 2012). Material use increased by a factor of 3.8 (Figure 17). If one imagined that India would complete its transition until 2050, with a metabolic profile resembling Japan which is currently the most efficient economy among the mature industrial countries, this "[…] development alone would lead to an increase of global material use by 30%" (Singh et al. 2012). As India is still in its take-off phase of the sociometabolic transition, it would be highly desirable if it managed to establish a different transition pathway than the resource intensive strategy of industrialization followed by the neighbouring booming Asian-Pacific economies (Schandl and West 2010)

Figure 17 **Domestic Energy Consumption in India, from 1961 - 2008**



Source: own calculations, based on Singh et al. 2012 and IEA 2010

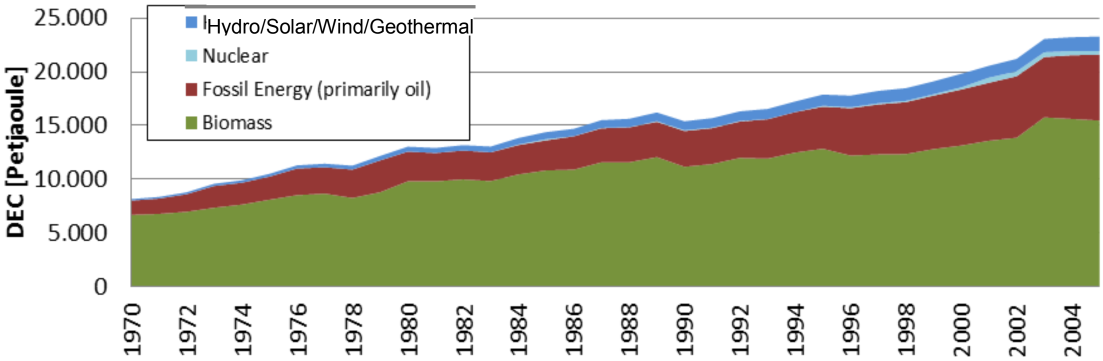
Figure 18 **The sociometabolic transition in India, from 1961 – 2008**



Source: Singh et al. 2012

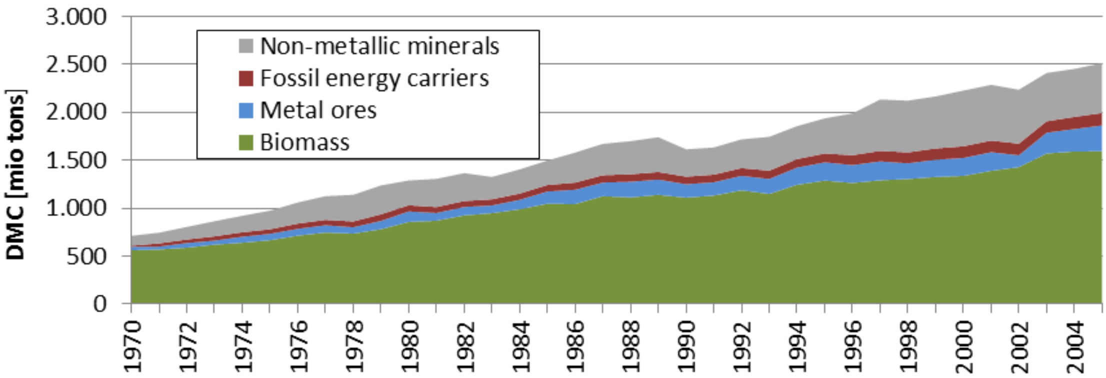
The sociometabolic transition in Brazil follows a slightly mixed pathway of industrialization, with a large share of biomass in the DEC due to high land-availability, which allows for the large scale production of modern biofuels and cash crops dedicated to export (Mayer 2010). Per capita DEC and DMC for the year 2005 have been estimated at 125 GJ and 13.4 tons, respectively. During the observed time period from 1970 - 2005, overall DMC grew by a factor of 3.5, while total DEC increased by a factor of 2.8. The time series of the metabolic profile of Brazil suggests that it is within the acceleration phase of the sociometabolic transition (Figures 19 and 20), but continuing to rely on an untypically high share of biomass.

Figure 19 **Domestic energy consumption in Brazil, from 1970-2005**



Source: Mayer 2010

Figure 20 **Domestic material consumption in Brazil, from 1970-2005**



Source: Mayer 2010

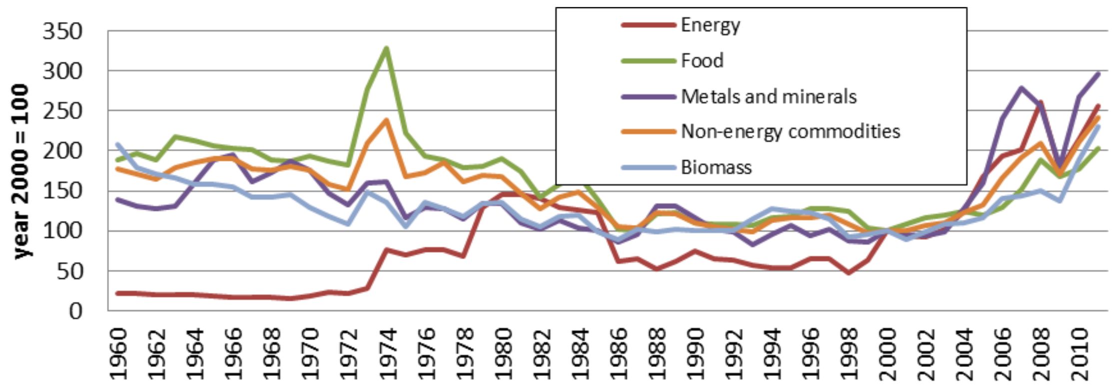
In effect, it is apparent that what economists call "emergent economies", are countries in a take-off or acceleration phase of the sociometabolic transition from the agrarian to the industrial regime, following pretty much the pathway the mature industrial countries had been taking in the centuries and decades before, based on the use of fossil fuels (increasingly again: of coal). Due to their much larger populations, the ecological impact of their transitions, in terms of climate, biodiversity, soils, air and water pollution, depletion of fish stocks in the oceans, nutrient washout into the oceans will be huge, much larger than the impact of the historical transitions of the mature industrial countries. From the point of view of resource scarcity, though, it remains questionable whether this process will indeed take place, or whether it will be suffocated in the middle of its acceleration.

2.5 Preliminary conclusions from global non-linear development dynamics for future European biophysical constraints

Chapter 2 demonstrated, with quite some long-term empirical detail, that the biophysical base of the European economies is and – more so – will be undergoing major transformations. The long-term perspective is useful because it shows that these transformations, beyond the crisis that currently draws so much attention, play on an unprecedented historical scale.

The sociometabolic transitions on-going in emerging economies in combination with relatively stable but quite high levels of resource consumption in the mature industrial countries reflect themselves as increasing pressure on the world's resources, leading to "the most extended and steepest boom of commodity prices ever" (World Bank 2009). With a short interruption by the economic crisis 2007/08, commodity prices keep rising since the beginning of the 21st century (Figure 21). This is of major importance, as the past sociometabolic transitions of the mature industrial countries have all happened in a global context of easily available fossil fuels and plenty of commodity frontiers for further exploitation (Bunker and Ciccantelli 2005; Bunker 2003). But this global context has changed and will be quite different in the future.

Figure 21 **Global commodity prices in constant prices, year 2000 $**



Source: WorldBank (2009)

The German WBGU's flagship report "World in Transition" came to similar conclusions: "The idea that all people should be able to enjoy a lifestyle that equals today's predominant lifestyle in the industrialised countries, characterised by the use of fossil energy carriers, cannot be realised. To avoid non-sustainable development paths, the developing and newly industrialising countries would have to leapfrog technological development stages. The industrial countries should therefore lead the way off current development paths to demonstrate that it is also possible to follow sustainable paths. A lifestyle must be found that is consistent with the guiding principle of global sustainable development. It must also allow the catch-up development of poorer countries, equally guided by the criteria of global sustainability, and allow for inclusion of the so far excluded 'bottom billion'." (WBGU 2011, p. 62).

This fundamentally changed global context and the need for systemic changes in policy and institutional settings have also been acknowledged by several other major institutions regularly reporting on the state of the world and the world-economy.

UNEP, for example, states in its recent report on the green economy: "Indeed, most economic development and growth strategies encouraged rapid accumulation of physical, financial and human capital, but at the expense of excessive depletion and degradation of natural capital, which includes our endowment of natural resources and ecosystems. By depleting the world's stock of natural wealth – often irreversibly – this pattern of development and growth has had detrimental impact on the well-being of current generations and presents tremendous risks and challenges for future generations. The recent multiple crises are symptomatic of this pattern." (UNEP 2011c, p. 1).

The US National Intelligence Council which conducts regular strategic risk studies, also recognizes these issues, and states that „With the emergence of rapid globalization, the risks to the international system have grown to the extent that formerly localized threats are no longer locally containable but are now potentially dangerous to global security and stability. At the beginning of the century, […] a new generation of global challenges including climate change, energy security, food and water scarcity, international migration flows, and new technologies – are increasingly taking centre stage" (NIC and EUISS 2010, p. 4). They also explicitly recognize the fundamental challenges posed by increasing global demand for resources and fossil fuels and the importance of security of supply (NIC 2008, p. 41-57). "Unprecedented global economic growth – positive in so many other regards – will continue to put pressure on a number of highly strategic resources, including energy, food, and water, and demand is projected to outstrip easily available supplies over the next decade or so. For example, non-OPEC liquid hydrocarbon production […] will not grow commensurate with demand. Oil and gas production of many traditional energy producers already is declining. Elsewhere – in China, India and Mexico – production has flattened. Countries capable of significantly expanding production will dwindle; oil and gas production will be concentrated in unstable areas. As a result of this and other factors, the world will be in the midst of a fundamental energy transition away from oil toward natural gas, coal and other alternatives (NIC 2008 p vii). "[…] an energy transition, for example is inevitable: the only questions are when and how abruptly or smoothly such a transition occurs. An energy transition from one type of fuel (fossil fuels) to another (alternative) is an event that historically has only happened once a century at most with momentous consequences." (NIC 2008, p. xii)

The two most important changes that are on-going refer to the increasing international competition for resources, with large countries like China and – less visibly, because somewhat delayed, but no less relevant – India catching up and so far emulating the Western fossil fuels based resource intensive pathway, and an unprecedented rise in the price of natural resources. Both changes will create a context for European economic development that contrasts strongly with the 20th century context of Western dominance and a gradual decline in resource prices.

These structural changes, in many scenario exercises and projections, tend to be disregarded. In terms of available natural resources, Europe faces a future more uncertain than often recognized.

3. Towards resource use scenarios for Europe

3.1 UNEP's global resource use scenarios

UNEP's International Resource Panel published a report in 2011 assessing the potential of decoupling resource use and environmental impacts from economic growth. On a global level, this report presents a similar picture of the dynamics of resource use during the 20th century as we have been showing in the earlier chapters. The main conclusion provided was that although a decoupling between resource use and GDP could be observed, this did not prevent global annual resource extraction from skyrocketing (materials: an eightfold increase, energy a tenfold increase in the course of this one century). A more detailed analysis by groups of countries according to their development status revealed that it was the increasing per capita resource use that mainly had been driving the rising resource consumption of high income countries while it was rather population growth that had been driving resource use of developing countries. In the last two decades though a substantial catch-up of developing countries in terms of per-capita consumption took place – a convergence process of sociometabolic patterns towards the level of high income industrial countries. This triggered a new acceleration in annual global resource extraction that would, if convergence to this level continued (a continuation of observed trends), imply a tripling of global annual extraction of material resources, with the severest environmental consequences. They find that this scenario "probably represents an unsustainable future in terms of both resource use and emissions, exceeding all measures of available resources and assessments of limits to the capacity to absorb impacts." (UNEP 2011a, p. 29). On the other hand, a global convergence of sociometabolic rates is considered welcome from the standpoint of international equity. The scenarios constructed are supposed to respond to this dilemma: achieve global equity while not transgressing environmental boundaries.

The scenario calculations were based on an analysis of past sociometabolic data in which, besides income, population density proved to be very relevant for a country's metabolic rate, independent of economic development: the higher the population density, the lower the metabolic rate at the same level of income. In each scenario, this difference by population density was also maintained for the future, while population dynamics was drawn from UN-estimates (medium variant). For the process of convergence of developing with industrial countries it was also assumed that the composition of material resources used would emulate the current industrial pattern, i.e. a transition from biomass-based to fossil fuel based energy sources, and a substantial rise of the amount and share of metals and minerals would occur.

The three scenarios are:

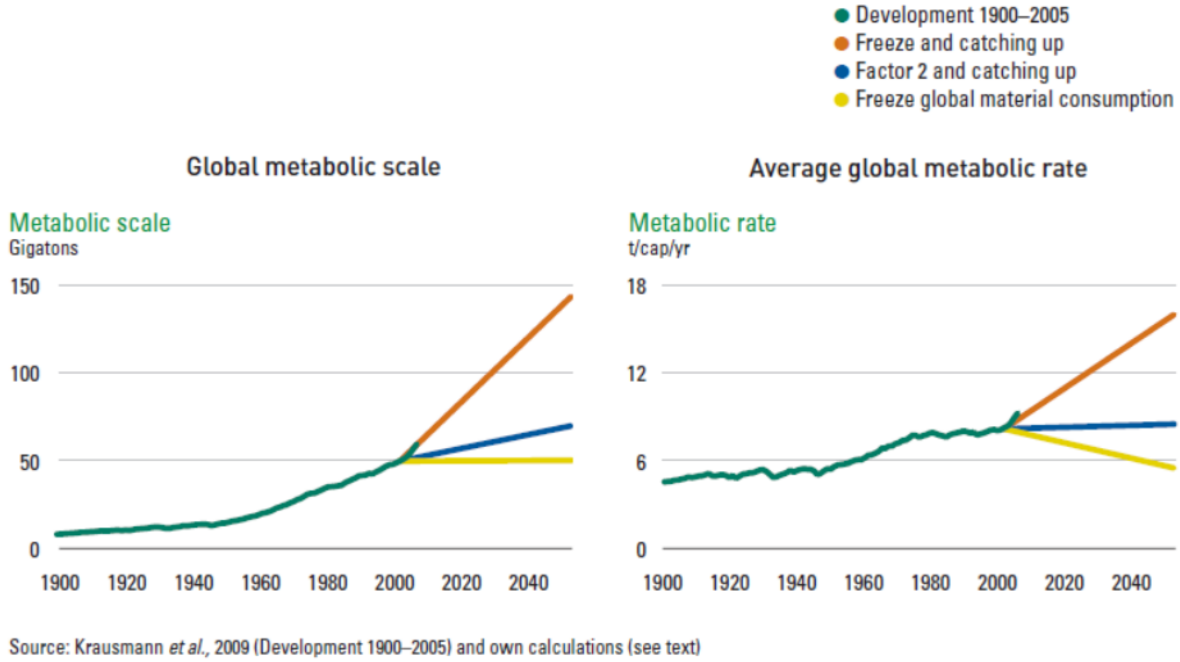
1. The **trend scenario**, assuming high income industrial countries to maintain their per capita resource consumption, and developing countries to increase their consumption rates to the same level until 2050. This would lead to a tripling of global annual resource extraction by 2050 at a world average metabolic rate of 16t/cap*year (13t for high density, 24t for low density countries);

2. **moderate contraction and convergence**, in which high income industrial countries halve their per capita resource consumption by 2050, and developing countries increase their metabolic rates to the same level. This would lead to a 40% increase in global annual resource extraction by 2050, and a world average metabolic rate of 8t/capita and year, differentiated into high density countries (6.5t/cap*year) and low density countries (12t/cap*year);

3. **tough contraction and convergence**, in which total global resource consumption is maintained at the year 2000 level, and all countries converge to the same per capita resource consumption. This by definition would keep global annual resource extraction at its current levels, but allow for an average metabolic rate of no more than 5,5 tons/capita and year.

On the basis of these assumptions the scenarios were calculated as presented in Figure 22.

Figure 22 **Resource use according to three different scenarios as developed and calculated by UNEP's international resource panel up to 2050**



Source: UNEP 2011a, p. 30

It was concluded that a continuation along the pathway of the *trend scenario*, even as this scenario assumed no further increase in material use on the part of the mature industrial countries beyond the level of the year 2000, was not only fairly catastrophical (annual per capita carbon emissions, for example, would be expected to triple and total carbon emissions to quadruple by the year 2050 – this is more than the highest scenarios in the IPPC estimates, (Nakicenovic and Swart 2000), but also unrealistic in terms of global availability of resources. Nevertheless, until the crisis in 2008 the world stayed on this pathway.

In the *moderate contraction and convergence* scenario the industrial countries commit to an absolute reduction of resource use by a factor of 2, while developing countries would moderately increase their metabolic rates and catch up to these reduced industrial rates by 2050. This scenario presupposes substantial structural change. For the industrial countries, achieving a factor 2 reduction would imply resource productivity gains just triggered by resource use reductions of about 2% annually (which is within the range of the productivity gains of the past decades), net of any income-based rebound effects (Greening et al. 2000).

The *tough scenario of contraction and convergence* mainly illustrates how far one needs to go if humanity's burden upon the environment should not exceed present (already high, and in some ways too high) levels. As a policy goal such tough constraints hardly would be accepted.

These scenarios are useful as they are based upon indicators that deliver fairly comprehensive information on resources required and used by economies. They also illustrate that European resource use levels play a double role: as relevant share in global resource consumption, and as a model for the developing world to emulate. In the longer run, this is also self-defeating: it nourishes competition over the world's limited resource base and speeds up its depletion.

3.2 Resource use scenarios for Europe

Our efforts now are directed at constructing resource use scenarios for Europe that comply with the spirit of UNEP's global scenarios. The European countries are only part of the "high income industrial countries" figuring in UNEP's scenarios, and they are distinct both in current metabolic rates and in population density (particularly from other large parts such as the US, Canada and Australia). On the other hand, there is a certain internal heterogeneity that needs to be taken account of in order to achieve sufficiently analogous results.

For the development of European resource use scenarios we can build on the global scenario assumptions in two ways:

a) the observation that high income countries have experienced a saturation of their domestic material consumption over the last decades (see chapter 2 of this report) and

b) the observation that this saturation takes place at much higher levels for countries with low population density than for high density countries.

Since European countries, except for some of the new member states, are high income industrial countries by UNEP's definition, we need to review the empirical data if both the saturation and population density hypotheses formulated at the global level hold true for Europe as well. Such an empirical analysis of past material use patterns in Europe would provide us with a sound background for developing and calculating scenarios (chapter 3.2.1)

We will then proceed in analogy to UNEP's scenarios and develop a trend or business as usual scenario, a scenario of freezing the present levels of material use and one transformation scenario corresponding to the above scenario 2 of moderate contraction and convergence. We add a best practice scenario which uses the strongest resource use reductions of some countries as a general tendency for all EU 27 countries. Chapter 3.2 will describe these scenarios and their assumptions. Chapter 3.3 will discuss the scenario results.

We will present our resource scenarios for the EU 27 on the aggregate level since this is the level of analysis the macroeconomic model will use. Furthermore in constructing resource use scenarios we are challenged with a transition away from fossil fuels. What we know is that there exist manifold and strong interlinkages between energy and materials. At the same time due to the fundamental structural change future developments cannot be deducted from past observations. Thus insights based on internal consistency of the past might only be partially useful since shifting energy sources might change resource use patterns - especially the proportion of the various material categories. We trust that the sum total as aggregate is the best indicator to capture various substitution effects as they might happen in such a transition.

In some analytical steps we include Norway and Switzerland into our analysis since the domestic material consumption of these countries is closely interlinked with EU 27 and they can provide a broader basis when discussing country clusters.

3.2.1 Income and resource use patterns in Europe over the last decades

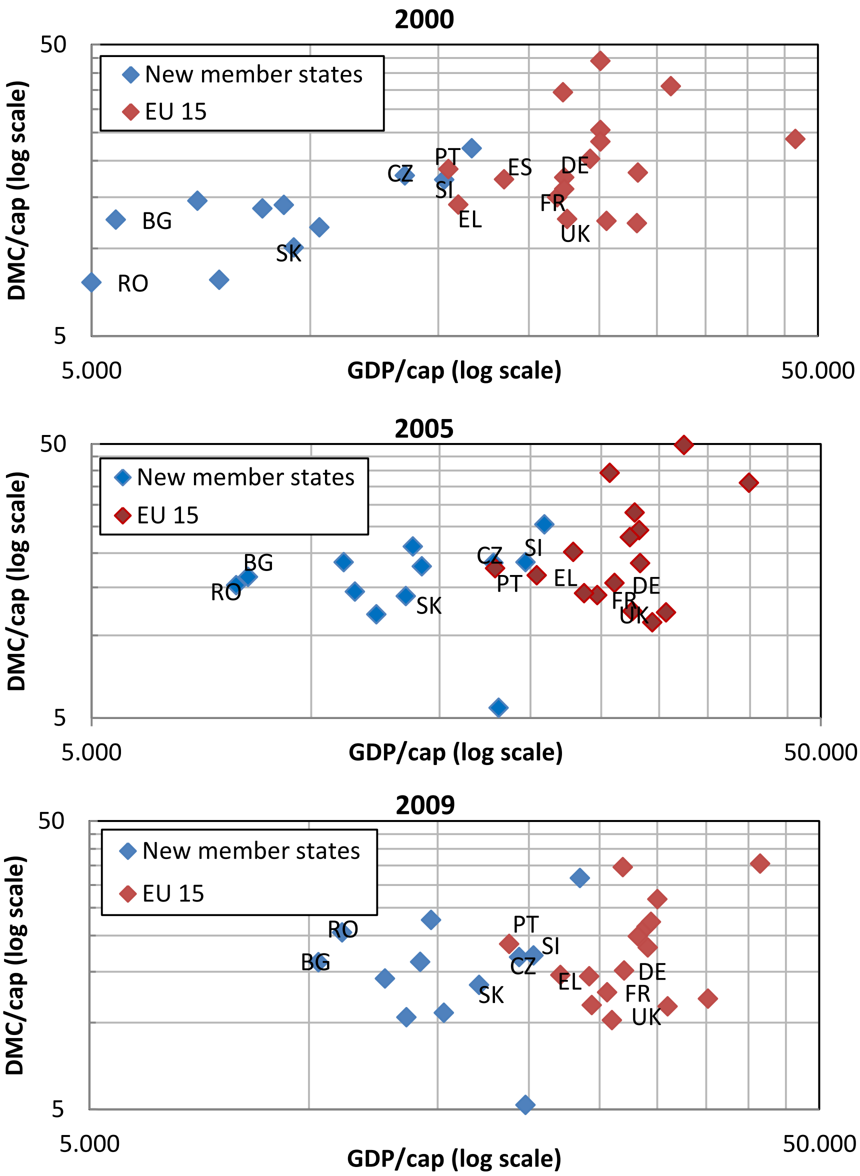
For the discussion of resource use patterns the official Eurostat data are the first choice. This online database offers data on domestic material extraction (DE), on imports and exports (both intra and extra EU trade) and on the domestic material consumption (DMC) from the year 2000 onward for each of the EU 27 countries and for the EU 27 as an aggregate. We will rely on these data for analysing the clustering of countries and for discussing the different levels of resource consumption in dependency from population density.

For analysing longer term patterns we need to refer to a second source: Weisz et al. (2005) presents the indicators direct material input (DMI), domestic material consumption (DMC) and physical trade balance (PTB) for EU 15 countries (but not for the new member states) for the period 1970 to 2000 and analysed their trends and patterns in relation to population and GDP. This data set was later extended up to 2004 (Krausmann et al. 2011b). A comparison of these data with the Eurostat source reveals differences: Eurostat data are always about 5% higher than the data from the SEC data base. For discussing the longer term trend of material consumption in the EU15 countries this difference can be neglected..

In terms of the classification UNEP is using, EU27 countries are heterogeneous: there are major differences both in income and in population density. While all of EU15 may be considered as high income countries, the 12 New Member States have substantially lower income, and also display patterns of resource use more closely related to what UNEP classifies as “developing” (see also the analysis of Moll et al. (2012)). In the time period documented by data (i.e. between the year 2000 and the year 2009) the new member states, can be characterized by a small rise in income, but a strong rise in their metabolic rates, even beyond the level of EU15 (see Figures 23 and 24). We assume the increasing metabolic rates to be a temporary phenomenon due to enhanced investments in infrastructure in the course of the accession process. This kind of temporary overshoot may happen also in emerging economies. In our scenario calculations we will therefore deal with them in analogue to the treatment of developing countries in the UNEP scenarios: we will assume a gradual convergence with EU15 (see also Rapacki and Próchniak (2009).

In Figure 23 we present GDP and DMC data from Eurostat (2013a) for EU 15 plus Norway and Switzerland (the latter as countries associated with the EU) and the new member states for the years 2000, 2005 and 2009.

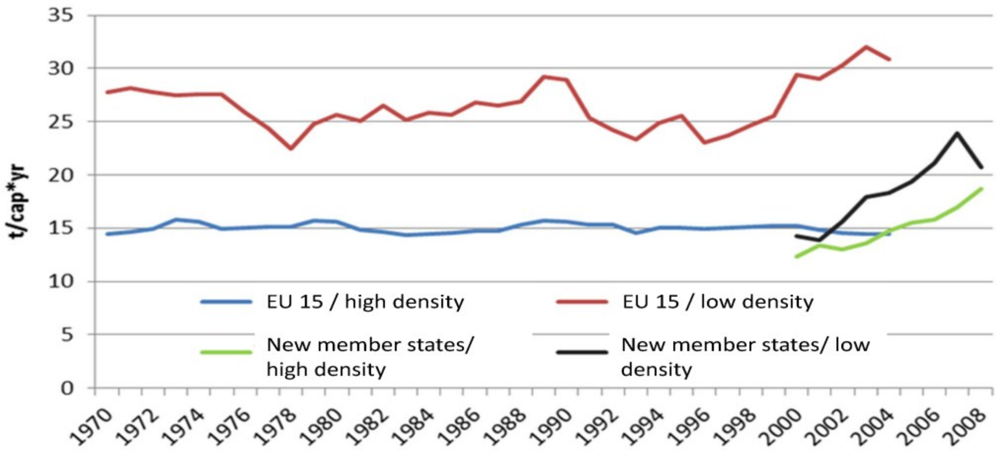
Figure 23 **Resource use and income in Europe, 2000, 2005, 2009 (DMC/cap, GDP/cap)**



Source: Eurostat 2013a

Figure 24 shows the average per capita material consumption for EU15 countries with low and high population density as well as for new member states with low and high population density. The DMC/capita of EU15 high density countries has remained at about 15t/cap for the last three decades. EU15 countries with low population density have as well by and large a stable DMC/cap. Since this is a very small number of countries (see Table 7), the line is not as smooth as for the high density countries. In contrast to the more or less stabilized per capita DMC of EU15 countries, the new member states are characterized by a high growth rate in per capita DMC. This applies for both low and high density countries; the low density countries as expected have a higher per capita DMC than the high density countries.

Figure 24 **DMC per capita for EU15 and new member states by density class**



Sources: for EU15 based on Weisz et al. 2005, Krausmann et al. 2011b; for new member states Eurostat 2013a

Table 7 summarizes the structural differences within EU27 we have to take care of in our scenario exercise. We create 4 country clusters for each of which we can make distinct assumptions in line with the UNEP scenarios on the global level.

Table 7 **Cross-classification of EU27 by income level and population density associated with different metabolic growth patterns**

	Population density	
	Low density (< 50 inhabitants per km^2)	**High density** (> 50 inhabitants per km^2)
EU 15	Stable at 22-32 t/cap (period 1970-2004) NO, FI, SE	Stable at 15 t/cap (period 1970-2004) AT, BE, GE, FR, UK, IE, NL, DK, LU, EL, IT, ES, PT
New member states	Growing from 14 to 21 t/cap (period 2000-2008) LT, EE	Growing from 12 to 18 t/cap (period 2000-2008) BG, CZ, CY, LV, HU, MT, PL, RO, SI, SK

Sources: own calculations, based on Weisz et al. 2005, Krausmann et al. 2011b and Eurostat 2013a

3.2.2 Constructing European Resource Use Scenarios

The baseline for our scenario calculations is the material consumption as provided by Eurostat for the year 2005. We did not use the year 2000 as our base year (as with UNEP 2011a), as in this year data on the new member states are available for the first time. The year 2005 is the latest available year with sufficiently reliable data for both groups of countries (data for this year have already been used and cross-checked for several purposes). We did not choose a later year as they soon are marked by the financial crises that induced a downward turn in resource use dynamics that up to date is difficult to assess. It could be a once-off effect that will be (over)compensated in the following years, or it could reduce material consumption for the EU27 in the long run.

Given this context we develop four scenarios:

Trend scenario

European high income countries maintain their per capita material consumption. Low density transitional economies converge with the level of EU15 low density countries. High density transitional economies still grow for a short period and then they reduce their per capita consumption to the level of EU15 high density countries.

Rationale and assumptions

EU15 countries have already stabilised their domestic material consumption as shown in Figure 24. In the trend scenario they just continue with their 2005 per capita consumption. For transitional economies, Rapacki and Próchniak (2009) investigate the economic convergence with EU-15 by econometric tests and convergence analysis. According to their projections, the process of real convergence between individual CEE-10 economies and the EU-15 may take between 8 and 33 years. We assumed that the material consumption follows the economic alignment. This means that new member states with low density catch up in terms of per capita material consumption by the time the GDP according to Rapacki and Próchniak (2009) has aligned with high income low density countries. Similarly we assumed that new member states with high population density will match EU15 high density countries according to the timeframe provided by Rapacki and Próchniak (2009). Since some of the high density new member states had already higher DMC/cap values than the EU15 high density countries, we assumed a slowing down of the growth phase till it reaches a plateau after a third of the time till full economic convergence and then shrinks to the level of EU15 high density countries. This can be justified by the necessary modernisation processes of infrastructure and industries. In the DMC of these countries it can be seen in the increased material use in construction minerals (see Figure 32 below). As soon as this one-time catching-up process of investments is concluded the material consumption can shrink to the level of EU 15.

To calculate the total material consumption we multiplied the DMC/cap values with the UNPD's population forecast (medium fertility variant, UNPD 2011).

Freezing scenario

All EU 27 countries freeze their per capita domestic material consumption at the level of the year 2005.

Rationale and assumptions

This scenario is supposed to serve as a reference for the other scenarios. It is analogous to the “high income” component in UNEP’s trend scenario[19]. The calculation just prolongs each country’s DMC/cap from 2005 till 2050. To calculate the total material consumption we multiplied the DMC/cap values with the UNPD’s population forecast (medium fertility variant, UNPD 2011).

Best practice scenario

We assume the domestic material consumption per capita to decrease in all EU 27 countries as in the countries with the strongest observed decline since 1970. The feasibility of this scenario is justified by best practice of Germany, UK and France which developed their economies while reducing their per capita material consumption at the same time.

Rationale and assumptions

Germany, UK and France as the biggest economies in Europe experienced a decrease of their joint per capita domestic material consumption of about 28% over the period from 1970 to 2004. This decrease was then applied to the baseline values of all EU 27 countries as an annual percentage for the period 2006 to 2050. The assumption is that all European countries can emulate these large economies with respect to shrinking material demands, while these forerunners continue on their declining pathway.

Radical transformation scenario

The EU 27 halves its per capita domestic material consumption until 2050. This is done by a simple geometric function applied to per capita material consumption rates of EU27 as a whole.

Rationale and assumptions

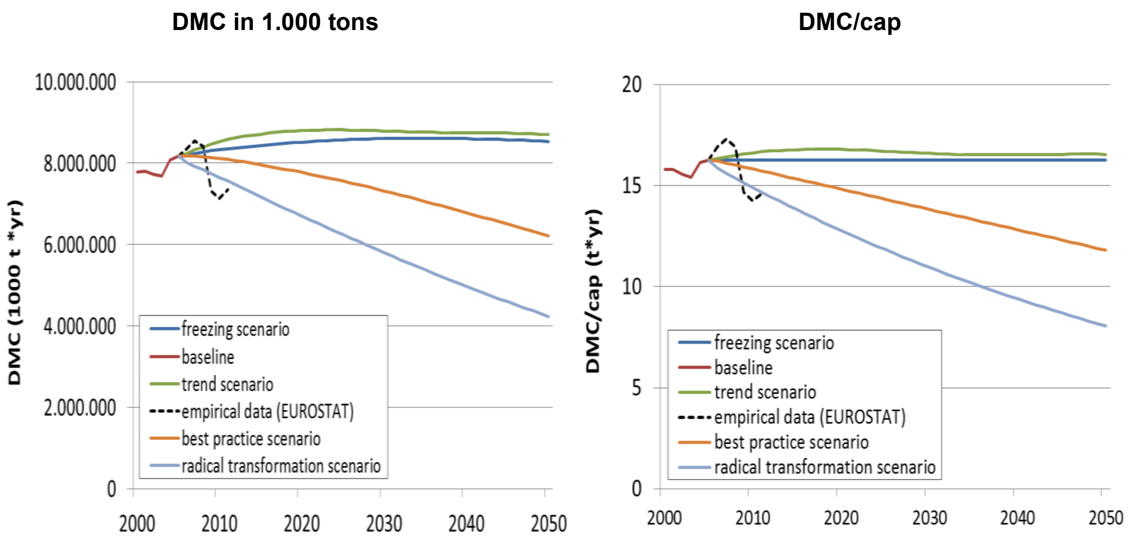
This is a simple application of the “contraction” rule used in the UNEP moderate contraction and convergence scenario above, asking high income industrial countries to halve their metabolic rates (while the rest of the world catches up to these rates). One could of course also apply a linear function. In its “roadmap to a resource efficient Europe”, as we discuss in more detail below, the European Commission adopted such a strategy as one of a number of variants.

[19] UNEP uses the year 2000 as a reference year. Thus our scenario uses a slightly higher base level.

3.3 Discussion of scenario results

In none of the scenarios, Europe's material consumption will grow significantly. The trend scenario shows only slight increases above the freezing of per capita consumption. The best practice scenario provides a moderate change and achieves a reduction from 16 t/cap to 12 t/cap on average. The radical transformation scenario according to its assumptions halves the per capita material consumption and results in those 8t/cap*year figuring in UNEP's "scenario 2: Moderate contraction and convergence" as shared world average (UNEP 2011a, p.31) (low density 12 t/cap and high density 6,5 t/cap).

Figure 25 **Material consumption of EU 27 according to four resource use scenarios**

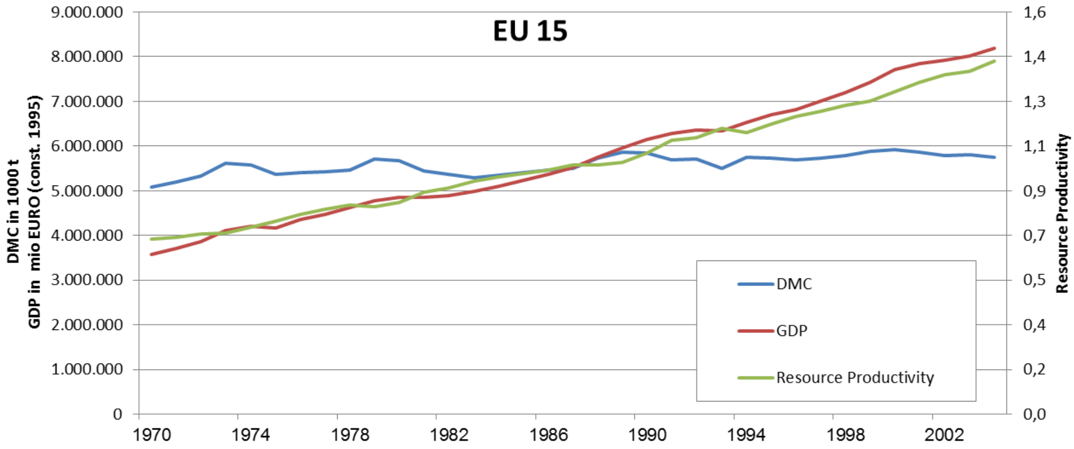


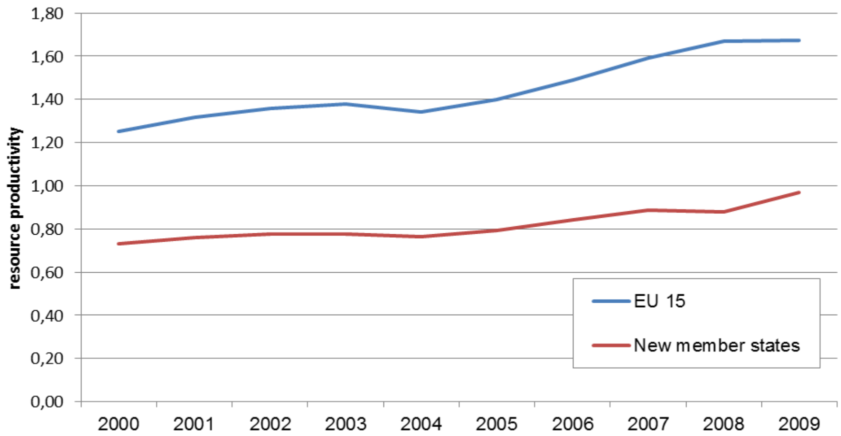
Source: Eurostat 2013a, b (empirical data[20]), own calculation (scenarios)

Apparently, there is hardly any difference between the trend scenario and the "freezing" scenario: In both cases, a metabolic rate of about 16t/cap*year is maintained. These scenarios build on chapter 2 of this report that demonstrates a stagnation of European resource use. Thus it appears that achieving these scenarios would not require particular policy efforts. Basically, they result from an on-going continuous increase in resource productivity in line with the rate of economic growth (see Figure 26). Further down we will refer to a pioneering study that delved into this more deeply (Steinberger et al. 2013). Without a more sophisticated analysis, in the face of stagnating resource use, the statement that resource productivity follows GDP is no more than a tautology.

[20] No data are available for Norway for the period 2009-2011 and for Switzerland for 2011

Figure 26 **Material resource productivity (GDP/DMC) for EU15 and the new member states**



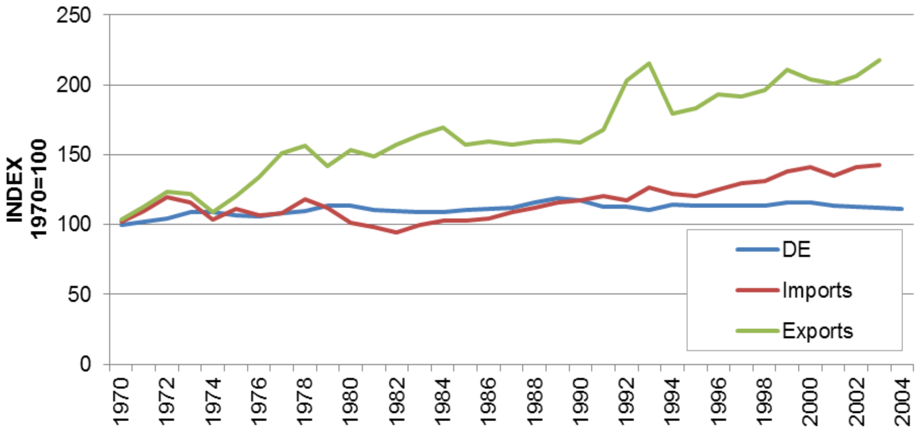


Sources: Weisz et al. 2005 (1970-2004), Eurostat 2013a (2000-2009)

It is important to check, though, whether stagnating resource use in Europe is mainly a result of outsourcing material and energy intensive production processes into other countries and feeding rising domestic consumption by imports. E.g. Ghertner and Fripp (2007) provide evidence that the USA has traded away environmental damage in terms of global warming potential (GWP), energy, toxics and air pollutants for the USA for the period 1998 to 2004. Studies like this one triggered a large number of studies dealing more specifically with material and energy issues related to trade. The findings suggest that the so-called “raw material equivalents” (RME) of imported goods (that is, the material use triggered in the countries of origin on top of the weight of the traded commodity itself) are about twice as high as the imports themselves. Thus by importing a country saves on domestic material (and energy) flows. A recent study concludes that the difference between (direct) domestic material consumption and an indicator including embodied material flows can be as much as 195% as this is the case for The Netherlands. UK shows in this study a difference of 55%, France 49% and Germany 34% (Bruckner et al. 2012). Recently, various approaches including the one used by Bruckner et al.

(2012) to account for embodied material flows were compared for the case of Austria (Schaffartzik et al. 2013). The differences in raw material consumption (RMC) of the various studies were identified as significant and range from an RMC of 21 to 30 tons/cap for Austria for the year 2007[21]. Against this background results like the one from Bruckner et al. (2012) need to be dealt with cautiously as long as the differences amongst the various studies are not fully understood. However, on the aggregate level we are quite confident that outsourcing effects only play a minor role. This we justify on the basis of time series on domestic material consumption and the physical trade balance. The aggregate level of EU15 (Figure 27) shows, that most of the dynamics in trade referred to extra-EU exports: these exports were growing considerably since 1970, while imports showed just a slight incline.

Figure 27 **EU 15 domestic material extraction and extra EU trade (Imports, Exports). Index: 1970 = 100, from 1970 to 2004**



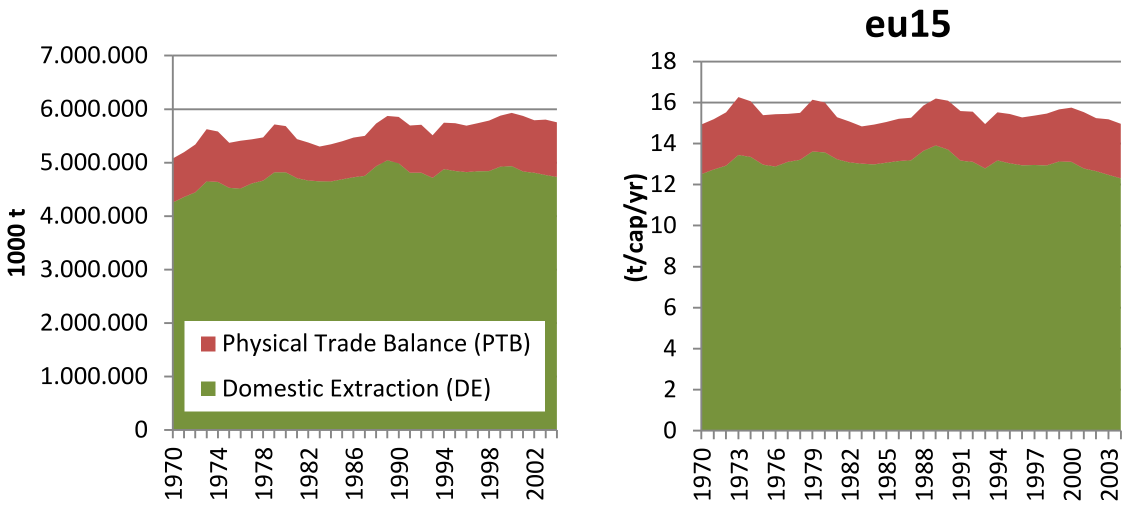
Source: Weisz et al. 2005, Krausmann et al. 2011b

Figure 28 indicates that in both absolute and per capita terms the physical trade balance[22] has hardly changed.

[21] As a comparison: Austria's DMC was 25 tons/cap in 2007

[22] Domestic material imports minus domestic material exports

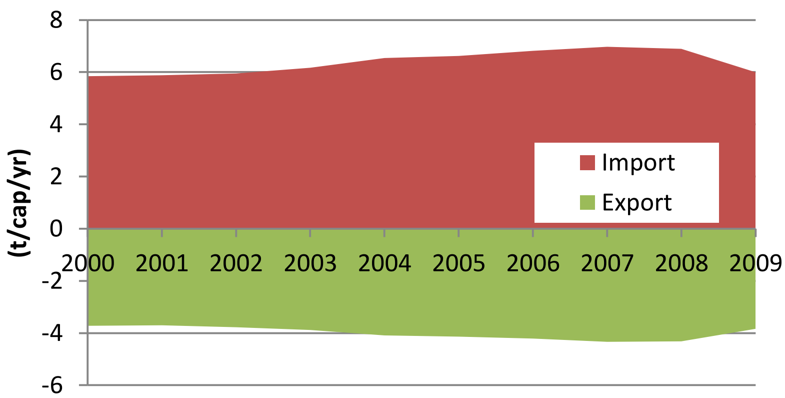
Figure 28 **EU15 domestic material extraction plus physical trade balance (= domestic material consumption), from 1970 to 2004; left side in absolute numbers, right side in per capita values**



Source: Weisz et al. 2005, Krausmann et al. 2011b

Expanding this view to the EU27 for the years 2000 to 2009 shows that up to 2008 slow growth processes for both imports and exports. The year 2009 presents a decline for imports and exports at the same time reducing the physical trade balance from 2,5 to 2,1 tons/cap and year.

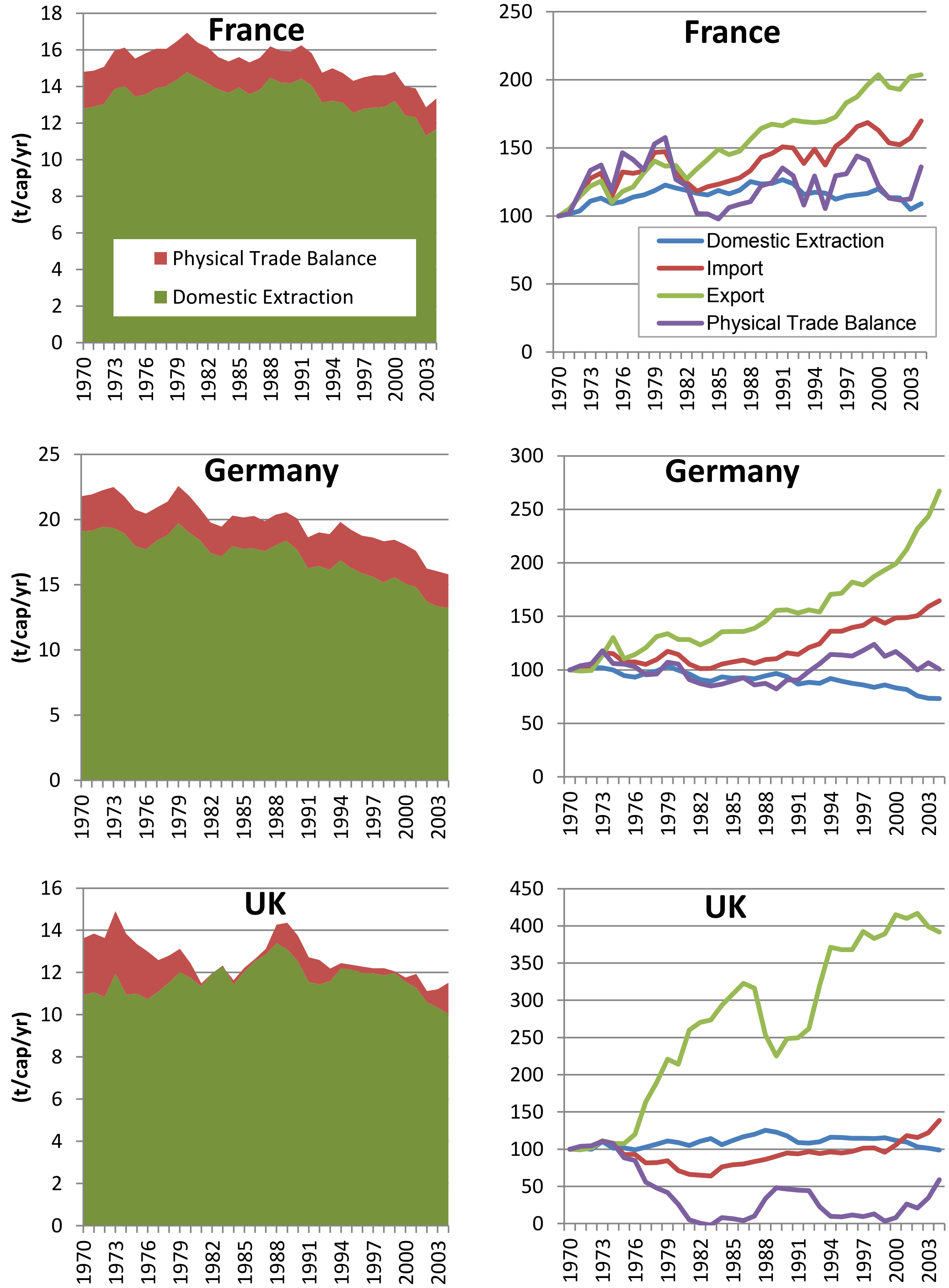
Figure 29 **EU27 material imports and exports, from 2000 to 2009**



Source: Eurostat 2013a

A closer look at the three most significant countries of EU27 shows quite similar pictures. Exports grow the fastest in all three countries. In France and Germany there are very small changes in the physical trade balance over time. In the case of UK the figures show high volatility that can't be interpreted as a process of outsourcing over time.

Figure 30 **Domestic material extraction plus physical trade balance of France, Germany and UK (= domestic material consumption), from 1970 to 2004**



Source: Weisz et al. 2005, Krausmann et al. 2011b

From these data, we cannot conclude that in Europe there may have been a substantial rise in domestic material consumption, just concealed by it being increasingly covered by imports. Thus we end up with a diagnosis of material saturation in Europe that may be expected to continue without major policy efforts or structural breaks.

But, as explained in chapter 3.1 above, from an international equity and environmental point of view, freezing European material consumption is not enough: European resource use needs to be substantially reduced.

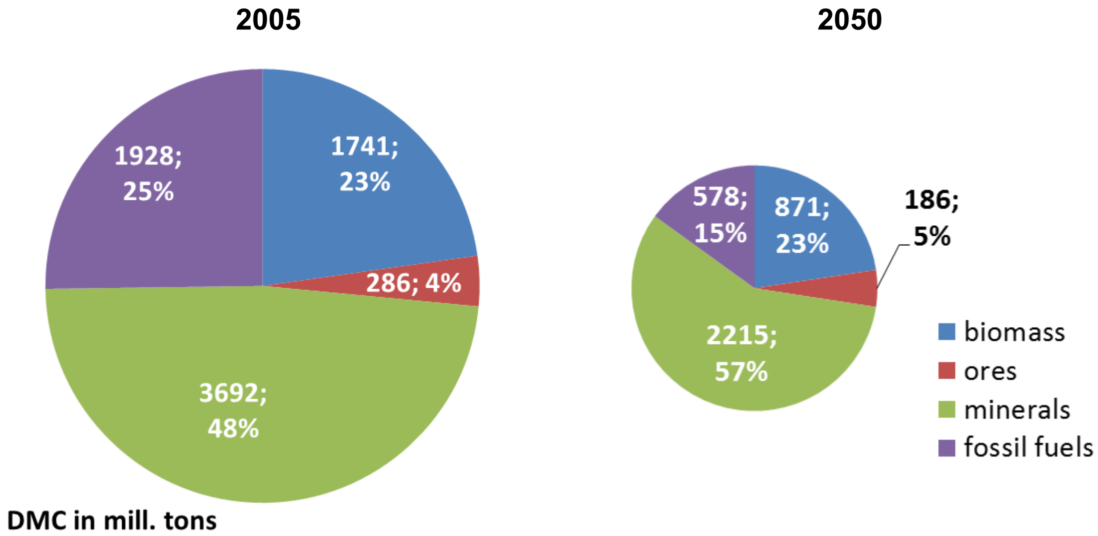
The *best practice scenario* demonstrates the extent of such a reduction under the assumption that the other European countries emulate the practices of those European countries (namely the UK, France and Germany) that in fact had a reduction of their per capita domestic material consumption in the period 1970-2000 of – on average – a little more than a quarter (28%). Emulating the same degree of reduction in all European countries between 2005 and 2050 would lead to an average metabolic rate of 12t/cap year in 2050. This scenario has the disadvantage that in each of the countries that did achieve such a reduction in the past, very specific circumstances were responsible for this (such as a far-reaching de-industrialization in the UK and the German reunion with closing down inefficient production sites in the East) – circumstances that cannot simply be "emulated" by other countries, nor do they necessarily remain the same for the forerunners. Nevertheless, this scenario teaches an important lesson: shrinking material use is not necessarily associated with economic decline.

The *radical transformation scenario*, finally, demands for halving European material consumption by 2050 and achieves what is asked for in UNEP's moderate contraction and convergence scenario: an average metabolic rate of 8t/cap*year. How could this be brought about?

To answer this question, it is useful to draw attention to the composition of European material consumption and to discuss plausible reduction strategies for each material category for the period up to 2050[23] (fig. 31).

[23] In the discussion of strategies to reduce consumption of the four material categories, interlinkages between the categories are considered but no calculation method has been used. Given the fundamental change implied with halving the material consumption there are too many uncertainties in the quantitative relationships and elasticities cannot be derived from empirical data of the last decades.

Figure 31 **The composition of EU27 material consumption in 2005 and a projection for 2050**



Source: Eurostat 2013a, own calculation, see assumptions in the text

Almost one quarter of it consists of fossil fuels (including derived products, a relatively small amount in relation to fuels). If Europe takes its climate policies seriously, this amount should be drastically reduced (see literature below). The use of most renewable energy sources, as soon as investments are taken, is associated with a substantially lower amount of materials. In our projection we assume that achieving 80% GHG emissions by 2050 entails a 70% dematerialization of the energy supply. This also has major implications for reducing the demand for transport infrastructure.[24]

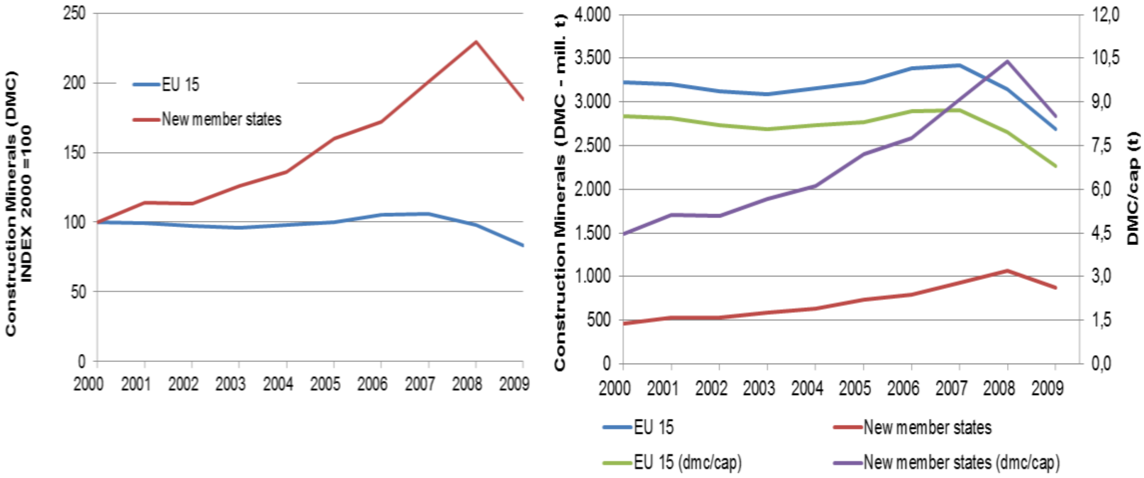
Somewhat less than a quarter consists of biomass (food, feed, timber, textiles…), the large majority of which is related to human nutrition. Reducing the animal share in human nutrition, and reducing food waste, could account for halving biomass use in a way co-beneficial for human health and the environment. Again there are co-implications for transport and transport infrastructure.

Half of the materials used consist of construction minerals (cement, sand, gravel) that are usually extracted domestically, and a large proportion of them are used for constructing and maintaining public infrastructure (roads, harbours, dams and the like). Some of this is a one-time investment in the course of modernization processes, as can be seen below from comparing the construction materials use of EU15 and new member states in the last decade. In our projection for 2050 we assume a saturation of infrastructure. Consequently additional construction activities can be minimized and the main use of construction minerals is to

[24] Fossil fuels, in terms of tons, amount to 50% of world transport (according to trade flows as presented by Krausmann et al. 2008b).This is distributed between ships, pipes and road transport. Reducing fossil fuel use would have major consequences in reducing transport volumes and the need for transport infrastructure.

maintain already existing infrastructure. We assume a 40% reduction of construction minerals compared to 2005. Since about 70%[25] of metals are used for infrastructure the same 40% reduction as for construction minerals is assumed for ores.

Figure 32 **The use of construction minerals in EU15 and the new member states**



Source: Eurostat 2013a

In a recent assessment for DG Environment, beyond climate related policies, the following two strategies were suggested as most potent to reduce materials and energy use and at the same time providing health and other benefits: changing the human diet and stabilizing the stocks of built-up infrastructure.

- "Changing the human diet towards a lower share of animal based food. Tackling this will have several effects:
  - Positive effects on human health (less obesity, less cardiovascular diseases, lower risk of livestock-related epidemics)
  - Decreasing livestock and thus lowering pressure on land because less land area is needed for agricultural production (i.e. market fodder for livestock)
  - Lowering pressures on groundwater (nitrification)
  - Savings of energy (cooling, transportation)
  - Decreasing GHG emissions from ruminants
  - Savings on water use
- Steady stocks of built-up infrastructure and densification of settlements, reducing urban sprawl
  - decreasing material use, i.e. construction minerals, metals use in infrastructure,
  - facilitating a continuous recycling of construction materials

[25] Wang et al. (2007) calculate that 75% of the iron used in Europe is added to stocks in 2000. Since iron is about three quarters of the overall metal consumption the figure can be used as an orientation. 70% was taken as a conservative estimate.

- decreasing energy use for the construction of infrastructure, in transport and in the use phase (more efficient heating, shorter distances)
- decreasing use of land area and sealing of land"

Food and infrastructure have also been targeted by the European "Roadmap to a resource efficient Europe" (European Commission 2011); one of its milestones reads as:" By 2020, incentives to healthier and more sustainable food production and consumption will be widespread and will have driven a 20% reduction in the food chain's resource inputs. Disposal of edible food waste should have been halved in the EU." (p. 18). Another milestone says that "by 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The life-cycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient, and policies for renovating the existing building stock will be in place so that it is cost-efficiently refurbished at a rate of 2% per year. 70% of non-hazardous construction and demolition waste will be recycled." (p. 18, 19) A further milestone says "By 2020, EU policies take into account their direct and indirect impact on land use in the EU and globally, and the rate of land take is on track with an aim to achieve no net land take by 2050" (p. 15).

Table 8 **Resource use reduction targets for EU 27**

	Ambitious	Moderate	Conservative
GHG emissions (baseline 1990)	-30% by 2020 -95% by 2050	-20% by 2020 -80% by 2050	-20% by 2020 -50% by 2050
Energy consumption (GIEC) (baseline 2005)	-20% by 2020 -40% by 2050	-15% by 2020 -30% by 2050	-10% by 2020 -20% by 2050
Material use (DMC) (baseline 2005)	-30% by 2020 -70% by 2050	-10% by 2020 -30% by 2050	-5% by 2020 -20% by 2050
Land use	Zero net demand of foreign land by 2020	Zero net take of artificial land by 2020	Limit annual net increase of artificial land to 200 km^2 by 2020
Water use Water Exploitation Index (WEI)	<20% WEI by 2020 <10% WEI by 2050	<25% WEI by 2020 <20% WEI by 2050	<30% WEI by 2020 <25% WEI by 2050
Legend for feasibility:	Possibility to achieve targets with significant changes in levels of activity and significant advancement from known and future technologies	Possibility to achieve targets with slight changes in levels of activity and greater investments in known technologies	Possibility to achieve targets while maintaining current levels of activity and cost effective investments in known technologies

Source: BIOIS, SEC & SERI (2012), p. 96

In the European Commission's "Roadmap to a resource efficient Europe" (2011) unsurprisingly "resource productivity" is suggested as a provisional lead indicator to measure the principal objective of this Roadmap, of "improving economic performance while reducing pressure on natural resources and the environment", complemented by indicators on key natural resources such as water, land, materials and carbon, that will take account of the EU's global consumption of these resources. (European Commission 2011, p. 4). This resource productivity on the macro level is defined as GDP/DMC, the latter being the indicator we based our scenarios upon. If resource productivity is used as the main indicator for targeting future development, this implies making assumptions about the growth or decline of GDP. Under the conditions given in Europe in the last decades with stagnating DMC/cap, resource productivity rises practically only depend upon the rise of GDP (given that also population is fairly constant), as obvious in figure 26 above.

In a recent very thorough econometric analysis, Steinberger et al. (2013) explored the interrelation between GDP, resource use, resource productivity and carbon emissions for country clusters (industrialized and emerging/developing countries) for the time period 1970-2004. For each country, they calculated "coupling coefficients" of income and material consumption (income elasticity), finding these coefficients generally low for mature industrial countries (sometimes even negative, thus implying absolute decoupling), and consistently higher for the developing/emerging group, particularly for minerals and fossil fuels.[26] The most interesting finding from the full panel analysis is the time trend identified: it can be interpreted as the time-dependent (and income-independent) rate of improvement of material and carbon efficiency, related to technical improvements rather than to economic growth. This time trend coefficient is small but significant for DMC and carbon emissions across the whole sample (with all R^2 for the full equation exceeding 0.98). The existence of this time trend allows for some economic growth while absolute dematerialization may occur. A narrow limit, though: it amounts to 1.4% economic growth annually without affecting DMC, and only 0.9% without affecting carbon emissions (the authors term this "autonomous technological progress")[27]. By implication, stronger and more successful efforts at improving resource efficiency and adopting renewable energies than occurred in the past 35 years would be required to allow for higher growth rates in GDP while permitting reductions in resource use.

[26] A test using a quadratic (Kuznets) function instead of a log-linear did generally not render significant results.

[27] This type of shift over time has also been seen in life expectancy vs. income (Preston 2007) and human development (HDI) vs. energy and carbon emissions (Steinberger and Roberts, 2010).

4. Concluding remarks

As stated in the introduction, a long bridge is required to span the gap between an environmental and a macroeconomic perspective on the future of human development. The socioecological analysis of socioeconomic resource use as attempted in this report is an important pillar to support such a bridge. Still, the bridge has to be walked on from both sides. Attention for causalities is typically divided: Environmentalists care for how economies will impact upon the environment and that they potentially might trigger environmental changes detrimental to long-term civilization and survival. Economists care for securing the (typically much shorter term) conditions of economic growth, employment and consumption opportunities. Environmentalists see nature as a dynamic force, economists focus on the agency of humans. The differences in time horizons alone make it difficult to meet mid-way.

This report, within the limits of a socioecological framework, seeks to employ both perspectives. It seeks to describe global changes that will impact the European economies via biophysical effects, world market price effects for commodities and potential policy regulations (along the analytical pathways sketched in Figure 1), and on a macro-level it analyses the impacts economies have on the extent of natural resource extraction and use, and concomitant environmental consequences. The most general take-away insight is that there is a strong interdependency: environmental change feeds and constrains the economies, and the economies trigger environmental change. It appears that there is major structural change on-going in this relationship to which Europe will need to adapt.

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Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs a change: The financial crisis has exposed long neglected deficiencies in the present growth path, most visibly in unemployment and public debt. At the same time Europe has to cope with new challenges ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundations for a new development strategy that enables a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four year research project within the 7th Framework Programme funded by the European Commission started in April 2012. The consortium brings together researchers from 33 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). Project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

Contact for information

Kristin Smeral

WWWforEurope – Project Management Office

WIFO – Austrian Institute of Economic Research

Arsenal, Objekt 20

1030 Vienna

wwwforeurope-office@wifo.ac.at

T: +43 1 7982601 332

Domenico Rossetti di Valdalbero

DG Research and Innovation

European Commission

Domenico.Rossetti-di-Valdalbero@ec.europa.eu

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