

## **The relation between resource productivity and competitiveness**

*Project ENV.G.1/ETU/2007/0041  
Part: Resource Productivity*

Prof. Dr. Raimund Bleischwitz (coordination)  
Bettina Bahn-Walkowiak  
Mathias Onischka  
Oliver Röder  
Sören Steger

With further support by Michael Ritthoff, Piet Hausberg, Rafael Habba, Verena Hötzel, Burkhard Schaffitzel

# Contents

<b>PREFACE .....</b>	<b>6</b>
<b>EXECUTIVE SUMMARY.....</b>	<b>7</b>
<b>1. DEFINITIONS AND MEASUREMENTS OF RESOURCE PRODUCTIVITY .....</b>	<b>19</b>
1.1. Introduction .....	19
1.2. Macro level .....	22
1.3. Meso level .....	24
1.4. Micro level .....	25
1.5. Discussion .....	26
1.6. Conclusions.....	29
<b>2. EMPIRICAL RESULTS: ARE THE EU AND OTHER ECONOMIES ON TRACK TOWARDS DECOUPLING? .....</b>	<b>31</b>
2.1. Resource use in the EU27, Turkey, USA and Japan.....	31
2.2. Resource productivity of the EU27, Turkey, USA, and Japan .....	33
2.3. Development of resource productivity compared to labour productivity.....	42
2.4. The correlation of resource consumption and per capita income .....	48
2.5. Resource productivity and competitiveness .....	51
2.6. Conclusions.....	57
<b>3. DRIVING FORCES OF RESOURCE USE AND RESOURCE PRODUCTIVITY .....</b>	<b>59</b>
3.1. Definition of driving forces .....	59
3.2. Theoretical basis of the selection of variables .....	59
3.3. Selection of variables for drivers .....	61
3.4. Methods of regression analysis .....	65
3.5. Results of regression analysis.....	68
3.6. Conclusions.....	74

<b>4. INDUSTRIES AND RESOURCE PRODUCTIVITY .....</b>	<b>75</b>
4.1. Why a sectoral approach is relevant .....	75
4.2. Why these industries have been selected .....	80
4.3. Automotive Industry .....	81
4.3.1. Economical Status Quo .....	81
4.3.2. Key challenges .....	82
4.3.3. How resource productivity may enhance competitiveness .....	92
4.4. Cement Industry .....	96
4.4.1. Economical Status Quo .....	96
4.4.2. Key challenges .....	98
4.4.3. How resource productivity may influence competitiveness .....	106
4.5. Steel industry .....	110
4.5.1. Economical Status Quo .....	110
4.5.2. Key challenges .....	112
4.5.3. How resource productivity may enhance competitiveness .....	120
<b>5. CONCLUSIONS AND POLICY RECOMMENDATIONS .....</b>	<b>126</b>
5.1. Automotive industry and EU policy .....	128
5.2. Cement industry and EU policy .....	131
5.3. Steel industry and EU policy .....	133
5.4. Data requirements: towards knowledge-creating institutions .....	135
<b>6. REFERENCES .....</b>	<b>138</b>
<b>7. ANNEX .....</b>	<b>150</b>

## Figures and tables

Figure 1-1:	Indicators/measurements of resource productivity and goals of the subtask.....	19
Figure 2-1:	Resource use per capita in 2000.....	32
Figure 2-2:	Resource productivity of the EU15 and the USA for 1980 and 2004/2000 .....	35
Figure 2-3:	Resource productivity of the EU27, Turkey and the USA for 1992 and 2000.....	35
Figure 2-4:	Resource use in relation to GDP (EU15 countries, Japan and the USA, 1980=100).....	36
Figure 2-5:	Resource use in relation to GDP (new member states of the EU and Turkey, 1992=100).....	40
Figure 2-6:	Resource and labour productivity in relation to GDP (EU15 countries, Japan and the USA, 1980=100) .....	43
Figure 2-7:	Resource and labour productivity in relation to GDP (new member states of the EU and Turkey, 1992=100) .....	46
Figure 2-8:	Relationship between GDP per cap and resource use per cap .....	49
Figure 2-9:	Value based share of selected raw materials in total EU15 imports .....	51
Figure 2-10:	The relationship between the score of Global Competitiveness Index (GCI) published by the WEF and resource productivity (GDP in PPP US\$ per kg DMC).....	53
Figure 2-11:	Test statistic of the regression analysis Global Competitiveness Index (GCI) against resource productivity .....	54
Figure 2-12:	Relationship between the score of Macroeconomic Environment Index (MEI) published by the WEF and resource productivity.....	55
Figure 2-13:	Test statistic of the regression analysis Macroeconomic Environment Index (MEI) against resource productivity .....	55
Figure 2-14:	Relationship between the score of Public Institution Index (PII) published by the WEF and resource productivity.....	56
Figure 2-15:	Relationship between the score of Technology Index (TI) published by the WEF and resource productivity.....	57
Figure 4-1:	Direct and indirect resource use by economic activities in Germany in 2000.....	76
Figure 4-2:	Sectoral Innovation Model.....	78
Figure 4-3:	Profitability of European car manufacturers.....	82
Figure 4-4:	Reported cost structure in German automotive industry .....	88
Figure 4-5:	Material inputs of selected cars.....	89
Figure 4-6:	Effects of innovation in automotive industry.....	90
Figure 4-7:	Cement Consumption 1998-2005 .....	97
Figure 4-8:	World Cement Production 2007 (Cembureau, 2006) .....	98
Figure 4-9:	Impact of alternative fuels on overall CO2 emissions .....	100
Figure 4-10:	Development of cost structure in cement industry in Germany .....	102
Figure 4-11:	Production process of "Ecocement" using ash and heavy metals.....	104
Figure 4-12:	Largest steel producers worldwide .....	111

Figure 4-13:	Use of steel in European industries.....	112
Figure 4-14:	Expected additional annual cost for carbon emissions rights for selected EU industries in 2020.....	113
Figure 4-15:	Cost structure of the German primary and secondary steel production .....	114
Figure 4-16:	Share of cost block in steel processing industries in Germany 2006.....	115
Figure 4-17:	Development of cost structure in metal industry in Germany .....	116
Figure 4-18:	Global production of steel and possible substitutes .....	118
Figure 4-19:	Imported and exported scrap by grade in EU27 .....	121
Figure 4-20:	Share of scrap in metal production .....	122
Figure 7-1:	Correlation-matrix EU15 1980-2000, limited variables .....	153
Figure 7-2:	Correlation-matrix EU27 1992-2000, limited variables .....	154
Table 1-1:	Summary of indicators and measures to calculate resource productivity at macro level .....	23
Table 1-2:	Summary of indicators and measures to calculate resource productivity at meso level.....	25
Table 1-3:	Summary of methods to calculate resource productivity at micro level.....	26
Table 3-1:	Test statistic for EU15, 1980-2000 .....	68
Table 3-2:	Test statistics for EU27, 1992-2000.....	70
Table 3-4:	Test statistics resource intensity for EU15, 1980-2000 .....	71
Table 3-5:	Test statistic resource intensity for EU27, 1992-2000.....	72
Table 4-1:	Global Production of Vehicles.....	86
Table 4-2:	Expected global sales in automotive industry.....	86
Table 4-3:	Selected Potentials to reduce the usage of materials in compact class car (VW Golf) .....	91
Table 4-4:	Cost structure in cement industry .....	102
Table 4-5:	Fuel energy use in cement manufacturing in the EU-25.....	105
Table 4-6:	Share of used alternative fuels .....	106
Table 4-7:	Indicators for the cement industry .....	109
Table 4-8:	Selected economic indicators for EU steel industry .....	112
Table 4-9:	Selected potentials and barriers to improve resource productivity .....	117
Table 4-10:	Scenarios towards a steel cycling economy in EU – potentials of secondary steel and reduction of carbon emissions .....	123
Table 7-1:	Overview of variables and expected signs:.....	151

## Preface

This report is part of a project on „The links between the environment and competitiveness“ conducted on behalf of the European Commission, DG ENV (No. ENV.G.1/ETU/2007/0041). It is the final report within the project part on resource productivity; comments on the draft final report (as of November 30, 2008) provided by internal reviewers and by the Commission have been incorporated.

Following the inception report (final version of June 18th 2008), which gives an overview on the main literature on definitions and measurements of competitiveness, on the links between environmental policies and competitiveness as well as on the relation between resource productivity and competitiveness, two definitions are of relevance for this final report:

- The World Economic Forum defines competitiveness as “the collection of factors, policies and institutions which determine the level of productivity of a country and that determine the level of prosperity that can be attained by an economy” (Global Competitiveness Report, 2007).
- The European Commission defines competitiveness as achieving “high and rising standards of living of a nation with the lowest possible level of involuntary unemployment on a sustainable basis”.<sup>1</sup>

Our report seeks to test the hypothesis that such understanding may also include resource productivity as a driver of competitiveness. The aim of the Lisbon Agenda and the EU SDS – to decouple GDP from Resource use – as well as the EU Thematic Strategy on Sustainable Use of Natural Resources (COM(2005) 670 final) can be seen as an important milestones in that regard.

This final report now delivers findings on the following subtasks:

- **Subtask 1:** Measurements of resource productivity at the levels of firms, sectors, and economies.
- **Subtask 2:** Empirical results: resource productivity performance of the EU25, Japan, and USA.
- **Subtask 3:** Driving forces of resource use and resource productivity.
- **Subtask 4:** Industry and resource productivity with sectoral analyses on
  - Automobiles,
  - Cement,
  - Metals.
- **Subtask 5:** Conclusions and policy recommendations.

---

<sup>1</sup>[http://ec.europa.eu/enterprise/enterprise\\_policy/competitiveness/1\\_eucompetrep/eu\\_compet\\_reports.htm](http://ec.europa.eu/enterprise/enterprise_policy/competitiveness/1_eucompetrep/eu_compet_reports.htm).

## Executive summary

The aim of this report is to analyse the relationship between resource productivity and competitiveness at a European level. It is part of a project on „The links between the environment and competitiveness“ conducted on behalf of the European Commission, DG ENV (No. ENV.G.1/ETU/2007/0041). The issue is timely because prices on raw material markets had been skyrocketing since the year 2000 and are now back on lower levels – mainly due to the financial crisis. Most experts expect a comeback of high raw material prices as soon as the global economy will recover.

The relationship between resource productivity and competitiveness however is broader and more challenging than a short look at raw material prices reveals. Since the EU is home to a variety of manufacturing industries, the use of materials in industries as well as the potential quality improvements matter. A guiding question for this report thus is as follows: Can companies spur their competitiveness and can the EU as a whole enhance its competitiveness through improving material efficiency and through developing new products and services that lower the overall resource intensity? In doing so, the report follows the EU definition on competitiveness as achieving “high and rising standards of living of a nation with the lowest possible level of involuntary unemployment on a sustainable basis”.

The issue of resource productivity has a clear environmental dimension. All stages of the resources’ life cycle – extracting natural resources, transforming them into goods, and subsequent processes of recycling and disposal – put pressure on the environment. This has clearly been outlined by the EU’s Thematic Strategy on the Sustainable Use of Natural Resources (COM(2005) 670 final); it is furthermore integral part of the OECD (2008) handbook on measuring material flows and resource productivity. The recently established UNEP International Panel on Sustainable Resource Management has been set up to get scientific evidence on the environmental dimension of managing resources. The policy-oriented aim of the current report thus is to align the economic interest in cutting material purchasing costs and innovation with the environmental issue of reducing environmental pressure. The focus on resource productivity can be seen as advantageous in that regard, since resources are used in all industries and productivity is a key concept for economic development.

Our report seeks to test the hypothesis, that resource productivity leads to an enhancement of competitiveness through lowering material purchasing costs and through developing new products and services that lower the overall resource intensity. In doing so, the report has been structured along the following chapters:

1. Analyses the definition and measurements of resource productivity,

2. Displays empirical results on decoupling, i.e. discusses to what extent industrialized countries are able to decouple GDP from the use of natural resources and draws conclusions
3. Analyses driving forces of resource use and resource productivity
4. Develops a sectoral approach and analyses three key industries in Europe (automotive, cement, steel)
5. Draws overall policy conclusions.

## **Chapter 1: Definitions and measurements of resource productivity**

Resource productivity describes the relation between economic outputs in monetary terms ( $Y$  – numerator) and a physical indicator ( $M$  – denominator) for material or resource input. According to the OECD (2008) the term ‘resource productivity’ is [...] put in a welfare perspective and is understood to contain both a quantitative dimension (e.g. the quantity of output produced with a given input of natural resources) and a qualitative dimension (e.g. the environmental impacts per unit of output produced with a given natural resource input).

At the level of economies, economy-wide material flow analysis (EW-MFA) and derived indicators are most commonly used to quantify the level of material and resource use by using the indicator Direct Material Input (DMI), Domestic Material Consumption (DMC) or Total Material Requirement (TMR), Total Material Consumption (TMC).

At the sectoral level, physical and monetary input-output tables can be used to relate the economy-wide resource requirement to individual sectors and/or to the different categories of final use. At the micro level, two different approaches can be used to quantify resource productivity: a product-based approach and a company-based approach.

Expressing resource productivity by means of material flow indicators has a number of advantages. MFA indicators are deeply rooted in the material balances of countries – considering used and unused materials, imports and exports. They emphasise and investigate the material base of an economy and are easy to understand while using a common mass unit (metric tons). Thus, one advantage of the MFA approach can be seen in a consistent multi-level methodology. Combining, however, a monetary and a physical unit in one indicator also leads to questions on the reliability of both.

Following the OECD handbook of 2008, the measurement methodology now can be seen as internationally harmonized at the macro level of countries. The data situation and reliability are at a reasonable but amendable level, especially for the indicators DMI and DMC. Since shiftings of environmental pressures through imports and relocations of industries are not monitored by these two indicators, much needs to be done regarding the data and calculation of TMR and TMC. In particular, there is a general lack of data regarding indirect resource flows of processes, products and services, i.e. material and energy requirements along the up-stream stages of a production process (also called ecological rucksacks) as well as data on material cost structures. The **estab-**



**ishment of an international data base and data centre on the resource intensity of products and services** is urgently needed, in order to monitor the success of strategies and measures to increase resource productivity, on the macro-economic level, for industries and the level of companies and product-service-systems including the customers and consumers activities.

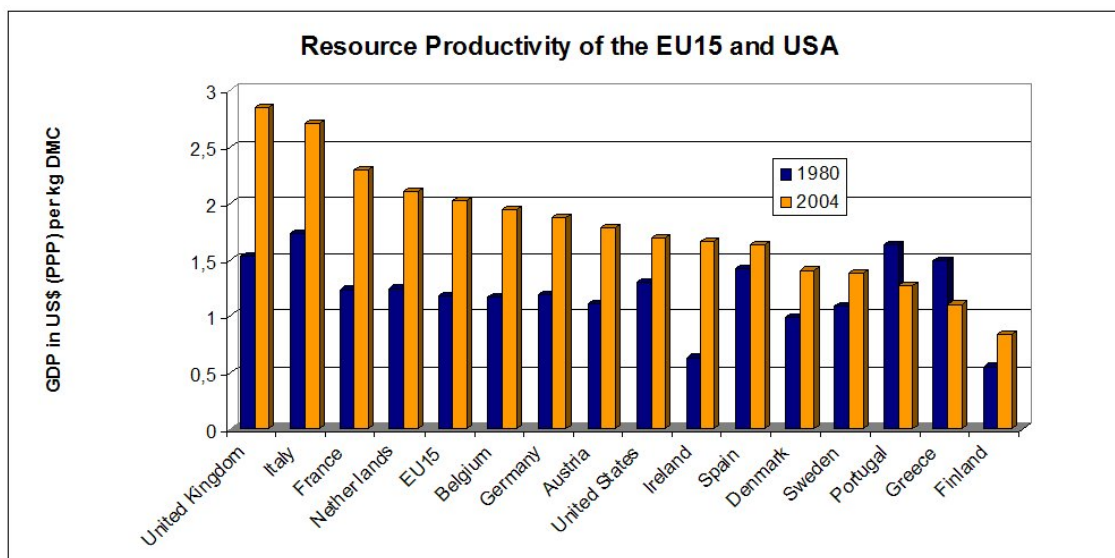
## **Chapter 2: Empirical results – Are the EU and other economies on track towards decoupling?**

The report uses the term of “resource productivity” – the precise empirical notion according to OECD (2008) is “Direct Material Productivity” since it refers to DMI / DMC as denominator; the conclusions of chapter 1 apply. Using existing data, the report analyses time series for EU27, USA and Turkey for the years 1992-2000 and for the EU15 from 1980-2004. The empirical analysis reveals that the use of resources (measured as DMI or DMC, without hidden flows and ‘ecological rucksacks’) tends to be higher in the EU15 countries than in the new EU Member States and Turkey. But even within the EU15 the DMI per capita varies between 45t per capita (Finland) and 14t per capita (Italy) – a significant difference.

The resource productivity in the EU15 countries is higher than in the Eastern European countries. But even within the EU15 countries there are **remarkable differences** in their respective resource productivity performance. While the Netherlands, France, Italy, and Britain obtain low levels in resource consumption per capita as well as high levels of resource productivity, the relatively low resource consumption per capita in Portugal is not in line with high resource productivity. In Germany and Austria, however, a fairly high level of resource productivity is achieved with a high amount of resource consumption. The very high per capita consumption of resources in Finland reduces the Finnish resource productivity to the lowest level within the EU15, but is still higher than in some new member states.

Almost all analysed countries could **improve** their resource productivity over time. With Greece and Portugal, however, at least two EU15 member countries **have dropped their resources productivity**; this drop has also occurred in Lithuania. It is worth noting that in 1980 Greece and Portugal were the most efficient economies of the EU15 regarding the use of materials and energy and now they are both at the bottom of the ranking together with Finland. In contrast, UK and Ireland increased their resource productivity significantly in the same period, Ireland for example more than doubled its productivity number (Fig. 2-2). In the New Member States (NMS), the resource productivity is not only lower (with the exception of Malta and Hungary), but from 1992 to 2000 the overall improvement was also significantly lower in many NMS and Turkey than in the old Member States.

Figure 2-2: Resource productivity of the EU15 and the USA for 1980 and 2004/2000



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004); USA: WRI Database, GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>

For EU25, Turkey, Japan and the USA data shows, that a majority of the countries could ameliorate their resource productivity. In most cases, however, resource productivity increased slower than GDP in the investigated country. Therefore, only a relative decoupling of resource use and economic growth can be witnessed in these countries. An absolute decoupling or “dematerialisation”, i.e. economic growth along with a decrease of resource use, occurred only in Germany regarding the DMC so far. Though, a few other countries could at least stabilise their resource use. The growth rates of resource productivity (2,5 %/a for EU-25 and 2,9 %/a for EU-15) fall behind the aims of the EU’s resource strategy. Thus, the **EU is not yet on track towards decoupling resource use from GDP**.

A few specific results shall be pinpointed here: Countries with high resource productivity levels are not necessarily the ones with the strongest dynamic in ameliorating resources productivity. For instance, resource productivity in Ireland is rather average amongst the investigated countries but increased between 1980 and 2004 at an average rate of 6.8%.

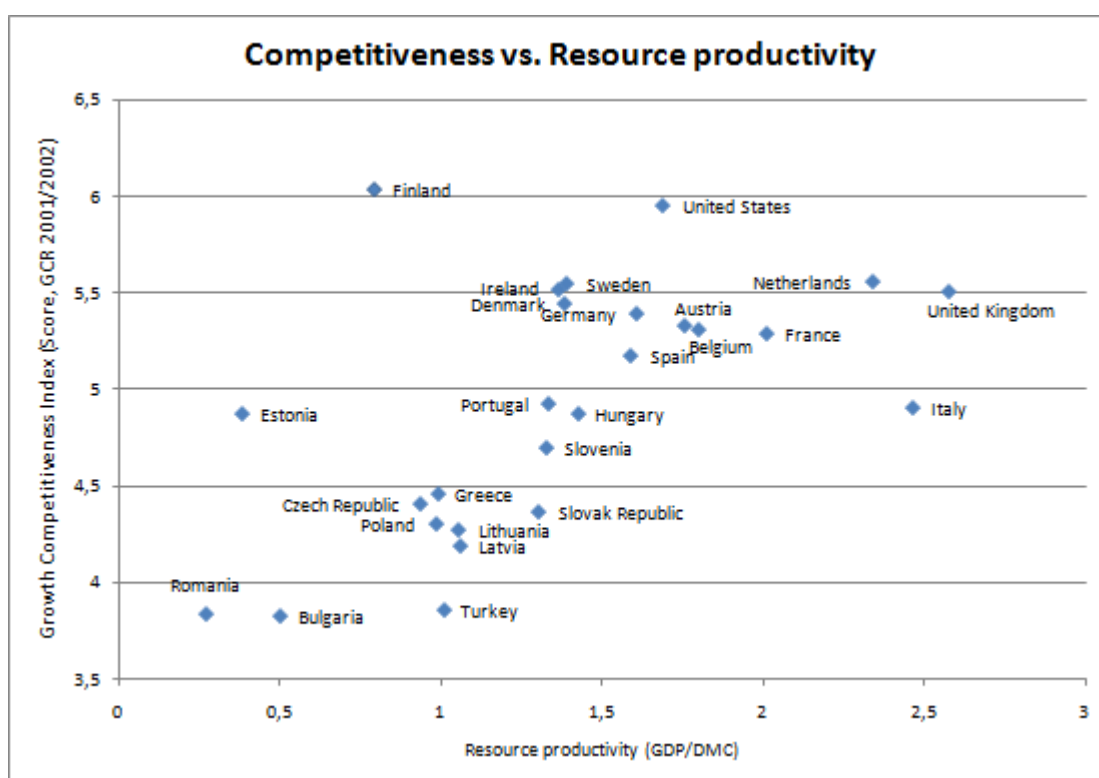
The huge difference in resource use between countries of similar developing levels (measured by per-capita income) possibly can be interpreted as a potential for further improvements in the range of a factor 2 – 4, depending on country-specific features as well as technological and institutional capabilities.

With a view to absolute reduction targets, data suggests a conclusion that there is a current minimum level of necessary resources for developed industrialised countries in the order of 12t per capita (DMI/DMC). This indeed is neither a statement about current potentials to save resources nor about any future possibilities. It however indicates a

window of opportunities for improvements since the average EU25 resource use per capita is in the order of 35t per capital ( $DMI_{cap}$  2000).

Our analyses demonstrate that in general there is a **positive relation between competitiveness of economies and their resource productivity**. There is empirical evidence that resource productivity correlates positively with competitiveness. The causality between both variables has been tested in this report; however it is not yet entirely clear, especially with regard to the Scandinavian countries, where specific factors determine the resource use and are more momentous. It is also interesting to note that the relative share in total raw material imports grew between 1998 and 2004 from around 10% up to 15%. As well in these cases, research is requested to obtain better insight in respect of determinants of resource use and resource productivity from further in-depth analysis. The methodology used in this report is feasible to produce results provided that sufficient data for time series can be accessed.

Figure 2-10: The relationship between the score of Global Competitiveness Index (GCI) published by the WEF and resource productivity (GDP in PPP US\$ per kg DMC)



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003): Kiew Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.ne>, RP: own calculation, GCI: WEF (2002)

### Chapter 3: Driving forces of resource use and resource productivity

Chapter 3 gives an overview on recent findings of driving forces for decoupling resource use from GDP. Based on these findings and data availability, it selects 68 variables for drivers and undertakes a regression analysis for various panels of different countries and periods of time for both the DMC per capita as well as for resource intensity measured as DMC in kilograms per 1000 U.S. \$ in purchasing power parity (PPP).

In the best-fit model for the panel EU15 and the period from 1980 to 2000 the important variables for explanation the DMC per capita are the **energy consumption per capita**, the **length of motorways per capita**, the **number of completed dwelling units** and the **share of import of GDP**. One explanation for the positive correlation between high share of import of GDP and high per capita DMC may be that countries with a strong industry structure such as Germany have a higher share of import and export than countries with a small industrial base. The reason lies in the global production chains, where raw materials and intermediate goods are imported, domestically refined into finished products and also globally traded, i.e. re-exported.

The share of imports in GDP is also the most influential factor: an increase in the import share by 1% would raise the DMC per capita by 0.225%. In contrast the increase of energy consumption per capita by 1% would lead to an increase in DMC by 0.177%. The length of the motorway network per capita and the completed dwelling units per 1000 inhabitants have approximately the same explanation power. Finally, the variable 'year' shows, that under ceteris paribus conditions, DMC per capita would fall by 1.27% p.a., because of the autonomous technological progress.

The results lead to the following conclusions:

- The energy use has a high significance for resource use per capita as well as resource productivity. This indicates potential synergies between climate policies and resource policies.
- As the DMC in most countries is dominated by construction minerals, the construction sector and its industries have an high impact on both, resource use and resource productivity. This indicates the relevance of all related policies (planning procedures, incentives and programmes for new dwellings). However the discussion on the denominator should also be taken into account for a more comprehensive view.
- Mobility variables are also of critical importance for resource use and resource productivity, especially when 'hidden flows' and 'ecological rucksacks' of metals are accounted for. Although only one of the mobility variables (length of networks) have turned out to be part of the best-fit-models in this study, an analysis of driving factors of the consumption of construction minerals shows also a high relevance of the car possession as a driving factor. This results are directly linked to the automotive industry.

These findings are of special relevance in regard to current policy responses to the financial crisis. It can be estimated that the new and additional programmes lead to new investments in motorways and dwellings as well as to purchasing of new cars – and slow down potential improvements in resource productivity.

The report also shows that these results depend at least partly on the length and data quality of the time series as well as on the chosen country panel. Since the database used in this chapter ends in the year 2000, the sharp increase of prices for raw materials and energy fuels in the last years has not been incorporated in our analysis. Further detailed analysis with longer time series and broader country panel would deepen the understanding of driving factors.

#### **4. Industries and Resource Productivity**

The first part of this chapter argues that a sectoral approach is important for three reasons: the relevance of key industries, sectoral innovation patterns, and synergies with climate policy. The three industries selected reflect this approach. Methodologically, this chapter is carried out via desk top analysis.

##### **4.1 Automotive industry and EU policy**

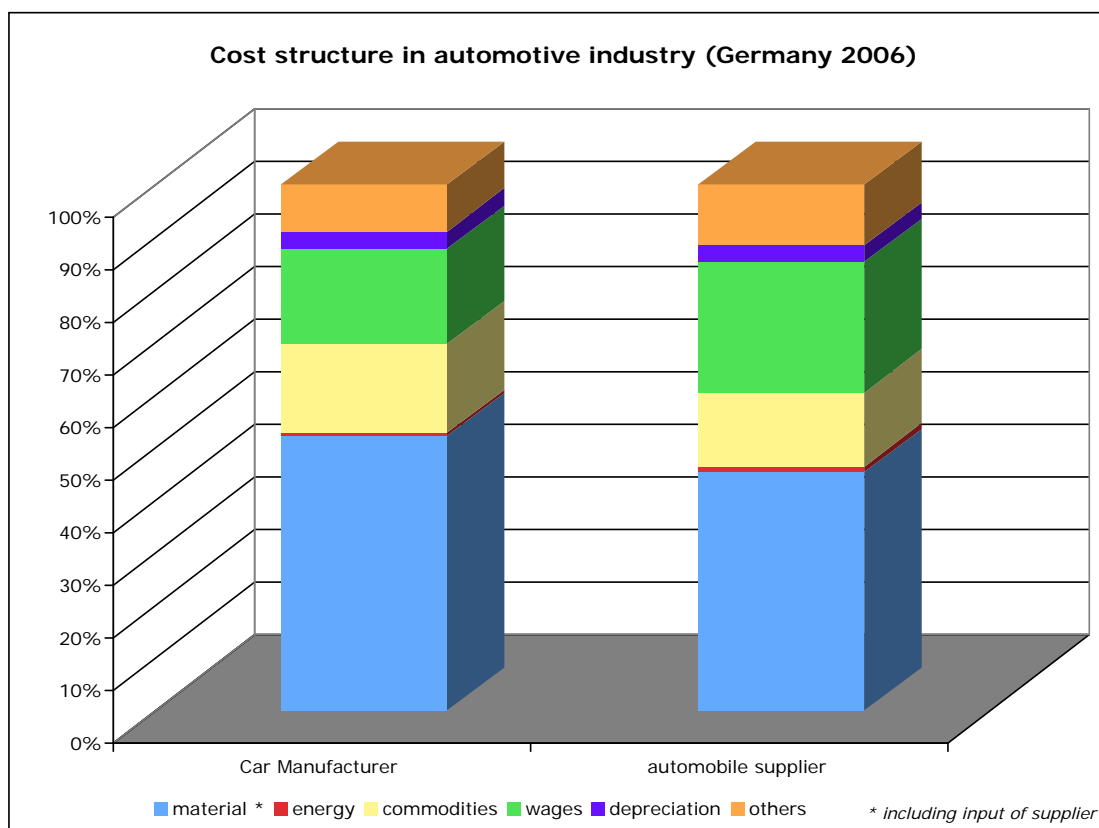
There are significant potentials to improve resource productivity in the automobile sector. Within the industry the share of material cost as part of the total costs is very high so that less material and resource input will in principle have a positive effect on the cost structure.

Analysis has shown that resource productivity offers scope for improving competitiveness regarding cost reduction and quality improvement. Given fundamental uncertainties however policy is in demand to improve the incentive structures in order to initiate the exploitation of the existing potential in resource productivity. The report concludes on selected strategic approaches:

- Better information: A requirement to report on material intensity and costs (the latter at least on an aggregate level) would boost markets for material efficiency and give a basis for further measures by policies, research and development. A first approach could be the expansion of the regulation of energy labelling with an obligatory report about the material intensity. Additionally it is worthwhile to build up a systematic material flow accounting (taking into account the International Material Data System of the ELV-Directive) because those information can be of special interest for several stakeholders.
- Synergies with climate policy: The planned carbon regulation of the automobile industry has already acted as a catalyst with respect to the development of fuel-saving cars. Even if the aspect of fuel consumption is not enough for a significant improvement of resource productivity, the importance of small-class cars as well as the issue of down-sizing is rising. The emphasis on weight in the current regulation therefore can be seen

as an advantage and a door opener to regulate and downsize the material intensity of cars.

Figure 4-4: Cost structure in German automotive industry



Source: VDA 2008.

- Beyond CARS 21:<sup>2</sup> It is proposed to establish a Technology Platform for light-weight cars. Not only will a Technology Platform like that unite car manufacturers and main suppliers, but a broad spectrum of metal industry, other material-producing industries, recycling industry, designer and material science.

- Reconsider waste policy and ELV-Directive: the strict quotas of the ELV-Directive and their constraints on the automotive industry on introducing new materials might be reconsidered. Though there is good potential to increase the use of secondary steel and aluminum, the system of recycling quota may not be in favour of using new materials. The report suggests that instead of those recycling quota two complementary criteria may be applied: firstly, to certify the recycling routes to be used after mandatory take-back according to their primary resource requirements, and secondly (and even more important), to limit the primary resource requirements for the production and use phase of vehicles (e.g., per person kilometer guaranteed by the manufacturer).

<sup>2</sup> The European Commission has launched a new strategy for long term viability of European car industry called CARS 21. See: Rapid Press Release Europe <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/157&format=HTML&aged=0&language=EN&guiLanguage=en>

- **New Products:** The low-cost-market provides the opportunity for certain system innovations; not only on driving systems but also to initiate significant changes in the use of resources and materials because in this segment the sensitivity regarding material costs is much higher than in the mid-size, full-size or luxury class. In order to implement such system innovations also into the mid-size and luxury class of conventional models, it seems appropriate to support accordant research projects. In particular the European automobile suppliers will have an excellent opportunity to position themselves in these growth markets.

- Furthermore, the report pledges to establish a sectoral dialogue with the automotive industry that covers environmental core concerns as well as resource productivity. Such a dialogue could provide regulatory certainty, support for R&D and even market introduction programmes. A possible outcome would be a negotiated agreement. In addition, the issues of sustainable consumption and alternative patterns for the use of cars deserve attention.

## **4.2 Cement industry and EU policy**

The cement industry has some options at hand, which can improve its resource productivity; in the long run however there seems to be limited possibilities and potential to improve its resource productivity if efforts are not aligned with sustainable construction initiatives. Though, taking the importance of the industry for the European long-term climate targets into account, it is very important to exhaust this potential and to get clarity on the long-term perspectives. The following incentives for the industry may enhance resource productivity:

- **Better regulation:** In principle resource productivity can be improved by implementing a front runner regulation because not all production sites are using the latest production technology as a result of the long operating life. Especially the reduction (later even the prohibition) of energy-intensive wet processes would be a substantial contribution to exhaust the technical potential for energy efficiency.

- **Aligning with the ETS:** To avoid unsustainable competition resulting from cement imports from non-EU neighbouring countries, which are linked with significant additional emissions and ecological side effects from the transportation, it may be reasonable to require CO<sub>2</sub>-certificates for imported cement according to its carbon intensity. Alternatively, one may offer a scope for expanding the ETS within the cement industry beyond the EU (e.g. for EU-based companies producing outside the EU).

- **Industrial symbiosis of energy and materials:** The use of alternative fuels (e.g. waste, tyres) to a greater extent is an excellent possibility to reduce the macroeconomic demand for primary energy sources. Clear guidelines and public information campaigns could help increase the use of waste in cement kilns. One could think of regulations which either offset the cement industry for avoided emissions from fossil fuels, set standards for the caloric value of waste or even prescribe the use of such secondary fuel to certain quota. Another option is the possibility to provide discounts for emission

rights for the use of alternative fuels in the production process. At this juncture it should be explored how an integrated assessment can be conducted and what incentives can be given to optimise systems e.g. via cascading use of waste, including biomass and via a by-production of heat.

- Creating lead markets: Principally it should be examined which kind of political instruments can support a larger production as well as demand for pozzolane cements or other forms of 'eco-cement'. Even if pozzolanes are not suitable for all kind of applications, they have a significant higher resource productivity as well as climate balance. The European cement standard EN 197 should be assessed against such alternatives. An indirect diffusion into the market might be achieved if targets for saving of carbon emissions will be applied for the industry that cannot be realised with the production of Portland only.

- Sectoral dialogue: a strategic dialogue on sustainable cement, supported by e.g. the European Technology Platform on sustainable construction minerals, which explores systematically into using waste and other by-products for cement production, to improve the recyclability of cement and the resource productivity over the whole life cycle. Downstream construction industries should be invited to participate in order to assess viable options for similar minerals. The EU should support the development and use of alternative building materials, taking into account the material contribution to multifunctional roofs and walls as well as options to produce energy. As part of these dialogues the discussion should be deepened if and to what extend recycling of cement / concrete might be an option to improve resource productivity.

- Measuring and Reporting: There are already some elaborated suggestions – e.g. from the WBCSD / CSI – for measuring and reporting on key performance indicators, ecological impacts, carbon emissions as well as safety & health. These proposals for the cement industry should be promoted to develop minimum standards, reporting requirements and benchmarks; currently there is still a lack of consistent, extensive and recent data in terms of material usage, energy consumption as well as cost structures. A more extensive reporting would help to develop accurate solutions for the discussion problems of the industry.

- Promoting Private-Public Partnerships for Urban Mining: The recovery of materials from outdated urban infrastructures is considered to be a market opportunity constrained by information deficits and regulatory uncertainties. The EU could encourage and support demonstration projects between construction and waste industry and public authorities with the aim of recovering materials and developing high-level re-use systems.

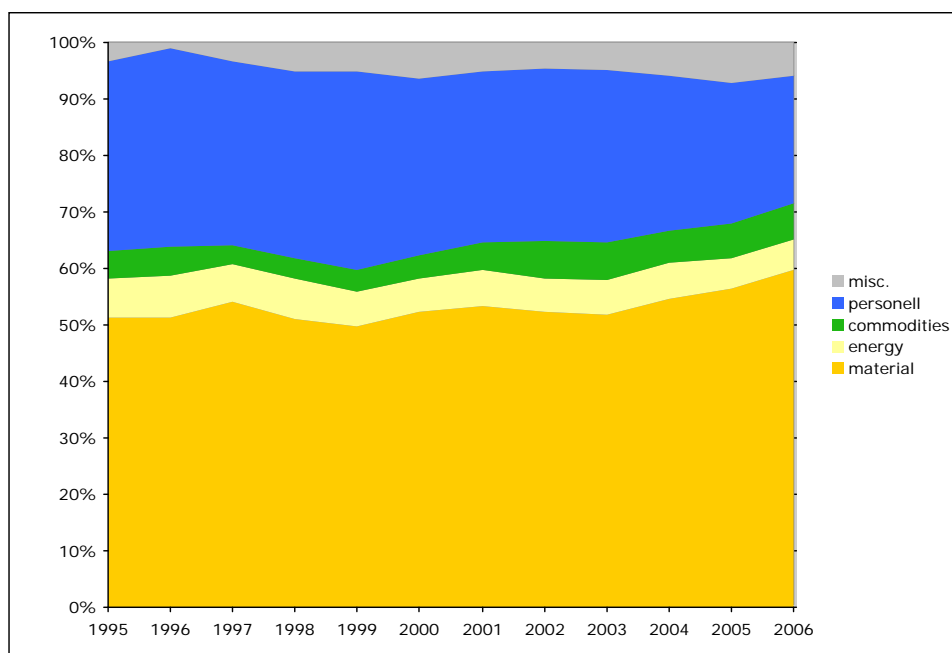
#### **4.3 Steel industry and EU policy**

Europe has a very innovative and diversified steel production. Developing solutions that minimize material and energy input is to a large extent part of the economic interest. The challenges are certainly the tightening regulations for CO<sub>2</sub> emission in Europe,



which could have negative influence on competitiveness of the European steel industry. Without an international carbon regulation there is some risk that new steel production plants might be built in countries without strict regulations (so-called carbon leakage). A close dialogue between politics and industry can prevent a massive dislocation of production. Competitive substitutes are rare and ubiquitous application of steel from ship industry to home appliances will secure high demand.

Figure 4-17: Development of cost structure in metal industry in Germany



Data: DESTATIS

- Lead markets: Suitable strategies can make an important contribution to develop lead markets for resource friendly technologies and products. The European steel industry already connects the most important area applications on its technology platform ESTEP (European Steel Technology Platform): construction, automotive, mechanical engineering and metal goods. Here the research and development for products follows an integrated approach, which considers the resource and energy efficiency comprehensively. The EU also promotes corresponding innovation in the context of a lead market initiative for Europe (e.g. sustainable construction, recycling). These lead markets have high relevance for the steel industry because steel is found in all lead markets, sometimes as high-tech material, sometimes as mass product. However the life-cycle perspective is essential for any comprehensive approach and should be addressed stronger.

- Standardization: Standards and (technical) norms are very important if innovative and new approaches, processes and materials shall be applied in practice. Certain existing standards can limit the potentials of those new innovations, also with regard to resource productivity. One example is the application of high-tensile steels restricted due to inflexible technical regulations.

- Implementation of efficiency targets as well as a life-cycle perspective in infrastructures: The largest potentials to achieve resource productivity can be exploited in steel applications, which are connected with the need for large amounts of steel. With regard to steel, all kinds of infrastructures (incl. construction and buildings) play an important role, whereas decisions about the renewal and expansion of both public infrastructures and industrial production structures characterize the use of steel and other resources for long periods. Therefore, at an early planning phase it should be considered how the potentials of steel – as well as other materials – can be used to improve resource productivity in a life-cycle and systemic perspective.

- Light weight materials and products: These activities can be aligned with the proposal on a Technology Platform for lightweight products, in particular for cars, because the automotive sector is one of the largest customers of steel industry.

The report concludes that the EU system of technology-oriented and information-based instruments should fully be applied to harness the increase of resource productivity. In addition, market-based incentives ought to be considered: it is recommendable to expand the current base of eco-taxes gradually from energy to non-energy resources (construction minerals, land, metals, industrial minerals, other fossil fuels). Acknowledging the relevance of construction minerals and the difficulties to regulate metal commodities, the proposal is to introduce a **European-wide minimum taxation on construction minerals** as a pillar for increasing resource productivity in the construction area.

*"Successful political and economic systems have evolved flexible institutional structures that can survive the shocks and changes that are a part of evolution."  
Douglass C. North (1994) AER 84/3 p. 359*

# 1. Definitions and measurements of resource productivity

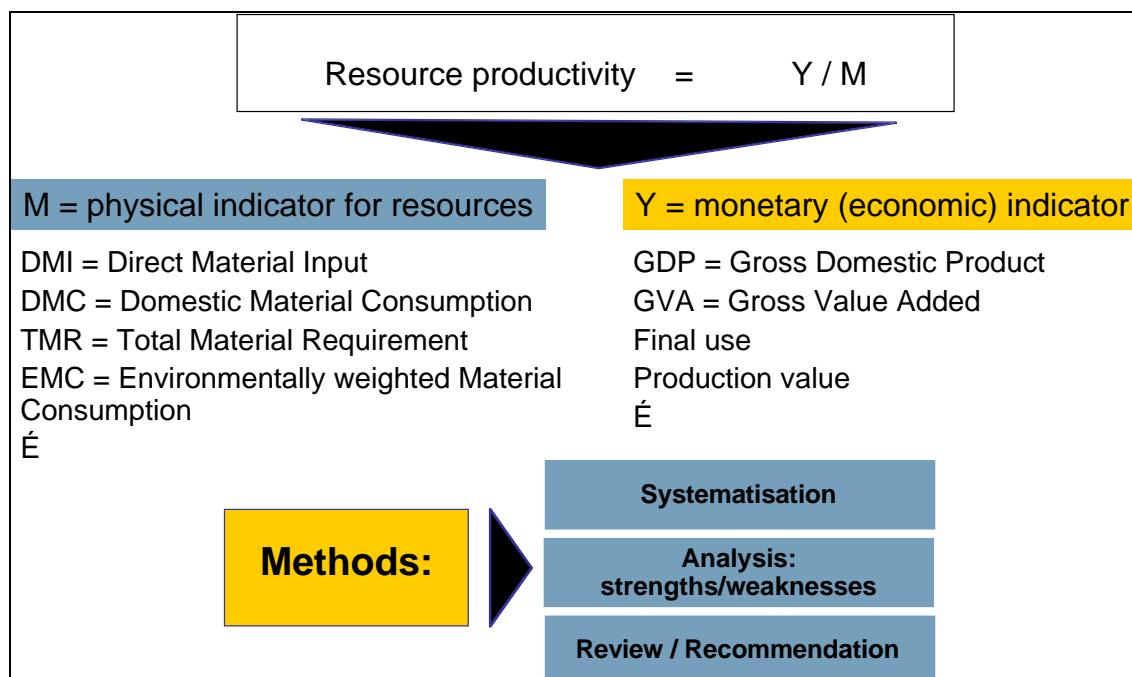
Bettina Bahn-Walkowiak, Raimund Bleischwitz, Sören Steger

## 1.1. Introduction

Resource productivity describes the relation between resource inputs and economic outputs. Since there is no such thing as a “productivity theory”, there is no single, clear-cut definition hitherto. Instead, definitions vary among the scientific articles/studies and policy documents using the term. A recent handbook by OECD (2008) now has brought clarity in this debate.

The following sections will give an overview of the main definitions and arguments in terms of different applications of resource productivity and will then systematise the definitions and related indicators (measurements) with respect to their application fields and policy levels. Furthermore, strengths and weaknesses towards competitiveness and environmental policy will be analysed and inconsistencies will be explored and discussed (see figure below).

Figure 1-1: Indicators/measurements of resource productivity and goals of the subtask



The conventional definition applies resource productivity as a ratio between a monetary indicator (Y - numerator) and a physical indicator (M - denominator) for material or resource input. Voet *et al.* refer however to the conceptual problem that “*resources themselves do not generate value added if no labour is put into the extraction and refining of resources*” (Voet *et al.*, 2005, p. 87)<sup>3</sup> and therefore suggest the term resource efficiency. Quite a few differences exist regarding the question whether the inverse of productivity is intensity or efficiency (e.g. Voet *et al.*, 2005, OECD 2008a, p. 142) or if both are the same (e.g. OECD 2003, p. 13; Moll and Gee, 1999, p. 10). Many authors define resource efficiency as the reciprocal of productivity. In turn, Dahlström and Ekins argue that this ratio is called intensity because an efficiency indicator had to raise two identical (physical) variables, such as material output divided by material input (Dahlström and Ekins 2005, p. 175). They thus use the monetary indicator Y for the productivity *and* the intensity terms. Differently, the MIPS (Material Intensity Per Service unit) concept uses exclusively physical units MI (material intensity) in kg / service unit and argues that the reciprocal of this is the resource productivity of a certain good (and could even be called eco-efficiency) (Schmidt-Bleek 1994, p. 118). Although the issue has not been solved finally, several contemporary environmental scientists and economists prefer the resource productivity term due to the analogy of labour and resource productivity that calls the attention to the serious disproportionate increases of labour and resource productivity over time (Weizsäcker, 2007; Bleischwitz, 1998). The following box gives some examples how resource productivity developed from a concept to a measure.

### Box 1: Resource productivity – from concept to measurement

“In formal terms, ‘resource productivity’ is a ratio: welfare / use of nature. This ‘ecoefficiency’ ratio expresses how much benefit or welfare is achieved from one unit of ‘nature’. Increasing ‘eco-efficiency’ means therefore, ‘achieving more from less’ which is an important element of sustainability”.

$$\text{resource productivity} = \text{welfare} / \text{use of nature}$$

$$\text{eco-intensity} = \text{use of nature} / \text{welfare} \text{ (Moll and Gee, 1999, p. 10)}$$

•

“Resource productivity [...] focuses on new technologies to reduce material inputs while generating the same or even better ultimate services from outputs. Such an increase in resource productivity is the mirror image of a decrease in material intensity as proclaimed by the MIPS indicator” (Bartelmus, 2002, p. 173).

•

“The strategic approach to achieving more sustainable use of natural resources should lead over time to improved resource efficiency, together with a reduction in the negative environmental impact of resource use, so that overall improvements in the environment go hand in hand with growth. The overall objective is therefore to reduce the negative environmental impacts generated by the use of natural resources in a growing economy – a concept referred to as decoupling. In practical terms, this means reducing the

<sup>3</sup> This statement may provoke discussion with ecologically oriented economists who consider nature as value provider; however we do not enter this discussion here.

environmental impact of resource use while at the same time improving resource productivity overall across the EU economy” (CEC, 2005).

•

“[...] the term ‘resource productivity’ is [...] put in a welfare perspective and is understood to contain both a *quantitative* dimension (e.g. the quantity of output produced with a given input of natural resources) and a *qualitative* dimension (e.g. the environmental impacts per unit of output produced with a given natural resource input). Energy efficiency is excluded, although it is recognised that energy efficiency and resource productivity are interrelated” (OECD, 2008e, pp. 1 and 4).

•

“Resource Productivity: The indicator is defined as the ratio between gross domestic product (GDP) and domestic material consumption (DMC). DMC equals domestic extraction used plus imports minus exports (expressed in physical units). Domestic Material Consumption measures the annual amount of raw materials extracted from the domestic territory of the focal economic area, plus all physical imports minus all physical exports. It is important to note that the term ‘consumption’ as used in DMC denotes ‘apparent consumption’ and not ‘final consumption’” (Eurostat, 2008).

The EU *Thematic Strategy on the Sustainable Use of Natural Resources* (CEC, 2005) has formulated the objective to design a highly aggregated but comprehensible indicator for the material side, comparable to the economic indicator Gross Domestic Product (GDP). This indicator shall include environmental pressures and then be called *eco-efficiency indicator* – a term that is presently rather associated with company- or product-based approaches. Overall, the interpretation and the usage of the terms productivity, efficiency and intensity are still inconsistent in the literature and call for further clarification.<sup>4</sup> As expressed above, our study focusses on resource productivity. The resource productivity term will here be used as relationship between the monetary indicator as numerator to indicate the economic output and the physical term as denominator to indicate the material input as it best corresponds with labour and capital productivity (Moll and Bringezu, 2005, p. 12ff.). Consequently, we follow the latest Eurostat definition for resource productivity (see Box and Chapter 2) as a ratio of two highly aggregated economy-wide indicators (GDP/DMC). However, the current quality profile of the indicator points to restrictions for monitoring and reporting due to the restrictions associated to the use of the denominator DMC and grades this indicator type C<sup>5</sup>.

Resource productivity can be expressed at different levels, depending on the scale of interest. At the level of economies, for example, GDP (Gross Domestic Product) is usually used as the economic parameter, whereas at the meso-level GVA (Gross Value

<sup>4</sup> Another interpretation is that the economic indicator expresses the driver and the physical indicator the pressure which is somewhat plausible for resource productivity but inappropriate for labour and capital productivity.

<sup>5</sup> An indicator is graded “C”, if one or both of the following conditions is fulfilled: Data might have to be interpreted with care, as methodology/accuracy does not meet high quality standards. There are some serious shortcomings with regard to comparability across countries (including the lack of data) and breaks in series for several countries which seriously hamper comparison over time (including the lack of data). GDP, for example, is graded A because the measurement is consistent all over Europe due the council regulations on the European system of national and regional accounts.

Added) is most commonly used (e.g. Acosta-Fernández, 2007b). At the level of firms, resource productivity does not necessarily have to be expressed in economic terms but can also be related to the use (service units, mechanical output) of the produced goods and services (e.g. Ritthoff, Rohn and Liedtke, 2002).

## 1.2. Macro level

At the level of economies, *Economy-wide Material flow analysis* (EW-MFA) and derived indicators are most commonly used to quantify the level of material and resource use by using the indicator **Direct Material Input – DMI** (OECD, 2008, e.g. Government of Japan 2003 for Japan), **Domestic Material Consumption – DMC** (e.g. Voet *et al.* for Europe) or **Total Material Requirement – TMR**, (e.g. ETC-WMF, 2003; Eurostat 2007 for Europe). Sometimes different resource productivities and decoupling performances are compared using different material flow indicators (e.g. ETC-WMF, 2003 for Europe). Many theoretical combinations of the economic (GVA, GDP, production value, final use) and physical parameters (DMI, DMC, TMR, TMC) are possible.

The methodology of MFA is internationally widely established and harmonised (e.g. via an OECD working group with participation of the Wuppertal Institute) at the macro level, thus allowing for cross-country comparison in case the measurements of the material data correspond. Difficulties are associated with the quantification of the indirect material flows (ecological rucksacks) of imports, which hinders the correct calculation of the TMR.

Yet recent studies conducted for the EU and its Member States, the USA and Japan (Bringezu and Schütz, 2001a; ETC-WMF, 2003; Bringezu, 2002; Scasny *et al.* 2003, Mäenpää *et al.*, 2001; Moriguchi, 2002; Rogich/Matos, 2002) have shown that an increasing share of resource requirement and associated environmental burden is shifted abroad. The resource requirement of national economies is thus systematically and to an increasing extent underestimated.<sup>6</sup>

The following table shows main physical and monetary indicators and gives a short note on strengths and weaknesses for each. Following the Eurostat definition of resource productivity (GDP/DMC) that will be used in the course of this report (empirical investigation of European resource productivities, see Chapter 2) further important indicators will be presented here in order to give an impression how the application of indicators can influence the results.

---

<sup>6</sup> Former approaches differed between domestic resource productivity and total resource productivity (see e.g. Hinterberger, Moll and Femia, 1998).

Table 1-1: Summary of indicators and measures to calculate resource productivity at macro level

SUMMARY OF INDICATORS AND MEASURES TO CALCULATE RESOURCE PRODUCTIVITY			
Economic entity	Indicator	Strengths	Weaknesses
<b>MACRO - economy-wide MFA International / national</b>	<b>DMI</b> (Direct Material Input) $DMI = DEU + Imports$	components based on statistical sources that are easily available, good data basis for EU and most OECD countries	only accounts for materials that enter the domestic production system (no domestic hidden flows) and also disregards upstream indirect flows of imports, i.e. it does not monitor 'shiftings' through the import of raw materials
	<b>DMC</b> (Domestic Material Consumption) $DMC = DMI - Exports$	components based on statistical sources easily available; preferable in the context of highly raw material exporting and trading countries (Rotterdam effect)	only accounts for materials that enter the domestic consumption system (no domestic hidden flows) and also disregards upstream indirect flows of imports, i.e. does not monitor 'shiftings' through the import of goods and semi-manufactured goods
	<b>TMR</b> (Total Material Requirement) $TMR = DMI + HF$	accounts for all used and unused primary materials and indirect flows associated to import needed for the domestic production system, thus monitors transboundary 'shiftings' by imports as unused materials for these usually remain in the country of origin	data availability restricted, has to use coefficients to extrapolate / conversion of unused materials and indirect flows into raw material equivalents, due to partly insufficient data controversially discussed
	<b>TMC</b> (Total Material Consumption) $TMC = TMR - exports - HF \text{ of exports}$	includes all primary materials used and unused and indirect flows associated to domestic consumption	does not consider exports which in fact contribute to domestic economic performance
	Recycling rate	shows progress in closing the material loop when used as time series	data inconsistent and hardly reliable; none of the indicators above measures recycling rates directly, may show them indirectly by decreasing inputs

	<b>Nominal GDP</b> in current prices	<b>Monetary indicators</b>	easily available	not appropriate due to great range of prices
	<b>GDP in PPP</b>		one-point-in-time comparisons, cross-country comparisons	not for over time comparisons
	<b>GDP in constant prices</b> (market value of all final goods and services produced within a geographical entity within a given period of time)		world wide usage; over time comparisons, monitoring of progress, indexing (start year to 100), cross-country comparisons	data must be available for base year, otherwise not comparable; does not differentiate between ecological "constructive" and "destructive" (economic) activities

Source: Own compilation, WI 2008.

### 1.3. Meso level

At the sectoral level, physical and monetary input-output tables can be used to relate the economy-wide resource requirement to individual sectors and/or to the different categories of final use. The incorporation of indirect flows associated with upstream sectors does, however, pose problems. There are also some methodological difficulties arising from the use of monetary input-output tables, concerning the attribution at the sectoral level. For instance, distortions can emerge due to potentially fluctuating resource prices over time and the fact that quantities do not necessarily correspond with prices (e.g. Acosta-Fernández, 2007a). The equalisation and comparability of PIOT and MIOT is continuously under discussion (e.g. Weisz and Duchin, 2004). A less advanced and less comparative measurement may be based upon calculation by industry (see e.g. the sustainability report by the European Aluminum Association 2007).

The following table shows main physical and monetary indicators and gives a short note on strengths and weaknesses for each. Following the Eurostat definition of resource productivity (GDP/DMC) that will be used in the course of this report (empirical investigation of European resource productivities, see Chapter 2) further important indicators will be presented here in order to give an impression how the application of indicators can influence the results.



Table 1-2: Summary of indicators and measures to calculate resource productivity at meso level

SUMMARY OF INDICATORS AND MEASURES TO CALCULATE RESOURCE PRODUCTIVITY			
Economic entity	Indicator	Strengths	Weaknesses
MESO - sectoral	<b>DMI-P</b> (Direct Material Input related to sectoral production)	includes biotic/abiotic material inputs for further processing	does not consider unused, unvalued materials
	<b>TMR-P</b> (Total Material Requirement related to sectoral production)	includes primary material input, incorporated materials in intermediate inputs and indirect flows	data insufficiencies
	<b>ITMR</b> (Total Material Requirement Induced by production for final demand)	linkage of sectoral TMR with produced amount for final use (cumulated sectoral resource use)	requires mathematical computation model; TMR data insufficient
	<b>GVA</b> (Gross Value Added)	easily available	does not consider intermediate inputs; basically a measure for economic performance and additional value created by the respective production
	<b>GDP</b> (sectoral)	monetary value of all domestically/sectoral produced goods and services	excluding intermediate imports contributing to this
	<b>ZP</b> (monetary value of intermediate production output)	accounts for intermediate outputs	not standardised
	<b>LV</b> (monetary value of production for final use)	accounts for products and services induced by final use and exports	not standardised
	<b>GO</b> (monetary value of overall output)	accounts for products and services induced by intermediate and final demand	not standardised
	<b>Physical indicators</b>		
	<b>Monetary indicators</b>		

Source: Own compilation, WI 2008.

## 1.4. Micro level

At the micro level, two different approaches can be used to quantify resource productivity: a *product-based approach* (e.g. MIPS, JEMAI, 2004) and a *company-based approach* (e.g. Busch, Liedtke and Beucker, 2006; EnvIMPACT 2006). Product-

based approaches include life cycle analyses or assessments, which by definition do not correspond to company-based or economy-based approaches. Due to the inclusion of the process and value added chains the system boundaries diverge. Statistical data concerning the resource use of companies are usually only published on a voluntary basis, for example, in form of environmental reports and environmental management systems, which are often not made public. Quantifying resource productivity at the level of firms is thus not at all an easy task. In addition, due to slightly different approaches taken by different firms, results are often not comparable amongst each other nor are they compatible with the quantifications at the macro and meso level.

Table 1-3: Summary of methods to calculate resource productivity at micro level

<b>SUMMARY OF METHODS TO CALCULATE RESOURCE PRODUCTIVITY</b>			
<b>MICRO - Firm / Plant / Product</b>	<b>Method</b>	<b>Strenghts</b>	<b>Weaknesses</b>
	Business/local based approach	specific information for health, chemicals, wastes, etc.	complexity of supply chains; poor availability of data, particularly downstream
	<b>LCA</b> (Life Cycle Assessment - Product based approach)	includes all material and energy flows, helps identify product-based environmental pressures and effective intervention points	labour-intensive, allocation of pressures to product components is difficult and somewhat arbitrary
	<b>SFA</b> (Substance Flow Accounts - substance based approach)	useful to identify hot spots for critical substances such as chlorine, sulphur, mercury, etc.	labour-intensive

Source: Own compilation, WI 2008.

## 1.5. Discussion

Expressing resource productivity by means of material flow indicators has a number of advantages. MFA indicators are deeply rooted in the material balances of countries – considering used and unused materials, imports and exports. They emphasise and investigate the material base of an economy and are easy to understand while using a common mass unit (metric tonnes). As soon as a resource productivity indicator shall serve as a tool for measuring and benchmarking competitiveness, some conceptual and statistical problems have to be mentioned.

It is significant that the resource productivity ratio (as defined by most of the authors) is a physical/non-physical parameter measuring two things in different units. This is partly due to insufficient data but also owing to the political target to reduce the environmental

pressures without reducing economic output (Acosta, 2008, p. 87). A combined factor can observe both at the same time. However, at least three threads of critique can be identified in the context of resource productivity measuring.

- There is an overall concern related to the use of monetary indicators such as GDP at the macro level.
- A second line expresses misgivings in the context of using of the abovementioned indicators at the meso level.
- Another strand is objections raised against the overall use of physical mass indicators.

GDP is the monetary market value of the total amount of goods and services produced in a country in a given period (minus the goods and services used for intermediate consumption). It is a measure of gross output.<sup>7</sup> *“Everything that has a price and is commercially traded adds to GDP. This happens by the mere fact alone that it is produced and bought”* (Goossens *et al.*, 2007, p. 12). Any good or service that does not have a price simultaneously does not enter the GDP calculation, in particular (and important for this context) environmental damages and other **negative externalities**.<sup>8</sup> Although it is not differentiated between costs and benefits within GDP calculation (which is another serious point of criticism not dealt with here), unpriced environmental costs are left unconsidered contributing to a systematic overestimation of a country’s wealth (Bergh, 2007, p. 8). Consequently, growth strategies that are coupled to GDP growth do not only strive for the increase of the economic benefits but also for the inbuilt environmental and partly unknown (in economic prices) damages. One of the alternative indicators, e.g. SNI (Sustainable National Income), has made its way into the official Handbook of National Accounting but is far from being used as a standard measurement.

Against this background Acosta (2008) questions the reasonable use of Gross Value Added (GVA) at the meso level because it may not consistently reflect the physical input in monetary terms. Instead and due to its correspondency to the income accounting, intermediate inputs and outputs are left out of consideration leading to partly enormous distorting effects for the measuring results and to misinterpretations. Acosta therefore emphasises the essential conceptual **compatibility** of input and output figures as is done, for example, in the computation of labour productivity (number of working hours/Gross Value Added incl. wages and salaries): *“Input and output figures are compatible when the monetary output figure reflects what is actually produced on the basis of the physical input figure”* (Acosta, 2008, p. 93). To put it simply: Depending on the market prices, for example, a clever businessman could achieve an

---

<sup>7</sup> See e.g. the recent EU discussion on this issue at: [www.beyond-gdp.eu](http://www.beyond-gdp.eu). The GPD critique is very elaborated by now and can be traced back to the 1960s. For a detailed and ongoing discussion see Bergh, 2007 and Goossens, 2007.

<sup>8</sup> See e.g. the relevant EU data and methodology with emphasis on energy related externalities at: [www.externE.info](http://www.externE.info).

increased resource productivity resulting from a successful business management and a good operating profit since the GVA not only includes depreciations but also profits.

Another issue is that production sectors require the intermediate inputs eventually for the satisfaction of **final demand**. Sectoral accountings using DMI/DMC figures do not display the actual physical final demand but what is needed for the production process itself. This is why service sectors can gain good results because they – by definition – do not use many resources for their business activities at first sight. Their business activities however induce material inputs in other sectors, e.g. for mobility, that are not displayed in the sectoral calculation and hence carry on with the problem of non-captured and unvalued physical inputs. As an approach to this problem, the gross value of the intermediate output (production value) and/or the material input induced by the final demand may be used substituting the sectoral GVA in order to mirror the monetary value of the material input in a more appropriate way (Acosta, 2008, figures on the German economy available).

Skepticism is frequently expressed with respect to the **aggregation** of qualitatively different materials like is done in the accounting of DMI and DMC. Measuring the weight of materials would not provide enough details concerning the environmental impacts and pressures (Pearce, 2001) and biodiversity losses or changes in the environmental quality were not captured (Goossens *et al.* 2007, p. 45). As a matter of fact, highly aggregated indicators such as DMI at national level possibly hide “*important variations in their constituent variables*” (OECD, 2008, p. 80), i.e. the quantities of certain materials may change from year to year while the aggregated figure remains constant. Since different material categories are associated with different environmental pressures the aggregated figure may contain – owing to the economic structure of a country – completely different environmental impacts. Detailed analyses of the structural components along with a display of material groups, for example, within the scope of a structural decomposition analysis, can defang this problem (Hoekstra and van den Bergh, 2002).

Another approach is **weighting** materials with pressure coefficients. Voet *et al.* introduced the ‘*environmentally weighted material consumption indicator*’ within a recent study and showed evidence that large consumption volumes are nevertheless associated with high pressures (Voet *et al.*, 2005). As long as the weighting by coefficients is no standardised method, material flow indicators definitely serve as proxies for potential environmental pressures associated with various material groups. Pearce extended this problem to the measuring of resource productivity and suggested a ‘*toxicity weighted resource productivity*’ while emphasising this being a highly complex task (Pearce, 2001). Further suggestions for improving the resource productivity indicator advocate including the damage costs into the calculation (Pearce, 2001) or a population factor for regional assessments (Hanley *et al.*, 2004).

The system boundaries and overlaps between unused materials, hidden flows, ecological rucksacks and indirect flows give sometimes cause for confusion. While the

OECD report (2008, referring to Eurostat 2001) gives three slightly different definitions for the terms **hidden flows, indirect flows and ecological rucksacks**, according to Bringezu (2004) they may be used synonymously irrespective the unused and associated materials are called extraction-, concentration- and processing-wastes or life-cycle-wide material and energy requirements, which are either crossing or not crossing the country border. They are not physically embodied into the product and economically accounted for yet, i.e. they are not internalised as economic and environmental costs. For the issue of shifting environmental problems abroad it is nevertheless important to precisely discriminate which materials enter the domestic economic system and which do not.

## 1.6. Conclusions

Following the OECD handbook 2008, the measurement methodology has been further harmonised at the macro level of countries. The data situation and reliability are at a reasonable but amendable level, especially for the indicators DMI / DMC. Reporting should be advanced regarding standardisation and legal obligation. Since shiftings of environmental pressures through imports and relocations of industries are not monitored by these two indicators much needs to be done regarding the data and calculation of TMR and TMC. The research on hidden flows, ecological rucksacks and indirect flows respectively, captured via TMR / TMC should deserve a higher priority. To put this message clear: relying on DMI / DMC alone features a too narrow understanding of resource productivity. On this account, a data base for coefficients of indirect material flows of finished goods as well as raw materials and semi-finished products traded at the world market should be advanced and established (Schütz and Ritthoff, 2006).

Policy has to carry on with the discussion and evaluation of the main indicators and indicator sets that need to be chosen for the measurement and comparison of resource productivities on national, EU, OECD and UN level. This is being done within the follow-up process of the *Thematic Strategy on the sustainable use of natural resources* aiming at the identification of a basket of indicators to picture the environmental impacts of nations from the use of natural resources (Best *et al.*, 2008a and 2008b). It should also be targeted though to the optimisation of a reporting system that is able to capture the economy-wide domestic and external demand for resources of nations which is a necessary complement for the further development of indicators like the EMC (Environmentally Weighted Material Consumption). For the time being, there is no European legislation concerning the indicators resource productivity and DMC.

Given the interest in material efficiency for industry, the data harmonisation and gathering at the meso level and the micro level should become a top priority, i.e. data comparable with DMI / DMC should first be supported by an international data hub, then followed by more comprehensive approaches. Further development of physical input-output tabulation has to aim at a realistic attribution of the material inputs to the receiving and processing sectors and periodic updates. In addition, policy should

encourage the development of a reporting system of economic sectors which could establish a basis of sectoral policies for the increase of resource productivity in material intensive industries (Schütz and Ritthoff, 2006).

However, inherent limitations and related tasks such as externalities not included in GDP and GVA should not be forgotten. There is an urgent need to address the level of resource use and environmental impacts. The aim should be an open access international data hub, including economic data and scenario analysis (prices, performance, value added of industries). The EU shall thus encourage industries to collect data on resource productivity and it might also take the lead to establish an expert group with Japan to support the G8 3R initiative and the UNEP Panel on Sustainable Resource Management.

At the moment, it is unavoidable to use the indicators which are best qualified to measure and compare resource productivities among as many nations as possible; these are the indicators that can be gained most easily and are statistically robust. For the future, it is most important to advance and extend current methods and statistical bases.

## 2. Empirical Results: Are the EU and other economies on track towards decoupling?

Sören Steger, with contributions by Raimund Bleischwitz

### 2.1. Resource use in the EU27, Turkey, USA and Japan

In this chapter we present an **overview of the development of material consumption** in different economies. We also seek to reveal the difference in material consumption between these countries in relation to the per capita level (Fig. 2-1), the development over time as well as the level of resource productivity (Fig. 2-2 and 2-3).

For the EU15, Japan and the U.S. there are data series available for the period from 1980 to 2000 or until 2004. For the new member states<sup>9</sup> and Turkey DMI / DMC data exist only for the period of 1992-2000. Therefore figure 2-2 displays the data for the EU15, Japan<sup>10</sup> and the United States for the period 1980 to 2004 (or 2000 for Japan and the U.S.) and figure 2-3 shows the data for the entire panel between 1992 and 2000.

The **use of resources** (measured as DMI or DMC, without hidden flows and ‘ecological rucksacks’) **tends to be higher in the EU15 countries than in the new EU Member States and Turkey**. But even within the EU15 the DMI per capita varies between 45t per capita (Finland) and 14t per capita (Italy) – a significant difference. While the majority of new member states plus Turkey has a lower per capita resource consumption than Italy, Cyprus and Estonia are already well above the average for the EU15. United States’ resource consumption per capita is in the top quarter of the countries studied. By contrast, Japan has a resource consumption below the EU average and therewith one of the lowest levels of the industrialised countries within the OECD.

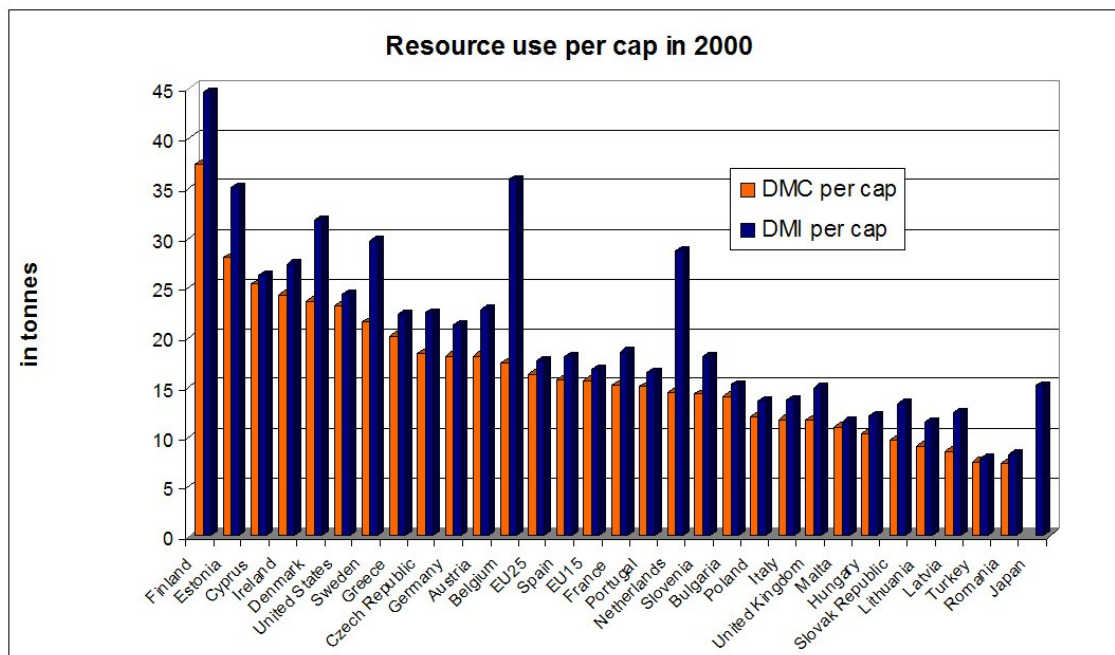
Furthermore, figure 2-1 shows that **in some countries the difference between DMI and DMC is large**; in others the two per capita values are almost identical. While the DMI per capita for Belgium and the Netherlands are well above the average for the EU15, their DMC per capita is only half of the DMI. In both countries the uses of resources are strongly influenced by the **"Rotterdam effect"**, i.e. the impact of exports on these figures. Other countries with a significant disparity between DMI and DMC export parts of their natural endowments and products thereof (wood and wood products

<sup>9</sup> For this study we use data created before the enlargement of the EU to 27 countries. Therefore this study only covers the EU15 and the EU25, although the EU now also includes Bulgaria and Romania. Another feature is the joint compilation of resource use by Belgium and Luxembourg. The data for Belgium thus always refer to Belgium and Luxembourg together.

<sup>10</sup> For Japan, recent data are only available for the DMI.

as well as iron ore in Sweden and Finland, natural gas in Denmark, and oil shale in Estonia).

Figure 2-1: Resource use per capita in 2000



Source: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new Memberstates plus Turkey (ACC): EEA (2003); Kiev Report Annex C; Japan: WI database, USA: WRI Database

There is **significantly less data for the TMR and TMC** than for the DMI / DMC. Often, there is only one year as an example for TMR/TMC, but no continuous time series. Or there are only outdated data series. This is caused by the difficulty of estimating the hidden flows and ecological rucksacks (see previous chapter) and especially the approximation of the ecological rucksacks of imports and exports.<sup>11</sup>

The aim of this chapter is to give a comprehensive picture of resource consumption and resource productivity of economies and to compare the EU27 countries in their use of resources and productivity with non-European countries. Therefore, the poor data situation on the ecological rucksacks makes it reasonable to concentrate on the data for direct material consumption (DMC), despite their methodological weaknesses<sup>12</sup>.

<sup>11</sup> Currently the EU research project "INDI LINK" (<http://www.indi-link.net>) researches different methods of examination, which - if successful - could reduce the burden of assessment in the medium term and thus improve the data situation for TMR and TMC data series.

<sup>12</sup> The DMI or DMC has several weaknesses (see chapter 1): Firstly, due to the lack of ecological rucksacks, these indicators do not indicate the total potential of environmental impact and secondly, the imports and exports are recorded only with their own weight, whereas the local raw materials are measured in "raw material equivalents". This has the consequence that a ton of imported steel is "lighter" than a ton of domestically produced steel, whose iron ore was locally extracted (Moll/Bringezu, 2005, p.9). Thus the increasing shares of imports of raw and semi-finished products in many industrialised countries reduce the DMI and DMC indicators artificially.



## 2.2. Resource productivity of the EU27, Turkey, USA, and Japan

The **resource productivity** results from the ratio of GDP and resource consumption of an economy within a time period, usually a calendar year. The ratio indicates how many units GDP an economy could generate with one unit of resources. To ensure the comparability of data, the countries GDP are weights for purchasing power parity<sup>13</sup>, so that the different purchasing power of one U.S. dollar in the respective countries is considered and exchange rate distortions are excluded. For the denominator the indicator DMC is used, as this indicator seems more suitable for benchmark analyses than the DMI. The report uses the term of “resource productivity” – the precise notion according to OECD (2008) is “Direct Material Productivity” since it refers to DMI / DMC as denominator; the conclusions of chapter 1 apply.

Most of the EU15 countries consume a significantly higher amount of resources per capita and year compared to the new EU member states. However they are able to achieve a significantly higher level of GDP with it. The **resource productivity in the EU15 countries is higher than in the Eastern European countries** (Fig. 2-3). Despite the higher consumption in the EU15, energy and raw materials are used more efficiently than in the new EU member states – a reference both to the potential for increasing the resource productivity as well as the need for addressing the absolute level of resource use.

But even **within the EU15 countries** there are remarkable **differences in the resource productivity**. While the Netherlands, France, Italy, and Britain obtain low levels in resource consumption per capita as well as high levels of resource productivity, the relatively low resource consumption per capita in Portugal is not in line with high resource productivity. In Germany and Austria, however, a fairly high level of resource productivity is achieved with a high amount of resource consumption. The very high per capita consumption of resources in Finland reduces the Finnish resource productivity to the lowest level within the EU15, but is still higher than in some new member states.

Almost all analysed countries could improve their resource productivity over time. With **Greece and Portugal**, at least two EU15 member countries **have dropped their resources productivity**; this drop has also occurred in **Lithuania**. In the new Member States, the resource productivity is not only lower (with the exception of Malta and Hungary), but from 1992 to 2000 the overall improvement was also significantly lower in many new member states and Turkey than in the old Member States. It is worth noting that in 1980 Greece and Portugal were the most efficient economies of the EU15 regarding the use of materials and energy and now they are both at the bottom of the ranking together with Finland. In contrast, UK and Ireland increased their resource

<sup>13</sup> The data for GDP in purchasing power parity was used from the database of the EUKLEMS project (<http://www.euklems.net>). Specifically, the GDP data were converted to a 2005 price level with updated 2002 EKS PPPs.

productivity significantly in the same period, Ireland for example more than doubled its productivity number (Fig. 2-2).

We have first classified the data (for each indicator) into four intervals based on natural breaks in the data, i.e. the biggest gaps in the dataset were used to classify the data into groups. We used this classification method to ensure that similar observations were grouped together in the same interval. With reference to these data, the groups have been labelled as follows: very good, good, fair, and poor performance:

1) **Very good performance:** UK, Italy, France and Netherlands

All four countries show a notably high resource productivity. This is predominantly due to their lower DMC.

2) **Good performance:** Austria, Belgium, Germany and Spain

In the second group are countries which exhibit a relatively high resource use but equally achieve a high GDP (Austria, Germany, and Belgium). In contrast, Spain has a considerably lower resource use per capita but correspondingly a likewise lower GDP per capita.

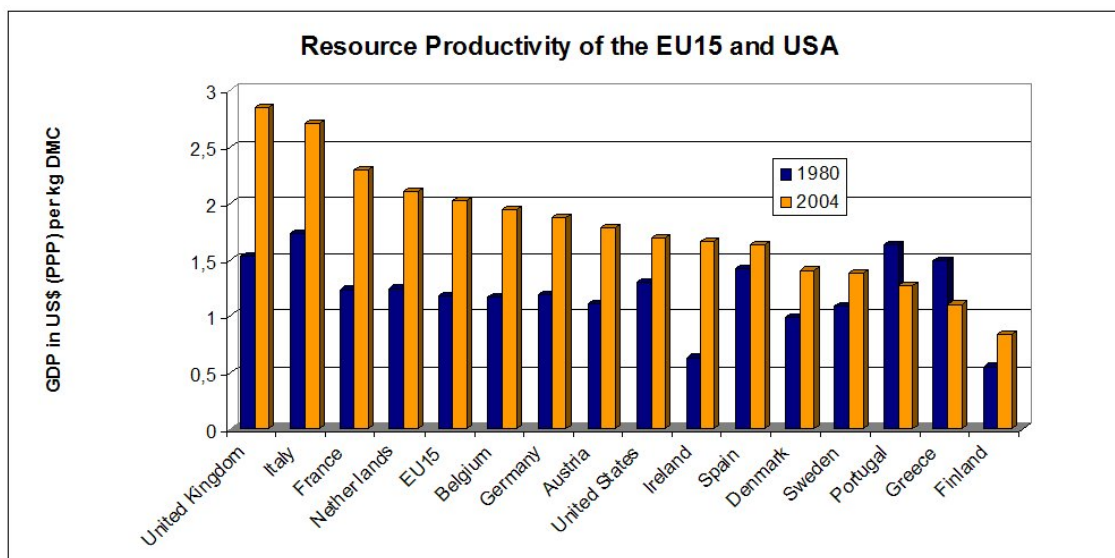
3) **Fair performance:** Ireland, Sweden, Denmark, Portugal and USA

Similarly to the second group this one consists of countries which either are characterised by a very high resource use (Sweden, Denmark, USA) and thus have – despite their high GDP per capita – a resource productivity below average or – as Portugal – show a below average GDP in relation to which the DMC is high.

4) **Poor performance:** Finland, Greece and new member states

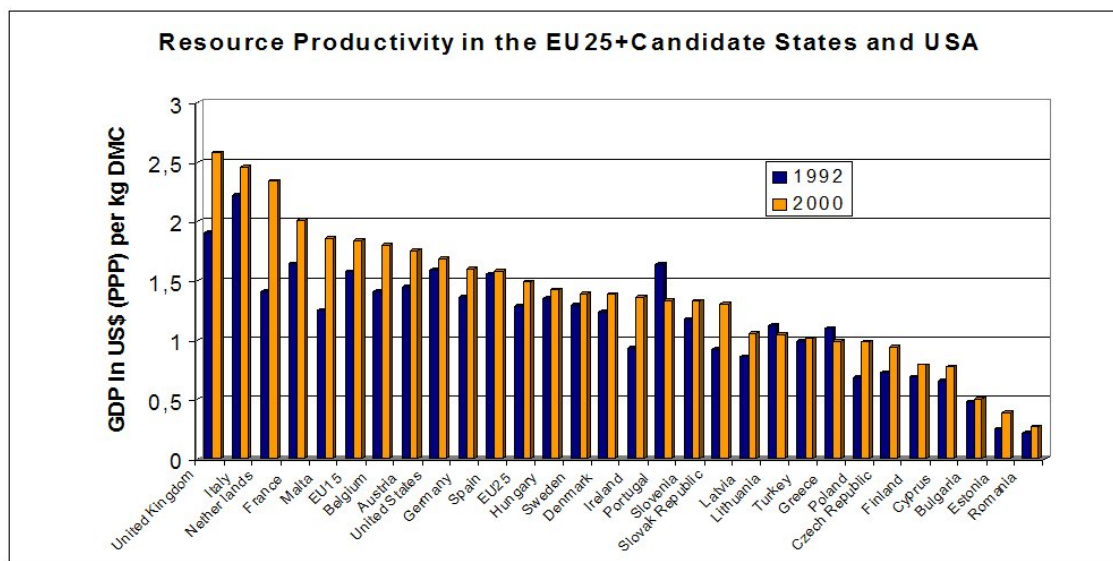
With respect to resource productivity almost all new EU Member States and Turkey are far from EU15 average while in the majority of these countries the DMC per capita is lower than in the old EU15 countries, because the difference regarding the GDP per capita is even bigger. Finland has to be assessed a special case. Notwithstanding its high relatively high GDP per capita it demonstrates a very poor resource productivity due to its exceptionally high DMC.

Figure 2-2: Resource productivity of the EU15 and the USA for 1980 and 2004/2000



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004); USA: WRI Database, GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>

Figure 2-3: Resource productivity of the EU27, Turkey and the USA for 1992 and 2000



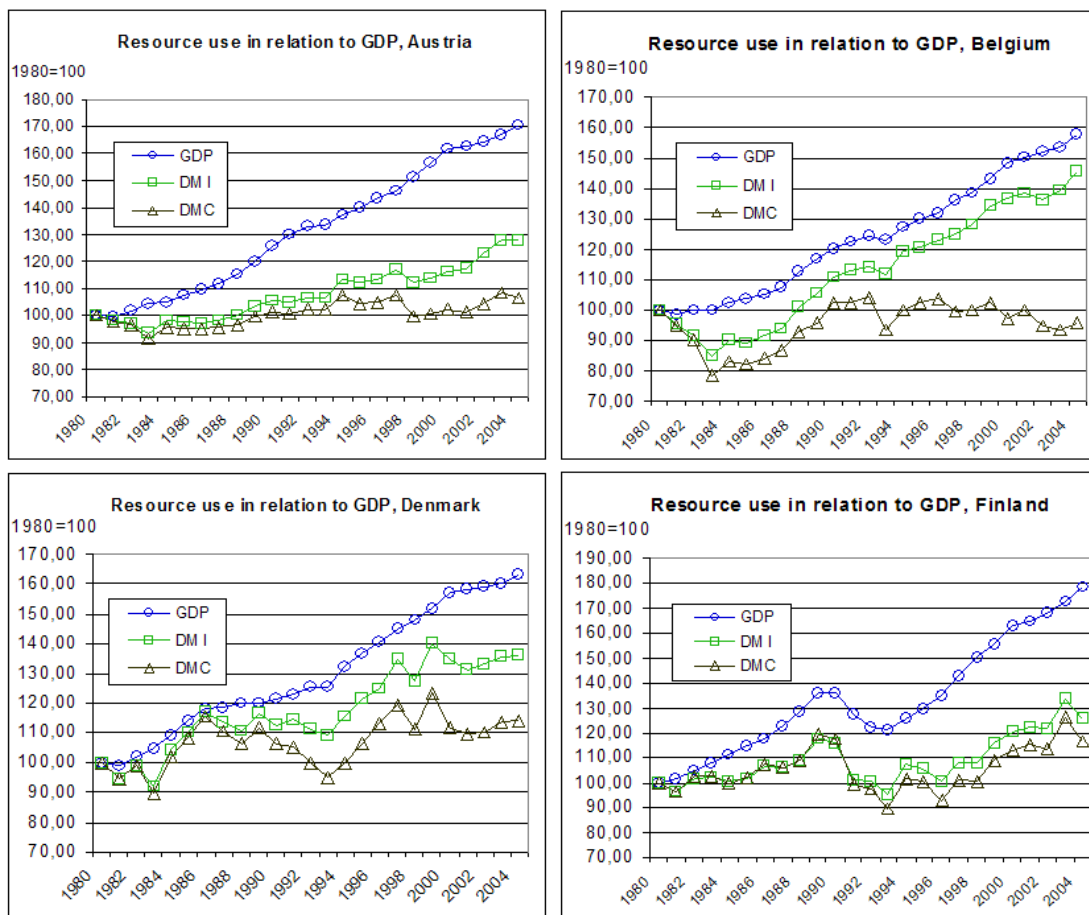
Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003): Kiev Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>

Analysing these data, it becomes clear, that an increasing resource productivity can correspond with an increasing use of resources, namely if the GDP is growing faster than the use of resources. Therefore, increasing resource productivity is not necessarily associated with a reduction in the overall use of resources. From the figures below, it is rather clear that the majority of the EU15 member states have achieved a **relative**

**decoupling between economic growth and the use of resources, but not an absolute decoupling.** In some countries such as France, Italy, and the UK the resource consumption has been stabilised at least in the long term. For Germany,<sup>14</sup> an absolute decoupling of economic growth and resource consumption was detected.

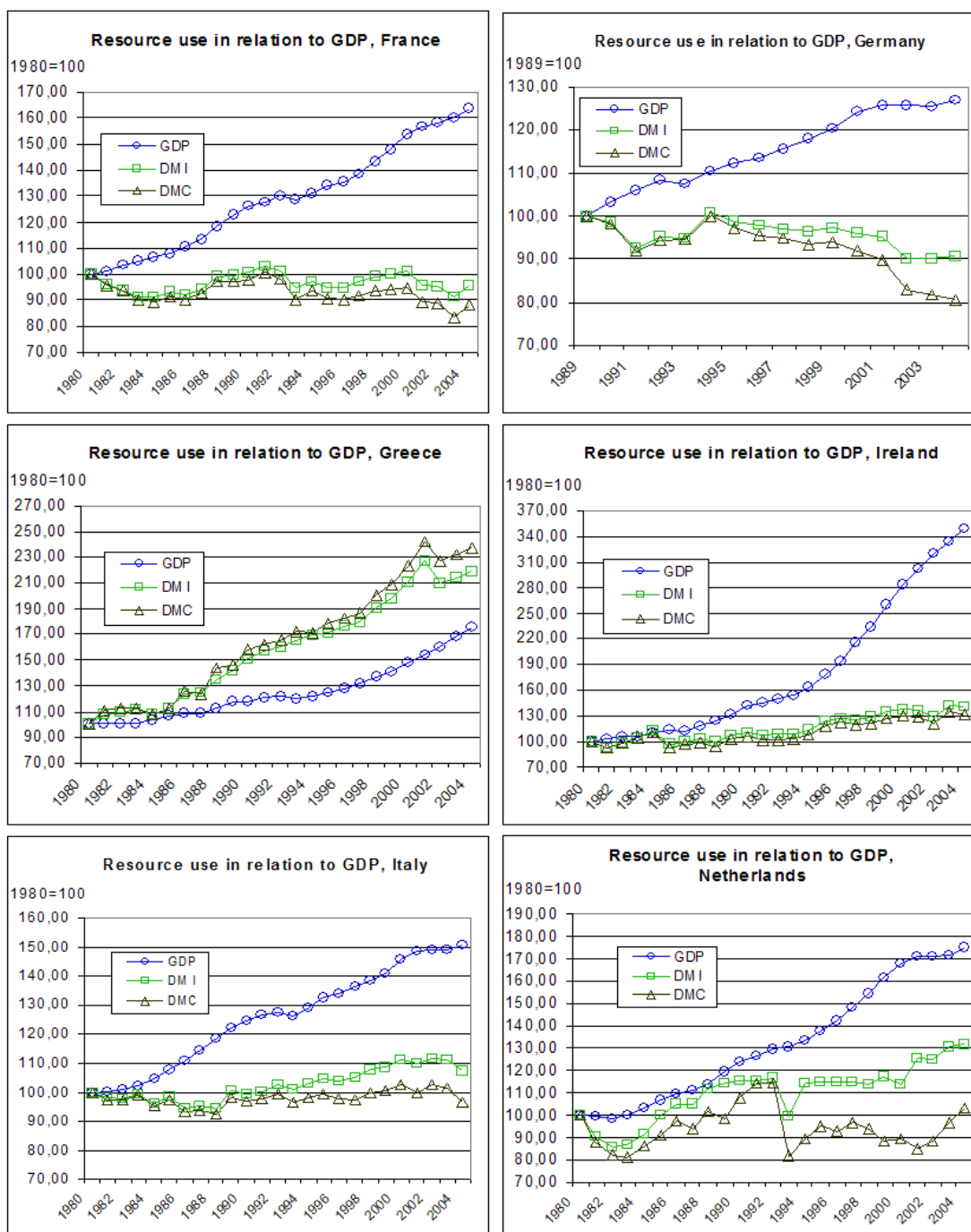
The **average yearly increase in resource productivity was 2.5% or lower** in many countries, thus below the EU resources strategy target of 3% per year.<sup>15</sup> However, there are also countries like France and the UK, whose resource productivity increased with more than 3% per annum since 1980. The EU15 as a group increased its resource productivity since 1980 by an average of 2.9% per year.

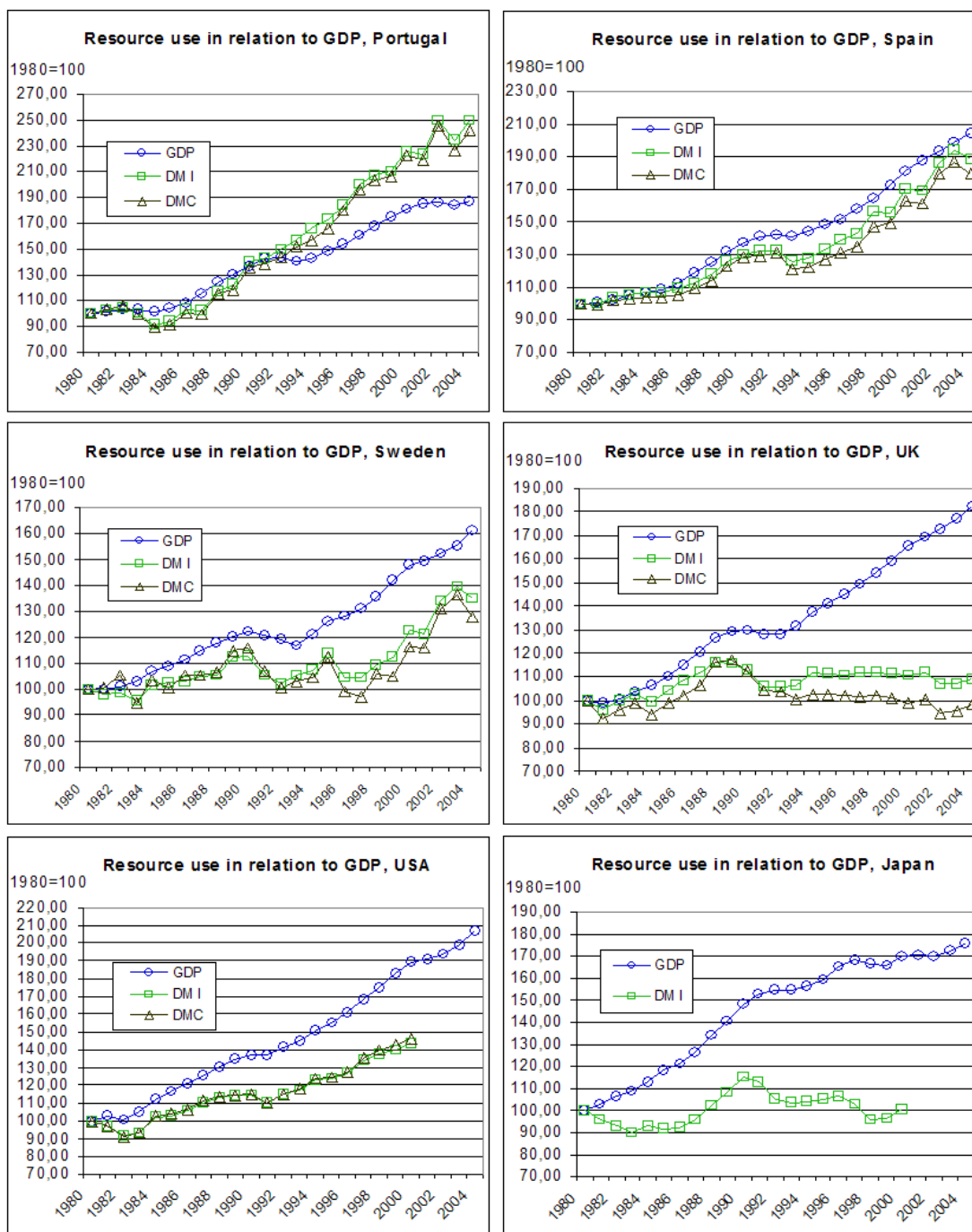
Figure 2-4: Resource use in relation to GDP (EU15 countries, Japan and the USA, 1980=100)

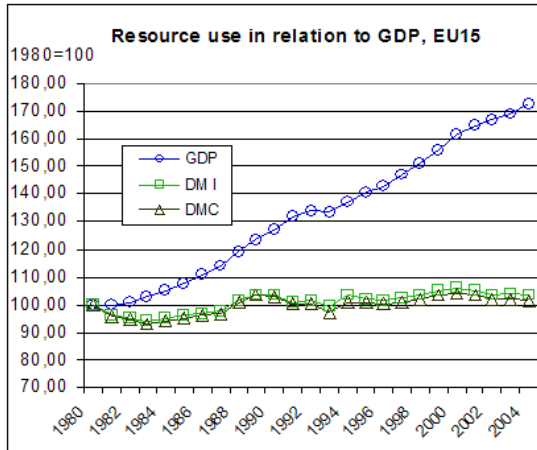


<sup>14</sup> Due to the use of GDP data in terms of purchasing power parity there are only reasonable GDP data for Germany from 1989 onwards available. Therefore, the figures for Germany only cover the period 1989-2004. Since the DMC for the reunified Germany was significantly higher in 1980s than the figure of 1989 and due to the fact that the DMC values for West Germany in the 80s also showed a downward trend, it can be assumed that the shortened time series do not falsify the results.

<sup>15</sup> Cf. CEC (2005), Annex 1 and Schepelmann et al. (2006).



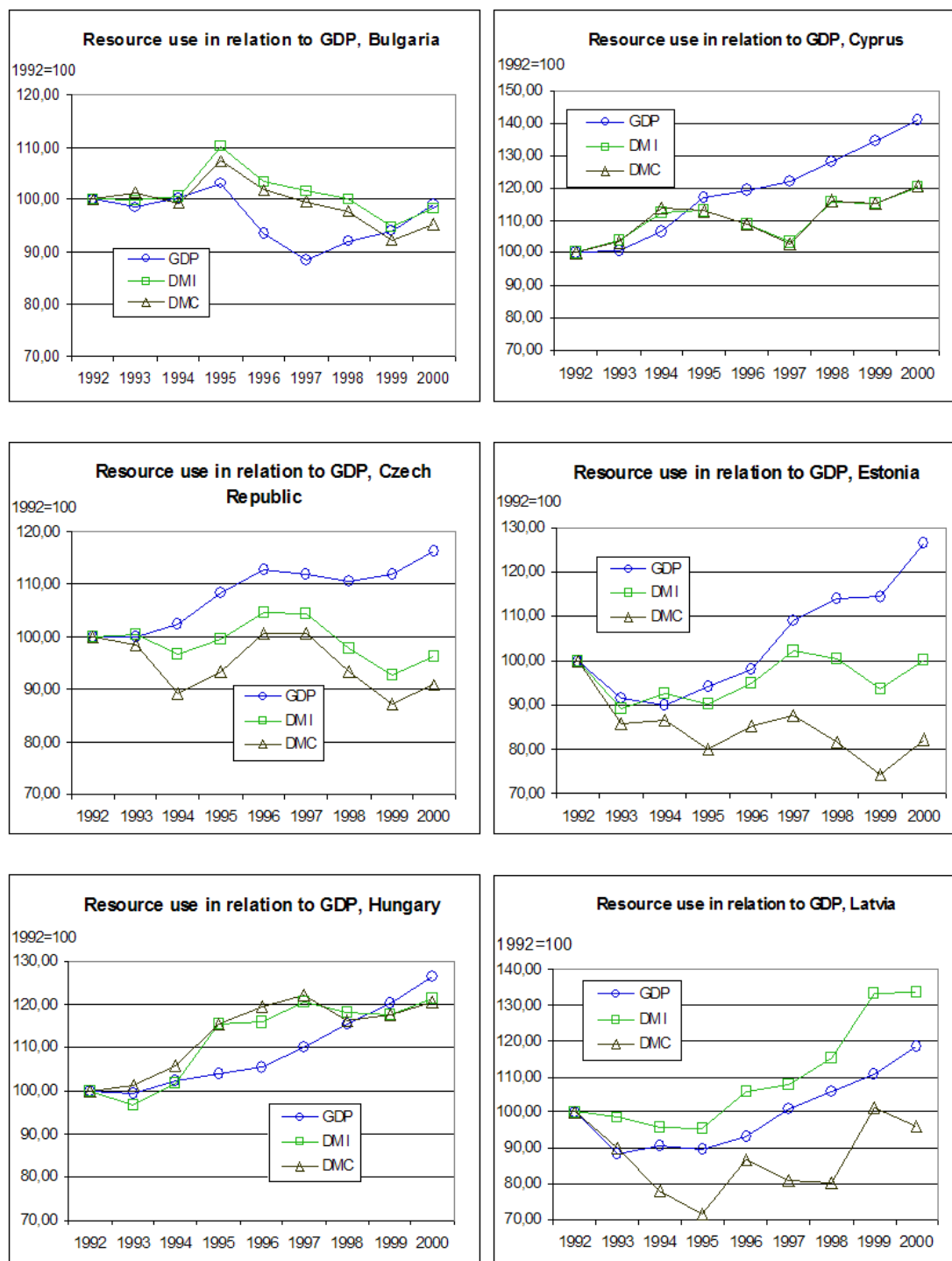




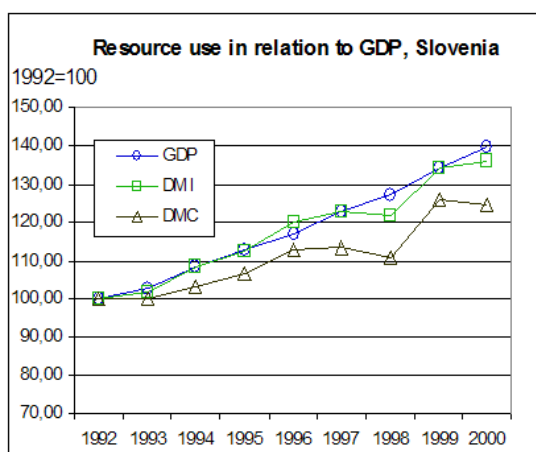
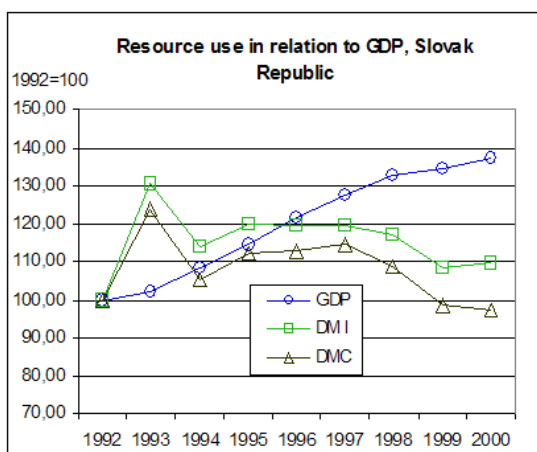
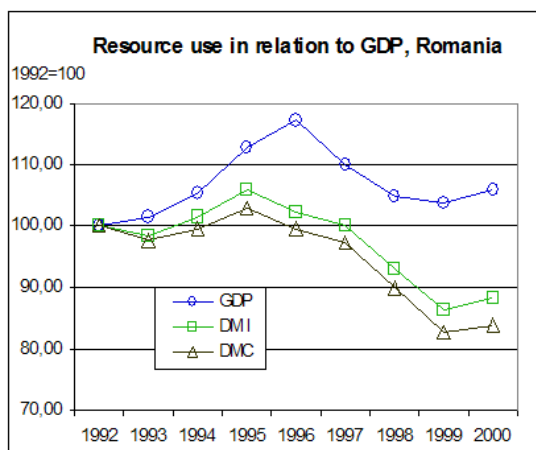
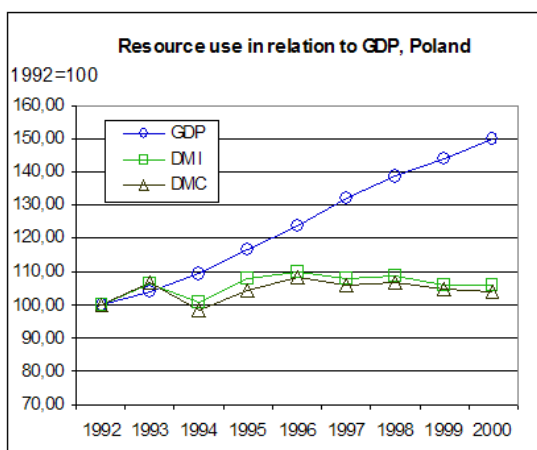
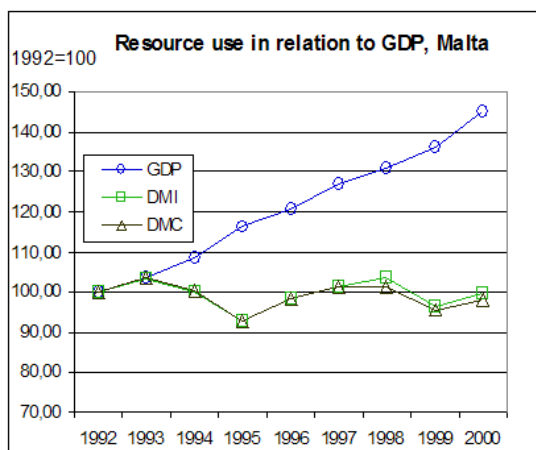
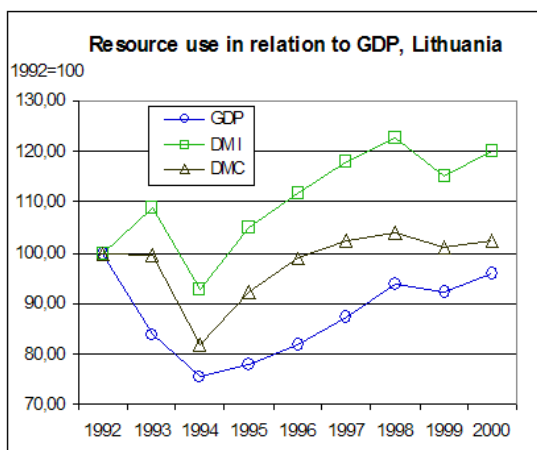
Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; Japan: WI database USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>

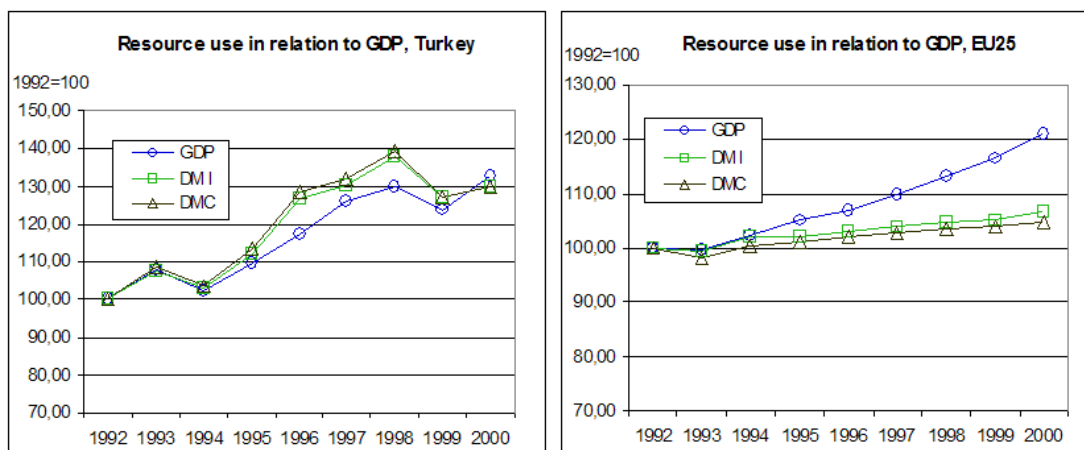
For the new member states and Turkey the development of resource use and the GDP is not as consistent as the longer time series of EU15 countries, Japan and the United States. In many Eastern European countries, a painful transition process took place since the collapse of the old economic system entailing a high level of unemployment, deindustrialisation and impoverishment of large sections of the population – at least on a temporary basis. Consequently, **the GDP fell in many transition countries in the early 1990s. This was often accompanied by a sharp decline in use of resources, indicating an inefficient use of resources in the previous years of socialism.** With the economic recovery starting in the mid-1990s, in most new member states the resource consumption increased again. But there are also Eastern European countries, such as Poland, where a continuous GDP growth could be achieved with stagnant use of resources.

Figure 2-5: Resource use in relation to GDP (new member states of the EU and Turkey, 1992=100)









Source: DMC: EEA (2003): Kiew Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>

## 2.3. Development of resource productivity compared to labour productivity

The **hypothesis** is often stated that economies, sectors and companies have been experienced a focus on labour productivity<sup>16</sup> since the beginning of industrialisation and may do better if they managed to catch up their level of resource productivity (Bleischwitz 2001 and 2005). The rationale lies in the fact, that, in recent years **labour productivity has outweighed the increase in resource productivity** and, as claimed, this in balance goes along with socially undesirable consequences, such as further compression of work, dismissals, increasing burden on the remaining employees, and overuse of natural resources.

Our data (resource productivity as GDP in PPP US\$ per unit DMC in kg,<sup>17</sup> labour productivity as GDP in PPP US\$ per employee) show, however, that at least for the macroeconomic level, any such correlation is only partially to observe. In **several countries of the EU15 and Japan resource productivity has increased faster than labour productivity between 1980 and 2004/2000**.<sup>18</sup> It is hence interesting to look at regional patterns: in the Scandinavian countries, characterised by a high level of resource consumption and in Spain, with a low level of resource productivity, labour productivity has increased faster than resource productivity. In Greece and Portugal the

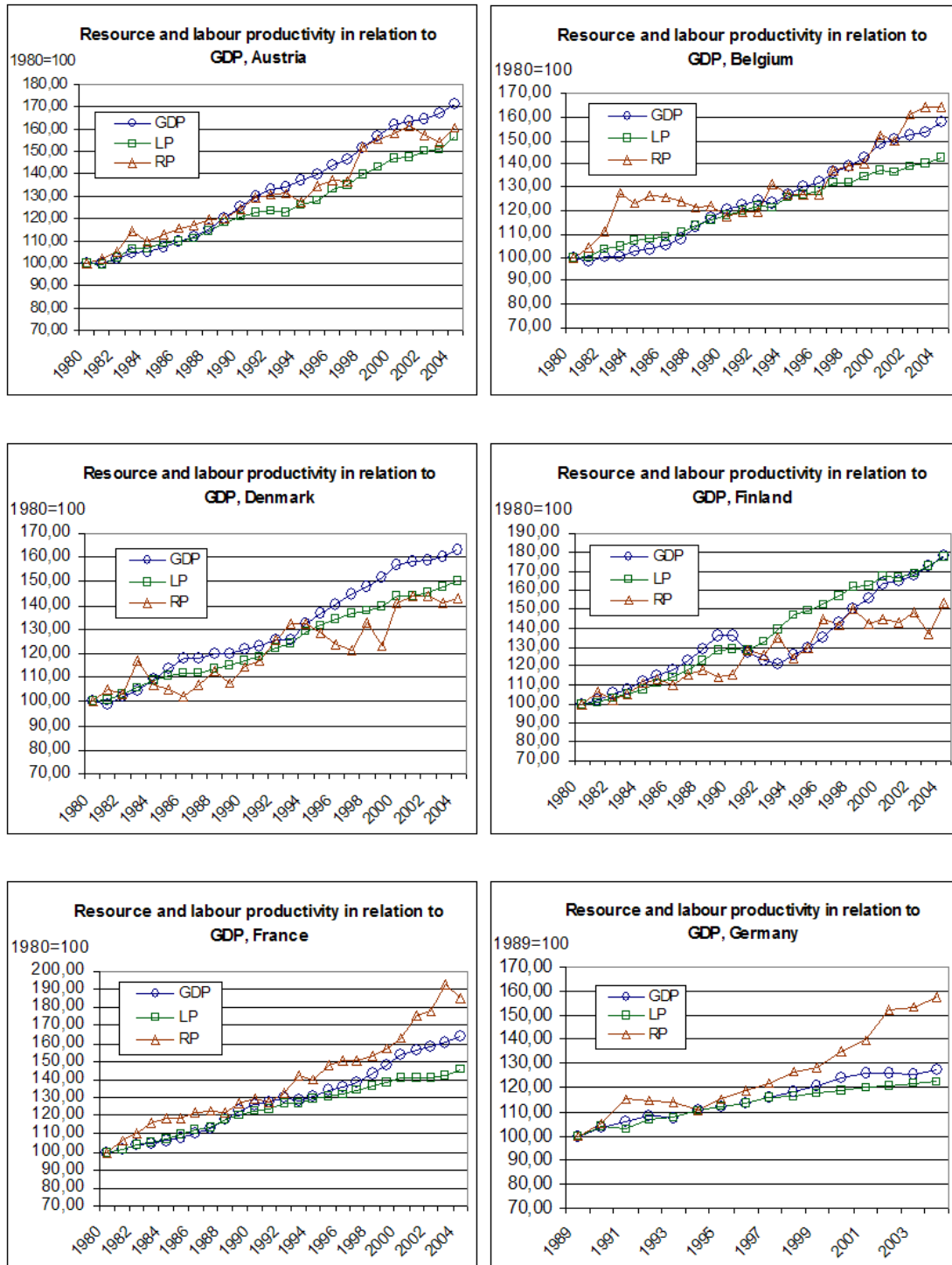
<sup>16</sup> Labour productivity can be either calculated as GDP per worker or GDP per working hour. The KLEMS database provides both indicators. The series of GDP per working hour, however, exhibit larger data gaps than those of GDP per employee. Therefore, GDP per employee was used as an indicator of labour productivity. The varying volumes of working hours between different countries are not observed therewith, calling for more in-depth research on the issue.

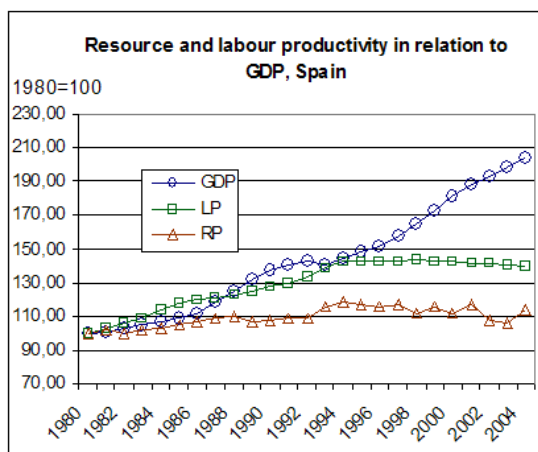
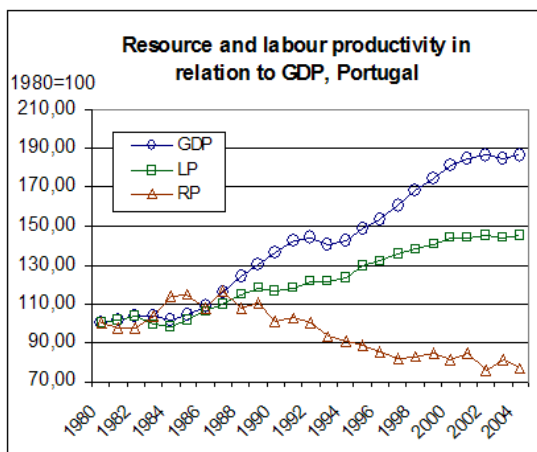
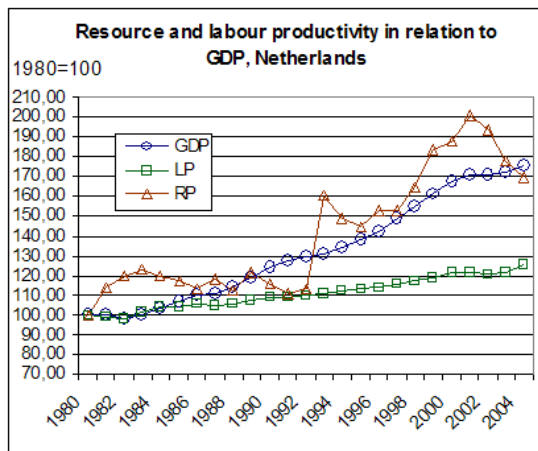
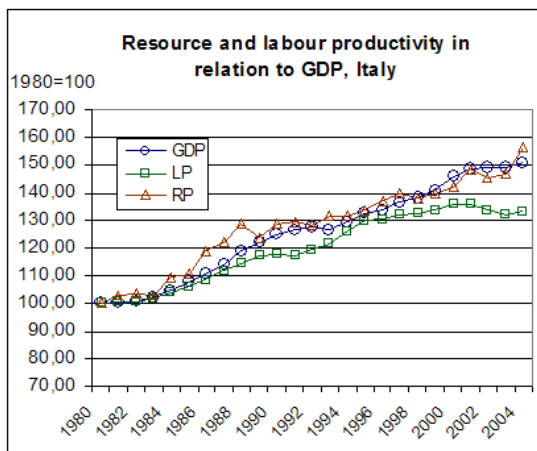
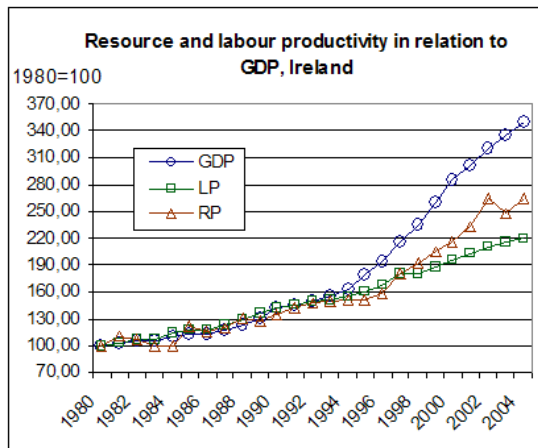
<sup>17</sup> The report uses the term of "resource productivity" – the precise notion according to OECD (2008) is "Direct Material Productivity" since it refers to DMI / DMC as denominator; the conclusions of chapter 1 apply.

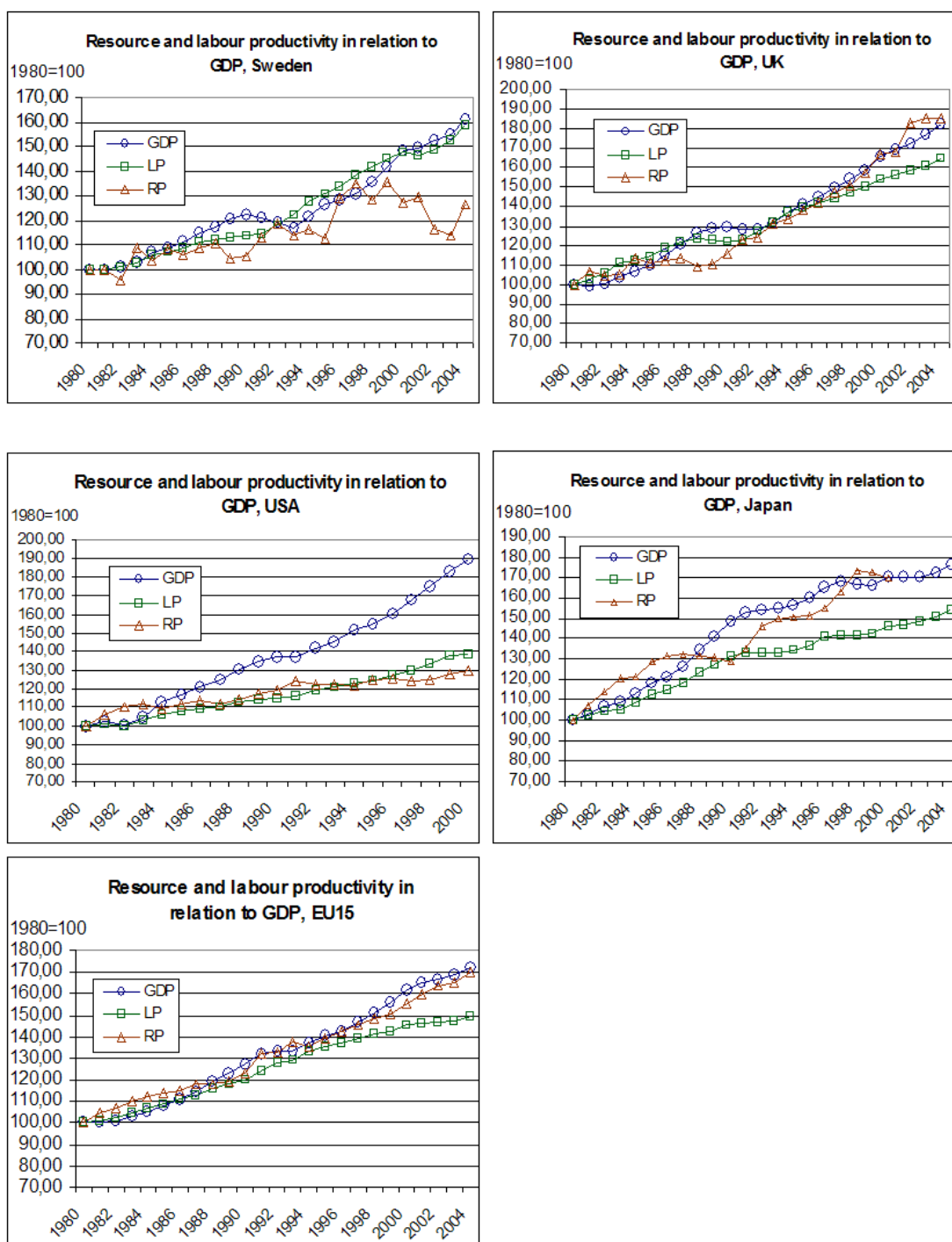
<sup>18</sup> It cannot be ruled out, that this is partly due to a shift of resource intense sectors or production processes abroad and partly due to a trend towards more part-time employment as well as to a therewith nominally lower labour productivity compared to a calculation based on man-hours.

resource productivity has even fallen – as mentioned above – in the period from 1980 to 2004.

Figure 2-6: Resource and labour productivity in relation to GDP (EU15 countries, Japan and the USA, 1980=100)





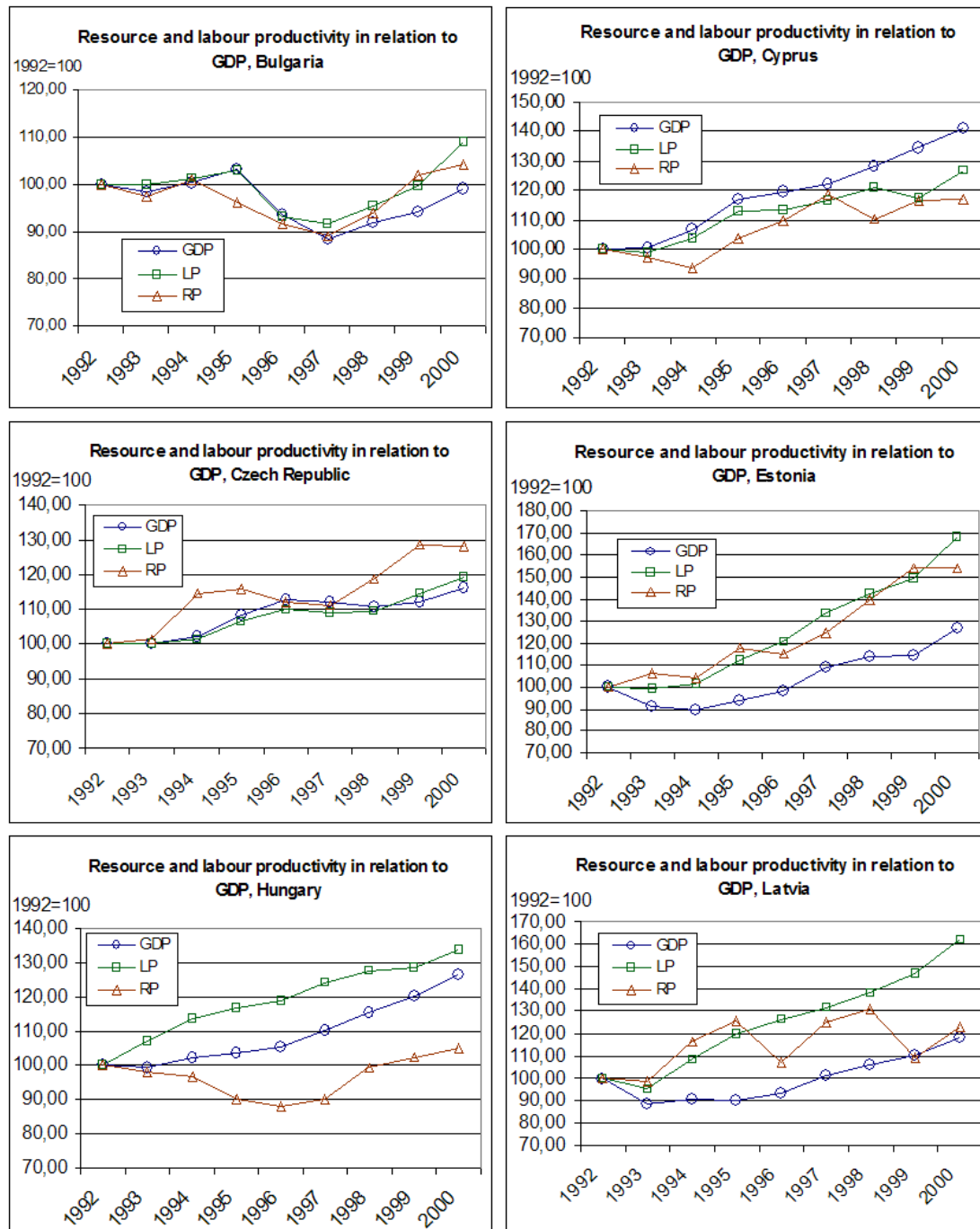


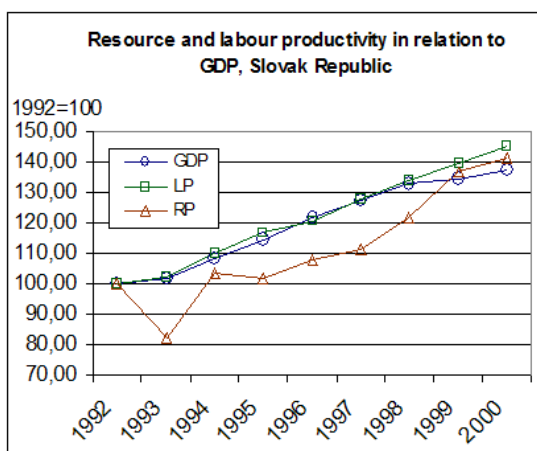
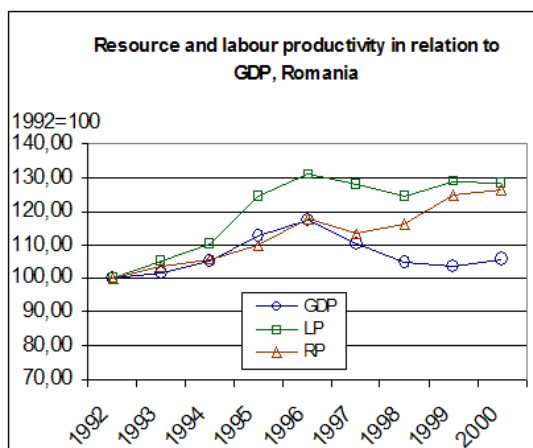
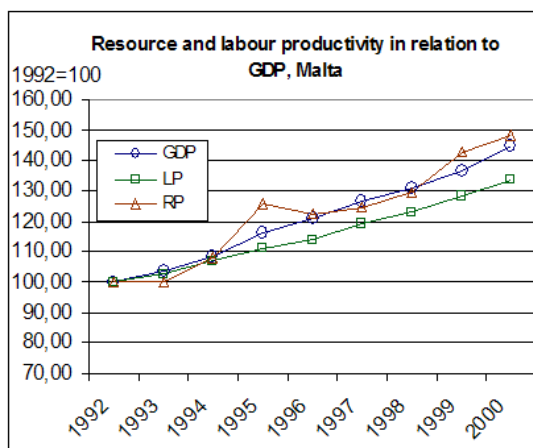
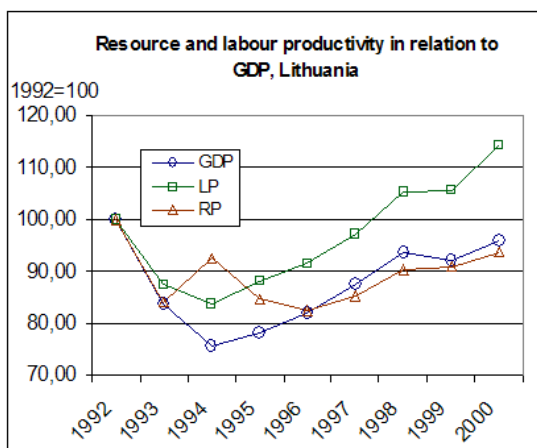
Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004; Japan: WI database; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdgc.net>, RP and LP: own calculation

The analysis for the new member states and Turkey is very uneven – as before. On the one hand, one can witness countries with a higher growth rate in resource productivity than in labour productivity (Czech Republic, Malta). On the other hand, in countries which have already opened their economies partly for capitalist companies in the 1980s, and which also had well-trained skilled workers available and therefore were primarily interesting for foreign investors after the collapse of the communist system –

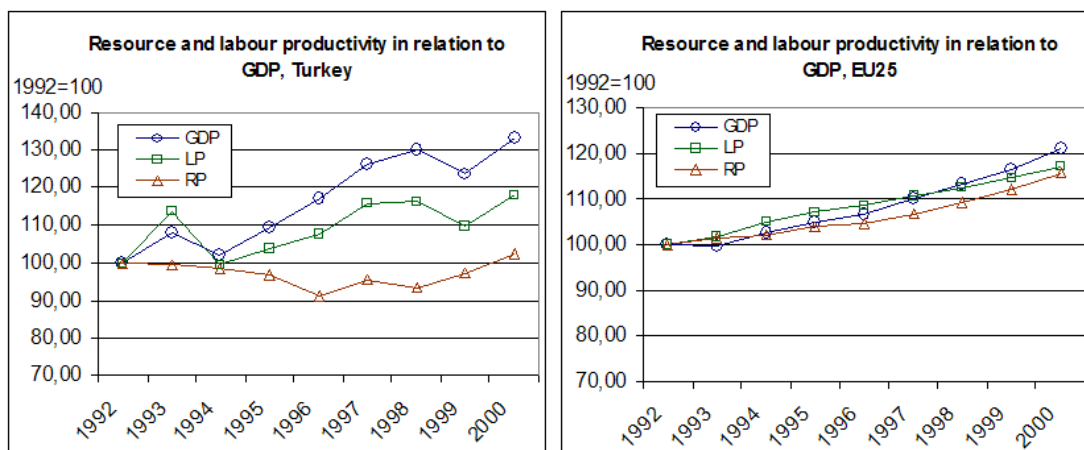
like Hungary and Slovenia – labour productivity increased much faster than resource productivity. But there were also countries where both productivity ratios grew nearly in the same growth rate between 1992 and 2000 (Poland, Estonia).

Figure 2-7: Resource and labour productivity in relation to GDP (new member states of the EU and Turkey, 1992=100)









Source: DMC: EEA (2003): Kiew Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.net>; RP and LP: own calculation.

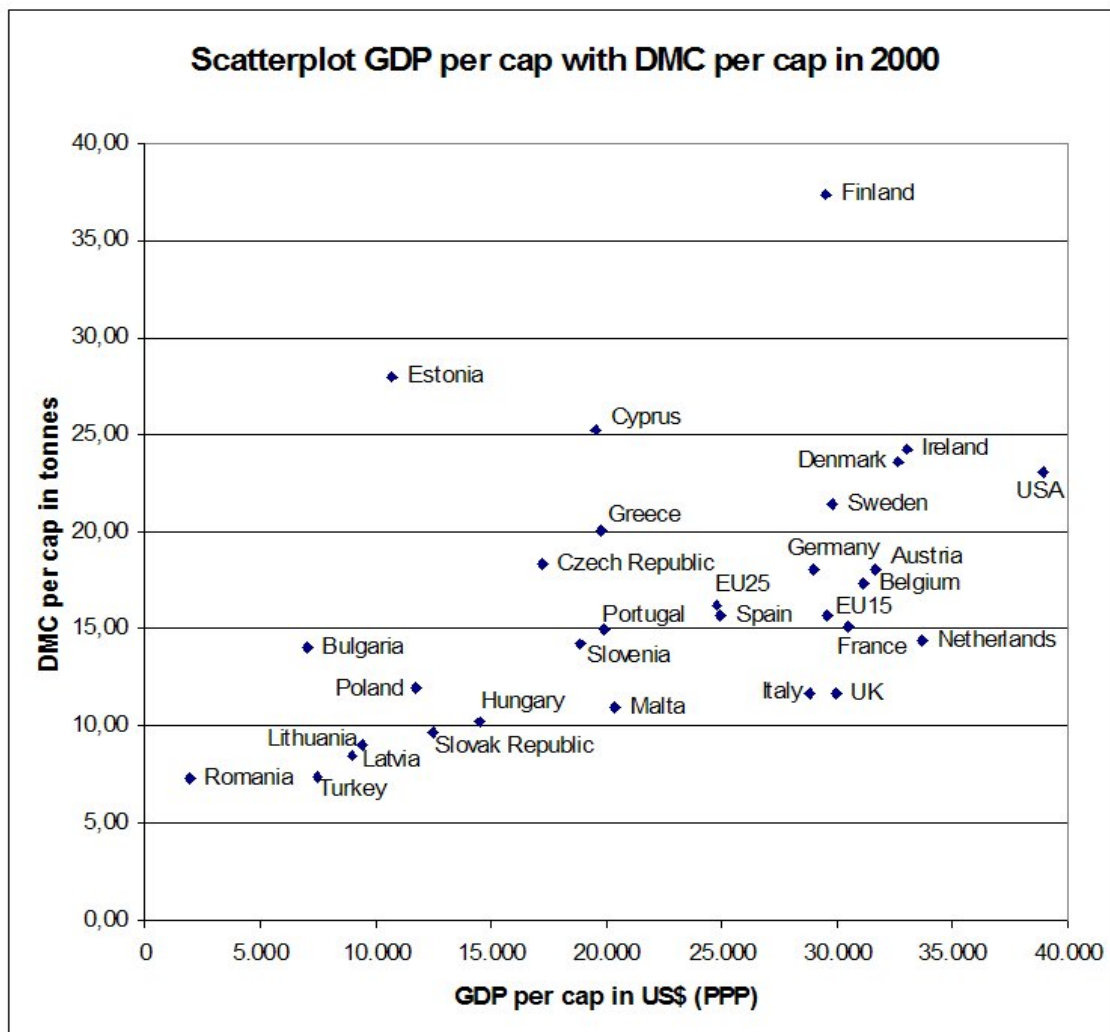
## 2.4. The correlation of resource consumption and per capita income

The data presented here show a **clear link between economic growth and the use of resources**: the EU15 countries, Japan and the United States with their high economic power usually consume significantly more resources than the new member states in Eastern Europe (Fig. 2-8). At the same time, however, the resource productivity is higher than in the new member countries. The data also show, that – as already mentioned – with exception of Germany no absolute decoupling of resource use and economic growth has been achieved and thus a **higher per capita income still correspond to a higher consumption of resources**. Therefore, a strategy for higher growth rate of GDP currently only seems attainable on the acceptance of a further increase in the use of resources. On the other hand, Italy and the UK show that a per capita income in the EU15 average is achievable with a much lower level of resource consumption than in the Scandinavian countries. This seems to indicate level of improvements among the EU 15 countries.

Figure 2-8 also indicates that **Finland and Estonia both are special cases** within the countries surveyed here. Both countries have a very high level of resource consumption per capita (based on the DMI there would be even higher values) with appropriately low resource productivity. The high levels are caused by exploitation of their natural endowments: Finland (see Box) makes use of its enormous stocks of forests and inhibits significant metal deposits. In order to use these deposits, substantial investments in infrastructure are necessary, which involve a very high consumption level of aggregates. Estonia exploits its deposit of oil shale, where huge amounts of oil shale must be processed to win relatively little amounts of crude oil. Since in both countries the first – and above all very raw material processing – stage of these resources is taking place (pulp industry, refineries), the DMC is high, despite the fact that a large proportion of these products is exported later on.



Figure 2-8: Relationship between GDP per cap and resource use per cap



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003); Kiev Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdcc.net>

### Material Efficiency in Finland

Finland, as a resource intensive country, offered the highest domestic material consumption (DMC) per capita within Europe in 2000. The total material requirements (TMR) increased by 45% between 1980 and 2003 (from 380 Mt to 550 Mt) with a use of more than one-half of the TMR for export good production. Because of its high rates of DMC and TMR, the so-called Finish energy agreement took place between 1997 and 2007. It referred to a goal of reducing the national energy consumption by 10-15% compared to a level that would have been reached without any actions. To achieve this ambitious goal the Negotiated Environmental Agreement (NEA) was tested. It is a concept between the government and organisations or business units. The NEA is an agreement to support the material efficiency (MEf) field. The MEf-NEA should generate information about material- and eco-efficiency of Finish resource-intensive industrial sectors step by step. The sectors with the biggest amounts of natural resources are the construction sector, the mining industry, the food and the forest industry. The highest share of DMI with 37% is attributed to the Finish construction sector. This sector is especially interesting because of its large domestic material consumption. Some of the participating companies of this sector pointed out that MEf aspects are often less important because other issues as heat or noise insulation are getting more attention. The construction sector is working on guidelines for environmental declarations for products. With a MEf-NEA there could be a push towards the recyclability of products, and the use of secondary raw materials could be promoted.

Especially in the metal industry an end-of-life steel products recycling ratio was mentioned. This could support a sector specific life-cycle treatment and promote waste prevention; a pilot study in the metal sector is asked for that should represent the whole value chain and include companies from smelters to milling, metal product manufacturing and surface finishing.

Up to now, the biggest problem of the MEf-NEA is that the majority of the agreements does not include quantitative goals or a stringent compliance system. The participants were concordantly unwilling to give quantitative targets for the potential MEf-measures for a specific sector. An MEf audit would be necessary before an evaluation of the own potential would be possible. A lot of participating companies do not see the NEA as a very attractive instrument to promote MEf of products. Still, product standards, eco-labels and green procurement are sensed more efficient. Resource taxes, waste taxes on landfills and other economic instruments do not have a strong political backing in Finland.

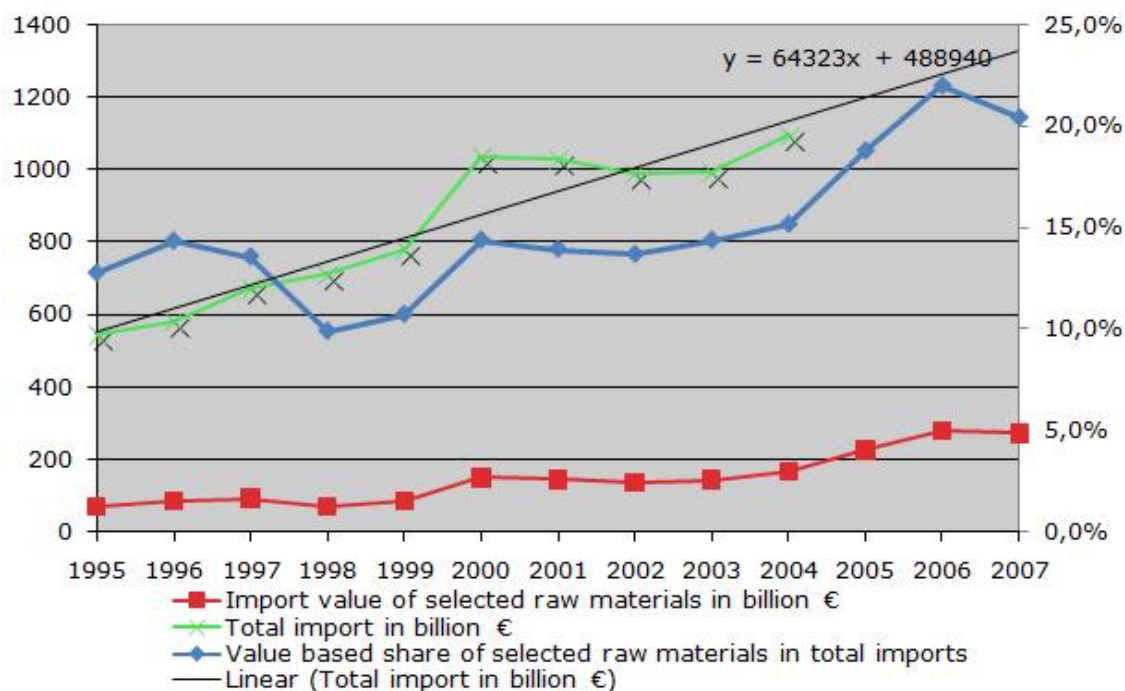
The advantage of NEA is that the concept would provide access to external consultants that are specialised in material efficiency issues and know-how could be easier distributed across the sector boundaries. This makes the NEA a potential platform to promote new product-service concepts or more material efficient product value chains.

Source: Lilja 2008.

Furthermore, it can be seen from Figure 2-9, that the growth path of total EU15 imports is quite steep and that the value of the selected raw materials imported to the EU15 grows even faster. Therefore, the **relative share in total raw material imports grew between 1998 and 2004 from around 10% up to 15%**. If total imports continued to grow more or less linearly, this share may have accrued to ca. 20% in 2007 as suggests a

very roughly estimation based on a univariate OLS regression. Although this cannot be regarded as a robust estimate, it can, however, indicate a future field of further attention in subsequent analyses.

Figure 2-9: Value based share of selected raw materials in total EU15 imports



Source: The data was taken from EUROSTAT 05 June 2008. The selected raw materials are: Ores, concentrates, wastes and scraps of iron, copper, nickel, aluminium, lead, zinc and tin as well as coal, briquettes, lignite, peat, coke and semi-coke of coal, petroleum oils and natural gas, whether or not liquefied.

## 2.5. Resource productivity and competitiveness

An investigation limited to Finland would come to the conclusion that there is no positive correlation between competitiveness and resource productivity at all. Finally, Finland is on top in most studies regarding the ranking on the competitiveness of economies<sup>19</sup>. Whether it is the Global Competitiveness Index of the World Economic Forum (WEF), the Economic Freedom of the World Index of the Fraser Institute or the Economic Freedom Index of the Heritage Foundation: Finland is occupying top positions. At the same time however, our results reveal that Finland has one of the lowest levels of resource productivity due to its very high level of resource consumption. However, our tentative cross-country analysis also leads to the conclusion that Finland certainly is a special case.

<sup>19</sup> For more details on the individual rankings and their criticism see Ochel/Röhn (2008).

This can be confirmed when the data on resource productivity are analysed in combination with the data of the Global Competitiveness Report (GCR) of the WEF. For this study we have examined whether there is a **statistical correlation between competitiveness and resource productivity**.<sup>20</sup> We plotted the score values of the Global Competitiveness Report<sup>21</sup> with the resource productivity of 2000 and applied a correlation analysis.

The **GCR** is probably one of the **most important indicator-based country rankings** and consists of a variety of different indicators. The main indicator (Growth Competitiveness Index<sup>22</sup>) is composed of various sub-indices, which consist from weighted statistical indicators (hard facts) and/or figures based on surveys (soft facts). Therefore the GCI is based on a much broader selection of indicators as the EFW Index, Index of Economic Freedom, or the Bertelsmann Index, whose indices focus on economic freedom and deregulated markets as a condition for competitiveness (Ochel/Röhn 2008). Worth to mention: the GCR has been revised several times to incorporate important soft factors such as governance, institutions and environmental policy more appropriately.<sup>23</sup>

---

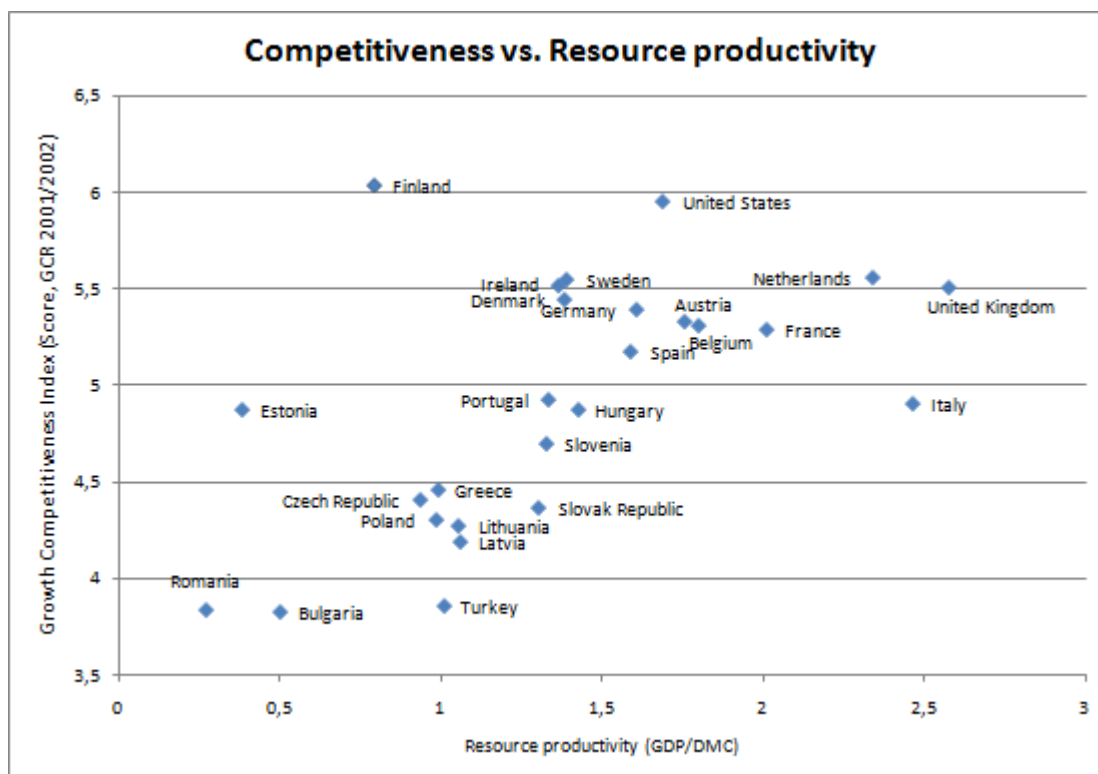
<sup>20</sup> The report uses the term of “resource productivity” – the precise notion according to OECD (2008) is “Direct Material Productivity” since it refers to DMI / DMC as denominator; the conclusions of chapter 1 apply.

<sup>21</sup> We have used the data of GCR 2001/2002, since no older reports were available. The data should not be changed dramatically within a year. We have examined whether the data between 2001/2002 and 2002/2003 have changed. This was not the case.

<sup>22</sup> The calculation of the main indicator of the GCR changed several times. In addition, in earlier studies the indicator was called Growth Competitiveness Index, now the authors call the index Global Competitiveness Index.

<sup>23</sup> See also the inception report of this project.

Figure 2-10: The relationship between the score of Global Competitiveness Index (GCI) published by the WEF and resource productivity (GDP in PPP US\$ per kg DMC)



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003): Kiew Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.ne>, RP: own calculation, GCI: WEF (2002)

Figure 2-10 delivers good reasons to suppose, that there is a **positive relationship between the resource productivity of economies** (measured by GDP in PPP U.S. \$ per kg DMC) **and the score value<sup>24</sup> of the GCI**. The higher the level of resource productivity, the higher the level of competitiveness, although Finland and Italy are examples, that despite a high value in one indicator the value of the other indicator may be underrepresented.

However, it is difficult to decide whether the resource productivity is the depending or the independent variable. The **causality** is not easy to clarify between the value of the index of competitiveness and the level of resource productivity. Does high resource productivity result in improved competitiveness? Or is a high level of competitiveness a precondition for high resource productivity? This is not clear, yet. It is also possible, that both variables are explained together by third variables. For regression analysis with time series the issue could be answered by using the Granger causality test. But in

<sup>24</sup> We used the score values instead of ranking positions for the regression analyses. The score values provide us with information about the relative distance of the individual countries. For rank correlations, we would lose this information. For this reason we did not make regression analyses with the Business Competitiveness Index, as this index only existed as a ranking.

our case we have only a correlation analysis for one year. The frequent changes in the composition of the GCI index do not allow for the creation of a consistent time series of the competitiveness index. Therefore, the Granger-causality test is not applicable to our issue. As a result, we can only assess correlations but no causalities. Since the imputed causality could not be tested the following results are **only preliminary results**. Therefore, it would be too early to conclude that an improvement of resource productivity leads to an improvement of the competitiveness.

The test statistics shows that **the resource productivity explains the GCI with a  $R^2$  of 0.30**. Both the t-statistics as well as the F-statistics are in the 95% significance level. The residuals are normally distributed and both, the Breusch-Pagan test as well as the White-Test did not reject the zero-hypothesis of constant variance. In other words, we can conclude there is no heteroskedasticity.

Figure 2-11: Test statistic of the regression analysis Global Competitiveness Index (GCI) against resource productivity

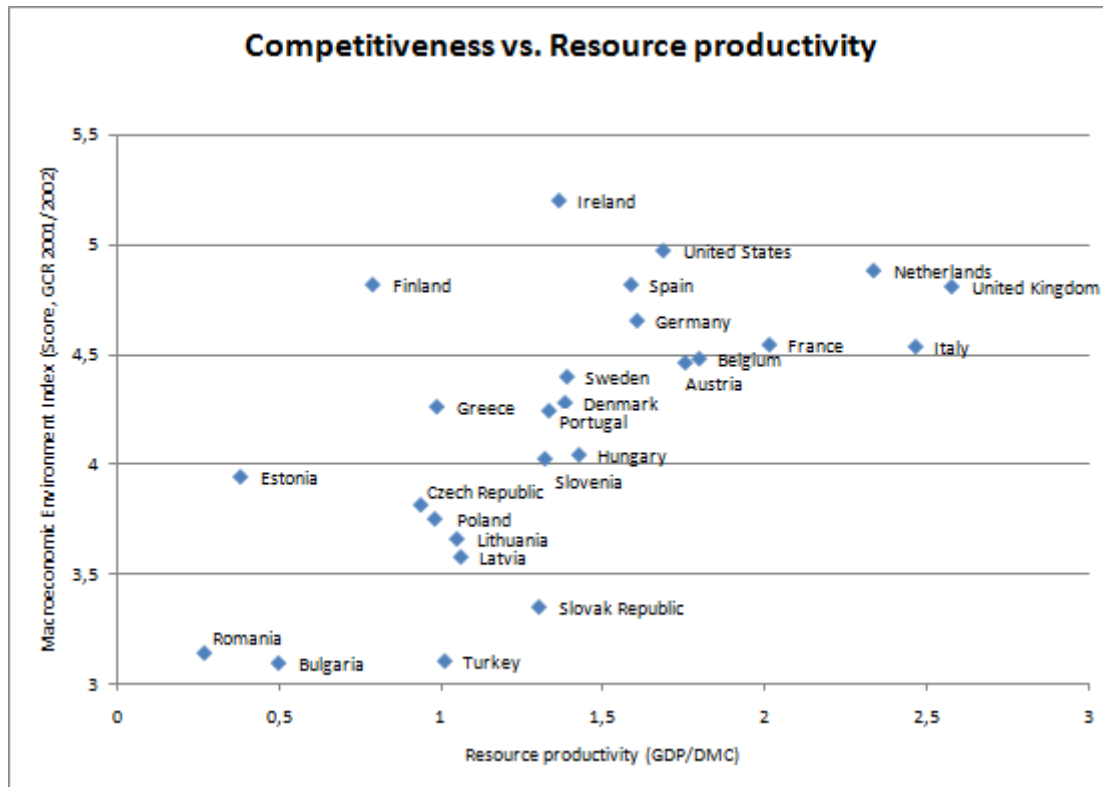
Source	SS	df	MS	Number of obs = 26		
Model	3.41180988	1	3.41180988	F( 1, 24) = 11.56		
Residual	7.08520617	24	.295216924	Prob > F = 0.0024		
Total	10.497016	25	.419880642	R-squared = 0.3250		
				Adj R-squared = 0.2969		
				Root MSE = .54334		

gci2001	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
rp	.6282369	.1847999	3.40	0.002	.2468287	1.009645
_cons	4.063201	.2725912	14.91	0.000	3.500601	4.625802

We have followed with an analysis of the three sub-indices of the GCI (**Macroeconomic Environment Index** (MEI) (Figure 2-12), Public Institution Index (PII) and Technology Index (TI)) with the resource productivity. For the correlation of the MEI with the resource productivity, the test statistics is improving (Figure 2-13). Moreover, the tests on heteroskedasticity have also improved.

Figure 2-12: Relationship between the score of Macroeconomic Environment Index (MEI) published by the WEF and resource productivity



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003); Kiev Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdnc.ne>, RP: own calculation, MEI: WEF (2002)

Figure 2-13: Test statistic of the regression analysis Macroeconomic Environment Index (MEI) against resource productivity

Source	SS	df	MS	Number of obs = 26		
Model	3.9494561	1	3.9494561	F( 1, 24) = 17.85		
Residual	5.31019056	24	.22125794	Prob > F = 0.0003		
Total	9.25964666	25	.370385866	R-squared = 0.4265		
				Adj R-squared = 0.4026		
				Root MSE = .47038		

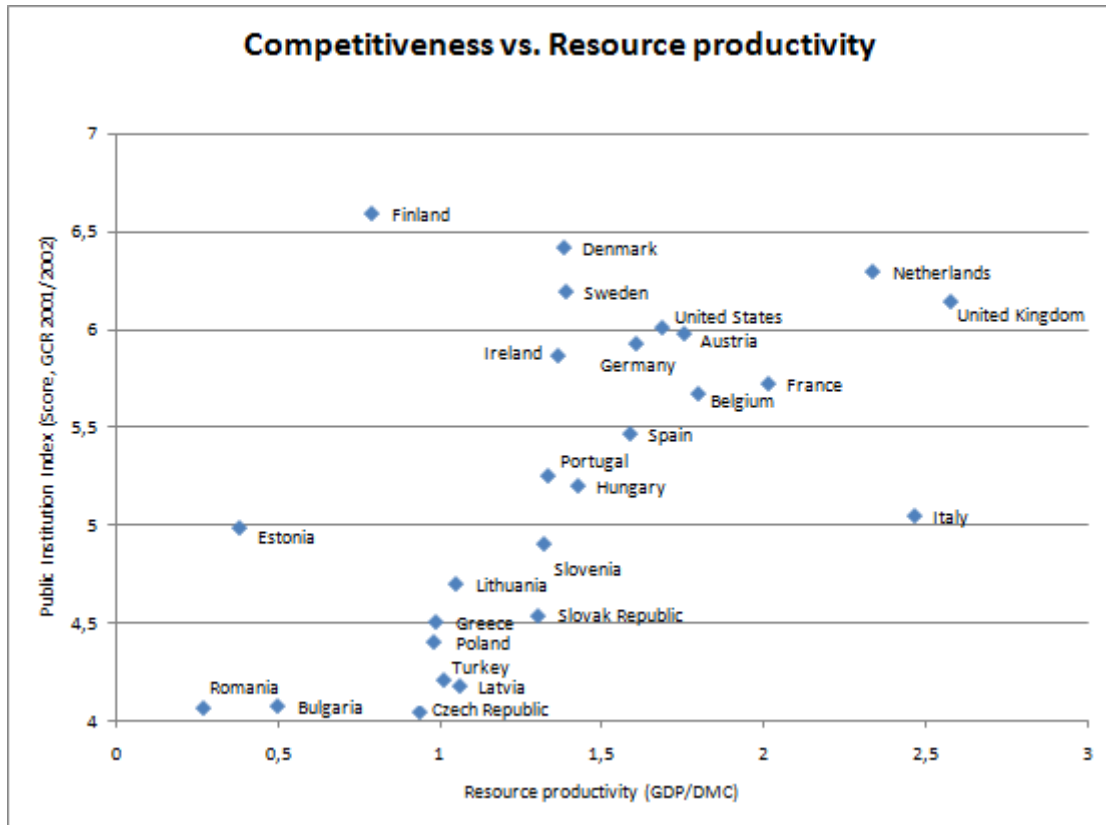
  

mei2001	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
rp	.6759268	.1599854	4.22	0.000	.3457331	1.006121
_cons	3.267684	.2359884	13.85	0.000	2.780628	3.75474

The analysis of the **Public Institution Index (PII)** with the resource productivity has a similar explanatory content as the regression with the GCI. Although the test for normal distribution and heteroskedasticity delivers good results, the review of the scatter plot

(Figure 2-14) makes the test results questionable. There are too many outliers on both ends of the PII in the values of resource productivity. An improved data situation and therewith more countries could give more clarity on the relationship between the quality of public institutions and the level of resource productivity in future analyses.

Figure 2-14: Relationship between the score of Public Institution Index (PII) published by the WEF and resource productivity

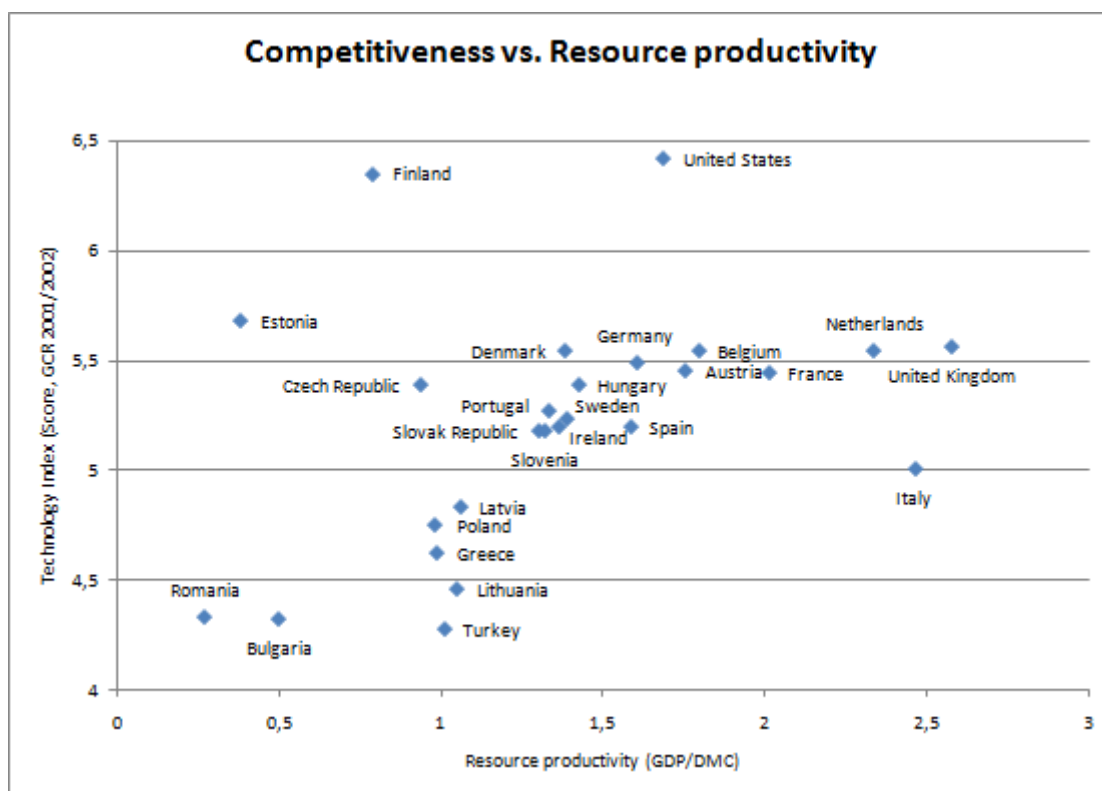


Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003); Kiev Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdg.net>, RP: own calculation, PII: WEF (2002)

When visually inspecting the **Technology Index** through scatter plot (Figure 2-15) it tends, in fact, to be correlated positively with resource productivity, but there are several outliers visible, too. As well the regression statistics show only a very small  $R^2$  with an F- and t-statistics only in the 90%-significance level. Therefore we cannot conclude with certainty from these results, that there is a statistical relationship between the technological level of an economy and its resource productivity.



Figure 2-15: Relationship between the score of Technology Index (TI) published by the WEF and resource productivity



Source: DMC: EU15: 1970-2001: Eurostat/IFF (2004), 2002-2004: New Cronos; new member states plus Turkey (ACC): EEA (2003); Kiew Report Annex C; USA: WRI Database; GDP: Groningen Growth and Development Centre and the Conference Board, Total Economy Database, <http://www.ggdc.ne>, RP: own calculation, TI: WEF (2002)

## 2.6. Conclusions

For EU25, Turkey, Japan and the USA data shows that **a majority of the countries could ameliorate their resource productivity**. In most cases, however, resource productivity increased slower than GDP in the investigated country. Therefore, **only a relative decoupling of resource use and economic growth** can be witnessed in these countries. An absolute decoupling or “dematerialisation”, i.e. economic growth along with a decrease of resource use, so far, occurred only in Germany regarding the DMC. However, a few other countries could at least stabilise their resource use. The growth rates of resource productivity (2,5 %/a for EU-25 and 2,9 %/a for EU-15) fall behind the aims of EU’s resource strategy. Thus, the EU is not yet on track towards decoupling resource use from GDP.<sup>25</sup>

<sup>25</sup>

This assessment refers to Annex 1 of the Thematic Strategy: “In the period 1980-2000 the resource productivity (€/kg) of the EU-15 economy increased by 52%, which is 2.2% per year. On the basis of this trend, and assuming that proper implementation of this strategy will lead to at least a modest increase in resource productivity, it is **reasonable to expect a rate of 3% resource productivity im-**

A few specific results shall be pinpointed here: Countries with high resource productivity levels are not necessarily the ones with the strongest dynamic in ameliorating resource productivity. For instance, resource productivity in Ireland is rather average amongst the investigated countries but increased between 1980 and 2004 at an average rate of 6.8%.

The huge difference in resource use between countries of similar developing levels (measured by per-capita income) possibly can be interpreted as a potential for further improvements in the range of a factor 2-4, depending on country-specific features as well as technological and institutional capabilities. Further analyses concerning the driving forces probably will lead to new insights here.

With a view to absolute reduction targets, data suggests a conclusion that there is a current minimum level of necessary resources for developed industrialised countries in the order of 12t per capita (DMI/DMC). This indeed is neither a statement about current potentials to save resources nor about any future possibilities. It however indicates a window of opportunities for improvements since the average EU25 resource use per capita is in the order of 35t per capital (DMI<sub>cap</sub> 2000). It would be an interesting question for further research, whether the supposed minimum level results only incidentally or can be explained by technology or other factors.

Our analysis demonstrates, that in general there is a **positive relation between competitiveness of economies and their resource productivity**. But the causality between both variables are not yet clear, especially with regard to the Scandinavian countries, where specific factors determine the resource use and are more momentous. As well in these cases, research is requested to obtain better insight in respect of determinants of resource use and resource productivity from further in-depth analysis. The methodology used in this report is feasible to produce results provided that sufficient data for time series can be accessed.

---

**provements** per year for the period 2000-2030. This would represent a slight acceleration compared to the previous 20 years." See also the statement by Schepelmann et al. (2006).

### 3. Driving Forces of resource use and resource productivity

Sören Steger, with contributions by Raimund Bleischwitz

#### 3.1. Definition of driving forces

The aim of this chapter is to **identify common driving forces of resource consumption and resource productivity** of the analysed economies. However, the precise understanding of the interaction of potential drivers and resource use is not yet very pronounced and little explored. In addition, there is no clear definition of driving forces. One of the commonly used definitions in the context of the sustainability debate comes from the OECD, which defines in the *Driving Force-State-Response Model* (DSR) driving forces as “human activities, processes, and patterns that impact on sustainable development” (OECD 1996). The European Environmental Agency (EEA) has enhanced the DSR model to a *Driving Forces-Pressure-State-Impact-Response Model* (DPSIR) (EEA, 1998). But the question of the definition of driving forces remains similarly vague. However, in the DPSIR model feedback loops (response) that influence the driving forces themselves are explicitly incorporated in form of e.g. policy instruments. Baedeker et al. (2008, p. 10) distinguish between drivers and driving forces. In addition, the term driving forces (of private consumption) is divided in two sub-terms: external driving forces, which shall be understood as drivers beyond individual influence and internal driving factors which are open for individual control.

#### 3.2. Theoretical basis of the selection of variables

The selection of variables should always result from a theoretical basis. However, the problem is that up to now no solid theoretical framework exists for the driving forces behind material consumption of resources and productivity. There are very few literatures on this subject and only a few empirical studies (i.a. Weisz et al. 2006, van der Voet et al. 2004, Steger/Bleischwitz 2007), which predominantly deal with the description of the material consumption. In principle, there are hundreds of conceivable variables that could be used for an analysis. The indiscriminate testing of these variables is not a workable approach to this analysis and will likely lead to random results. Alternatively, the **Intensity of Use-Hypothesis** from Malenbaum (1978) and the derived discussion in recent decades about the possibility of a dematerialised economy and an **Environmental Kuznets Curve (EKC)**<sup>26</sup> are a first approach to design a theoretical explanation, from which a selection of explanatory variables can be taken. This approach

---

<sup>26</sup> There is a wide literature about EKC and the empirical results are often very weak. But the concept of the EKC offers a suitable approach for selecting variables.

is suitable to the Thematic Strategy on the Sustainable Use of Natural Resources and can also be translated to industry sectors. Malenbaum studied the global consumption of 12 mineral resources in the period from 1955-1975 and concluded from his findings that economies achieve a declining material intensity once reached a certain level of development. In the literature on the subject of a declining intensity of use of certain resources or EKC, there are five factors basically mentioned as causes of such a development (Cleveland & Ruth 1999, Special Issue Environment and Development Economics 2 / 1997, Stagl 1999):

- **Technological progress:** The development of new products, services and materials allows to produce the same volume of goods and services with fewer raw materials. At the same time, technological progress can also be expressed as material efficient organizational changes.
- The technological progress develops the possibility of **substitution** of certain environmentally harmful materials by other often new materials.
- A **change in the structure of demand** towards service sectors and new goods, e.g. ICT products<sup>27</sup>, which in turn also leads to a postponement of the importance of individual industries and sectors. A change in consumer preferences towards less material needs (car-sharing, etc.) can also result in a change of the structure of final demand.
- It is presumed that with a higher level of development the need for infrastructure investment declines and the building of an industrialised economic structure is finished. As a result of this **saturation effect** the demand, especially for mass commodities such as construction materials, iron and steel will decrease.
- According to the EKC hypothesis, the level of environmental pollution will increase initially. However, with rising per capita income, the demand for better environmental conditions will also increase. It creates a political pressure for the **introduction of environmental regulations and minimum standards**. This leads to the introduction of end-of-pipe technologies to reduce pollution or forces pollution intensive sectors to drain in regions with less stringent environmental legislation, if the cost of avoidance is too high (pollution haven-hypothesis).

The material intensity is the inverse of material productivity, so material quantity per unit of GDP or GVA when it comes to sectoral considerations ( $IU_t = M_t / Y_t$ ). Thus, the quantity of materials consumed (M) is the sum of income (Y) multiplied with the material intensity of use (IU). Therefore, the quantity of materials consumed can be affected by the size Y and IU (van der Voet, 2005, p. 63). Y in this case symbolises the economic growth, the change in the material intensity can be traced back to a change in economic structure and technological changes by the method of decomposition analysis.

Three effects therefore can be distinguished roughly in the analysis of the driver:

- Growth effect

<sup>27</sup> But meanwhile it is clear that new equipment is not per se be environmentally friendly.

- Structural change
- Technological progress

In addition, it is presumed that **institutional factors** like the level of environmental legislation, the influence of the ecologically oriented part of population and the importance of environmental issues in the social discourse also have an impact on the consumption of raw materials. Moreover, factors are possibly involved, which have an influence on consumption of the economies, but cannot – or only marginally – be influenced politically, e.g. **climatic and topographic conditions** or **population density**. Finally, **lifestyle** and **consumption patterns**, as well, influence the resource consumption of economies.

Variables, which map these effects, should have a big influence on resource use. However, this also indicates the difficulty of selecting variables: What are the variables with which e.g. technological progress can be mapped? Might it be the monetary expenditure in research and development? The number of registered patents per 1000 inhabitants? The proportion of employees with a university degree? Moreover, the variables influence each other and it is often difficult to distinguish whether they are a driver themselves or just a consequence of the change of another driver. In addition, the selection is limited by the used methodology of regression analysis and associated with this the data availability.

Some of the variables are described in more detail below.

### 3.3. Selection of variables for drivers

Economic growth is usually measured as an annual increase of GDP in %. At the same time, according to the EKC hypothesis, the **per capita income** determines crucially the level of material consumption. The empirical results in the previous chapter will also provide initial empirical references. Since in our analysis the explanatory variable is measured on a per-capita basis and not as a percentage change over the previous year, we use the GDP per capita (in PPP) as variable. Considering the time periods, however, the effect of GDP growth to the change in resource use is indirectly tested.

GDP commonly is expressed as  $Y = C + I + EX - IM$ . Income,  $Y$ , is usually determined to a large extent by consumption,  $C$ , that is the consumption expenditures of households and the government. Investments are often made in material intensive infrastructure projects. A high **proportion of gross investment in GDP** could be accompanied by a high demand for resources. The high relevance of the expenditure of households in GDP leads to a high level multicollinearity between these two variables, so that the consumption expenditure of households is not used as an independent variable.

Whether a **high proportion of foreign trade in GDP** is connected with a high consumption of resources or more with less material consumption cannot easily be identified. A high influence of import on GDP can be a consequence of trends in shifting re-

source intensive sectors to other parts of the world, which is reflected in rising imports of semi-finished and finished products. This would cause a negative correlation between the import share of GDP and DMC/DMI. A high proportion of imports and exports in GDP could also be interpreted as an indicator of an open economy. Open economies are competing in global competition and are therefore always forced to use the latest production technologies, which are often more resource and energy-efficient than previous technologies.

Besides the level of GDP, the **sectoral structure of an economy** is of great importance for the consumption of raw materials. How strong is the service sector? Have resource-intensive sectors such as the mining or steel industry a significant stake in economic performance of economies? The NACE share of each sector in the overall GVA expresses this structure. However, in official statistics, data is often available in NACE distinction of only 4 sectors (agriculture, industry, construction and services).

Like the NACE shares of the various sectors of total GVA, the **structure of employment** provides notes to the respective importance of individual industries. Highly developed economies are usually characterized by a higher proportion of employees in the service sector in total employment. In turn, a high proportion of workers employed in the agricultural sector suggests a pre-industrial level of development. Either way, this implicates a negative correlation with the consumption of resources. But the results of chapter 2 indicates that highly developed economies are positive correlated with the level of resource consumption. Therefore, the correct sign for this variable is yet unclear. Additionally, the number of employees does not show different levels of labour productivity in the analysed countries and therefore the pure number of employees could be a misleading indicator.

**Technical progress** can reduce material consumption. Innovations in new products and processes, new materials and efficient technology can open up new markets and strengthen competitiveness. But how can technical progress represented adequately? Economists argue based on the new growth theory of Romer (1990), that technical innovation can be achieved through increased investment in human capital. In this sense, the **share in GDP of government expenditure in research and development or in education** would be a good indicator for technical progress. Another indicator could be the **number of patents per million inhabitants**. With the exception of the last years the data situation is not particularly good. A negative correlation with the consumption of resources is assumed for both variables.

Households influence the resource consumption of an economy quite decisively by the structure and level of final demand for goods and services. Therefore, variables which indicate the **lifestyle and consumption of households** should have an effect on the consumption of resources. Here are several different variables conceivable. For example, the daily amount of animal fats consumed is an indicator of a lifestyle that could reflect many of the ecological problems such as land availability. The analysis of van

der Voet et al. (2005) showed no significant correlation between DMC per capita and this indicator. Other possible variables could be:

- **Number of cars per 1000 inhabitants:** A high proportion of cars indicates a lifestyle that is based on a strong individual mobility structure. However, this structure is highly material and energy intensive.
- **Average per capita living space:** In most of the countries, the building sector is responsible for a big part of resource consumption. A larger need for living space which is caused by the desire for larger homes on the one hand, and on the other hand by new municipal structures (single detached houses in rural area or high proportion of single households), leading to an increasing demand in the construction sector. The number of **new housing units** is the concrete indicator for the construction sector's demand for material and energy. Unfortunately, it lacks sufficient data series on the stock and the new construction of commercial real estate and the amount of office space. Therefore building indicators remain limited on dwelling properties.
- The **length of the different transport networks per capita** could be a good indicator for the demand of construction minerals in the transport infrastructure. However, the population density also has an effect on these variables. Thus, the length of route per capita is low in densely populated countries like the Netherlands, even with a dense route network, whereas in sparsely populated countries like Finland or Sweden the length per capita is high even with a small transport network in absolute figures. An alternative variable could be the **length of route per km<sup>2</sup>**. Furthermore, the data situation in the EU27 countries on transport networks is neither uniform nor in good quality, especially for data on local streets.
- Another indicator of lifestyle could be different waste figures, for example the **amount of municipal waste collected in kilograms per capita**. The recycling portion would be an indicator whether a high proportion of waste is recycled, and thus decreases the demand for primary material. However, the data situation in the waste statistics is likewise not particularly good.
- Price and tax could also be major variables to influence the consumption of resources. High energy prices give appropriate monetary incentives to use energy efficiently. Possible prices used for an investigation could be energy **prices for end-users**, or the **fuel prices**. Still, it would be interesting to see whether the system of an eco-tax has an impact on the consumption of resources. But here, as well, the data situation is only in a few of the studied countries adequate.

The energy mix (the share of the various fossil energy sources or the **share of renewable energy sources** in total energy consumption) has also considerable influence on the DMC or DMI. Countries whose energy mix is predominantly based on coal or lignite exhibit significantly higher resource consumption than countries whose energy mix will be covered in large part by nuclear and/or renewable energy sources.

Apart from these indicators, so-called country variables will be involved in the investigation. These are indicators, which potentially influence resource consumption but are not suited for an active influence through policy measures. These include the already mentioned population density, size of a country or climatic conditions.

Table 7-1 (in the annex) provides an overview of the variables initially selected for the study. As far as possible, the direction of the suspected relationship was indicated in the table. A + thus indicates the assumption of a positive correlation between the variable and the resource consumption as measured by DMC per capita.

As mentioned before, there is a weak theoretical basis for the selection of variables. Hence, a fairly wide range of variables was chosen for the analysis initially. Basically more variables would be conceivable. However, there are often only random data or qualitative results from surveys available, which are of fairly limited use in a regression analysis. Thus, the selection of variables cannot be made without considering the availability of data. The ultimate selection of variables used for the regression analysis, however, is curtailed significantly. On the one hand some variables are not used due to poor data quality. This can be the result of large data gaps (e.g. percentage of university degrees in science and engineering per 1000 inhabitants), significant breaks in the existing time series for certain countries (e.g. road data in Italy), or completely missing values for individual countries (e.g. passenger-km in Belgium or Greece). The other reason for elimination of certain variables is multicollinearity between the independent variables. Taking into account these two aspects, the original list of 68 variables (Table 7-1) is reduced to 33 variables, which are tested as explanatory variables. Figures 7-1 and 7-2 (Annex) show, that between some variables, a high multicollinearity still exists but, however, much less than in the first matrix with 68 variables (see below).

We basically used two available panels: for the EU15, data series exist from 1980 to 2000. For the new member states, data is available from 1992 to 2000. As DMI/DMC-data exists until 2004, it would be coherent to update the database of the independent variables also to 2004. Due to changing of calculation methods of data in constant prices this wouldn't be an easy task, as a simple stretch of the old data wouldn't be possible. As a result we would have to renew all variables, which were calculated based on constant prices. This was beyond the scope of this study, but clearly would improve our database and potentially our results.

Even for a number of variables listed in Table 7-1, there are strong data deficiencies. Thus, for certain variables, no data exists for individual countries while for other countries and variables there are more or a less large data gaps, or the calculation basis of the data differs from country to country. To improve the quality of data as high as possible, we tried to use the data by international sources, and to a less extent from the national statistical offices. Partly, we used data from Eurostat, KLEMS database, or AMECO database, data from the IEA, OECD and the WRI.



We run our regression analyses for various panels of different countries and periods of time for both the DMC per capita as well as for resource intensity measured as DMC in kilograms per 1000 U.S. \$ in purchasing power parity (PPP).

### 3.4. Methods of regression analysis

In this chapter, we describe the methodical approach in the search for driving forces behind the resource use. With the description of the different possible variables in the chapter above, it is clear that there is **no single explanatory variable**. There rather are various different forces affecting the consumption of resources and resource productivity that, in addition, exhibit certain interdependencies. Although a univariate correlation analysis could be helpful for understanding the influence of various variables on resource use and resource intensity, it would be an incomplete picture. Multivariate regression analyses, which estimate the influence of several different variables simultaneously, are an appropriated method for our questions. However, regression analyses have to be carried out carefully, as the false use of statistical methods potentially leads to misleading results.

For our analyses, a first problem encountered was, that the time series are too short and the countries panel is not particularly extensive. Moreover, by carrying out pure time-series analysis, we will hardly find common drivers for all the countries studied. To improve the sample, that is augment the number of degrees of freedom and enhance the quality of the estimators, we used **Time Series Cross-Sectional (TSCS) data**. As the name shows, TSCS data are composed of both, a time-series and a cross section. The cross-sectional data are just multiplied with the respective country's time series. This increases the size of the sample significantly. Some methodological problems are associated, however, with multiplying cross-sectional data with time-series data: Unlike large panels (such as household surveys), the individual data points in TSCS data are not independent from each other. The time series structure of individual countries has to be included in the overall panel and must be considered in the analysis and the selection of the estimator. As Baltagi (1995) and others also noted, it is also very likely that – due to the TSCS data designs – certain assumptions of the linear regression analysis are violated.

But first it needs to be clarified, whether it can be assumed a **linear relationship between the independent and dependent variables** at all. In the economic literature little can be found, with the exception of some studies on the relationship between GDP per capita and the consumption of resources (Canas et al. 2001, Bringezu et al. 2002, Weisz et al. 2006, Weisz et al. 2002). If an EKC existed for resource use and per capita income, this would implicate a square function. However, Bringezu et al. (2002) show that the statistical differences between a linear, a logarithmic and a quadratic function are extremely low when testing the EKC hypothesis between GDP per capita and DMI. On the one hand, all data points still stand on the left side of a possible peak point and, on the other hand, the slope of the coefficient is very flat, so there are almost no differ-

ences between a linear and logarithmic function. It is not very likely that the results are different when using DMC instead of DMI.

In order to identify the individual relationship of the many different independent variables with the dependent variables, we ran a correlation analysis with all independent variables and the dependent variable. Contemporaneously, we use this correlation matrix (Figures 7-1 and 7-2) to check which of the independent variables are highly correlated with each other. When independent variables are highly correlated with each other, it is spoken of **multicollinearity**, which increases the standard error of the estimator, and therefore is less accurate and thus no longer BLUE (best linear unbiased estimator).

The correlation matrix with all 68 variables showed that a high number of variables were strongly correlated with each other. This, however, was hardly surprising. From the list of variables in Table 7-1 (Annex) it is very likely, that some of the variables are highly correlated with each other. It is not surprising, that a high share of building investment in GDP highly correlates with the share of gross value added of the construction sector. Similarly, the per capita income is probably not just a driver for the suspected use of resources, but also for some of the independent variables in the list. Patents are probably applied both in the U.S. as well as in the EU, or the employment rate correlates with the unemployment rate. A complete elimination of correlations between explanatory variables is usually not possible, especially in macroeconomic variables and country panels. Even after reducing the number of variables used to 33, there are still some variables which strongly correlate with each other. As an indication whether this multicollinearity is within the tolerance range, the value of the so-called variance inflation factor (VIF) is to be used. If the value is under 10, the multicollinearity is in a tolerable range.

The estimation of parameters is done in an iterative process. It is important that the data is determined in such a way that the country and time structures of the data are maintained. We used a “bottom up”-approach to fit our models, i.e. they have been expanded gradually. The t-value of the simple regression of all variables served as the indicator which variables would be chosen first. The aim was to find a **best-fit model** where all variables are in the 95% or 90% significance range and could not be improved anymore. Such a model, where the adding or removing of variables no longer improves the model, is to be considered as best-fit. Usually Akaike’s information criterion (AIC) or the Bayesian information criterion (BIC) is used as criterion for improvements. Thereafter, we have to assess, whether the supposed country effects of a **fixed-effects model** actually exist or it rather is a random-effects model. For this the **Hausman test** is used. If the  $H_0$ -hypothesis on non-systematic differences in the coefficients (individual intersection) can be rejected, there exist country effects and the specification as a fixed-effects model would be correct.

However, further tests are necessary to ensure the outcomes of the best-fit model are classified as statistically correct. We have to verify whether the estimation with the least

squares method is feasible and whether the FE-estimators are consistent and efficient. Otherwise, the results of the regression tests would be without expressiveness. To answer this question, we have to test how far **simultaneous correlation**, **group-wise heteroscedasticity** and **autocorrelation** exist. Should this be the case, the least squares method with fixed-effects specification is not permitted. The experience with country panels and macroeconomic variables suggest that all these assumptions of the least squares methods are violated. The **Breusch-Pagan-test** estimates for cross-sectional independence in the residuals of a fixed effect regression model. A likely deviation from independent errors in the context of pooled cross-section time-series data (or panel data) is likely to be contemporaneous correlations across cross-sectional units. However, to run this test we need a completed or balanced data set where for all cross-section units (countries) the data for all time points are available. In our data, only for a few variables, the data sets are completed, and so the test can normally not be applied. Another requirement for regression models with TSCS data is that the residuals within their cross-section units are homoscedastic. That means within the cross-sections units, the variance of the residuals is equal. Two testing methods are available to check these assumptions. First we can run the **LR-test** and second there is the **modified Wald-test** available. Both tests have the  $H_0$ -hypothesis for group-wise homoscedasticity. If the  $H_0$  is rejected, the variances also vary within groups and hence group-wise heteroscedasticity occurs. Finally, we have to test whether an **autocorrelation of the first order** exists. Is this the case, the variables are influenced from the previous period and thus are not independent from each other. If autocorrelation exists, you can either try to integrate the previous period as an explanatory variable in the model or to transform the data so that they cope with first-order autocorrelation. Many statistic programs offer this as a data option automatically. To integrate the previous period as an explanatory variable in the investigation sounds initially plausible, but it has the great disadvantage that all other variables lose most of their explanatory power or even become insignificant, because the model is almost entirely explained from the data of the previous year.

If heteroscedasticity is available, one method to handle this problem would be to run the regression analysis with the so-called **panel corrected standard error (PCSE) method** (Beck/Katz 1995, Beck 2006). If there is also an autocorrelation of the first order in our regular fixed-effects model, the PCSE regressions can be adjusted even to this. It is very likely that the best fit fixed-effects model from the previous analysis is no longer best fit when using the PCSE method. Some of the explanatory variables may no longer be significant with the corrected standard errors. In this case, the selection of variables must be repeated. For this purpose, we ran a univariate regression analyses again but this time with the PCSE methods. Here again, we used the explanatory content of each variable to fit our model with the “bottom up”-approach. In addition, we included country dummies in the PCSE regression model in order to account for the country effects of the fixed-effects model.

### 3.5. Results of regression analysis

Table 3-1 shows the test statistic for the panel of the EU15 countries for the period from 1980 to 2000. The LR test and the modified Wald test of the regular fixed effects model showed that group-wise heteroscedasticity existed. The Wooldridge test was also significant with an error probability of 5%. The null hypothesis of missing autocorrelation could therefore be rejected.

For complying with the heteroscedastic residuals as well as the autocorrelation we had firstly to use the PCSE method, and secondly, we had to include the disturbance term in a first-order autoregressive form. In addition, we used country-dummies in the PCSE regression for dealing with the regular specification as a fixed-effects model. The best-fit model is shown in Table 3-1. The very high  $R^2$  is explained by the estimation of the model with country-dummies<sup>28</sup>. All explanatory variables lie within the 5% significance level. Since all the variables were used as log-variables, the coefficients directly reflects the importance of each variable.

Table 3-1: Test statistic for EU15, 1980-2000

Group variable: index Time variable: jahr Panels: correlated (unbalanced) Autocorrelation: common(AR1) Sigma computed by pairwise selection Estimated covariances = 105 Estimated autocorrelation = 1 Estimated coefficients = 19				Number of obs = 191		
				Number of groups = 14		
				Obs per group: min = 4		
				avg = 13,643		
				max = 16		
				R-squared = 0,9803		
				Wald $\chi^2(17) = 7999,95$		
				Prob > $\chi^2 = 0,000$		
logdmc	Coef.	Panel-Corrected Std. Err.	z	P> z	[95% Conv. Interval]	
logeendvcap	0,1777414	0,0750796	2,37	0,018	0,030588	0,3248947
logmw	0,0776095	0,0154185	5,03	0,000	0,0473898	0,1078292
logdwellcom	0,0761744	0,0231251	3,29	0,001	0,0308501	0,1214988
heat	0,0050402	0,0014359	3,51	0,000	0,002226	0,0078545
logimpan	0,2251379	0,0845001	2,66	0,008	0,0595207	0,3907552
jahr	-0,0127078	0,0037391	-3,4	0,001	-0,0200364	-0,0053792
_cons (dropped)						
rho		0,5200233				

In the best-fit model for the panel EU15 and the period from 1980 to 2000 the important variables for explanation the DMC per capita are the **energy consumption per capita (eendvcap)**, the **length of motorways per capita (mw)**, the **number of completed dwelling units (dwellcom)** and the **share of import of GDP (impan)**. About the detour on energy consumption, climate conditions such as heating days (heat) influence also the DMC per capita. The variable **year (jahr)** symbolises again the automatic technical progress. With the exception of 'impan' all variables have the expected signs. One explanation for the positive correlation between high share of import of GDP and high per

<sup>28</sup> All regressions are calculated with country-dummies, but we omitted the dummies in the tables of our test statistics.

capita DMC may be that countries with a strong industry structure such as Germany have a higher share of import and export than countries with a small industrial base. The reason lies in the global production chains, where raw materials and intermediate goods are imported, domestically refined into finished products and also globally traded, i.e. re-exported.

The share of imports in GDP is also the most influential factor: an increase in the import share by 1% would raise the DMC per capita by 0.225%. In contrast the increase of energy consumption per capita by 1% would lead to an increase in DMC by 0.177%. The length of the motorway network per capita and the completed dwelling units per 1000 inhabitants have approximately the same explanation power. Finally, the variable 'year' shows, that under ceteris paribus conditions, DMC per capita would fall by 1.27% p.a., because of the autonomous technological progress.

However, the value of rho (0.52) indicates that this model is **heavily influenced by autocorrelation**. A common rule of thumb is, that a value for rho < 0.3 can be considered as unproblematic and the influence of the autocorrelation is low. In our case, we can infer from the high value of rho that DMC per capita is strongly influenced by the previous period. In a normal fixed-effects model (without the corrected standard error) this AR1 coefficient could be calculated and be expelled. However, the integration of DMC per capita of the previous period as an explanatory variable in the analysis wouldn't be a solution, since this variable would dominate the entire model and the other variables would no longer be significant.

The problem with autocorrelation is not really to solve, especially because pure time series analysis with time series of about 20 years are too short. The fact, that fixed-effects models or PCSE models with country dummies are time dominated procedures, poses another problem. I.e. these procedures estimate the influence of the different variables on the time trend of the explanatory variables. If you would like to explain the differences in the levels of DMC per cap, we must calculate either between-estimators instead of within-estimators of the fixed-effects model or a pure cross sectional analysis for one year. However, the Hausman test has shown that a fixed-effects model exists and therefore the between-estimator would be biased and inconsistent. In turn a cross-sectional analysis suffers from the small size of the panel of just 15 or 27 countries. With the low number of degrees of freedom, we could integrate in the model only a very few variables.

In Table 3-2, the test statistics for the full panel of the EU27 from the period between 1992 and 2000 is shown. For the full panel we have been identified other variables as explanatory variables as in the EU15 panel. Here again all variables are within the 5% significance level. With exception of **EU patents per 1 million inhabitants (patent)**, all the variables have the expected sign. However, the influence of the patent variable is comparatively low.

Table 3-2: Test statistics for EU27, 1992-2000

Group variable: index Time variable: jahr Panels: correlated (unbalanced) Autocorrelation: common(AR1) Sigma computed by pairwise selection Estimated covariances = 300 Estimated autocorrelation = 1 Estimated coefficients = 31				Number of obs = 186		
				Number of groups = 27		
				Obs per group: min = 3		
				avg = 7,75		
				max = 9		
				R-squared = 0,9822		
				Wald chi <sup>2</sup> (17) = 323465,87		
				Prob >chi <sup>2</sup> = 0,000		
logdmc	Coef.	Panel-Corrected Std. Err.	z	P> z	[95% Conv. Interval]	
logbevdict	-0,739	0,419	-1,76	0,078	-1,561	0,083
logbaua	0,259	0,045	5,75	0,000	0,171	0,348
logbws2	0,188	0,087	2,17	0,030	0,018	0,358
logarprod3	0,153	0,036	4,23	0,000	0,082	0,224
logpatent	0,039	0,013	2,92	0,003	0,013	0,065
logeend	0,439	0,101	4,33	0,000	0,240	0,637
jahr	-0,006	0,003	-2,21	0,027	-0,011	-0,001
cons.	10,820					
rho	0,142					

**Population density (bevdict)** has the strongest influence on DMC per cap. An increase in population density by 1% would lead to a reduction of DMC by 0.74%. However, the increase in population density by 1% is a very high dimension. This would require a very significant increase of population in absolute numbers, which in turn would explain the high relevance of this variable. The high impact of **final energy consumption per capita (eend)** on DMC per capita is surprising in comparison to the EU15 panel: if energy consumption per capita were increased by 1%, DMC per capita would rise to at least 0.44%. Perhaps the energy mix differs significantly between the EU15 and EU27. One hypothesis would be that – similar to Germany and Greece – the energy mix of Eastern European countries is still based heavily on fossil energy sources – mainly coal –, so that a higher energy consumption influences DMC more directly than in France and Italy, with their high proportion of nuclear power<sup>29</sup> or the Scandinavian countries and Austria, with their large share of energy from hydropower. The **share of employees in the construction sector in total employment (BAuA)**, the **share of gross value added of the industrial sector in GDP (bws2)** and the **labour productivity in construction (arprod3)** have also a high explanation power on DMC per capita. For all three variables, the correlation with DMC per capita is positive. Again, the variable **year (jahr)** explains the influence of an autonomous technological progress on DMC per capita under ceteris paribus conditions. The shorter time series leads, on the one hand, to lower value of the variable year, but, on the other hand, reduces or eliminates our problem with first order autocorrelation. The rho value lies with 0.142 considerably below the critical mark of 0.3.

<sup>29</sup> In the case of Italy, the energy from nuclear power sources are imported from France. Italy has no nuclear power station by itself

In a next step, it was also analysed which drivers may influence the resource productivity, that is their reciprocal value the resource intensity (ri). Again we used different panels for two different models (Figure 3-3 and 3-4).

Table 3-3: Test statistics resource intensity for EU15, 1980-2000

Group variable: index				Number of obs = 171		
Time variable: jahr				Number of groups = 12		
Panels: correlated (unbalanced)				Obs per group: min = 11		
Autocorrelation: common(AR1)				avg = 14,25		
Sigma computed by pairwise selection				max =16		
Estimated covariances = 78				R-squared = 0,9957		
Estimated autocorrelation = 1				Wald $\chi^2(17) = 28893,5$		
Estimated coefficients = 20				Prob > $\chi^2 = 0,000$		
		Panel- Corrected				
logri	Coef.	Std. Err.	z	P> z	[95% Conv. Interval]	
logindust	1,171	0,158	7,41	0,000	0,861	1,480
logimpcap	-0,202	0,047	-4,25	0,000	-0,295	-0,109
logarprod2	0,256	0,102	2,51	0,012	0,056	0,455
logbws3	0,341	0,078	4,38	0,000	0,188	0,494
logbev	0,712	0,340	2,1	0,036	0,046	1,378
logpee	-0,101	0,039	-2,59	0,010	-0,178	-0,025
logdwell	0,408	0,162	2,52	0,012	0,091	0,725
logbaua	-0,192	0,090	-2,12	0,034	-0,369	-0,014
cons.	-1,323					
rho	0,545					

Because of resource intensity and productivity being a ratio of GDP and DMC, it is not surprising, that in the univariate regression analysis GDP in U.S.\$ in PPP out of all variables has the highest correlation with resources intensity. For this reason we exclude GDP in U.S. \$ PPP in our multivariate regression analysis as an explanatory variable. As with the analysis of the drivers of resource consumption per capita, the results of the two panels are different with regard to their explanatory variables.

The resource intensity of the EU15 countries over time from 1980 to 2000 are explained by **the share of employment in the manufacturing sector in total employment (industrial)**, **the imports per capita (impcap)**, **the labour productivity in the industrial sector (arprod2)**, **the share of the construction sector in GDP (bws3)**, **the population density (bev)**, **the primary energy generation per capita (pee)**, **the dwelling stock (dwell)** and **the share of employees in the construction sector in total employment (BAuA)**.

All variables again are logarithmised, so that again a direct ranking of importance of each variable on the change of resource intensity can be read. A 1% increase in the **share of employment in the manufacturing sector in total employment** would result in a 1.17% increase of the resource intensity, or, in another way, to a deterioration of the resource productivity. This result is not really surprising because the direct material consumption in the industrial sector is significantly more resource intensive than in the service sector. Analyses with input-output methods (Acosta et al. 2007), however, indi-

cate that the service sectors use a lot more resources as often assumed because of the interlinkages with upstream sectors.

Higher **imports per capita**, on the other hand, lead to a declining resource intensity and would therefore support the hypothesis that a high proportion in foreign trade would be an indication for open economies with very high competitive pressure. This competitive pressure would lead to an efficient use of resources and energy. In contrast, an increase in **labour productivity in the industrial sector** would result in a decline in resource productivity. The first explanation for this initially apparently paradox result is probably the fact that highly productive industrial sectors are also very effective sectors. Alongside with high shares of GVA and employment levels this leads to a high level of resource consumption originating from high volumes of industrial production. This pure quantities and growth effect is likely to be at the expense of the development of the resource productivity.

Other variables such as 'BauA', 'bws3' and 'bev3' show surprising signs that cannot be easily justified. It is not obvious, why a higher **population density** leads to a decline in resource productivity. Intuitively, one would rather expect the opposite. For example, a low population density finally leads to the fact that the necessary material expenditures for infrastructure systems per head are higher. The univariate regression analysis between resource intensity and population density then delivers a negative sign for the coefficients. The different sign between the proportion of **employees in the construction sector** in total employment on the one hand and the gross value added of the construction sector on the other hand is also not easy to explain. One would expect that both have an equal sign. Here, too, the sign for 'BauA' changes from a positive sign in the univariate investigation to a negative sign when integrated into a multivariate model in context with other variables. Perhaps the change in the sign results from the interplay between the variables of the industrial sector and the construction sector.

The negative sign for the **primary energy generation per capita** is probably due to the high proportion of non-fossil energy sources, mainly hydropower and nuclear power in the energy mix in many EU15 countries. The positive correlation between the dwelling stock and the resource intensity indicates that a huge dwelling stock requires a lot of construction minerals for maintaining this stock.

As with the EU15 panel with DMC per capita as explanatory variable, we also have problems with **strong autocorrelation** in the test statistics for the driver of resource intensity in the EU15.

Table 3-4: Test statistic resource intensity for EU27, 1992-2000



Group variable: index				Number of obs = 159		
Time variable: jahr				Number of groups = 22		
Panels: correlated (unbalanced)				Obs per group: min = 1		
Autocorrelation: common(AR1)				avg = 7,2273		
Sigma computed by pairwise selection				max = 9		
Estimated covariances = 253				R-squared = 0,995		
Estimated autocorrelation = 1				Wald $\chi^2(17) = 17163,64$		
Estimated coefficients = 29				Prob > $\chi^2 = 0,000$		
	Coef.	Panel-Corrected Std. Err.	z	P> z	[95% Conv. Interval]	
logindust	0,336	0,163	2,06	0,039	0,016	0,656
logbws4	-1,347	0,242	-5,56	0,000	-1,822	-0,872
logimpcap	-0,148	0,047	-3,14	0,002	-0,240	-0,055
logdwellcom	0,044	0,026	1,73	0,085	-0,006	0,095
lograil	-0,520	0,152	-3,43	0,001	-0,817	-0,222
logarpro2	-0,265	0,104	-2,54	0,011	-0,469	-0,060
logpee	0,078	0,045	1,74	0,082	-0,010	0,166
cons.	17,524					
rho	0,209					

For the EU27 panel with its shorter time period from 1992 to 2000 the autocorrelation is no problem due to the short time series (Figure 3-4). For the full panel of EU27 countries the following variables have been identified as crucial variables: the **share of employment in the manufacturing sector in the total number of employees (industrial)**, the **share of the services sector in GDP (bws4)**, the **imports per capita, the number of completed dwelling units per 1 million inhabitants (dwellcom)**, the **length of the rail network (rail)**, **labour productivity in the industrial sector (arbprod2)** and the **per capita primary energy generation (pee)**. Thus many variables in both the EU15 panel of the longer time series as well as in the EU27 panel with the shorter time series are significant. However, 'arprod2' and 'pee' have changed their signs in comparison to the EU15 panel. This suggests that the total energy mix in EU27 panels is stronger based on fossil fuels than in the EU15 countries and thus an increase in primary energy generation per capita leads to declining resource productivity in the total panel of EU27. On the other hand, a rising labour productivity in the industrial sector in the new member states are often the result of new investments, often accompanied by foreign direct investments (FDI), which improves the capital stock dramatically with the side-effect that the new equipment works significantly more resource-efficient as older ones. As a result, the labour productivity of the industrial sector would be negatively correlates with the resources intensity.

The strongest connection lies between the share of the service sector in GDP and resource intensity. An increase in the share of the tertiary sector in GDP by 1% leads to a reduction of resource intensity by 1.347%.

### 3.6. Conclusions

The regression analysis in chapter three indicates some interesting results. However, our analysis also shows, that these results depend at least partly on the length and quality of the time series as well as on the chosen country panel. Further detailed analysis with longer time series and broader country panel would deepen the understanding of driving factors.

However, the results for our two panels lead to the following conclusions:

- The energy use has a high significance for resource use per capita as well as resource productivity. This indicates that some synergies exist between climate policies and resource policies.
- For DMC in most countries is dominated by construction minerals, the construction sector and its industries have a high impact on both, resource use and resource productivity. The results of our regression analysis indicate this impact. The two case studies of the next chapter (cement industry as well as steel industry) are highly connected with construction activities.
- Mobility variables are also of critical importance for resource use and resource productivity, especially when ‘hidden flows’ and ‘ecological rucksacks’ of metals are accounted for. Although only one of the mobility variables (length of networks) have turned out to be part of the best-fit-models in this study, an analysis of driving factors of the consumption of construction minerals (Steger/Bleischwitz, 2007) shows also a high relevance of the car possession as a driving factor. This results are directly linked to the third case study (automobile industry) in the next chapter.
- The service sector has also an influence on the resource intensity of economies. However, there are open questions with regard to indirect flows of resources within a economy. The method of regression analysis is not especially suited to deal with this problem. Interestingly however, our results are in line with findings from input-output analysis (Acosta et al. 2007) as well as life cycle analysis (Tukker et al. 2005).
- Overall productivity dynamics are unsolved yet: There are some open questions regarding labour productivity and resource productivity. The current data situation on labour productivity on the basis of a number of employees cannot capture the working hour differences between countries. Better time series data on working hours across countries and sectors will help to improve quality of research in future, and help to tackle the question of driving forces for total factor productivity growth.
- Since the database used in this chapter ends in the year 2000, the sharp increase of prices for raw materials and energy fuels in the last years has not been incorporated in our analysis. An update of our database deems necessary and would give better insights about the impacts of foreign trade on resource productivity,.

## 4. Industries and Resource Productivity

### 4.1. Why a sectoral approach is relevant

Raimund Bleischwitz

There are evident reasons to approach industry and business when resource productivity ought to be increased; but there are three main reasons why a sectoral approach reveals specific advantages in that regard:

- A   Relevance of key industries
- B   Sectoral innovation systems
- C   Synergies with climate policy and related sectoral agreements

(a) Relevance of key industries: Quantifying resource use on a sectoral level requires observation regarding two different aspects: direct and indirect resource use. Direct use refers to the actual weight of the products, which are traded between different sectors and countries, and thus does not take into account the life-cycle dimension of production chains. Indirect flows, however, indicate all materials that have been required for manufacturing a final product (also called up-stream resource requirements or ‘hidden flows’). The flows of goods and transactions between economic activities, both within a national economy and with the rest of the world, can be illustrated in so-called input-output tables (IOTs). These tables are used for the investigation of economic structures of national economies and the analysis of the direct and indirect effects of changes in final demand, prices, and wages on the entire economy as well as its individual components. Detailed analyses of sectoral resource use however are only scarcely available for some EU countries and so far missing for the EU.<sup>30</sup>

Research done at the Wuppertal Institute (Acosta et al. 2007) reveals that ten production sectors account for more than 50 % of German Total Material Requirements (TMR). Three areas are of strategic importance because here a huge number of technological interactions among production sectors take place:

- stones, construction, and housing

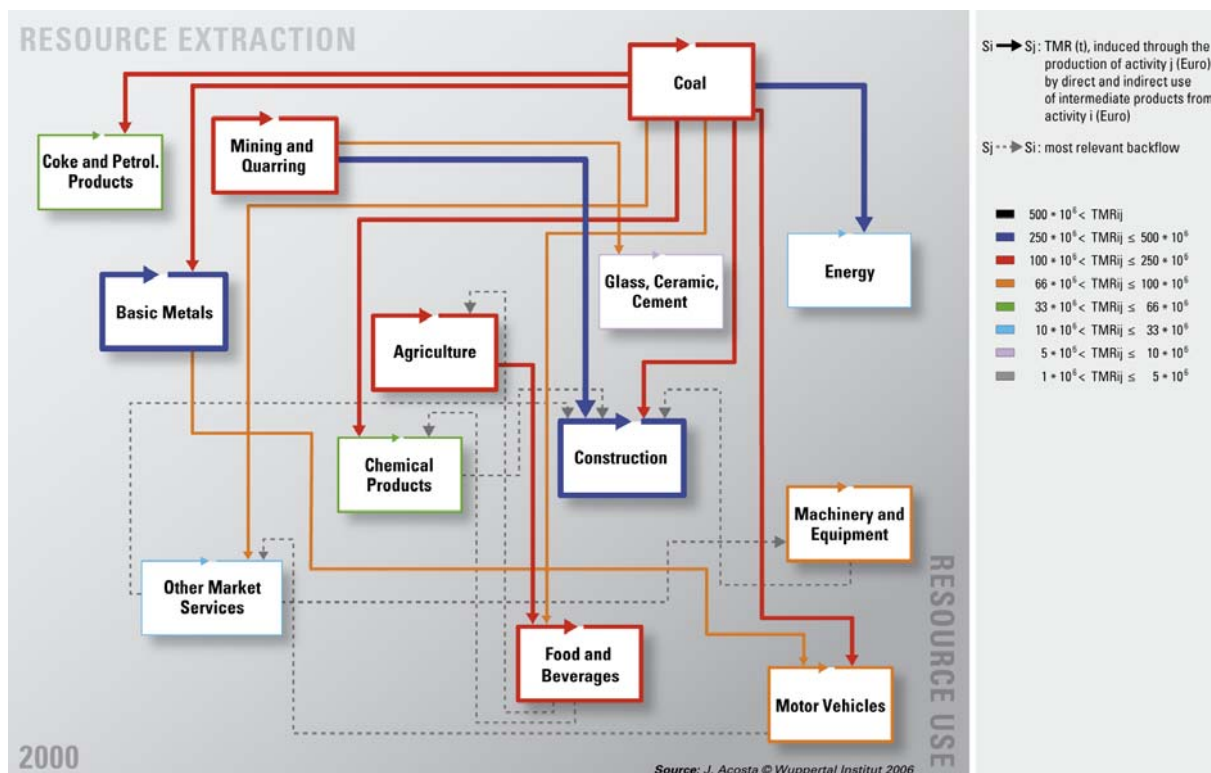
---

<sup>30</sup> So-called “physical input-output tables (or PIOTs)” are valuable tools to analyse direct resource use of different sectors in an economy. PIOTs describe the flow of materials from nature into the economy and back to nature through the economic activities of processing and consumption. No reliable physical input-output table is so far available for the European Union as a whole.

- metals and car manufacturing
- agriculture, food and nutrition.

The following figure illustrates the share, which each of the sectors directly and indirectly uses to produce the outputs (according to TMR calculations). One may note that the relevance of metals increases when indirect flows and ‘ecological rucksacks’ are accounted for.

Figure 4-1: Direct and indirect resource use by economic activities in Germany in 2000



Source: Acosta et al. 2007.

The overall use of primary material in Germany is concentrated in just a few branches, which determine the overall level of resource use. Statistically, the share of the consumption of the private households is relatively small (only 3.5 %), whereas 96.5% of the abiotic resources are used in the production sectors. Compared with analysis of direct resource use, it can be noted that the resource extraction sectors have a much lower share, as they deliver almost all resources to other sectors, which further process primary materials. According to Acosta et al. (2007), “construction” accounts for 18 %, “metals” for 9 %, “food” for 9 %, “energy for 8 %, “automotive” for 6 % of direct and indirect sectoral TMR in 2000; i.e. these **five sectors cause 50 % of direct and indirect total materials flows in Germany**. The three sectors covered in this report (automotive, cement, steel) have been selected because they belong to these most resource-intensive sectors.

**(B) Sectoral innovation systems:** There are major differences in the rate of technical change and the organisation of innovation activities across industries. In some industries technical change is happening at a fast pace, whereas in others it is slow and gradual, and in some industries innovation is carried out by a small number of actors where in others it is distributed across a wider population of firms. This suggests however, that despite the high variation of innovation activities at the firm level, each sector shows specific patterns of behaviour despite this variation on the firm level reflecting differences in technological opportunity, appropriability and cumulativeness of knowledge. Differences in innovation activities of firms in specific industries are therefore not completely random. They show some commonalities giving rise to sectoral innovation modes. Research therefore has called for a sectoral system of innovation approach in order to develop better-targeted innovation policies (e.g. Europe Innova 2008; Malerba 2007).

Sectoral patterns of innovation, however, are neither independent of the national or supranational situation nor independent of the level of individual companies. The following figure captures the sectoral innovation model as developed by Europe Innova (2008: 9).

Figure 4-2: Sectoral Innovation Model

Zur Anzeige wird der QuickTime™  
Dekompressor „TIFF (Unkomprimiert)“  
benötigt.

Source: Europe Innova 2008: 9.

This model identifies the cumulativeness of knowledge, its appropriability, and opportunity conditions as basic parameters affecting the behaviour of firms in an industry. These are core aspects of what in the literature has been called “technological regimes.” They define the particular knowledge and learning environment in which firms operate.

Two factors are considered as being crucially important inputs into the innovation process: the **funding of innovation and human capital**. This however differs across sectors. The Europe Innova panel (2008: 26) notes that e.g. the automotive sector is least affected by financial barriers. Nevertheless, one third of the companies in this sector rank the lack of an appropriate source of finance within the enterprise or group as factor

hampering innovation. On the other hand, a large share of innovative enterprises receives public funding. The evidence suggests that the lack of finance in this industry is due to the selection and allocation function of financial markets and is therefore not related to any general failure in the market. In the cross-sectoral topic of eco-innovation however almost 30% of firms classified as eco-innovators indicate that innovation costs are too high. Experts indicate that the funding of eco-innovations is a major obstacle to the innovation process.

The central conclusion of research on SIS is that the European Union needs a **differentiated policy approach** to achieve its goal to become the most innovative economic area in the world: Policies and innovation support initiatives should not focus on R&D activities alone. Some very innovative industries rely heavily on technology transfer and the use of new technologies developed in upstream industries. Knowledge diffusion, vertical technological cooperation and non-R&D related activities are important drivers of innovation too. Policy initiatives affecting a larger number of industries in a number of complementary policy areas should focus on the shortage of skills and financial constraints in order to promote innovation activities and especially the development of new knowledge and ideas. Policies too should take into account the economies of the member states and their industrial structure.

**(C) Synergies with climate policy and related sectoral agreements:** A third reason why a sectoral approach matters stems from other areas of environmental policy, namely climate policy. Such sectoral approaches are not entirely new; especially voluntary sectoral agreements have been established in various industry sectors across different nationalities and for different purposes. In the evolving debate over new ways to reduce greenhouse gases, especially in the post 2012 period, sectoral agreements have gained increasing attention. Many industries have raised concern about their competitiveness because EU climate policy leads to cost increases for CO<sub>2</sub> / energy fuels. They expect that sectoral approaches can address their specific concerns in an appropriate manner (see also the discussion on sectoral innovation systems). In addition, sectoral approaches have the potential to address a variety of climate-related challenges such as mitigation, adaptation, research, capacity building, technological innovation and cooperation. It might even turn out that sectoral agreements can be formulated at the international level beyond the EU since many competitors outside the EU are used to comply with EU rules. Sure, any such sectoral agreement won't be done in isolation but as part of a larger policy mix.

Currently, sectoral agreements seem to be most promising in energy-intensive sectors such as iron and steel, aluminium, cement, pulp and paper, i.e. industry producing commodity goods exposed to international competition. Some experts even argue that sectoral agreements could be the basis for binding, technology-based agreements between nations.

Since these sectors are resource-intensive too, the issue of any sectoral climate agreement is closely linked with resource productivity. In a wider sense, this is a call for ana-

lysing the interrelations between energy and material flows. An integrated approach with the perspective to reach sectoral agreements may exploit additional potentials to save energy via economizing precious resources with high contents of ‘grey energy’ as well as saving materials via re-using heat, cascading use and sustainable design. It is not the purpose of this study to explore these interrelations, but it should be clear that a comprehensive perspective offers valuable tangible benefits. Of course, any such sectoral agreement will have to address crucial issues such as

- the definition of sectoral boundaries and the inclusion of important actors from either upstream suppliers or downstream customers (i.e. the parties to the agreement),
- the scope of the agreement (e.g. emissions, material intensity, resource productivity, technological cooperation, timetable),
- procedures for data provision, monitoring, reporting, accounting,
- the nature of any commitments and compliance procedures (targets, timetables, binding rules, enforcement and procedures for non-compliance, settlement of disputes etc.).

## **4.2. Why these industries have been selected**

Raimund Bleischwitz

For this part of the study three sectors that are different in many ways have been chosen for more in-depth analysis. These sectors are the automotive, the cement industry, and the steel industry. This is not only because they belong to the top five sectors of resource intensity (see Acosta 2007 above), but also for a number of other reasons.

The three different sectors vary in some interesting features. In the automotive sector there is a high level of vertical integration generated and the competitors are acting globally. That means vehicles from every country are available worldwide. The automotive sector focuses strongly on core competencies and generates economies of scale. Innovation activities therefore concentrate on two dimensions: product and process innovation. On the one hand the companies have to design attractive cars in large numbers (product innovation) for their customers, on the other hand they are geared by competition to use all possible sources of cost efficiency and productivity (process innovation). Particularly challenging is to balance these two dimensions. To be successful the companies have to create cars that fit in with the customers’ taste and need.

The steel industry is also a „global player“, but operates more upfront; it is closer to mining operations, and a bit more remote from final demand. It is not a consumer good industry, but part of metals and construction activities. At the same time, it can be considered a highly specialized industry with many applications as well as a high potential



for recycling. Worth to note, the European steel industry is subject to the emission trading system (EU ETS).

The market of the cement industry is differently drafted. Because the transport of building materials is not profitable in most instances, the cement market is predominantly defined at a regional scale. Therefore cement is mostly consumed in the circumference of the production facility. This market structure can be assumed to have a strong influence on the innovation philosophy. Technically, the potential for recycling of cement has been relatively low. The European cement industry is also subject to the emission trading system (EU ETS).

It would have been interesting to add other industries too, especially the area of agriculture, food and nutrition would have been of interest. But this is beyond the scope of this study and subject of further research.

### **4.3. Automotive Industry<sup>31</sup>**

Mathias Onischka, Oliver Roeder and Raimund Bleischwitz

#### **4.3.1. Economical Status Quo**

The automotive industry is one of the most important industries in the European Union with regard to employment, gross value added and R&D. More than 3 percent of European GDP is produced by the automotive industry, whereas more than 61 percent of the production of this share comes from car manufacturing. In other words, with ca. 7 percent car manufacturing holds a substantial stake of the total manufacturing output (ACEA 2008, Eurostat 2008).

With respect to the labour market the automotive sector accounts for more than 6 percent of the manufacturing industry. This corresponds roughly to 2.1 million or 1.5 percent of the total employees in EU15; additional 3 percent of total employment can be attributed if upstreaming inputs are considered. Together with related industries and services more than 12 million people are employed in the automotive sector. However, the employment factor is only for certain countries of high relevance: Regarding the manufacturing industry Germany has the highest share with 11 percent, followed by Sweden (10 %), Czech Republic (8%), Belgium (8%), Spain (7%) and France (7%) (Eurostat, 2008). During the last years the trend that car manufacturing is displaced from Western Europe to Eastern Europe has increased. It is expected that the share in the total European automotive production of Eastern Europe countries will increase up to 30 percent until 2012 (Ernst & Young 2007)

Germany is the only Western European country that makes a stand against this trend. Ernst&Young is forecasting an increase of Germany's car production up to 40% of total

---

<sup>31</sup> Several arguments of this part are based on: Roeder, 2009

European car production in 2012 (2002: 35 percent). Hence, Europe's automotive industry is strongly dominated by Germany: With 57 billion EUR, German car manufacturers make up almost the half of the total European production (47.1%). Together with French (13%), British (10%), Spanish (8%) and Italian (8%) manufacturers the share in overall sector production amounts to 86.1%.

For the European Union, the automotive industry is of prime importance in the fields of technological developments and innovation with yearly spending in R&D of 20 billion EUR (2005) or 20 percent of total R&D in manufacturing industry (ACEA 2007).

Figure 4-3: Profitability of European car manufacturers

Zur Anzeige wird der QuickTime™  
Dekompressor „TIFF (LZW)“  
benötigt.

Source: Moody's 2008

### 4.3.2. Key challenges

#### 4.3.2.1. *Important economic trends*

The automotive sector faces several car-related developments and trends, which will highly influence the business development as well as competitiveness of European car manufacturers. Environmental issues clearly belong to those economic trends since they have an impact on relevant factors such as costs and prices. Without going into details or discuss individual points, the most important trends are:

#### Regulatory trends towards emission reduction:

The European regulation of car emissions is tightening. In addition to previous climate policy and pollution control, the Commission has proposed that in future (2012) new cars have to meet emission limits of 130 g/km. Even if parts of the reduction of CO<sub>2</sub>-emissions will be based on biofuels car manufacturers need to react with more efficient drive systems and stronger focus on their low-powered car segments. Bearing in mind

the recent long-term targets of the European Union (such as the 20 20 2020 Council decision of Spring 2007), it is very likely that emission limits will need to be lowered further in future again. One may note however that some trade-offs exist: For instance, emission reduction via the catalytic converter has led to slightly decreased fuel efficiency of cars; the use of biofuels is under scrutiny because of its life-cycle wide impacts on the environment; the End-of-life-vehicle-Directive (ELV) is under discussion because its system of recycling quota may not be in favour of using new materials (Crotty / Kandlikar 2007; Ferrao / Amaral, 2006). In the long run, the hydrogen fuel cells car (HFC) might be an option for lowering emissions from well-to-wheel (see e.g. EU projects HyWays, HyLights, Roads2HyCom).

#### Technical trends:

Not least as a result of the carbon regulation, the drive engineering is going to change in the next two decades. At the moment the question still remains what kind of drive system will become widely accepted in the future (e.g. plug-in hybrid, other electric engines, hydrogen and fuel cells, other alternatives). In the medium term interim solutions like hybrids, clean diesel or otto engines with turbo superchargers could dominate the market.

The downsizing of the driving system will become more important to achieve improvements of car weights and therefore less material usage, less fuel consumption and therefore less GHG emissions (VDA, 2007). This possible trend however is counteracted by increasing demand for certain materials such as copper (used for automobile electronics) and platinum (used for catalytic converters, see RWI, 2006)) as well as by a rapidly increasing market share for large-size cars such as SUVs. Accordingly, the bodywork of most cars has already become lighter in the previous years, but this has been overcompensated by a demand for larger sizes and more electronic features (Technology Review, 2008). Due to a calculation according to MFA methodology, today's average car (Volkswagen Golf) induces total material requirements of roughly 22 t (v.d. Sand et al. 2007). Currently, there is no overall technological trend as regards to weight and materials reduction.

The latest medium-termed plans of European car manufacturers show that in the next decade cars with electric engines are supposed to hold a significant portion of the total car fleet, not least to meet the limits for the average carbon emissions of the whole fleet. Almost all manufacturers are developing appropriate models and drive systems, however, Renault has launched an extensive project: Until 2011, more than 25,000 electric cars (plug-in hybrid type) shall be brought into market in Denmark and Israel; furthermore there are already considerations to copy this business model in France. Due to a still limited range of a battery charge a corresponding infrastructure with charging stations all over both countries will be set up. If this project in Denmark and Israel is successful it will be expanded into large European countries (Renault, 2008).

By standardising parts as well as producing models from fewer platforms companies tried to achieve economies of scale. Due to further rising fixed costs for production sites / platforms this trend will not change in future, rather mass production will be one key for a proper cost structure.

#### Product related trends:

In the long term new concepts for different customer groups will be necessary, in particular for aging populations or cars for mega cities (Oliver Wyman, 2007).

The average age of cars in use has been increasing since the 1990s (e.g. the average age of cars in Germany: 1995 81 months, 2007: 97 months). There is no evidence that this trend of increasing operating life will significantly change (VDI, 2007). Taking this fact into account, manufacturers could face lowering sales and longer product-life-cycles respectively.

In association with the mentioned electronic car project of Renault a totally new business model, privately sponsored by the multi-millionaire Shai Agassi, will be tested: Instead of the purchase of an automobile, the car will be given away to the customers who will only pay for the usage of the car. Due to the fact that the electricity for the electronic cars is produced by efficient renewable sources the usage of cars is firstly expected to be significantly cheaper than the use of conventional cars and will secondly be very environmentally friendly (Agassi, 2008). Worth to mention that on lower scale these kind of pay-by-use business models have been tested as car sharing initiatives in like-minded communities all over Europe.

In emerging economies such as China and India but even in Europe there are certain endeavours to develop, produce and provide low-cost-cars, whereas the success of these projects is unpredictable. A representative example is the recent initiative of the RWTH University Aachen, which plans to bring a serial-qualified electronic car for at most 5,000 EUR to market until 2010 (Bernhard, 2008).

#### Structural trends:

Due to persistent specialization in R&D the technical product differentiations between carmakers will decrease, therefore an increasing part of production is likely to be transferred to suppliers (Wyman 2007). Car manufacturers however will have to take into account high transportation costs (especially for trucks and shipping cargo) and develop strategies to balance costs and risks.

The overall sales of cars will continue to rise, primarily driven by the emerging and developing countries. Due to their needs for individual transportation global sales will increase up to 23 percent until 2015 (ACEA 2007, Automobil-Produktion 2007). In spite of the low market growth in the industrial countries the manufacturers were forced to make full use of their capacities as a result of their high share of fixed costs of about

30 percent. This led to substantial over-capacities in the industry (KPMG, 2008). The result is strong price competition with high discounts, incentives (e.g. free supplementary equipment) and interest-free financing options (Al-Sibai, 2004). It is not expected that this situation will change in the near future (especially not under the impression of the ongoing financial crisis).

China is expected to become the world's main automotive market by 2020. Most of the car manufacturers have already established joint ventures and assembly plants in China (European Commission, 2006).

The existing overcapacities of domestic production plants (overcapacities in EU: ca. 20-25 percent) will probably not be reduced by increasing European sales because growth markets in Eastern Europe (readmission 2006: +2.2 percent) already fully absorb their increasing demand with their new production sites.

As a result of increasing prices for crucial resources (e.g. iron and steel) large car manufacturers think about downstream investments. Such a partnership in the mining and steel industry is based on the idea that future price rises can be compensated by profits in these stakes. So far this discussion is still very hypothetical and no corresponding activities are known.

In the course of the current global financial crisis a significant drop in sales is expected for the next 12 months (ACEA 2008). This reaction is explained by the importance of the financing of cars as well as general economic uncertainties. However, this recent development will not change the medium- and long-term trends considerably, at best structural changes (e.g. market concentration) will be accelerated.

#### **4.3.2.2.      *Selected international challenges***

At the moment the European automotive sector dominates the global market. More than 42 percent of global car production is made in Europe, however North America has a strong stake in trucks (a share of 56 percent) and Asia in buses (a share of more than 84 percent). However, the Western European market is mature and mainly a replacement market with a limited growth potential with current growth of readmission of only +0.7 percent. At the global level, car production will increase until 2015 up to 75 million units (which is a plus of 23 percent compared to 2005) whereas the segment of hybrids and alternatives will significantly gain weight. Even if this growth in developing countries does not necessarily lead to a crowding out of public transport systems, the share of total individual transport will probably improve in favour of cars (Mehne, 2002). To what extent these medium-termed market forecasts have to be changed as a result of the current financial crisis is not conceivable at the moment.

Table 4-1: Global Production of Vehicles

No of produced units	EU	North America	Asia	Russia
Cars	42%	21%	35%	
Trucks	14%	56%	30%	
Buses	<4%		hereof: 70% (China); 14% south Korea	4%

Sources: ACEA 2007, VDI 2007, Automobil-Produktion 2007

In particular European companies will be faced with a persistent cost pressure. According to a study from Oliver Wyman until 2015 a cost decrease of at least 11 percent (Eur 1,500 per car) is necessary to remain profitable (Wyman, 2007). There are several reasons for this cost pressure, for example overcapacities, competition with countries with low labour costs, increasing resource prices, etc. Therefore efficiency in all production and development processes needs to be increased significantly to achieve these cost targets. Savings in resources and material can play an key element, however also other strategies might be taken into account: Offshoring of R&D as well as strategic alliances; programs for product simplification, further standardizations, modularization; investments in lower cost locations; and last not least increasing the capacities of domestic plants. A stronger market concentration in form of mergers or joint ventures could as well be one answer to these challenges.

Table 4-2: Expected global sales in automotive industry

Year	Global sales	Otto	Diesel	Hybrids	Alternatives
2005	61 mill	77%	20%	3%	<1%
2010	72 mill	74%	20%	6%	6%
2015	75 mill	62%	21%	17%	17%

Sources: ACEA 2007, Automobil-Produktion 2007

Another important issue is a globally fast growing segment of low-cost-designs (that is cars less than 7,000 Euro): until 2015 at least 10 percent of all sales in the China, India and EU will be low-cost cars. The IFA-Institute forecasts sales of about 10.5 million low-cost-cars in 2015 in Asia and at least 3.6 million in Western Europe. Against the background of distinct environmental and climate sensibility in the developing countries, the car manufacturers face the challenge to provide not only cheap but also environment- and climate-friendly cars. At the moment, outriders in this segment are Tata, Toyota and Renault, but other companies might follow.

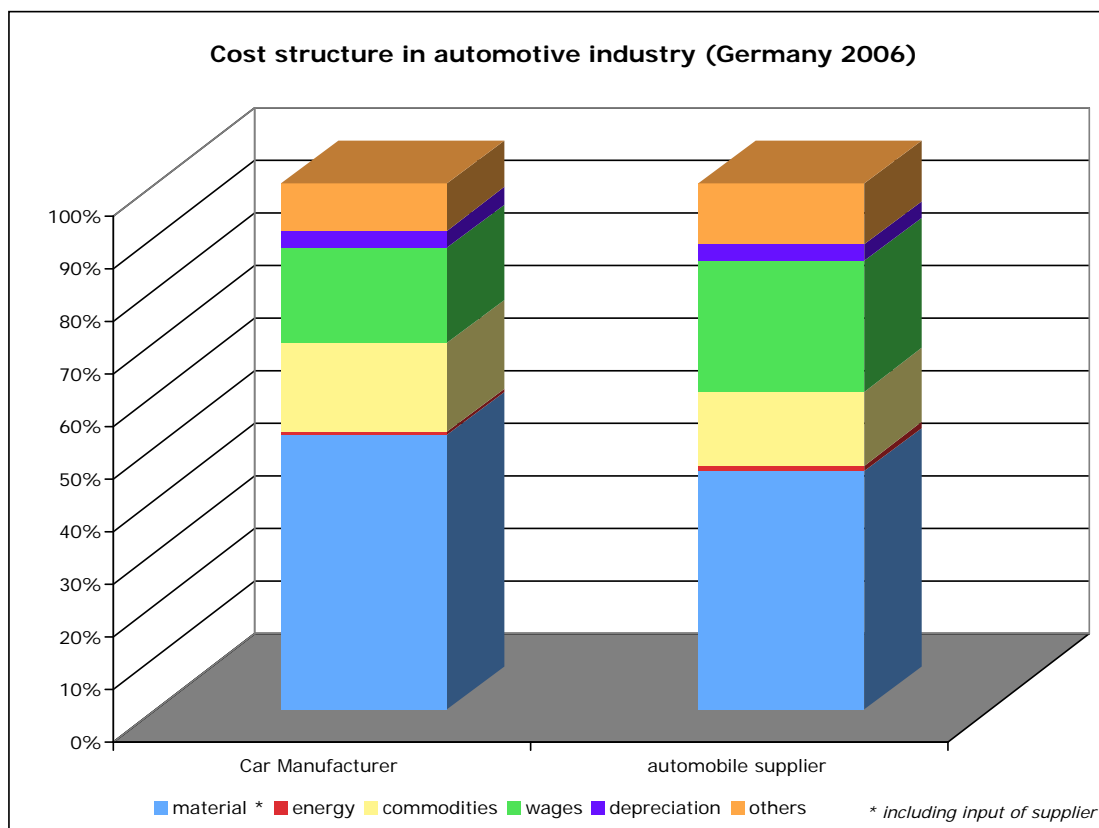
The global trend of market concentration is another important challenge that affects both car manufacturers and automotive suppliers. The number of independent car manufacturers declined over the last decades until 2004 from 52 to 12 (Deutsche Bank 2002, Niewenhuis 2003, Diez, 2001). Even today the seven largest companies have a cumulated market share of about 80 percent (Reuters, 2008). Anyhow, the process of concentration is still going on; it is expected that finally only four or five car-groups will remain (Kurek 2003, European Commission 2003, Bear 2000). A similar development can be observed regardubg automotive supplies (Radtke, 2004, Maurer 2003): A recent

study of HVB and Mercer Consulting forecasts a decline in suppliers to 3,500 until 2010 (2003: 5,500), from which the largest 20 companies will control more of 50 percent of the market (Stockmar 2004). The market concentration will have effects on the bargaining power between manufacturers and suppliers, especially R&D will be covered by suppliers to a greater extent. This will lead to a deteriorating added value of the manufacturer: Whilst 1980 for manufacturers the share of added value had been 70 percent, it declined to 35 percent until 2000 and is expected to fall to 25 percent in 2010 (Boston Consulting, 2005, Radtke 2004).

#### **4.3.2.3.      *Cost structure and material costs***

An important characteristic of the automotive industry is the relation between material cost on the one hand and personnel costs on the other hand. Almost all car manufacturers report a significantly higher material cost ratio than personnel cost ratio. The main reason is the falling real net output ratio of car manufacturers which led to an increase of the material cost ratio – which includes both intermediate inputs and material / resource costs – from 57 percent in 1980 to 71 percent in 2003 (Gromer, 2006). This means that the increased material cost ratio is by no means caused by increasing energy and resource costs only, but rather by an increase of vertical integration of the suppliers (IKB 2003). The reported personnel cost ratio of the manufacturers does not take into account that the cumulated personnel costs of the whole supply chain is much higher than this; industry experts assume that the cumulated personnel costs of a car sums up to at least 65 percent, “real” material and resource cost are about 30 percent of total costs (Becker 2007). This estimation puts the following figure into context; still it is a significant cost share.

Figure 4-4: Reported cost structure in German automotive industry



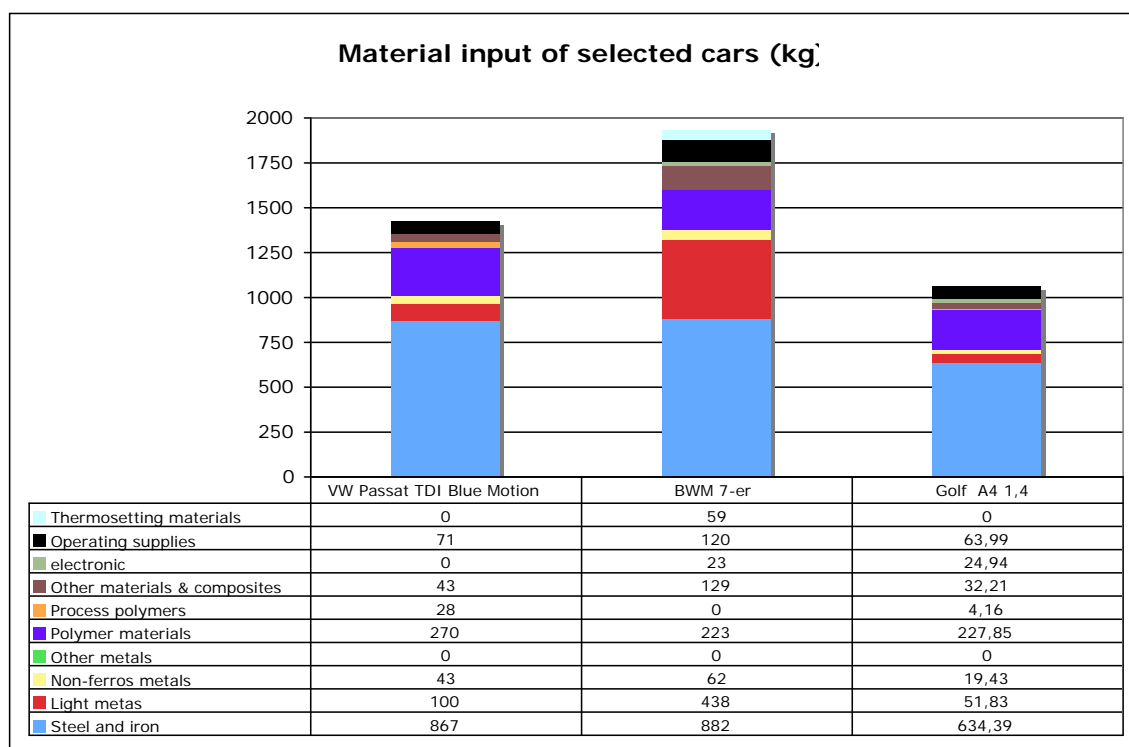
Source: VDA 2008

The current and historical development of the actual resource and material cost without input of suppliers are not published by the companies, the automotive associations or by the national or European statistics. In this respect the aggregated data of the VDA has only limited validity (see fig. 4-4). Setting the actual ratio of material costs aside, it is nevertheless obvious that increasing prices on the commodity markets will have a significant influence to the cost structure of the industry.

As a consequence of the increasing price fluctuations, hedging instruments (e.g. swaps, futures, options) become more important to smooth the volatility of the resource prices. However, a complete hedge of increasing prices without any additional costs is impossible so that it is essential to achieve a more efficient use of natural resources to reduce the share of material costs. But: Increasing raw material costs have only a limited effect to the price of the cars for final customers: If for example the price of one tonne of steel will increase by 50 percent or ca. 400 EUR, the price of a new car will only increase by 400 EUR taking into account that a car contains less than one tonne of steel (see fig. 4-5). Similar examples are possible with alternative materials like aluminium. If, however, all resource and material inputs showed similar price increases, the effect on the product price for the final customer would be significant due to the fact that more than 30 percent of total costs are material costs. Several studies forecast price increases for most resources in the next decades, but continuous price increases are expected to a low one-digit increase rate per year (RWI, 2007).



Figure 4-5: Material inputs of selected cars



Source: v.d.Sand 2007, Hessling et al. 2007, Volkswagen 2008

#### 4.3.2.4. Innovation & resource productivity

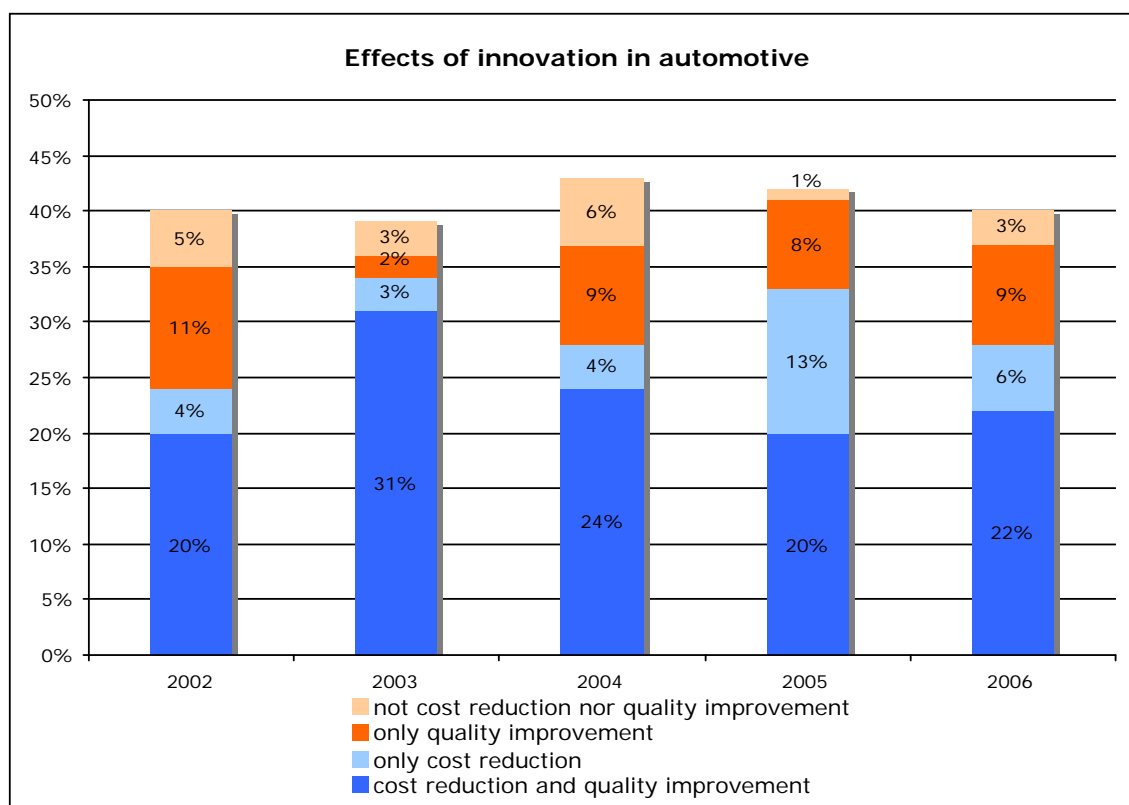
In order to assess the environmental impact of a car and its impact on climate it is necessary to consider the resource usage (and according emissions) during the whole life cycle including the production. A study done for the German Research Ministry reveals that car manufacturing ranks among the top five industrial sectors in terms of resource intensity for production (following building and construction, food, metals, and energy; data for Germany 2000) (Acosta-Fernández 2007). Among the top five sectors, which account for half the TMR, car manufacturing ranks fifth with 6 percent of the overall German total material requirement (Acosta-Fernández 2007). Several analysis came to the conclusion that 15-29 percent of the total energy consumption accrue during production whilst 71-85 percent during the usage (Nieuwenhuis 2003).<sup>32</sup> To reduce the ensuing ecological impacts not only process innovations are necessary but also product innovations and, possibly, system innovations including user behaviour. The spending for innovations is (at least in Germany) higher than in any other industry: Not least as a result of shortening product life cycles, about 57 percent of the turnover is based on new products (2006), which is almost twice the amount of an average manufacturing company (29 percent) (ZEW; 2008). The existing link between the amount of innovations, the profitability and competitiveness have been analysed by a recent study of ZEW (ZEW 2008). Nevertheless, historically many technical innovations in the automotive sector remained unsuccessful: Studies show that about 40 percent of R&D spending are

<sup>32</sup> Carbon emissions during the use of cars even sum up to 95 percent of total emissions during the life cycle (Hesse 2006).

disinvested, which means the innovations are not accepted by customers (Oliver Wyman, 2007).

So far, the potential for innovations to improve resource productivity and therefore to reduce material costs is not yet depleted. An analysis of ZEW shows that the largest part of expenditure for innovations is still spent on improving the product quality and for new electronic gadgets and features. Merely 6 percent of the innovation expenditures are used to reduce costs, whereas only a fraction will increase resource productivity (see Figure 4-6)

Figure 4-6: Effects of innovation in automotive industry



Source: ZEW, 2008

According to studies one reason for low success might be that car manufacturers as well as suppliers do not take the needs and necessities of the customers sufficiently into account. Nowadays customers are even overstrained by the extent of standard equipment and extras, particularly in the US. One of the most important purchasing criteria for costumers is the 'total cost of ownership', that is the total cost over the whole life cycle. In future, one of the most important issues will be innovations in alternative fuels and emission reduction which will sum up to about 240 billion Euro (Oliver Wyman, 2007) as well as additional costs of 700 Euro for a medium-sized car.

With respect to the discussion about climate change during the years the purchasing criteria have changed considerably. Oliver Wyman Consultants analyzed the customer's

expectations in Europe and the USA. It should be pointed out that environmental aspects have become more important: The most important criteria for the purchase of a car are still reliability, safety, value for money and total cost of ownership; but the environmental performance is already ranked number five before design, service and prestige (Oliver Wyman, 2007). Other studies also expect (e.g. KPMG, 2008) that the eco-friendliness (which includes fuel consumption) will be ranked number three in the near future, next to reliability and safety. However, all results also show that costumers are usually not ready to accept higher purchasing costs for improved resource productivity. Given the estimated share of material costs in total production value of about 30 percent and the impact of weight on fuel consumption, resource productivity strategies will more likely result in lower purchasing and running costs of automobiles.

The criteria of carbon emissions and fuel consumption of cars will be the clincher for the competitiveness and the success of car manufacturers in the medium and long term. For that reason the US car manufacturers currently demand a public credit of at least 50 billion USD to catch up their deficits in environment-friendly driving systems, 25 billion USD have already been approved by the US congress (Reuters, 2008). At this, in some cases, trade-offs between supposed environment-friendly innovations and resource productivity can emerge. A good example is the popular hybrid engineering, which attempts to reduce fuel consumption and carbon emissions. Often the circumstance stays unnoticed that the production of the hybrid technology (batteries) in particular is associated with a very high life-cycle resource usage as well as high carbon emissions. As a result of this the resource productivity of hybrids can be estimated to be lower than conventional drive systems, even on a life-cycle-basis the pretended advantages of hybrids often do not exist. Therefore, innovations in fields of resource productivity should preferably be integrated into a larger context and less within specific technical problems only. Future engines such as the plug-in hybrid or the HFC car need to be assessed according to comprehensive material intensity analysis. (OECD 2008).

Table 4-3: Selected Potentials to reduce the usage of materials in compact class car (VW Golf)

Strategy	Theoretical potentials to reduce the usage of materials in car production
1. Changing structure in production	23-29%
2. Substitution of materials - Substitution by aluminium (ratio secondary aluminium –/primary aluminium 9:1) - Substitution plastics vs. steel	Up to 20% compared with a conventional steel construction Up to 10% compared with a conventional steel construction
3. Changes in Product design	
Example: Loremo	49%
Example: PAC-CAR II	84%

Source: van der Sand et al. 2007: 63.

The potentials to improve resource productivity are not limited to more efficient driving systems only. Furthermore it is unavoidable to decrease the total resource use. A first

study reveals that the changing production structures may improve resource productivity up to 29 percent, the substitution of material up to 20 percent (see Table 4-3). However, these technical potentials cannot be lifted immediately, further R&D in these fields is crucial. In the case of substitution, much higher international recycling rates would be necessary. To verify and deploy those potentials, light construction (substitution of aluminium with high strength steel panels) is expected to play a central role for reducing weight, especially the so-called “classical substitution triangle” of aluminium, steel and plastic should be taken into more consideration (RWI 2007). Within the construction of engines the use of magnesium might also reduce weight. The steel industry already offers alternative steels like HSD-steel (high strength and ductility) that have similar characteristics and weight as aluminium, however, these substitutes usually lead to higher material costs. If the demand for such substitutes increases considerably, the current price differences will likely be compensated.

### 4.3.3. How resource productivity may enhance competitiveness

#### 4.3.3.1. *Improving cost structure*

A decrease of material usage will usually result in falling material costs. Since this is not an autonomous trend yet, additional action and incentives are needed which may – at least partly – compensate for the expected long-term raise in energy- and resource prices. Furthermore, innovations for material-saving end products usually correspond to other innovations in materials, processes, products and improvements of efficiencies. This might result in both significantly higher value added and falling costs per unit, which is obvious if the exceptionally high share of material costs on total cost (more than 40 percent) in automotive is taken into account (see cpt. 4.3.2.3). Some studies show, there are potentials for material and resource saving in manufacturing industry in double-digit percentage in the medium term; taking the high material cost share (30 percent estimated here, up to 57 percent) of the automobile sector into account, the cost relief would be substantial (v.d.Sand, 2007).

As discussed in cpt. 4.3.2.3, steel and iron are the dominant material inputs in cars with far more than 50 percent of direct material input (see fig. 4-5). First approaches for reducing this metallic input can be observed in the area of lightweight construction. The steel industry meets these concerns with the development of “tailored blanks”, that are customized steel plates<sup>33</sup>, as well as the application of new approaches of surface refinement. The quantity of material can be reduced significantly if the surface is refined, while the corrosion and hardness does not change for the worse (IKB 2007). These kind of material innovations would also increase the share of innovation which contribute to cost reduction which at the moment sum up to only 28 percent (see ctp. 4.3.2.4). In total, lightweight construction seems to offer huge potentials for both improving resource productivity and cutting material cost.

<sup>33</sup> For further information see: <http://www.tailored-blanks.com/produkte/tailored-products/thyssenkrupp-tailored-blanks.htm>

However, in some cases regulations or required standards need to be reconsidered since they limit cost improvements as a result of the reduction of resource usage. A good example is the obligatory quota for recycling of end-of-life vehicles from 2015 (quota of 95 percent) in the EU, which might prevent the use of certain innovative materials. In particular the recycling of composite and synthetic materials can be very cost-intensive, so that positive cost effects as a result of resource saving in the production process will be absorbed. However, at a certain stage of corresponding activity other costs like higher process costs or just substitutional cost can arise that reduce the net savings. A systematic long-term strategy with consequent life cycle cost assessment seems to be useful to avoid such kinds of trade-offs.

#### **4.3.3.2.      *Reducing risks***

Generally, improvements of resource and material productivity can support approaches to lower business risk and will avoid additionally arising risks because the following dependencies as well as threats can be avoided or at least reduced significantly:

Price risks: In recent years a steep increase in prices could be observed on the commodity markets (Biebel 2008). A price increase of commodities that are directly used in production leads – *ceteris paribus* – to a rise in production costs and in some cases even during the phase of the product usage. As already discussed, the automobile industry has high material inputs within the production and usage phase compared to other industries and is affected by higher commodity prices (Berenberg Bank 2007). Even if price increases of few resources had only limited effects on the cost structure of car manufacturers, substantial price increases for many relevant resources would (see chapter 2.3). Some forecasts expect that the demand for many resources will continue to rise while constant or even diminishing supply can result in resource shortages as well as continuing resource price increases (OECD, 2008). Due to the increasing demand from emerging countries there is a high uncertainty about the future price path even for the most important resources (e.g. steel). International markets for recycling materials are distorted, which reinforces the constraints on materials such as aluminium, steel, copper, and precious metals (OECD 2007, Umicore 2007, 2008). Out of this uncertainty about future prices risks of the profitability of internal project calculations as well as investment plans might arise. Lower demand for resources as a result of increasing resource productivity can help to reduce the unexpected influence of future price fluctuations on value drivers of companies.

Regulatory risks: A study by SAM/WRI shows that regulations of environmental, resource-related and carbon issues have the potential to influence value drivers and therefore the profitability significantly: There are differences in EBIT as a result of carbon regulation in the automobile sector from -10 percent (Ford) to +8 percent (Toyota) (SAM/WRI, 2004). Considering EU's climate targets, until 2050 further carbon regulations for the automotive industry are very likely. These regulations have the potential to exert influence on their product portfolio, whereas not only fuel-efficiency of cars but also alternative drive systems are of importance. Furthermore, for a necessary reduction of weights of cars a lower input of resources seems to be inevitable. In principle other

kinds of regulations can be relevant as well (like obligations of car recycling), so that a systematic resource conservation and a strategy to increase resource productivity reduce the regulatory risk involved.

Product risk: Without sufficient environmental-friendly or eco-efficient products the risk arises that costumers will sanction the company's products or change its consumption patterns. The example of hybrid cars shows, that these suppliers (e.g. Toyota) can improve their competitiveness, while others deteriorate (e.g. Ford). Furthermore, continuing successes in lowering material intensity are usually connected to corresponding innovations in functions or products as a whole.

Reputational risk: Companies which are observed with a non-environmental friendly [non-climate-friendly] production / products can be faced with a loss of reputation. On the one hand, this would have a backlash on the brand value and goodwill, which often represent a substantial part of the whole company value (Carbon Trust, 2005). On the other hand, the danger of significant short-term changes in sales as a result of losses of reputation cannot be ruled out (example: Brent Spar/ Shell in the 90th).

Legal risk: In the US federal state California lawsuits against car manufacturers are already pending. The lawsuits address the contribution of car emissions to climate change and damages / costs for selected regions in the US. According to a legal expert, in the long term judgments for indemnities in dimension of the lawsuits of the US tobacco industry in the 1990s (triple-digit billion USD) are possible. As the current development in California shows, the big car manufacturers with carbon-intense products might be one of the preferred targets in addition to utility and energy companies.

#### **4.3.3.3.      *Operate in new markets and segments***

The satiated market in Europe increases the importance of global competitiveness for domestic car manufacturers. The rising market volume in developing and newly industrializing countries will result in higher capacities in these countries and also new competitors. In principle there are two promising strategies (Porter) for European car manufacturers, cost leadership on the one hand or quality/innovation leadership on the other hand. Against the background of the very low labour costs in developing countries the share of material cost will become highly important for cost reduction.

Projections show that in particular in these growing markets the segment of low-cost-cars will play an important role. Particularly European companies (manufacturers as well as suppliers) can gain direct or indirect market shares based on according know-how and expertise for light weighting and material-conserving modules and design. The example of the announced Indian low-cost-car of the Tata Group shows that particularly German and European suppliers (e.g. Bosch, Mahle, Freudenberg, Behr) will benefit from this low-cost and downsized car. Regarding resource productivity special opportunities for European car manufacturers arise if these segments are considered as an enabler for new materials, production methods and construction principles. These significant changes seem to be necessary as a result of the high cost sensitivity or low margins

in this segment. Relevant issues might be the reduction of the content of metals to drop material costs, spumed light weight constructing parts, new designs of modules, redefinition of module boundaries, use of an integrated drive engineering (similar to motor scooters), laminated plastic windows, or even the centralization of the electronic parts as well as reduction of wiring harness. There is the possibility for a complete new start, which finally results in revolutionary materials, production modules & processes, which can be used in conventional segments for cost and material input reduction.

Hence, if European companies would position themselves as leaders in the area of material and resource productivity there is an excellent chance even to success in the new growth markets, i.e. the new important segment of low-cost-cars.

#### **4.3.3.4.      *Strategic positioning – towards system innovation***

A recent study of the Centre of Automotive found out that the car manufacturers can be grouped into three categories regarding their strategic positioning in environmental protection and resource productivity: Firstly, companies with no or vague strategy, secondly companies with fragmented strategies, and thirdly companies with quite developed strategies (Bratzel 2007). The European car makers direct their efforts to the obvious strategic deficits compared with Japanese companies, whereas German carmakers are expected to be the leader in the future (especially Volkswagen and BMW).

However, developments and innovations in the field of resource productivity usually require a medium- till long-term perspective, above all to avoid possible cost trade-offs. To obtain systematical and persistent improvements (even though improvements in the short term can be realized) this topic should be integrated as one central pillar of the corporate strategy. The complexity of this issue – in particular because of the heterogeneous requirements and starting points of customers, suppliers and competitors – requires an integrated and clearly formulated strategy for all elements of the value chain, production and R&D.

Due to the long-term perspective of appropriate action exceptional competitive edges may emerge for European companies. A systematic and extensive positioning at an early stage allows as first-mover to skim pioneer profits and to strengthen international market shares (example: Toyota & Hybrids). Admittedly, systematic and extensive action also means that the concentration on improvements of conventional drive systems to meet the carbon limits may not be sufficient to improve resource productivity. The focus on fuel-consumption is merely one of several relevant fields, the example of hybrids shows that with regard to resource productivity in some cases there might be even negative trade-offs between reducing fuel-consumption and resource-efficiency.

For the long-term success of carmakers it is crucial to reposition themselves in terms of system innovations at an early stage. System innovations are - based on the definition of Konrad / Nill – a combination of technical, organizational and social innovation, which imply new constellations of protagonists like suppliers, users and intermediaries; these system innovations are also called pathways changing innovations (Konrad / Nill,

2001). With regard to the automotive industry the substitution of combustion engines with electrical / HFC engines or/and new concepts in product usage - like the concept of Shai Agassi (Agassi, 2008) - will probably lead to significant structural changes within the industry. This can imply existential consequences, if such system innovations are recognized or faced too late, which can be currently observed in the US car industry.

## **4.4. Cement Industry**

Mathias Onischka; with contributions by Raimund Bleischwitz and Rafael Haba.

### **4.4.1. Economical Status Quo**

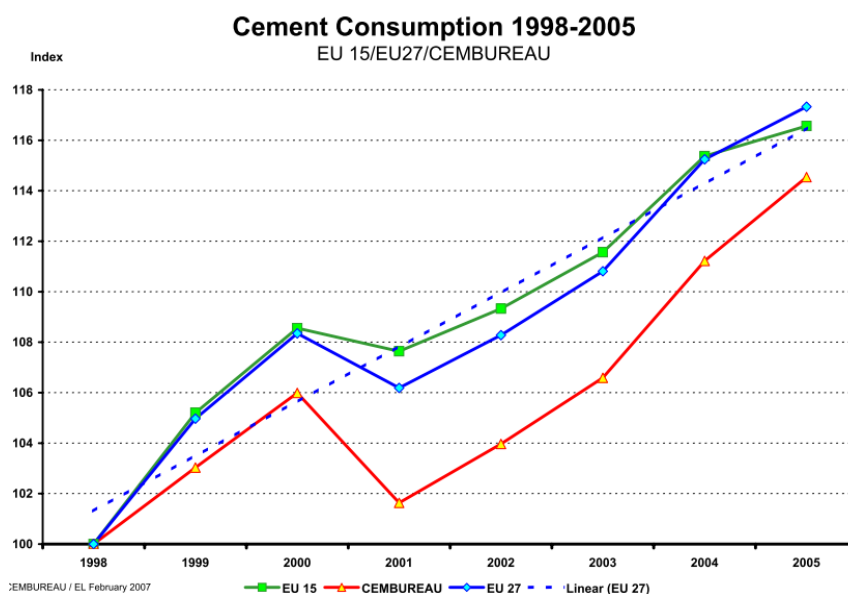
Cement is not only the key construction material but also the main ingredient of concrete, which is one of the most consumed materials worldwide (Cembureau, 2008). There are only few types of cement; the Portland cement and the composite Portland cement are the most important ones due to their material characteristics. Due to the low price per tonne of cement, it is only manufactured locally because transport costs would result in an enormous surcharge in price, especially if transported by road. If one takes into account that transport is only economical within a radius of about 200 km, it is not surprising that competition between producers is only existent on a local scale. Therefore, export is only an option if waterways can be directly accessed (Wagner, 2001).<sup>34</sup> The rate of EU export and import of cement is rather small as in many EU countries the rate of consumption corresponds to the rate of production: In 2006, from 174 Mt of cement and clinker that were produced 168 Mt have been used for domestic consumption (Wagner, 2001). Due to the homogeneity of cement, the price is the most important sale parameter and quality premiums are limited.

---

<sup>34</sup> There are indications that this is increasingly the case due to liberalisation of water and sea transportation (Bleischwitz/Bahn-Walkowiak 2007: 167 on aggregates).



Figure 4-7: Cement Consumption 1998-2005

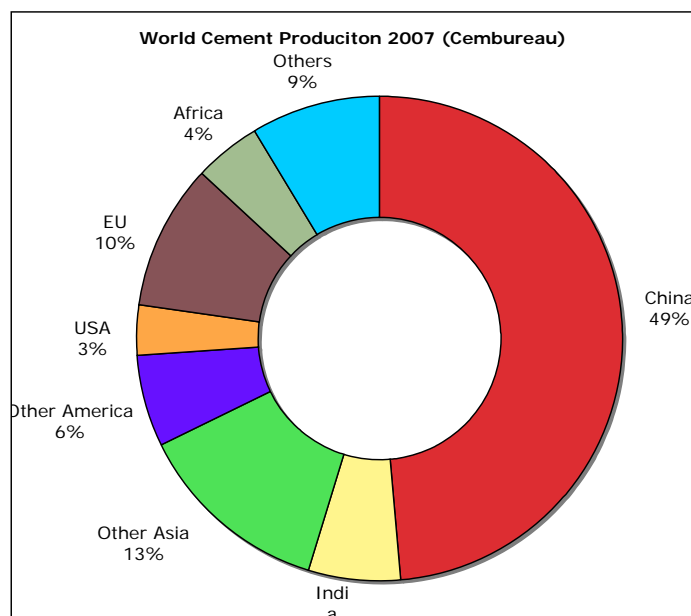


Source: Cembureau, 2006

On the one hand, in Europe, cement production has been increased by 1.8% in 2007, on the other hand, countries like Bulgaria, Poland, Romania and Luxembourg increased their consumption of concrete by more than 15%. Rises and declines in cement consumption are mainly determined by the economic activity in the building sector, especially in residential sector as well as infrastructure. Therefore, cement industry as a cyclical industry depends largely on growth of GDP and construction sector (Cembureau, 2008).

On a global scale, in 2007 the worldwide cement production has increased by 8 percent (equivalent to 77 billion tonnes), with Asia accounting for a share of about 70% of this growth. The largest cement manufacturers in this region were China with a total market share of 49%, followed by India with the share of 6.1% (Cembureau, 2008), Europe has a share of about 10% of global production.

Figure 4-8: World Cement Production 2007 (Cembureau, 2006)



Source: Cembureau, 2006

Modern cement plants are highly automated due to the development of modern automated machinery and continuous material handling. Therefore, for the operation of a plant, only 200 employees are needed nowadays, the most of whom even are only low skilled workers. As a result of this low labour intensity, the whole industry only represents 52,800 direct employees in the EU (Cembureau, 2008).

Structurally, few major multinational companies dominate the industry with interests in the EU, US and CEEC. The largest companies are Lafarge (FR), Holcim (SWI), Cemex (MEX), Heidelberger (GER) and Italcementi (IT). More than 50% of European cement production is accounted for by five major players, while the top 10 players hold about a 76% market share. It must also be mentioned that the top five players hold a large share in the global cement market of around 30% (McKinsey, 2006). Due to the strong focus on local markets as well as to the limited number of relevant suppliers, the industry is strongly watched by monopoly authorities in particular with regard to price agreements. Ownership structure of companies differs among the countries. Many small firms are in the ownership of their founder but a majority of the companies are owned by institutional shareholders.

#### 4.4.2. Key challenges

##### 4.4.2.1. Important economical trends

In the last years, the cement industry has faced a number of different challenges especially as a result of environmental regulation and increasing energy costs. The most important challenges are the energy demand and greenhouse gas emissions.

##### Energy demand

Depending on the cement variety and used process technologies, the production of one tonne of cement requires the equivalent of up to 130 kg of fuel (that is primarily oil or oil substitutes) and 110 kWh of electricity (Oss 2002; CCIC 2007). Due to the high energy intensity, the industry is strongly influenced by increasing energy prices, whereas – not least as a result of taxation – energy prices in Europe are the highest worldwide. At the end of 2007 energy was accounted for 80% of the variable cost for European cement plants (Cembureau, 2008). Taking the German cement industry as an example, only costs of electricity in 2002 did amount to 19% of gross value (Eikmeier et al., 2005). In future, the costs for fossil fuels, such as petcoke and coal, which are traditionally energy sources for cement production, are expected to rise as the stocks in natural deposits are limited and demand is likely to remain at a high level.

Accordingly, the industry has been forced to invest in measures, which help to cut the energy consumption on the one hand and to increase the use of such kind of alternative fuels, which are suitable for the cement burning in terms of heat.

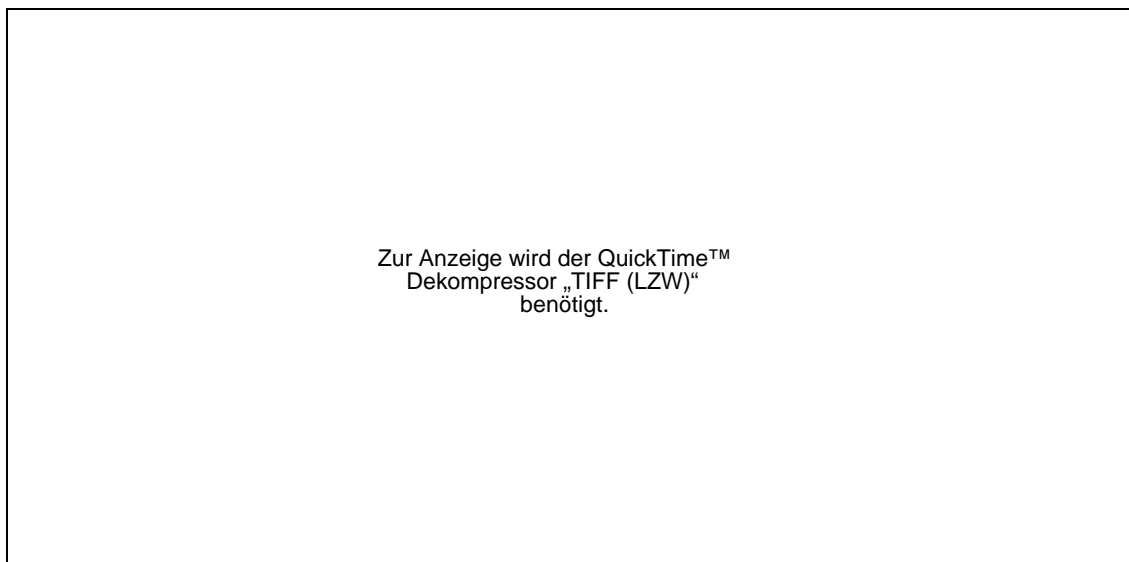
#### Reduction of carbon dioxide and other greenhouse gases

Cement industry is responsible for about 5% of global man-made CO<sub>2</sub>, of which 50% is from the chemical process, and 40% from burning fuel (WBCSD, 2008). Accordingly, cement plays an important role in the climate change debate with respect to the European Trading Scheme (UBS, 2007). Within the industry, the carbon regulation has led to quite a controversy: The industry argues that the EU's emission trade arrangements would have a destructive impact on competitiveness. Furthermore necessary investments cannot be made because the final objectives on CO<sub>2</sub>-reduction for the second phase of the EU ETS are yet unknown (CCIC, 2007). Even if the draft on the new emission trade arrangements (from Dec 2007) does not yet specify the reduction objectives, it is discernible that the new regulation will result in a burden for the cement industry anyway (Bleischwitz et al., 2007). Most of this cost increase is due to direct emissions, indirect impact from higher electricity prices make up only a small share of overall cost increase. Thus, depending on the ability to pass on costs to customers, the European cement industry on average will face a cost increase – moderate or neutral if the costs can be passed through. Potential cost increases will probably be seen close to seaports or EU borders (Greece, Spain, southern France, Italy) where the possibility of importing cement is the highest (McKinsey, 2006) and therefore costs cannot easily be passed on to final consumers.

According to official statements from the industry there are certain limitations for future reductions in greenhouse gas emissions. Firstly, the technological potentials for CO<sub>2</sub>-reduction are already exhausted if the most recent technology is used. Especially CO<sub>2</sub>-emissions resulting from burning fuels have already been reduced by according process engineering: While the production of one tonne of clinker releases 0.7 tonnes of carbon dioxide, only 25% are the result of burned fuel, the major emissions are the result of processing of limestone (IPCC 2007). Experience, however, suggests that there is capacity to cut back emissions by reducing clinker input and by using more non-fossil fuel

(CARBON TRUST, 2006) in case alternative fuels like used tires, wood, plastics, chemicals and other types of waste are hitherto used for the heating process (IEA 2007).

Figure 4-9: Impact of alternative fuels on overall CO<sub>2</sub> emissions



Source: CEMBUREAU, cited in: IEA 2007

The use of renewable fuels however is costly and limited; the use of biomass needs to be assessed by LCA. According to certain discussions, the sequestration of CO<sub>2</sub> might be another option to reduce the total CO<sub>2</sub>-emissions. However, there is a substantial limitation for a sequestration: With today's technology it is not possible to sequester the CO<sub>2</sub> within the burning process of cement due to moving mechanics, only the accruing emissions of the fuelling process can be sequestered. At the moment it is quite doubtful if carbon capture and storage (CCS) will ever be a solution for the cement industry, further fundamental research is necessary anyways especially in the field of the sequestration of CO<sub>2</sub> which is difficult due to the movements of the rotary kiln. (Fischedick et al., 2008)

Taking into account that from a general point of view the potential for reduction of CO<sub>2</sub> is – at least in the short run – limited regarding high-efficient cement plants, the cement producers will face significant cost to provide themselves with necessary emission certificates. If a price for certificates of 35 €/t of carbon dioxide is supposed, the cost of production would increase by 25 €/t that is the consumer price will rise by 50 percent. With such high prices, it might become cost-efficient to increase imports from neighbour countries or to consider possible substitutes that means the competitiveness of certain European cement companies is likely to decline. With other words, the aim of reducing greenhouse gas emissions might be achieved in the EU based on offshoring of production – at the expense of other nation's GHG emission performance and with doubtful progress.

#### 4.4.2.2. *Selected international challenges*

Due to the fact that the most common cement sort Portland can only be produced with substantial marl deposits close to the production site, there is still very limited international competition within the industry. From an international point of view one of the most important challenges for the industry is the availability of fuels. Not only the foreseeable carbon regulation might lead to a change in fuel-policy of the cement industry: Even today, a substantial share of the necessary fuel capacities is already satisfied by the burning of waste, in particular tires and waste oil. With regard to their high carbon intensity these and other alternative fuels are taken into consideration more strongly; in future it might be reasonable to use refined oil to reduce carbon emissions. Also alternative energy sources like renewable fuels from biomass, meat and bone meal etc. might be an option, however increasing energy demand and land use conflicts can limit available resources.

#### 4.4.2.3. *Cost structure and material costs*

The cement industry can be regarded as one of the most capital-intensive industries. The refinancing factor – in terms of the ratio *years of turnover required* which are related to the initial investment costs – is estimated to 3.0 for the cement industry, compared with other capital intensive industries like paper industry (2.7) or glass industry (2.3). To map it onto the cement production: as a rule of thumb, for a production site with a yearly production capacity of one million tonnes about 140 million Euro (USD 200 million) of initial investment is required.

Globally the cost structure of cement production varies depending on the local conditions, in particular as a result of employment costs, sort and quality of raw material, the age of the used technology, energy costs, transport distances and therefore transport costs. If due to a lack of rail- or waterways roads need to be used, transport costs can become the biggest cost block (Environment Agency, 2005). However, a comprehensive analysis of the cost structure of the cement industry in EU is very difficult, because detailed statistics are not available publicly.<sup>35</sup> Therefore, the following table only refers to figures from 1997. Especially costs for fuels and electricity have a more significant cost share of total unit costs nowadays, so it is quite obvious that mainly expenses for fuels and electricity make up the lion's share of the variable costs. If a reduction in the demand for energy and fuel is achieved, variable cost will fall significantly. Non-fuel raw materials itself count for less than 11% of total costs and 25% of variable costs only. (Shenoy et al 2007)

---

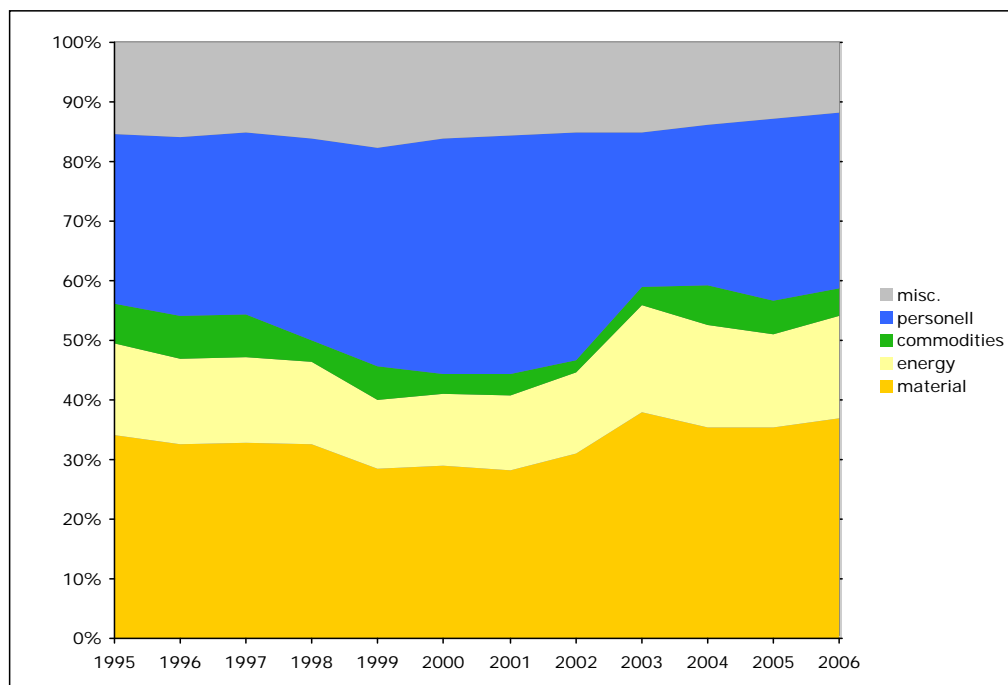
<sup>35</sup> CEMBUREAU (the European Cement Association) has not been able to disclose data on the cost structure either.

Table 4-4: Cost structure in cement industry

Costs	% of total unit costs	% of fixed costs	% of variable costs
<b>Fixed costs</b>			
Depreciation & financing charges	40%	70%	
Maintenance	8%	13%	
Personnel, rents, rates	8%	15%	
Admin. & Overheads	1%	2%	
<b>Variable Costs</b>			
Fuel (thermal)	16%		36%
Electricity	15%		35%
Raw Material	11%		25%
Paper bags, refractories, wear parts, lubricants, royalties	2%		4%

source: Shenoy, Chako, McGovern 1997

Figure 4-10: Development of cost structure in cement industry in Germany



Data: DESTATIS<sup>36</sup>

It should be added, that the percentage weight of each item within the total cost structure highly depends on the share and types of alternative fuels used and these again highly vary from country to country and also at plant level.

#### 4.4.2.4. Innovation and resource productivity

In contrast to other industries and technologies, the production of cement is connected with big technical boundaries. Caused by the calcination, there are required both, high

<sup>36</sup> The data aggregates the production and processing of different industries. However, it can be assumed that the cost structure of Germany is similar to other EU15 countries.

temperatures – that is large amount of fuels – and high material input. Furthermore, a large part of the emissions is process-related. This is of importance insofar as any focus on end-use energy efficiency does hardly address the cement industry. On the contrary, the analysis of material flows as well as production processes are absolutely essential for plausible argumentations. The process of production of Portland has already been optimized to a large degree so that important issues for innovations and improvements of resource productivity are rather energy consumption and alternatives of used material inputs.

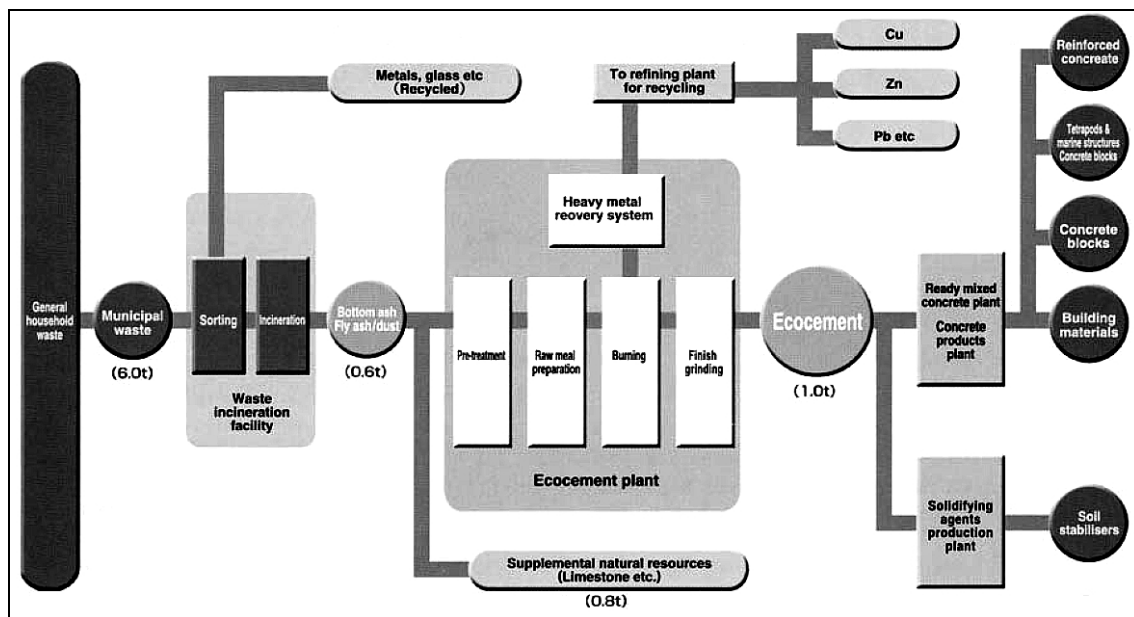
Basic material used for production of the cement is limestone that is mixed with various secondary materials such as marl, clay, bauxite, iron ore or sand. Approximately 1.5-1.6 tonnes of raw materials are required to produce one tonne of clinker.

As far as resource productivity of the process of Portland cement is concerned, there are only limited technical possibilities to reduce the resource usage or carbon emissions due to chemical and technical limitations in case the latest technology for standard cement production is used. Portland cement consists of about 95% of clinker, whose production is very energy intensive (Brandun, 2008). In principle, it might be possible to reduce the share of clinker but this results in changing characteristics of the cement (e.g. consistency, corrosion resistance). Eventually there seem to be at present only two viable options for *product-related* improvements of resource productivity: One option is the substitution of clinker with the usually called pozzolanic material such as fly ash, blast furnace slag or natural pozzolans. In contrast to Portland, the pozzolans will not be burned, which saves the major part of the fuel. Furthermore, with pozzolans, the most of process-related carbon emissions can be saved, which will result in significant cost reduction because of fewer expenses for emission certificates. However, pozzolans are no perfect substitutes because some parts of Portland is still required for its process and it cannot be used for all kinds of applications (e.g. dams). In addition, cements based on pozzolans have different technical characteristics than Portland – in particular resistance to corrosion – and imply limitation for certain building purposes. Moreover, pozzolans are no option for all cement companies and countries because their production requires adequate natural deposits, usually close to (former) volcanic areas. Non-natural pozzolans in form of fly ash or blast furnace slag can be extracted from production processes of coal-fuelled utilities, waste incineration or steel mills, but their availability is limited, too. Today, some companies already use pozzolans in their cement production. For instance, Lafarge replaced up to 60% of the clay in clinker in UK by using pulverised-fuel ash. The total share of slag, fly ash and pozzolan that Lafarge uses in their cement is about 15% (Lafarge, 2006).

Next to pozzolans another product-related alternative might become an option: Recent research results in building materials suggest that the enrichment of limestone with magnesia could reduce the process-related carbon emissions significantly (TecCement, 2006). The so-called “Ecocement” might even absorb CO<sub>2</sub> from the environment, which could result in a carbon-neutral cement production (Harrison, 2007). However, at the moment this kind of technology is still on a laboratory stage. It has not been tested on a

large scale yet; pretty much the same is true with tests to pour emissions in salty sea water in order to start a chemical reaction with the magnesium-containing salt (Taufetter, 2008). Other approaches of likewise called “Ecocement” uses incinerated ash as well as certain heavy metals which might not only reduce emissions and makes contaminants in municipals waste harmless (see Figure 4-11). According to researching Japanese cement producers, it might also have similar chemical characteristics than ordinary Portland cement (JSCE 2008). For all approaches referring to “Ecocement”, more in-depth feasibility studies and life cycle analyses need to be undertaken before these alternatives will be real options for the substitution of traditional portland in order to improve resource productivity as well as to reduce emissions.

Figure 4-11: Production process of "Ecocement" using ash and heavy metals



Source: JSCE 2008

Energy consumption can be lowered by the implementation of the “best available techniques” such as – in this case – dry processes where the addition of water is not necessary, which results in a more economical and less energy intensive drying process (see Table 4-5). This was not possible with earlier common wet and semi-wet methods where the raw materials were wet grinded and mixed together (Oss 2002, Oss 2003). Currently, about 78% of German cement manufacturers already apply the dry method, that is there is still some but limited potential for process innovation (VDZ, 2006). Even if there is no public data to what extent dry methods are used in all European countries, it is reasonable to assume that in particular in Eastern and Southern Europe a substantial share of cement is still produced with wet or semi-wet methods.



Table 4-5: Fuel energy use in cement manufacturing in the EU-25

Specific thermal energy demand (MJ/tonne clinker)	Process
3000-3953	Dry process
3300-5400	Semi-wet processes
5000-6400	Dry processes long

Source: European Commission 2007

Another relevant option might be the usage of secondary or substitute fuels, which have the advantage that the most of those fuels can be burned without the emergence of harmful gases under high temperature (for example: waste oil, waste, motor-car tires, animal flour or mature timber). These kinds of alternative energies do not reduce the demand of fuels itself but help to improve the cascade use of certain products and the demand for primary fuels like crude oil. A positive side effect is the fact that the thermal utilization of tyres allows to bind contained toxic materials within the limestone and/or cement. Presently, Europe-wide, the cement industry is striving to increase the portion of these alternative energy sources and to lower the portion from primary fossil fuels. Here the front-runners are Netherlands (ca. 80% of alternative fuels), Switzerland and Austria (each ca. 47%) (Environment Agency, 2008). However, there seem to be certain trade-offs while applying this strategy: The burning process of certain secondary fuels (like tyres) might lead to higher carbon emissions compared with the direct use of processed crude oil because of lower energy intensity of those materials. If cement producers are faced with additional cost for carbon emissions, at certain circumstances (e.g. moderate oil prices) it can become cost-efficient to use oil instead of secondary fuels. Despite such constraints there seems to be some limited potential to increase resource productivity with an extended cascade use of energetic products.

Table 4-6: Share of used alternative fuels

<b>Share of used alternative fuels</b>	
Country	Share %
Netherlands	83
Switzerland	47,8
Austria	46
Germany	42
Norway	35
France	34,1
Belgium	30
Sweden	29
Luxembourg	25
Czech Republic	24
UK	6
Denmark	4
Hungary	3
Finland	3
Italy	2,1
Spain	1,3
EU 15	12

source: WBCSD 2005

On European level, the issue resource productivity is heavily discussed at the European Construction Technology Platform ([www.ectp.org](http://www.ectp.org)), whereat cement or more precisely concrete as important building material plays an important role. Via a networking of producers, manufacturers, constructions companies and users, the ecological impact and life cycle costs shall be reduced, the convenience of use shall be increased and the users needs shall be taken into consideration more strongly. (ECTP, 2004). One important research focus of the ECTP is the improvement of resource efficiency of buildings and infrastructure in use through improved materials, in which certain issues like Ecocement are subject of discussion. Specific working groups work on suitable solutions and material-specific problems like new materials, standards, innovations for users, so that according results can be put in action in the medium till long term. (ECTP, 2005)

#### 4.4.3. How resource productivity may influence competitiveness

As a matter of principle, the influence of several economical and ecological variables on the competitiveness of the cement industry is limited. Even though cement is a very homogenous product, the low price in relation to its heavy weight is the main reason of this sector's low competition intensity compared to other industries. It is doubtful from an ecological point of view, whether a national or international competition is desirable, because the involved transport would lead to higher usage of resources and even higher carbon emissions, even if rail- or waterways were used. Nevertheless, depending on additional charges (like costs for CO<sub>2</sub> emissions) as well as transport cost (in particular the oil price) the pressure from importers might increase significantly for certain European regions.

At the moment, the competitiveness of the industry is mainly affected if significant changes that occur in terms of political regulations and/or changing cost structures.

Concerning this matter there are two main influencing parameters: Raising cost as a result of carbon emission regulations as well as the use of alternative materials that need less energy input in the production process.

#### 4.4.3.1. *Improving cost structure*

The cost structures are largely determined by the high investments in plants as well as cost for energy and raw materials (including energy for transportation). In future, additional cost might emerge for the auction/purchase of carbon emissions permits. Basically, owing to technically very advanced production processes, there is some scope for an increase of resource productivity and therefore improvements of material costs.

With regard to energy and material costs, which usually hold a share of 50 percent of total costs (see fig. 4-10), there is the possibility for a more intense use of some high-energy waste that can be obtained cheaper (e.g. tyres) than conventional fuels. As discussed in cpt. 4.4.2.4 there is huge potential for alternative fuels with respect to fact that the current share of non-conventional fuel is only 12 percent in the EU15 but 83 percent in Netherlands (WBSCD 2005). To be precise, the resource productivity would not increase within the cement industry directly, but as a result of the cascade usage it would improve on a macroeconomic level, and with proper accounting e.g. via input-output analysis this would improve the resource productivity performance of this sector, too. Nevertheless, cost savings can be significantly compared with conventional fuels and will reduce the share of fuels on variable cost which currently sums up to 36 percent (see tabe 4-4). Some countries have already exhausted their potential for this strategy to a high extent (e.g. Norway or Netherlands), but other countries have still scope for action. Another possibility to reduce energy costs is the application of dry processes all-over Europe: Compared with wet or semi-wet production processes up to 70 percent of energy can be saved which at the same time lead to 70 percent less energy cost and therefore a significant cost relief as well as competitiveness advantage.

With respect to the costs of carbon emissions the stronger usage of alternative materials can be an economical and an ecological strategy. In particular pozzolans – and in future any “Ecocements” (see above) – are important alternatives to avoid carbon related costs, if it is taken into account that costs for emission rights can induce a price increase up to 50% for Portland. However, this is not a strategy to substitute the whole Portland production because there are limitations for application as well as availability of pozzolan materials. Nonetheless, the exploitation of the available potential is an important strategy to reduce the intensity of CO<sub>2</sub> as well as energy for the whole industry. A second possibility to reduce carbon intensity is to use green electricity. How far the industry does already make use of this possibility is unknown (it is not reported in environmental reports), but the lack of information supports the speculation that the electricity of today’s plants is obtained from conventional electricity sources.

#### 4.4.3.2. *Reducing risks*

Generally, improvements of resource- and material productivity can support to lower business risk that is will avoid additional arising risks because following dependencies as well as threats can be avoided or at least reduced significantly:

Price risks: As a result of the low competitive-intensity risks, volatile that is rising energy prices do effect cement industry only indirectly, because increasing costs usually can be passed on to the end customers. Most companies are affected by rising energy prices likewise, so that there are only limited strategies to avoid them.

Regulatory risks: Apart from anti-trust action, the cement industry will be mainly affected by direct carbon regulations. On the one hand, this concerns possible targets for emission reduction for the whole industry. On the other hand, it concerns likewise the obligation to auction or purchase emission rights, which will lead to a significant mark-up on cement prices. Regarding this issue, it is not clear how the European regulation will finally be shaped, so that certain investments are not yet made. A real risk with regard to the competitiveness would only emerge, if in future according increases of prices will render economical the importation of cement from neighbour countries.

Product risk: Cement as product is highly homogenous, therefore, significant product risks are very unlikely yet. For this reason, competition in the cement industry is mainly price competition. In the future the stronger demand for pozzolanic cement or any eco-cement might become a relevant risk factor for producers of portland cement. Because of the long-term capital commitment of the production sites, it is not possible to switch from Portland production to alternative cements in the short- or medium-term. There is definitely the risk that the demand for expensive Portland will drop, if prices increase as a result of high energy prices and carbon-related expenses. Changes in production technology are not – or only under very high cost – possible.

Legal risk: According to legal experts, in the long-term judgements for indemnities in dimension of the lawsuits of the US tobacco industry in the 1990th (triple-digit billion USD) are possible for certain industries (Onischka / Schwenke, 2008). Given that the cement industry is responsible for about 5 percent of global carbon emissions but has only a very low share of global gross value added successful lawsuits would influence the competitiveness dramatically.

#### 4.4.3.3. *Strategic positioning – towards System Innovation*

From a general point of view companies have the option to absorb possible risk by means of international diversification; this is also in line with the Clean Development Mechanism of the Kyoto Protocol. With abroad production sites (e.g. in South America or Asia) it can be possible to compensate deteriorating profitability in Europe as a result of strict political regulation in Europe. Here, international benchmarks are certainly an option for improving quality. The IEA suggests the implementation of the following

indicators as international benchmarks regarding to the resource usage of cement companies:

Table 4-7: Indicators for the cement industry

<b>Indicator (Clinker ratio per tonne cement)</b>	<b>Unit %</b>
Energy intensity of clinker	GJ/t clinker
Alternative fuel use for clinker production	%
Electricity intensity of cement	KWh/cement
Total energy intensity of cement	GJ/t cement
Total primary energy intensity of cement (including upstream energy use in electricity)	GJ/t cement
Energy related CO <sub>2</sub> emissions per tonne cement	t CO <sub>2</sub> /cement
Energy and process CO <sub>2</sub> emissions per tonne cement	t CO <sub>2</sub> /cement

Source: IEA 2007

With respect to competitiveness and improvements of resource productivity it should be aimed for an international strategy, even if the priority is a domestic European perspective. Due to limited possibilities for the adaptation of existing plants, strategic decisions can be focused to the following, most significant points:

- Checking, planning and implementation of integrated resource management (e.g. cascade use of tyres and waste) to absorb raising energy prices and to improve the ecological assessment.
- Replacement investments or new cement plants, whereat the kind of produced cement (Portland or pozzolans) plays an important role. Even if the Portland may never be replaced completely – as additive a certain quantity is needed for the production of pozzolans – its demand may decline. Here the magnesium-based Ecocements seem to have the potential to reduce the process-related carbon emissions significantly. Taking into account that the long-term capital commitment of investments in plants determines the production process as well as profitability for decades, the industry needs to intensify its activities in Ecocement to find out if these new products are a realistic option to reduce the discussed business risks.
- The reduction of the dependence on the future price for emission right prices and utilising the power of market-based instruments. One strategy is the expansion of activities within the CDM/JI-project. First suchlike projects initiated by the cement industry have already started, for instance a JI-project in Kryciy Rih in Ukraine (CD4CDM, 2008). Currently it can be observed that – as a result of the uncertainties about the future carbon regulation – the industry has still a biding position with respect to the mentioned strategies. Evidently, the long-term strategic decisions will not be made as long as there is no sufficient planning reliability. According to the Stern-Review however (Stern 2008), the need to increase the scope of CDM-/JI projects becomes evident. The next steps to revise the Kyoto Protocol e.g. during the Copenhagen Conference in late 2009 therefore will be decisive on this issue.

- On a European level there are several initiatives for a sustainable construction (e.g. ETCP), in which a stronger commitment of the cement industry could lead to disadvantages in sales if substitutes are supported. But then – as active partner – it is reasonable to have a voice in the discussion process as well as to show a substantial contribution for increasing resource productivity and reducing carbon emissions. Certainly, sustainable construction is the context where any system innovation will take place.

## **4.5. Steel industry**

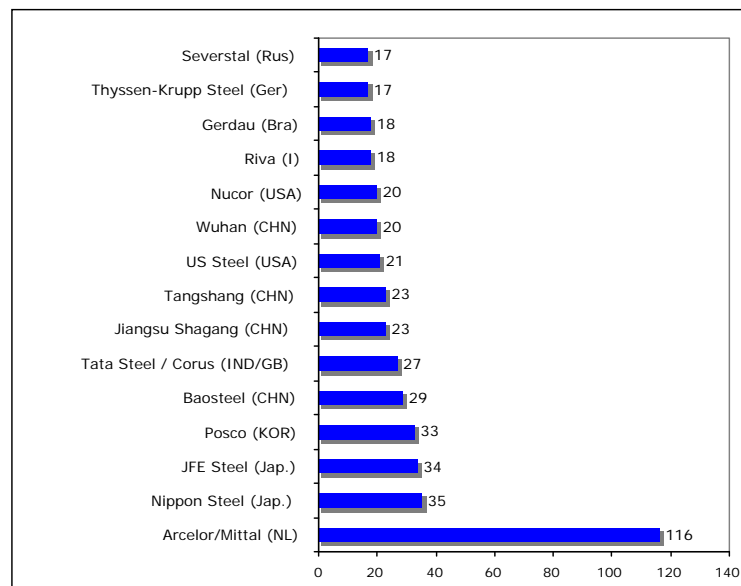
Mathias Onischka; with contributions by Raimund Bleischwitz, Burkhard Schaffitzel and Michael Ritthoff.

### **4.5.1. Economical Status Quo**

The metal industry has historically been a central industry to the European economies, it formed the nucleus of the EU, and it can be considered one of the key industries in the EU. The constantly high demand for metals over the last decades was related to the needs of Europe's manufacturing industries (in particular automotive, aerospace and mechanical machinery) and the construction sector to which metals have been a key input. In 2005, a total of 1,1 million employees worked in metal manufacturing which generated about 316 billion Euro in turnover (Eurostat 2007). The ferrous sector in Europe contributes more than twice to the value added than all non-ferrous industries combined (European Commission 2006).

On a global level, the steel production of the EU ranks second (only outreached by China with 18% of global steel output) and makes it one of the biggest steel exporters among which Japan, Russia and Ukraine (European Commission 2006). However, due to the expanding capacities in developing countries, Europe's global share in steel production is decreasing. The steel production is dominated by only a few large steel companies, in particular Arcelor-Mittal, Corus, Riva FIRE and ThyssenKrupp (ISII 2006). However, also a lot of small and medium-sized enterprises are operating in this field (with Germany, Italy, France and Spain being the most relevant countries in that context) whereat they supply certain market niches (ISII 2007). In contrary, European steel working is more diversified since it is a basic material for a variety of products in all major industrial fields (see Figure 4-12).

Figure 4-12: Largest steel producers worldwide

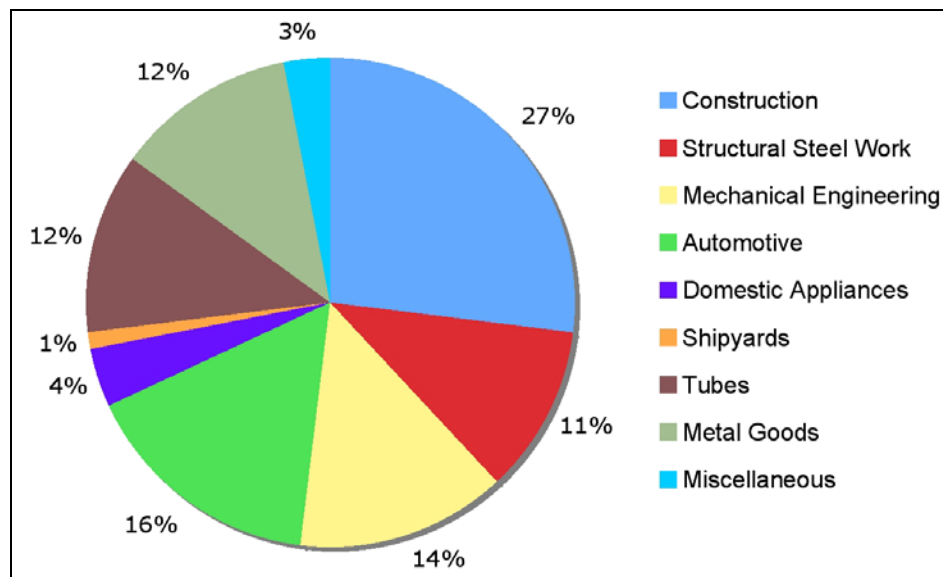


Source: Sturbeck 2008, steel production in Mt. 2007

After a long period of low turnover and weak margins the steel industry has reached a peak of an intensive growth from 2000 till 2006. Over the last years a sharp increase in metal prices on the raw material as well as on the refined material markets could be witnessed. Even the crucial scrap products have become a valuable and globally traded commodity. The major reason for the price rally is the rising demand in fast developing countries like India and China combined with limited production capacities and high market entry barriers. Along with the globally high demand for steel, during the last years European steel industry was recording almost maximum production capacities as well as record profits. It is expected that growth in both steel output and profit will relief in the future, however global steel demand is supposed to stay on a high level.

The produced steel is a crucial input for certain industries: In Europe industries like construction, mechanical engineering, automotive or structural steel work are the main buyers of steel (see Figure 4-13). These industries have significant market power so that their steel demand directly influence the output of the steel industry.

Figure 4-13: Use of steel in European industries



Source: Eurofer 2008

## 4.5.2. Key challenges

### 4.5.2.1. Important economical trends

The European metal business has faced increasing market consolidation and will probably continued to face it in the future. The dependence on raw material imports and the crucial proximity to downstream industries requires a minimum capacity for profitable steel production. Experts estimate this threshold at 70 – 100 million tonnes output annually (European Commission 2006). Because of its capital intensity the market entry barriers are exceptionally high, therefore vertical integration and joint ventures between ThyssenKrupp and CVRD are common: In 2006 both companies signed long term supply agreements which guarantees TKS at least 8,6 million tonnes in raw materials annually over a period of 15 years. They will be processed in a TKS-plant, in which CVRD has a 10% stake. (ThyssenKrupp, 2006).

Table 4-8: Selected economic indicators for EU steel industry

Indicator (2003)	Iron & Steel	Iron and steel castings	Non-ferrous metals	Non-ferrous metal castings
Number of enterprises	6294	2170	2575	3816
Employees (K)	597	144	204	116
Turnover (bill. EUR)	138	14	60	15

Source: European Commission 2006, Eurostat 2008

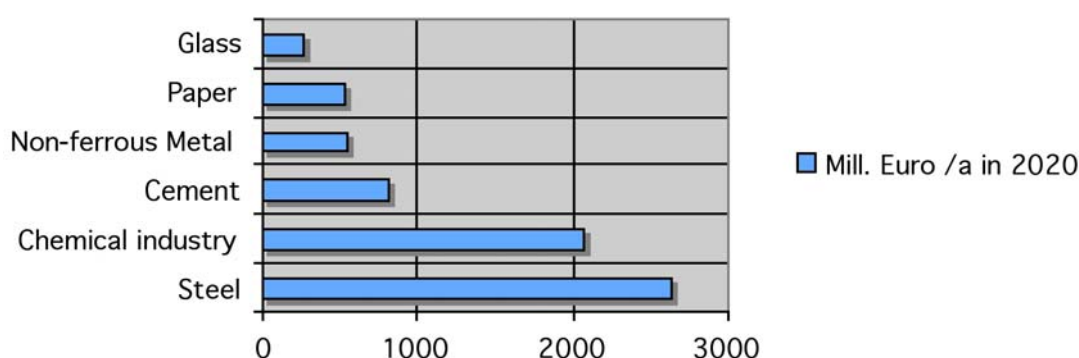
Historically, the highly cyclic steel industry has often suffered from stagnation and recession trends in major economies. The ongoing economical slowdown, especially in the USA and EU, is supposed to lead to lower market growth from currently 7% to 3-5% in the medium-term (Hennes, 2008) Producers can not raise prices according to



price jumps on the raw material and energy market so that margins will probably decline in the near future (Mütze, 2008).

Especially in Europe market conditions for steel production will become more challenging as the European Commission pushes its plans for the second phase of the EU ETS (Bleischwitz et al 2007: 20ff.). This will have a direct impact to the cost structure because the primary production is emission intensive due to process-related emissions; secondary production is linked to high energy demand, which causes indirect emissions. Companies in countries like Germany and Poland with high energy supply from coal-fired power plants will feel more cost pressure than those countries like France, where the rate of nuclear power amounts to 80% (Augter et al. 2008). Taking only the costs of direct emission of primary production into account, European steel industry will face the highest additional carbon cost for emissions rights compared to other energy-intensive industries (see Figure 4-14), however, the actual costs will depend on the development of the future price of the ETS carbon certificates. Above certain price levels for emissions rights, according costs could have an effect on the industries competitiveness; however, even under the assumption that these additional costs will not be passed on to the costumer, the industries' value added and current total profit may give scope for remaining profitable.

Figure 4-14: Expected additional annual cost for carbon emissions rights for selected EU industries in 2020



Source: Augter et al, 2008

#### 4.5.2.2. Selected international challenges

The world's total steel production amounted to 1,34 billion tonnes in 2007 (WV Stahl 2008; Lemken et al, 2008). Experts expect a further increase of the world steel production in 2008 whereas the growth rate might decrease (IKB, 2007)<sup>37</sup>. The immense growth in global steel production during last 10 years has changed the world's steel market significantly. Especially due to the fast growth of China, India, and other developing countries, competitors increasingly put the EU steel producers under pressure with a different production cost structure. While historically the EU metals producers had always been very competitive vis-à-vis their traditional trading partners, like USA

<sup>37</sup> This might change due to the current financial crisis.

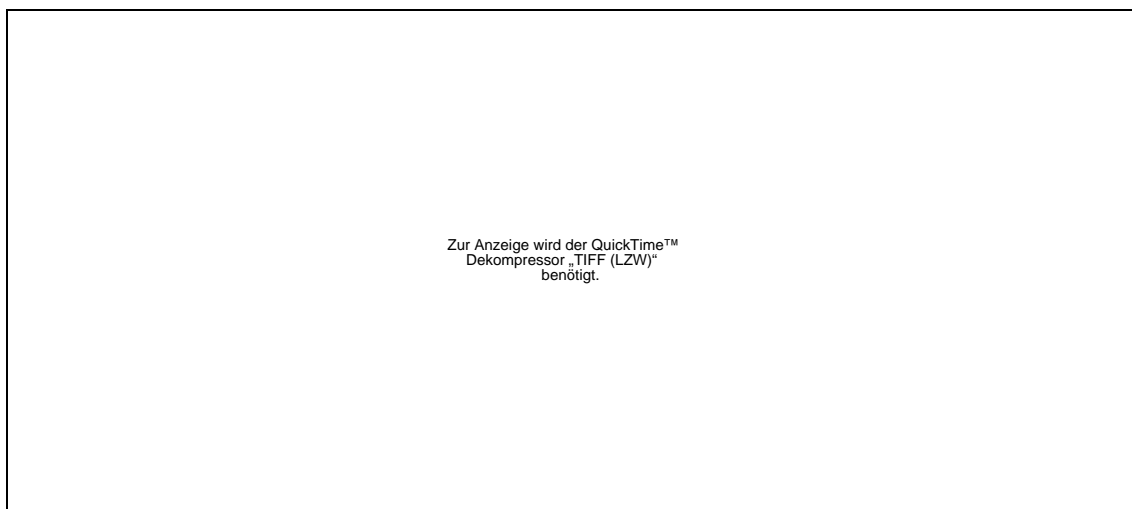
or Japan, newcomers now benefit from lower material costs and better access to raw materials and/or energy. Given that Europe depends on raw material imports the access to these commodities is a crucial element to ensure competitiveness.

The raw material market is dominated by three large players and price leaders: Rio Tinto, BHP Billiton and CVRD, which control 75% of the ore market (ThyssenKrupp Steel in: Ameling 2007; Ritthoff 2007). However, scrap material also serves as important input factor for Electric Arc Furnaces, which adds up to about 40% of steel output in Europe in 2003 (European Commission 2006, Eurometaux 2003). The long durability of steel products prevents the emergence of scrap material to keep pace with rising demand (Ritthoff 2007). On a global scale this trend will prevail since most steel application are on a long-term basis.

#### 4.5.2.3. *Cost structure and material costs*

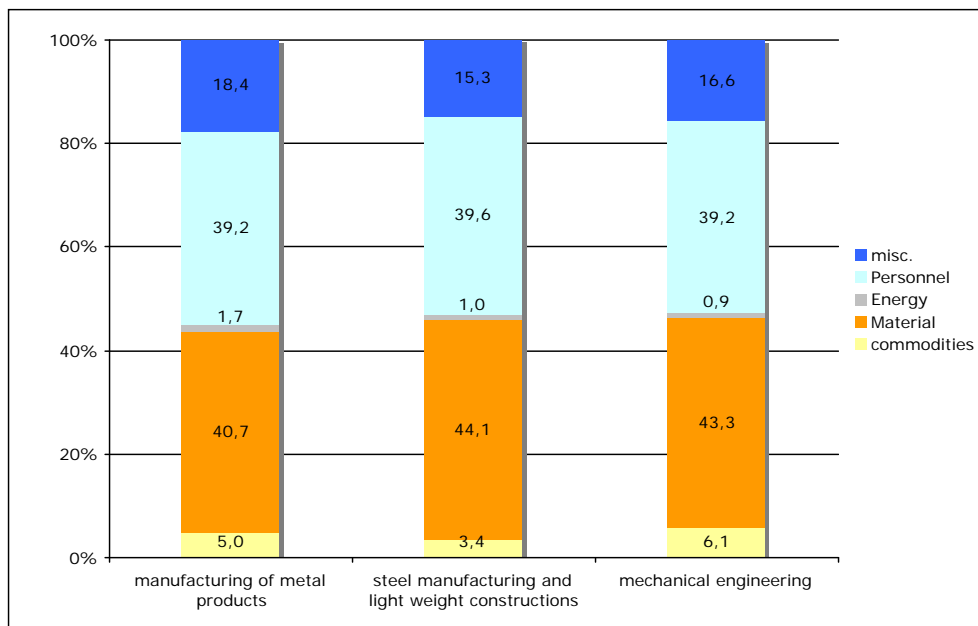
Raw materials and energy are the most important competitiveness factors for the EU's metal industries: Materials make up for 52% of total cost whereas energy counts for 24% for steel production (see Figure 4-15). Since raw materials for steel are globally traded commodities market discrepancies can cause manufacturers substantial challenges. Energy supply poses similar risks. The pressure on material and energy prices is well reflected and the industry is operating close to the technological optimum in terms of resource efficiency.

Figure 4-15: Cost structure of the German primary and secondary steel production



Source: WV Stahl, cited in: Kerkhoff 2008

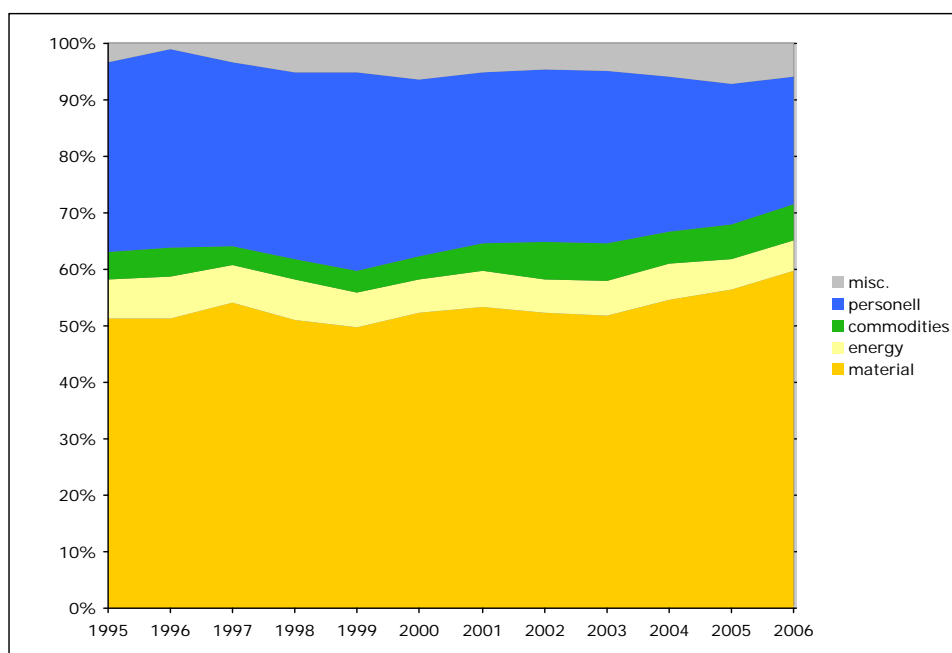
Figure 4-16: Share of cost block in steel processing industries in Germany 2006



Data: Destatis; in percentage of gross output value

As far as the steel processing industry is concerned there are no consistent data on a European scale available. However, data from German statistics (which are a very good proxy for the EU 15) show that even in the steel processing industry material and energy costs have a share of almost 50 percent of total expenses (see Figure 4-16). Furthermore the development of the cost structure reveals that the share of material costs have increased significantly since 1999. Therefore it is obvious that the slow-down of this trend or even a reversal – i.e. increasing resource productivity – is very important to achieve a competitive cost structure.

Figure 4-17: Development of cost structure in metal industry in Germany



Data: DESTATIS<sup>38</sup>

#### 4.5.2.4. Innovation & resource productivity

The steel production industry transforms raw materials and energy into products, which represent essential inputs for a wide range of investment goods (construction, machinery, heavy transport) and consumer goods industry (automotive, household appliances, packaging). The main input materials for integrated steel production are iron ore and coke. (European Commission 2006) In general steel can be produced in two different ways: Blast furnace route is based on raw materials, the main input factors being iron, ore, hard coke and energy. Ore is reduced to pig iron, which is then treated with oxygen to eliminate by-products like carbon, phosphorus and brimstone. Scrap is used in small quantities to cool down the sponge iron. The electric arc route uses scrap materials melting them back into steel. Steel is nearly 100% recyclable at relatively high quality (see below), a process which is significantly less energy-intensive than primary production.

Steel production itself has been optimized to large extent over the last decades, so that there is only very limited potential to improve resource productivity within the steel production: For example for the production of one tonne pig iron the theoretically minimum input of coke is 465 kg, currently the steel manufacturing requires about 475 kg. According to that, the potential is almost depleted (Buck, 2008).

<sup>38</sup> The data aggregates the production and processing of different industries. However, German metal industry is heavily dominated by steel production and processing so that trend trend gives an excellent approximation to the cost structure for steel industry in Germany as well as in Europe.

Table 4-9: Selected potentials and barriers to improve resource productivity

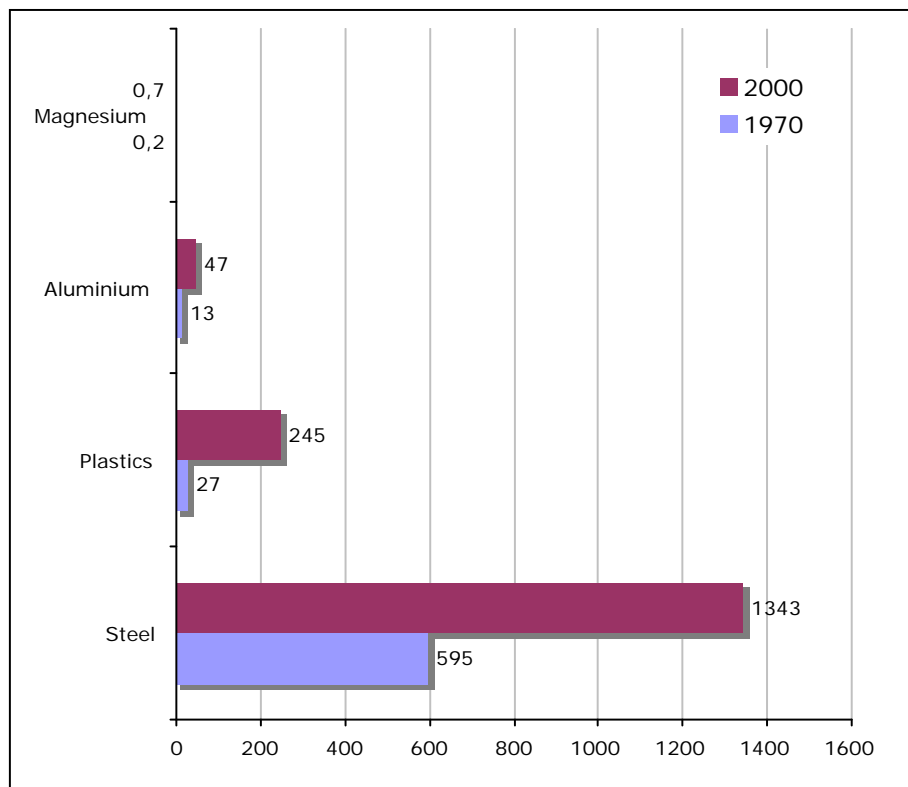
<b>Efficiency potentials</b>	<b>Possible barriers</b>
<u>Production of steel</u> - Savings of resources by more efficient processes (energy, resources) - Development of new processes (technological improvements, alloys)	- Ability for recycling and reparation - Lack of influence on recycling market - Design and costumers requests - Specific knowledge of materials and processes - Outdated guidelines and standards - Transferability of new materials and processes in SME - New materials and products vs. recycling - Resource intensity of alloys vs. resource savings - Rebound effects (savings due to efficient technologies are overcompensated by increased consumption)
<u>Processing of steel</u> - Composition of materials: new materials, composite materials - Design of constructions and products: light weight constructions, high quality steels - Modular systems - Integrated optimization	
<u>Systemic approaches and life-cycle perspective</u>	

Source: Lemken et al, 2008

However, if the total value added chain - from mining to manufacturing – is taken into account, opportunities to reduce the use of material and energy emerge. Key innovation factors to improve resource productivity in steel industry are:

- There are substitutes for steel, which can compete steel with respect to certain material characteristics, however, these substitutes are often more expensive to produce. As far as the reduction of weight of end products is concerned the so-called “classical substitution triangle” of aluminium, steel and plastic should be more considered (RWI 2006). The steel industry already offers alternative steels like HSD-steel (high strength and ductility) that have similar characteristics and product weight as aluminium, however, these substitutes usually lead to higher material costs. If the demand for such substitutes increases considerably, the current price differences will likely be compensated. Car manufacturers are currently working on chassis based on a magnesium-aluminium-alloy, which offers substantial weight reduction ([www.superlightcar.com](http://www.superlightcar.com)). Whether this more expensive construction is worthwhile depends on cost savings over the whole service period. From a material flow perspective steel has less environmental effects in terms of used material masses than other substitutes.

Figure 4-18: Global production of steel and possible substitutes



Source: Sturbeck 2008; in Mio. tonnes per year

- In cooperation with steel processing industries like car manufacturing, certain steel types can be optimized regarding its specific application. For example the use of high-quality steel in car chassis reduces weight by 40% (Velikonja, 2004). Specific steel sheets (so called tailored blanks), which lead to less metal waste or rather less material input, offering nevertheless high-strength and can be produced by using a new manufacturing technology. The materials, which are manufactured from HSD-steel, can lead to lower product weights than using aluminium (RWI, 2006). These kind of innovative steels are already used for manufacturing of cranes where the application of those highly specialized HSD-steels has increased performance noticeably (Floßdorf 2003 in: Ritthoff 2007).

- Beyond that the application of an innovative method of surface finishing of certain steel sorts can minimize the weight whereas corrosion prevention and hardness remain the same (IKB, 2007).

- Producing repairable parts for vehicles and other damage imperilled goods for replacement can be reduced (Lemken et al, 2008). Ensuring ductility and necessary stability might become a challenge for specialized steel producers and for example bumper manufacturers as a result of deteriorating sales.

- Recycling of steel is another important approach to increase resource productivity. Germany for example exported two million tonnes of steel scrap in 2006, which, if recycled, can significantly increase the share of secondary steel production (Ritthoff,

2007). However, there are technical limits for the use of scrap: Using the blast furnace process scrap can only be used up to certain amounts within the converter (Lemken et al, 2008). Furthermore, scrap is usually not (or very limited) used for the production of high-quality steels (excepting certain special steels) because even few impurities can change the characteristics of materials. (Lemken et al, 2008). The use of scrap to a higher degree might be possible if technologies of blast furnaces will be developed accordingly.

- Welding seam treatment: The use of high-tensile steels is not sufficient to improve resource productivity, rather crucial aspects like tensile strength, vibration fatigue strength and workability have to be considered in the optimization as well (Lemken et al, 2008). If the fatigue strength of an element shall be increased, the optimization has to point at welding seams (Nitschke-Pagel 2007). So far the low fatigue strength of welded connections has been a major restraint to use high-tensile steels for fatigue-stressed applications. Hence, it is necessary to examine both new materials and their practical application to develop useful instructions to which can be referred at later standardisations (Lemken et al, 2008).

- Alloys: The availability of several important resources, which are necessary to produce high-quality steels (e.g. nickel), is much lower than iron. The availability of those critical metals puts the steel industry at risk.<sup>39</sup> Beyond that, the most critical metals are connected with an exceedingly high resource usage. The development of new alloys without or with fewer amounts of such resource-intensive alloy components is an important strategy to improve the resource productivity of steels itself. Furthermore, from a life-cycle perspective it should be taken into account that high quality steel is connected with a high resource-intensity in production, nonetheless it has mostly excellent corrosion characteristics and is generally well suited for recycling (Lemken et al, 2008).

- Moulding and joining process: New and sophisticated moulding and joining processes are a requirement to improve the use of steel. The optimization of moulding and joining processes would lead to a significant reduction of weight of constructions, furthermore the time and effort for the production of units can be cut down (Lemken et al, 2008).

- Composite materials: There are a lot of application where the combination of several materials can improve important characteristics (e.g. tensile strength, weight, dilatation), in particular the joining techniques armoured concrete, galvanizing and sandwich-modules. Using these compositions the recycling of steel is made more difficult which has a negative impact to its resource productivity. On the other hand, composite materials usually extend the availability to use (e.g. galvanized cables). Due to the heterogeneity of these applications it is not possible to make general conclusions on their potentials for improving resource productivity.

---

<sup>39</sup> See e.g. Graedel, T. (2008): Defining Critical Materials. Contribution to the International Wuppertal Colloquium on „Sustainable Growth, Resource Productivity and Sustainable Industrial Policy – Recent Findings, new Approaches for Strategies and Policies“, September 17 – 19, 2008 at the University of Wuppertal. Proceedings in preparation; contact: Raimund Bleischwitz.

### 4.5.3. How resource productivity may enhance competitiveness

#### 4.5.3.1. *Improving cost structure*

As already discussed, raw materials make up the largest part of total costs in steel production. Even minor savings regarding the resource input have significant effects on the profitability and therefore competitiveness. However, the most of Europe's steel producer have almost depleted the saving potential for direct material and energy input, so that the potentials to improve the cost structure is minimal for the production process of steel.

However, from a holistic perspective of the industry there are in fact potentials to reduce the amount of used material, in particular steel, as discussed in chapter 2.4. For steel processing companies substitutions are at current price levels usually no economical alternative, considering that saved costs as a result of saved materials is overcompensated by higher prices for substitutional materials. As long as end customers are not prepared to accept higher prices for products with innovative steels or rather materials it is very unlikely that these approaches will spread widely into the steel processing industry. Furthermore, steel producers are only willing to support the trend of reducing total steel production (or rather growth of steel production) if the burden of less production is compensated with higher value added in those alternative steels.

An option to absorb those trade-offs is the vertical expansion of the value chain of steel producers both upstream and downstream. The upstream expansion into the business of raw material extraction reduces the dependence of price increases of commodities; rather there is a chance for extra profits because higher raw material prices would not really affect the producer's cost structure. More important might be the strategy for further downstream expansion: If a steel company provides even steel processing as well as mechanical engineering & construction, the substitution of steel by alternative materials (like aluminium or plastics) would be less problematic to the output of the total company. Certain steel companies implement both strategies; however, there is also a contrary trend on some companies to the specialization to certain special steels.

#### 4.5.3.2. *The effect of selected approaches on competitiveness*

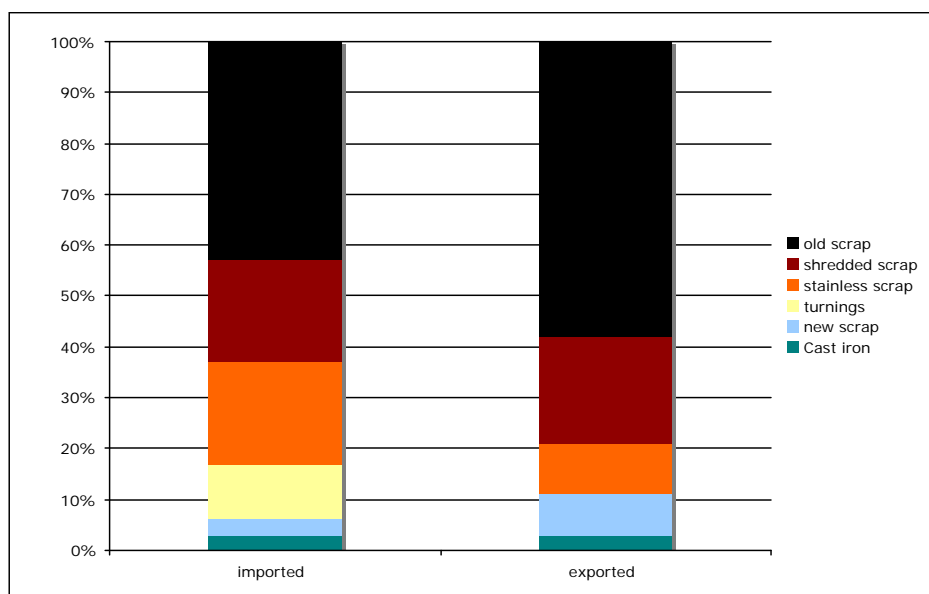
##### Scrap material

The issue of secondary material and waste is crucial for the competitiveness of EU steel industry. Scrap material is the main ingredient for the electric arc furnaces. Between 40-60 % of EU unwrought metal output comes from recycling. This figure could be higher but is limited by the availability of scrap metal (European Commission 2006). Since capacities are high and supply is steady the market has become tight. Trading volumes have increased by 70% in exports (1999-2004) compensated by an 48% jump in imports with fairly stable trading channels for steel scrap, mainly not leading to Asia (European Commission 2006). The increasing price has significant impact on European steel refiners. The refining margin equals the difference between the scrap price and the selling



price of refined steel. Since the cost structure is fairly rigid, an increasing scrap price directly melts down the refining margin.

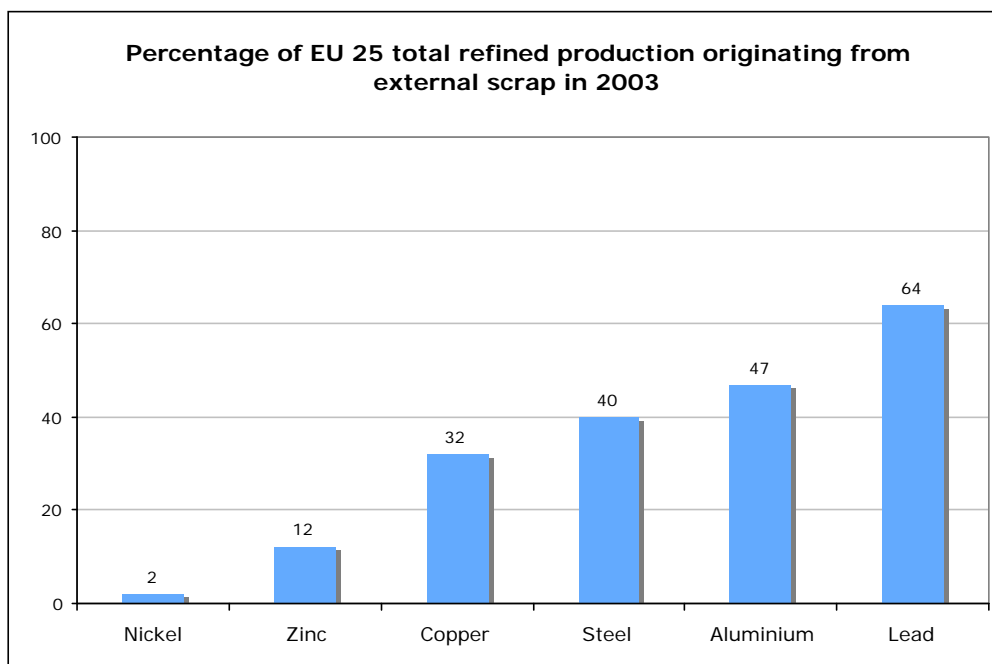
Figure 4-19: Imported and exported scrap by grade in EU27



Source: Eurofer 2008

The increasing importance of secondary production forces product development to integrate this aspect into product designs. Dismantling and recycling are important features of new steel products. An effective scrap collecting system – especially in Eastern and Southern Europe) can also contribute to increase secondary production (see also the chapter on the automotive industry and the EU ELV Directive). Recycling production residues from the complete supply chain will also induce more utility from resources. Therefore increasing secondary steel production is one of the promising strategies to reduce environmental impacts, improve economical performance and reduce energy consumption, though a completely substitution of primary production is not practicable.

Figure 4-20: Share of scrap in metal production



Source: European Commission 2006

From an environmental policy point of view the recycling of steel holds significant potentials because of the reduction of the resource use for mining or transport. It is estimated that the amount of steel accumulated in products that are presently used worldwide is 1.26 billion tonnes, about 20 times the amount of steel annually entering society with new steel containing products (60.03 Mt/year) (Source with reference to the Stocks and Flows Project of the Yale Centre for Industrial Ecology: Berkel 2007: 515). Beyond that, the use of secondary input needs significantly less energy and resources than the production of steel with primary input (oat) (IISI 1998). This will result in significantly less carbon emissions: A study of Moll et al. (2005) derived an annual saving potential of about 57 Mt CO<sub>2</sub>, if the secondary steel production can be raised up to 67 percent of total production (see Table 4-10). Thus, the use of scrap has also competitive-related aspects, however, the EU is a net exporter of scrap so that the supply of used steel is limited. Furthermore, the long life cycle of steel products implies that refiners are facing scrap from products based on steel application decades ago which has effects on the quality of new steels (Ritthoff, 2007).

Table 4-10: Scenarios towards a steel cycling economy in EU – potentials of secondary steel and reduction of carbon emissions

	Year 2000	Year 2060: scenario 'business-as-usual'	Year 2060: scenario 'eco-efficiency'
End-of-life goods arising (steel content)	90	128	111
thereof: for recycling in EAF 70%	63	89	78
Primary steel production	98 (60%)	67 (42%)	39 (33%)
Secondary steel production	65 (40%)	91 (58%)	80 (67%)
Less CO <sub>2</sub> of primary steel production		-31	-60
Additional CO <sub>2</sub> of secondary steel production		5	3
Total CO <sub>2</sub> savings		-26	-57

Source: Moll et al, 2005<sup>40</sup>

### Energy

Despite the expected expansion of world metals consumption, a large proportion of the European metal producers are already facing a critical situation caused by the rapid increase of specific energy and raw materials prices (European Commission 2006). The steel industry depends on several energy sources, like coal (primary production) and electricity (secondary production). Access to energy supply at competitive prices is therefore crucial. For metal producers the share of energy in their cost structure has always been a strong incentive to reduce energy consumption in the production processes: Despite a constant growth of steel production over the last 15 years, energy consumption of European basic metal industry has remained relatively constant. Since 1997 the trend even reversed with growing output and shrinking energy demand. Between 1975 and 2000 the EU steel industry has reduced its energy consumption by 47 % per tonne of finished steel (European Commission 2006). Using higher quality materials and increasing the share of recycling production can lead to a further increase of energy efficiency.

Until now, EU metal producers have secured their competitiveness with long-term electricity supply contracts. However, it seems that it is becoming more difficult to renew those agreements due to both the uncertain future on the energy market and further price mark-ups. Especially expected mark-ups as a result of the European plan to increase the more expansive renewable energies and to enforce the acquisition of carbon emissions rights for power plants will lead to additional costs for the steel industry as well. To which extent the competitiveness of a certain steel company is concerned heavily de-

<sup>40</sup> The analysis of Moll et al (2005) assumes that in a business-as-usual scenario the amount of steel incorporated in new goods going to stock will equal more or less the output of 'end-of-life' goods, in contrary, the 'eco-efficiency' scenario assumes a decrease by 0.5% annually. This results in increasing secondary steel production (scrap) which implies less carbon emissions. For further details see: Moll et al, 2005: 80ff.

depends on the location of its production plants: In countries with high nuclear power supply additional costs for electricity (e.g. France) may be much lower than in other countries. The demand for electricity strongly depends on the future share of scrap that is used as input; while on the one hand scrap can help to reduce costs for carbon emissions and raw material inputs, on the other hand additional costs for stronger need for electricity emerge.

### Carbon Emissions

In 2004 the steel sector accounted for about 4% of the EU's industrial greenhouse gas emissions with more than 100 Mt CO<sub>2</sub> (European Commission, 2006). The European steel producers have made respectable efforts to comply with the EU environmental framework. Especially in steel manufacturing CO<sub>2</sub> emission has not been successfully decoupled from output development because CO<sub>2</sub> is a natural by-product of primary productions. In principle it is possible to sequester large parts of carbon emissions so that carbon capture and storage (CSS) could be an option for steel industry in the long-term. However, for the next 10-20 year CCS is no competitive strategy because for the need of further necessary research as well as high costs (Fischedick et al 2008).

With regard to the European Union Emission Trading System the steel industry is faced with additional cost to obtain emission rights. The German steel association WV Stahl has calculated extra annual costs of more than two billion Euros for the European steel industry only (Kerkhoff / VW Stahl 2008). However, there are still debates for exceptions for certain industry in order to secure competitiveness on global markets. Long amortization periods and therefore long term planning might cause companies to move their production overseas („dirty outsourcing“), which would not help climate but hurt the European economy. However, taken into account that additional costs of two billion Euros only corresponds to about one percent of the value added of the steel industry, the discussed carbon regulation might affect the industry's profits negatively, the global competitiveness is concerned only slightly; other driving forces like the price of energy, coke, iron is much more important.

Interesting with regard to the cement industry: increasing the use of blast furnace of the steel production can be used as a substitute for clinker in cement production. It is estimated that these by-products can contribute with globally 140 – 185 Mt CO<sub>2</sub> reduction, which can reduce emissions for cement, but not in iron and steel production. (IEA 2007: 137)

### Material related approaches

Many of the discussed approaches to improve resource productivity on a material scale (see chapter 2.4) are already considered by the steel industry, admittedly with different efforts. The most of those approaches are connected with specific materials as well as innovative processes. If the European steel industry would pursue these trends more intense it would gain an unique selling proposition or rather competitive advantages

because the required qualities can not be produced with less efficient plant in India or China. However, the improvement of resource productivity is not the main driving force, more important for the industry is to avoid losses in value added as side effects. In fact there are risks that too much innovations on steel-related materials could, as already discussed, lead to non-compensable losses in sales and value added.

## 5. Conclusions and Policy Recommendations

Raimund Bleischwitz, with contributions made by all other authors

The empirical analysis (chapter 2) has revealed that a majority of the countries investigated have managed an increase in resource productivity. A few countries however are not yet on track; decreasing rates of resource productivity could be observed e.g. in Greece and Portugal. In total, the EU member states have not yet managed to accomplish the aim of the EU Thematic Strategy on Sustainable Use of Natural Resources to increase their resource productivity by 3 % per year;<sup>41</sup> accordingly, a reduction in the use of primary materials as envisaged by the recently launched EU Raw Materials Initiative<sup>42</sup> is not yet in sight.

The differences in resource use between countries at a similar stage of economic development (measured by per-capita income) are striking. Country-specific industry patterns certainly matter in this regard. However the empirical analysis (chapter 3) has revealed a tentative but robust set of driving forces, which can be managed by countries and the EU: **end-use energy efficiency, highway kilometers, dwelling activities**. Though this is preliminary and deserves more in-depth research and in particular an update taking into account the changes made by Eurostat in calculating time series, it indicates that the methodology of multivariate statistics is able to provide policy-relevant findings.

The findings on driving forces are of special relevance in regard to current policy responses to the financial crisis. It can be estimated that the new and additional programmes lead to new investments in motorways and dwellings as well as to purchasing of new cars – and slow down potential improvements in resource productivity.

Taking the best performing countries as a benchmark, the ability to improve resource productivity can be estimated in the range of a factor 2 – 4. In that regard, data suggests a conclusion that the current minimum frontier of resource requirements for best-performing industrialised countries is in the order of 12 t per capita (DMI/DMC). This is neither a statement about current potentials to save resources nor about any future possibilities. It however indicates a window of opportunities for improvements since the average EU25 resource use per capita is in the order of 35t per capita (DMI<sub>cap</sub> 2000).

<sup>41</sup> COM(2005) 670 final. Our assessment refers to Annex 1 of the Strategy: "In the period 1980-2000 the resource productivity (€/kg) of the EU-15 economy increased by 52%, which is 2.2% per year. On the basis of this trend, and assuming that proper implementation of this strategy will lead to at least a modest increase in resource productivity, **it is reasonable to expect a rate of 3% resource productivity improvements per year for the period 2000-2030**. This would represent a slight acceleration compared to the previous 20 years." See also the statement provided by Schepelmann et al. (2006) on the aims of the Thematic Strategy.

<sup>42</sup> COM(2008) 699.

Given that some researchers (e.g. Friedrich Schmidt-Bleek, World Resources Forum Davos) propose a future reduction to a level of 5 – 6 t per capita worldwide, it indicates the need to do more in-depth analysis on the potential to increase resource productivity and to reduce the use of primary materials via system innovation and changing patterns of consumption and production.

Our data analysis suggests a positive relation between competitiveness of economies and their resource productivity. This is likely due to a number of factors: the importance of material purchasing costs for manufacturing industry, the ability to innovate, the macro-economic environment and technological progress. The importance of material purchasing costs and the ensuing potential to improve material efficiency stems from

- Macro-economic factors: the relative share in total raw material imports grew between 1998 and 2004 from around 10% up to 15% and may have accrued to ca. 20% in 2007;
- Industrial-economic factors: referring to data for the German manufacturing industry, material purchasing costs hold a significant share in the overall production costs (Steel: 52 %, Cement: 50 %, Automotive > 30 % taking into account the vertical integration of the supply chain and the cumulated personnel costs).

In that regard, the economic potential to increase resource productivity seems enormous. As a strategy, the EU can exploit the potential to save material purchasing cost while at the same time investing in new products and services, and lighthouses such as ‘urban mining’ ‘light-weight car’, and ‘refurbishment of existing buildings’. The potential to save costs is even greater when negative externalities are accounted for.

Incentives have not been analysed in this study. Certainly research will have to carry out assessments on current regulation and its impact on resource productivity. This conclusion refers to specific regulation (e.g. Eco-Design Directive, Directive on the energy performance of buildings, Competitiveness and Innovation Programme), but also to the general climate and energy policy, agriculture, regional policy etc. Current analysis indicates that there is a good potential for synergies between climate policy and resource productivity, however trade offs cannot be excluded (see e.g. the issue of biofuels and the recycling quota of the ELV-Directive) and call for further research.

**Market-based incentives** should be considered when new policies to increase resource productivity will be formulated: bearing in mind

- The importance of construction as a driving forces of resource use (chapter 3),
- The relevance of the construction industry in the EU Lead market Strategy, and

- the manifold advantages of market-based instruments for environmental purposes (EEA 2006),

one can conclude to expand the current eco-tax base gradually to non-energy resources (construction minerals, land, metals, industrial minerals, other fossil fuels). Acknowledging the difficulties to regulate metal commodities and in order to prevent unintentional trade incentives and competition distortions, a proposal of this study is to introduce a **European-wide minimum taxation on construction minerals** as a pillar for increasing resource productivity in the construction area. The UK model on the taxation of aggregates (EEA 2008) is a useful guideline for the size of any such tax. Such a tax will stimulate material efficiency in the building sector, and likely have positive effects on steel and eco-cement. It has to be examined to what extent the budgets generated might be earmarked and follow an analogue target (through, for example, a resource efficiency fund, resource efficiency programs, etc.). In general, it will be most important to control the implementation and acceptance problems of the ecological tax reforms in Europe when dealing with fiscal incentives to increase the environmental performance. A fiscal approach, when specifically used to increase the resource productivity in the medium term, should therefore keep exceptional rules and tax exemptions as few as possible.

The sectoral approach as carried out in this study has revealed many additional insights. The following three subchapters summarize main findings in regard to the three industries analysed. The general policy recommendation is establish sectoral agreements for increasing resource productivity in the EU.

## 5.1. Automotive industry and EU policy

There are **significant potentials to improve resource productivity in the automobile sector**. Within the industry the share of material cost as part of the total costs is very high so that less material and resource input will in principle have a positive effect on the cost structure. However, the practice shows that resource productivity does not yet have the significance that it could have or should have. However, this analysis has shown that resource productivity offers scope for improving competitiveness regarding cost reduction and quality improvement. Given fundamental uncertainties however policy is in demand to improve the incentive structures in order to initiate the exploitation of the existing potential in resource productivity. Possible practical approaches are:

- **Better information:** Improvement of the reporting requirements of car manufacturers for a company as well at product level. Up to now there are no reliable industry or company related data about the real material and resource costs (labour input of suppliers excluded). Besides that there is only scarce information about the amount and weights of materials that are found in sold cars. A requirement to **report on material intensity and costs** (the latter at least on an aggregate level) would boost markets for material efficiency and give a basis for further measures by policies, research and development.



A first approach could be the expansion of the regulation of energy labelling with an obligatory report about the material intensity. Additionally it is worthwhile to build up a **systematic material flow accounting** (taking into account the International Material Data System of the ELV-Directive) because those information can be of special interest for several stakeholders. Since environmental regulation (e.g. with respect to waste, safety, noise, particulate matter) can lead to trade-offs with regards to resource intensity, another conclusion is to include MFA analysis in any regulatory impact assessment to be conducted.

- **Synergies with climate policy:** The planned carbon regulation of the automobile industry has already affected as a catalyst with respect to the development of fuel-saving cars. Even if the aspect of fuel consumption is not enough for a significant improvement of resource productivity, the importance of small-class cars as well as the issue of downsizing is rising. The competitiveness of certain carmakers will be noticeable affected by a strict regulation, but on an industry-level these company-related losses can be compensated by profits of other carmakers. In so far the intensification of the carbon regulation is a useful option, not only to face the challenges of climate change but to give incentives for resource-friendly cars at the same time. The emphasis on weight in the current regulation therefore can be seen as an advantage and a door opener to regulate and downsize the material intensity of cars. The so-called Integrated Approach (taking into account main suppliers and whole fleets) is generally in line with life-cycle thinking and economic incentives.

- Beyond CARS 21:<sup>43</sup> It is proposed to establish a **Technology Platform for light-weight cars**. Not only will a Technology Platform like that unite car manufacturers and main suppliers, but a broad spectrum of metal industry, other material-producing industries, recycling industry, designer and material science. Given the undoubted success of the HFC Technology Platform, which has resulted in the establishment of a Joint Technology Initiative with great commitments, this mechanism can be utilized to focus on improving resource productivity. It shall also be used to lower the carbon intensity of energy-intensive industrial processes upstream, which are partly outside the EU (e.g. aluminium melters). Following a recent evaluation (IDEA consult 2008), formulation visions and including the socio-economic dimension and stakeholders outside the industry should be part of such a new TP, i.e. support to formulating a vision and strategic aim to help the direction of search – e.g. through foresight exercises.

- **Reconsider waste policy and ELV-Directive:** according to this study, the strict quotas of the ELV-Directive and their constraints on the automotive industry on introducing new materials might be reconsidered. Though there is good potential to increase the use

<sup>43</sup> The European Commission has launched a new strategy for long term viability of European car industry called CARS 21. The objective is to improve the worldwide competitiveness of the European automotive industry making at the same time Europe more attractive for foreign investments and to keep the production of automobiles viable on a long term basis, at prices affordable to consumers. See: Rapid Press Release Europa  
<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/157&format=HTML&aged=0&language=EN&guiLanguage=en> consulted on the 21.09.2008

of secondary steel and aluminum, the system of recycling quota may not be in favour of using new materials. Two directions seem reasonable: firstly, to increase recycling and the recovery of strategic materials through efforts to keep old vehicles in the European Union, and, secondly, to develop new materials (see proposal above on the Technology Platform) that lead to light-weight cars in the mid term.

- **New Products: The low-cost-market**, which will gain in importance in Asia and South America, provides the opportunity for certain system innovations; not only on driving systems but also to initiate significant changes in the use of resources and materials because in this segment the sensitivity regarding material costs is much higher than in the mid-size, full-size or luxury class. In order to implement such system innovations also into the mid-size and luxury class of conventional models, it seems appropriate to support accordant research projects. In particular the European automobile suppliers will have an excellent opportunity to position themselves in these growth markets.

- **Sectoral dialogue:** The EU shall **establish a sectoral dialogue with the automotive industry** that covers environmental core concerns as well as resource productivity. Such a dialogue could provide regulatory certainty, support for R&D and even market introduction programmes. A possible outcome would be a negotiated agreement.

- **Towards sustainable consumption and market introduction:** A central leverage for changing production and product structures is the end consumers' demand. As soon as the demand for fuel-saving and resource-friendly cars goes up, carmakers will react to this market signal quickly in order to provide suitable car models. The aspect of information for retail as well as business customers play a central role: With help of appropriate information strategies, which address this target group directly and moves the issue of climate and nature conservation into the central point, it seems possible to achieve changes in demand for eco-friendly cars which later on will lead to pecuniary advantages as a result of economies of scale. Market-based incentives also have a good record for the introduction of clean cars. Accordingly, either material intensity can become part of any taxation scheme, or one needs a benchmark for the material intensity of cars that can be used for other market-based instruments (e.g. fiscal support, see the current example of France).

- **Alternative concepts for the use of cars**, like the company-project Better Place<sup>44</sup>, might be another useful option to achieve permanent and significant changes in consumer behaviour. Car-sharing is a prominent case where users interact in order to optimize the use of different cars. For car manufacturers, these kinds of business models may hamper the sales of carmakers, because intensity of use and durability are extended. Given the rising service intensity however, the perspective might be less gloomy. Policy may give incentives to consider these options, because only with a downstream enlargement of their added value it might be possible to compensate antici-

---

<sup>44</sup> [www.betterplace.com](http://www.betterplace.com)

pated losses in sales. Currently the car manufacturers refuse these kind of ecologically preferable concepts.

## 5.2. Cement industry and EU policy

Against the background of the previous discussion it can be summed up that the **cement industry has some options at hand, which can improve its resource productivity**; in the long run however there seems to be limited possibilities and potential to improve its resource productivity if efforts are not aligned with sustainable construction initiatives. Though, taking the importance of the industry for the European long-term climate targets into account, it is very important to exhaust this potential and to get clarity on the long-term perspectives. The following incentives for the industry may enhance resource productivity:

- **Better regulation:** In principle resource productivity can be improved by implementing a front runner regulation because not all production sites are using the latest production technology as a result of the long operating life. Especially the **reduction (later even the prohibition) of energy-intensive wet processes** would be a substantial contribution to exhaust the technical potential for energy efficiency. Currently more than 8 percent of all EU15 cement plants are still run with wet or semi-wet processes, contrary, in countries affiliated with the former Soviet Union in Eastern Europe only 12 percent of the cement production is made by dry processes (IEA 2007). Even if there are country-specific data from the cement industry available, it can be supposed that such a regulation will heavily affect production sites in Eastern and Southern Europe, especially for the new EU members.

- **Aligning with the ETS:** As soon as the industry has to pay for the allocation of emission rights, the competitiveness might deteriorate at the borderland of the EU. To avoid unsustainable competition resulting from cement imports from non-EU neighbouring countries, which are linked with significant additional emissions and ecological side effects from the transportation, it may be reasonable to **require CO<sub>2</sub>-certificates for imported cement** according to its carbon intensity. Alternatively, one may offer a scope for **expanding the ETS within the cement industry beyond the EU** (e.g. for EU-based companies producing outside the EU).

- **Industrial symbiosis of energy and materials:** The use of **alternative fuels** (e.g. waste, tyres) to a greater extent is an excellent possibility to reduce the macroeconomic demand for primary energy sources. However, very high substitution rates can only be accomplished if a tailored pre-treatment and surveillance system is in place. Municipal solid waste, for example, needs to be pre-treated to obtain homogeneous calorific values and feed characteristics. In Europe, the burning of alternative fuels in cement kilns is covered by Directive 2000/76/EC of the European Parliament and Council. However, in some countries their use is controversial, because cement kilns are not subject to emission controls as stringent as waste incineration installations. Clear guidelines and public

information campaigns could help increase the use of waste in cement kilns. One could think of **regulations which either offset the cement industry for avoided emissions from fossil fuels, set standards for the caloric value of waste or even prescribe the use of such secondary fuel to certain quota**. Another option is the possibility to provide **discounts for emission rights for the use of alternative fuels in the production process**. At this juncture it should be explored how an integrated assessment can be conducted and what incentives can be given to **optimise systems e.g. via cascading use of waste**, including biomass and via a by-production of heat.

- **Creating lead markets:** Principally it should be examined which kind of political instruments can support a larger production as well as demand for **pozzolane cements or other forms of ‘eco-cement’**. Even if pozzolanes are not suitable for all kind of applications, they have a significant higher resource productivity as well as climate balance. The **European cement standard EN 197 should be assessed** against such alternatives. An indirect diffusion into the market might be achieved if targets for saving of carbon emissions will be applied for the industry that cannot be realised with the production of Portland only (see also the section on the ETS).

- **Sectoral dialogue:** a strategic dialogue on sustainable cement, supported by e.g. the European Technology Platform on sustainable construction minerals, which explores systematically into using waste and other by-products for cement production, to improve the recyclability of cement and the resource productivity over the whole life cycle. Downstream construction industries should be invited to participate in order to assess viable options for similar minerals. As part of these dialogues the discussion should be deepened if and to what extent recycling of cement / concrete might be an option to improve resource productivity. Especially the involvement of building manufacturers as well as project designers and architects can promote the concept of „design for recycling“ and “design for resource productivity”.

- **Measuring and Reporting:** There are already some elaborated suggestions - e.g. from the WBCDS / CSI – for the measuring and reporting a certain issues like key performance indicators, ecological impacts, carbon emissions as well as safety & health (WBCSD 2005a, 2005b). These proposals for the cement industry should be promoted to develop minimum standards, reporting requirements and benchmarks which are still necessary for an adequate assessment of the industry; currently there is still a lack of consistent, extensive and recent data in terms of material usage, energy consumption as well as cost structures. A more extensive reporting would help to develop accurate solutions for the discussion problems of the industry.

- **From sustainable cement to sustainable construction:** The EU should support the development and use of alternative building materials. Taking into account that the sector has only a very low impact on the European labour market (less than 60,000 direct employees), a substitution of cement with other materials (incl. renewable materials) may also be an option to increase resource productivity. A sectoral dialogue on sustainable construction materials, including building designers, thus would be a real step for-

ward (Bleischwitz/Bahn-Walkowiak, 2007), with the perspective to enhance resource productivity system-wide for buildings, taking into account the material contribution to multifunctional roofs and walls as well as options to produce energy. E.g. wood as well as wooden-based materials can make an important contribution for the construction sector (Kristof et al, 2007).

**- Promoting Private-Public Partnerships for Urban Mining:** The recovery of materials from outdated urban infrastructures is considered to be a market opportunity constrained by information deficits and regulatory uncertainties. The EU could encourage model projects between construction and waste industry and public authorities with the aim of recovering materials and developing high-level re-use systems.

### 5.3. Steel industry and EU policy

Europe has the most innovative and diversified steel production worldwide. Developing solutions that minimize material and energy input is to a large extent part of the economic interest. The challenges are certainly the tightening regulations for CO<sub>2</sub> emission in Europe, which could have negative influence on competitiveness of the European steel industry. Without an international carbon regulation there is some risk that new steel production plants might be built in countries without strict regulations (so-called carbon leakage) (European Commission, 2008). A close dialogue between politics and industry can prevent a massive dislocation of production. Competitive substitutes are rare and ubiquitous application of steel from ship industry to home appliances will secure high demand.

**- Lead markets:** Suitable strategies can make an important contribution to develop lead markets for resource friendly technologies and products (Aho et al 2006). The European steel industry already connects the most important area applications on its technology platform ESTEP (European Steel Technology Platform): construction, automotive, mechanical engineering and metal goods. Here the research and development for products follows an integrated approach, which already considers the resource and energy efficiency comprehensively (ESTEP, 2005). The EU also promotes corresponding innovation in the context of a lead market initiative for Europe (European Commission, 2007). Within six identified lead markets innovative solutions are supported. These lead markets have high relevance for the steel industry because steel is found in all lead markets, sometimes as high-tech material, sometimes as mass product. Unfortunately the EU strategy has mentioned the basic target to improve resource and energy efficiency on the one hand, but no **life-cycle perspective** for the products and services to be developed has been included on the other hand, especially in R&D. The life-cycle perspective is essential for any comprehensive approach and should be addressed stronger.

**- Environmental research and the development of technologies:** Up to the present the environmental research and development of new technologies are mainly separated, direct links as well as cooperation are exceptions (Lemken et al., 2008). It seems to be

reasonable and necessary to promote an interdisciplinary research to connect both environmental / sustainable aspects and new trends and technologies in materials and technical processes. Existing approaches, like the discussed ESTEP platform, already give important impulses for an integrated perspective of competitiveness, resource productivity and sustainability. Further initiatives and approaches should be forced, so that technical potentials of resource productivity in the steel industry as well as associated industries can be depleted in the near future.

- **Standardization:** Standards and (technical) norms are very important if innovative and new approaches, processes and materials shall applied in practice. Certain existing standards can limit the potentials of those new innovations, also with regard to resource productivity. One example is the application of **high-tensile steels** restricted due to inflexible technical regulations.<sup>45</sup> Innovation can only evolve into mainstream if accordant standards and norms will have been adjusted to their specific characteristics, even if necessary adjustments can only be applied with a certain time lag. It seems to be reasonable to support a stronger cooperation of all involved parties to ensure fast standardizations as well as spread of those innovations. However, even new or adjusted standards and technical norms will only be successful in practice if their users get specialised trainings and qualifications (Lemken et al, 2008).

- **Implementation of efficiency targets as well as a life-cycle perspective in infrastructures:** The largest potentials to achieve resource conservation can be exploited in applications, which are connected with the need for large amounts of steel. With regard to steel, all kinds of infrastructures (incl. construction and buildings) play an important role, whereas decisions about the renewal and expansion of both public infrastructures and industrial production structures characterize the use of steel and other resources for long periods. Therefore, at an early planning phase it should be considered how the potentials of the material steel – in particular certain discussed high quality steels as well as composite materials - can be used to improve resource productivity in a life-cycle and systemic perspective. Thus, not the costs of construction should kept being focussed but rather a LCC approach which also considers the costs and resource use within the phase of usage (Lemken et al., 2008).

- **Light weight materials and products:** These activities can be aligned with the **Technology Platform** for lightweight products (see above), in particular for cars, because the automotive sector is one of the largest buyer of steel (see also the chapter on the automotive industry). Such a Technology Platform will bring together not only car manufacturers and main suppliers, but also steel producing and steel processing compa-

---

<sup>45</sup> Here, the EUROCODE 3 (DIN EN 1993-1-1; DIN EN 1993-1-12) does only consider steels with a yield strength up to 700 N / mm<sup>2</sup> (until June 2008 this limit was even lower with a yield strength of 460 N / mm<sup>2</sup>). However, there are already high-quality steels with strengths up to 1100 N / mm<sup>2</sup> available. The current standards suppose that conventional steels as well as high-tensile steels should be treated the same way, which leads to the problematical result that the fatigue characteristics of steels between 700 N / mm<sup>2</sup> and 1100 N / mm<sup>2</sup> is not regulated for practical application. This situation results in the fact that high-quality steels cannot unfold their potentials in both their application in practice and (therefore) in the improvement of resource productivity. (for further details see: Lemken 2008, Völling et al 2006))

nies as well as recycling industry, designer and material science. Similar platforms, like the undoubtful successful HFC Technology Platform, have shown that an integrated approach with producers (here: steel) and manufacturers (here: automotive) can lead to the establishment of a win-win Joint Technology Initiative, which can be utilized to focus on improving resource productivity.

## 5.4. Data requirements: towards knowledge-creating institutions

Data on DMI /DMC as a denominator have been provided and can be expected to be updated regularly. However, the ensuing notion of resource productivity as “Direct Material Productivity” does not capture the hidden flows and the “ecological rucksacks” and, thus, leads to a bias in favour of construction. Accordingly, a possible shifting of environmental burden to other countries is insufficiently captured. For that reason, the Total Material Requirements (TMR) should be preferred as the most complete indicator.

The data availability on material costs for manufacturing industries at the EU level is poor. A conclusion is to apply the scheme established at Destatis in Germany on a European level (i.e.: Eurostat) and in the ‘Community Innovation Survey’ (CIS).

Towards knowledge creation, incentives to increase resource productivity such as monitoring and reporting requirements for industry should be considered. The experience and evaluation of the UK Resource Efficiency Network or the German Material Efficiency Agency and their SME supporting programmes could be used as a model for programmes on dissemination and qualification at a European scale.

Taking into account the global transactions of the European economy, the establishment of an **international data base and data centre**<sup>46</sup> on the resource intensity of products and services is urgently needed, in order to monitor the success of strategies and measures to increase resource productivity, on the macro-economic level, for industries and the level of companies and product-service-systems including the customers and consumers activities.

It should also be envisaged to link the establishment of such data base to ongoing work at Eurostat, in particular the creation of the Data Centres for Natural Resources and Products. An international data base could complement the Eurostat data base particularly through providing coefficients of the indirect resource requirements of traded products and the unused domestic extraction of materials, which in many countries official environmental statistics do not report.

---

<sup>46</sup> We owe much thank to discussion with Stefan Giljum, Fritz Hinterberger (both SERI), Brigitte Biermann, Holger Wallbaum (both Triple Innova), Stefan Bringezu, Christa Liedtke, Michael Ritthof, Helmut Schütz (all WI) and the Aachen Foundation in a parallel project on the issue.

The main **objective** of an EU-wide and international data base is to provide users with validated, internationally harmonised and periodically updated data regarding the resource intensity and related key indicators of raw materials, semi-manufactured goods, finished products and services. These data support a sustainable management of material flows in value chains and economies and a dematerialisation of currently unsustainable production and consumption patterns. Such a database should contain

- Data on total material inputs (including unused extraction of raw materials) along the analysed production chains, in a cradle-to-material, cradle-to-product, cradle-to-grave and cradle-to-cradle format.
- Data on indirect resource flows of internationally traded raw materials, semi-manufactured goods and finished products. These data are required for analyses at the macro level, in particular for calculating comprehensive resource use indicators such as Total Material Requirement (TMR) and Total Material Consumption (TMC) of countries and world regions. At the same time, these coefficients are required to complete assessments at the micro level with regard to the consideration of indirect (up-stream) material requirements of raw materials and semi-manufactured goods in process analyses.
- Data on unused extraction per unit of used extraction. Huge data gaps can still be observed in the area of unused domestic extraction (UDE). Although efforts have started to integrate existing data bases on UDE coefficients (for example, WI and SERI have recently harmonized their UDE data bases), significantly more resources are required in order to generate a larger number of country- and raw material-specific factors, either through screening of existing literature or through expert interviews. In the medium run, a significant improvement of the data situation will only be achieved, if companies of the extractive sectors are actively integrated into reporting on material flows.
- Economic data to support input output analysis (PIOT and MIOT), including data on the share of material costs as part of overall production costs (see german DESTATIS). In addition, there should be a sectoral observatory for key industries with the task to monitor important development trends. This observatory can be linked with ongoing CIS (EU Community Innovation Survey) activities.
- In order to use synergies and to enable direct compatibility with other indicators, the data base should also contain (or at least link to) other categories of resource use, in particular GHG emissions / Carbon Footprint, land use / Ecological Footprint and water use. Thereby, all main components of eco-efficiency, which are of global importance, could be integrated within one consistent framework.



### **Key Policy Recommendations**

Establish performance targets on resource use and resource productivity for member states.

Establish sectoral dialogues with key industries such as automotive, metals, and construction on resource productivity performance (minimum standards, benchmarks, reporting).

Initiate a Technology Platform for Light-Weight Construction.

Introduce a European-wide minimum taxation on construction minerals.

Improve data base on material cost structure in industries and on total material requirements.

Establish an international data base and data centre on the resource intensity of products and services.

## 6. References

- ACEA, EU Economic Report, February 2007, Brussels 2007
- ACEA, EU Economic Report, February 2008, Brussels 2008
- ACEA, EU Economic Report, July 2008, Brussels 2008
- ACEA, European Automobile Industry Report, Brussels 2007
- ACEA: New Passenger Car Registrations, Brussels 2008,  
[http://www.acea.be/images/uploads/files/20080918\\_PR\\_PC\\_0807-08-FINAL\\_2.pdf](http://www.acea.be/images/uploads/files/20080918_PR_PC_0807-08-FINAL_2.pdf)
- Acosta-Fernández J. (2007a), *Identifikation prioritärer Handlungsfelder für die Erhöhung der gesamtwirtschaftlichen Ressourcenproduktivität in Deutschland*, Wuppertal Institute for Climate, Environment, Energy, Wuppertal.
- Acosta-Fernández J., Bringezu S. (2007b), *Sektorale Potenziale zur Verringerung des Ressourcenverbrauchs der deutschen Wirtschaft und ihre Auswirkungen auf Treibhausgasemissionen, Bruttowertschöpfung und Beschäftigung*, Wuppertal Institute for Climate, Environment, Energy, Wuppertal.
- Acosta-Fernández, J. (2007): Identifikation prioritärer Handlungsfelder für die Erhöhung der gesamtwirtschaftlichen Ressourcenproduktivität in Deutschland. Wuppertal 2007,  
[http://www.ressourcenproduktivitaet.de/download.php?datei=src/downloads/AP\\_21\\_SektoraleHotSpots.pdf](http://www.ressourcenproduktivitaet.de/download.php?datei=src/downloads/AP_21_SektoraleHotSpots.pdf)
- Acosta-Fernández, J. (2008), *Zur Messung von Ressourcenproduktivität von Wirtschaftseinheiten*. In: Hartard, S., Schaffer, A., Giegrich, J. (eds), *Ressourceneffizienz im Kontext der Nachhaltigkeitsdebatte*, Baden-Baden, Nomos, pp. 85 - 102.
- Agassi Shai: The Future of transportation,  
[http://www.projectbetterplace.com/files/Project%20Better%20Place%20White%20Paper%20The%20Future%20of%20Transportation\\_FINAL.pdf](http://www.projectbetterplace.com/files/Project%20Better%20Place%20White%20Paper%20The%20Future%20of%20Transportation_FINAL.pdf)
- Al-Sibai, J. / Hofer, M. B. (2004): Verkaufsfördermaßnahmen und Customer Incentives im Spannungsfeld zwischen Marktanteil und Gewinn. In: Ebel, B. / Hofer, M. B. / Al-Sibai, J.: *Automotive Management: Strategien und Marketing in der Automobilwirtschaft*, Berlin, Heidelberg, New-York, pages 475-486
- Ameling, D.; Endemann, G. (2007): *Ressourceneffizienz - Gute Argumente für Stahl*; Stahlinstitut VDEh, Wirtschaftsvereinigung Stahl, Düsseldorf, URL: [http://www.stahl-online.de/wirtschaft\\_und\\_politik/Umwelt\\_und\\_Energiepolitik/IISI\\_Ressourceneffizienz\\_deutsch\\_Internet.pdf](http://www.stahl-online.de/wirtschaft_und_politik/Umwelt_und_Energiepolitik/IISI_Ressourceneffizienz_deutsch_Internet.pdf)
- Ameling, Dieter (2008): *Ressourceneffizienz: Stahl ist die Lösung*, Dresden 2008.
- Augter / Wettach / Wildhagen (2008): No pardon. In: *Wirtschaftswoche* Nr. 39, S. 23 – 28, Düsseldorf 2008.
- Automobil-Produktion, Sonderausgabe Innovationen in der Automobilindustrie, Landsberg 2007
- Baedeker, C. et al. (2008), *Survey Public and Private Consumption*. Sub-task 1 Survey on consumption behaviour and its driving forces. Report for the EEA. Copenhagen.

- Baltagi, B. H. (1995), *Econometric Analysis of Panel Data*. John Wiley & Sons.
- Barandun, Angela. Holcim investiert in CO2 freundlicheren Zement, in: Tages-Anzeiger Online, 30.Juni 2008. <http://www.tagesanzeiger.ch/dyn/news/wirtschaft/901110.html>
- Bartelmus, P. (2002), *Environmental accounting and material flow analysis*, in: Ayres, R.U., Ayres, L.W. (eds.) (2002), *A Handbook of Industrial Ecology*, Cheltenham / Northampton, Edward Elgar
- Bear, S. C. I. E. R. (2000): *Auto Industry - Setting the Stage for the Next 100 Years*, New-York.
- Beck, N. (2006): *Time-Series—Cross-Section Methods*. In: Box-Steffensmeier, J., Brady, H., Collier, D. (eds.): *Oxford Handbook of Political Methodology*. New York: Oxford University Press.
- Beck, N., Katz, J.N. (1995), *What to Do (and Not to Do) With Time-Series Cross-Section Data*. In: *American Political Science Review* 89:634-647.
- Becker, H. (2007): *Auf Crashkurs. Automobilindustrie in globalen Verdrängungswettbewerb*, Berlin, Heidelberg, New-York.
- Berenberg Bank / HWWI (2007): *Strategie 2030 – Energierohstoffe*, Hamburg
- Bergh, J.C.J.M. van den (2007), *Abolishing GDP*. Tinbergen Institute Discussion Paper TI 2007-019/3. Amsterdam, Vrije Universiteit / Tinbergen Institute.
- Berkel van, Rene: (2007) *Eco-efficiency in primary metals production: Context, perspectives and methods*, in: *Resources, Conservation and Recycling* 51 (2007) 511–540.
- Bernhard, Lutz (2008): *Aus Freude am sparen*, in: FTD: 14.07.2008
- Best, A. et al. (2008a), *Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources; Report to the European Commission, DG Environment, EXECUTIVE SUMMARY*, Vienna, Brussels, Oxford, SERI / Ecologic / Best Foot Forward, [http://ec.europa.eu/environment/natres/pdf/footprint\\_summary.pdf](http://ec.europa.eu/environment/natres/pdf/footprint_summary.pdf), 2008-10-30.
- Best, A. et al. (2008b), *Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources, Report to the European Commission, DG Environment, FINAL REPORT*, Vienna, Brussels, Oxford, SERI / Ecologic / Best Foot Forward, <http://ec.europa.eu/environment/natres/pdf/footprint.pdf>, 2008-10-30.
- BFAI, Frankreich will Klimaschutz intensivieren, 16.04.2008: [https://www.bfai.de/ext/Export-Einzelsicht/DE/Content/\\_\\_\\_SharedDocs/Links-Einzeldokumente-Datenbanken/fachdokument,templateId=renderPrint/MKT200804158017.pdf](https://www.bfai.de/ext/Export-Einzelsicht/DE/Content/___SharedDocs/Links-Einzeldokumente-Datenbanken/fachdokument,templateId=renderPrint/MKT200804158017.pdf)
- Biebeler, H. / Mohammadzadeh, M. / Selke, J.-W. (2008): *Globaler Wandel aus Sicht der Wirtschaft, Forschungsberichte aus dem Institut der deutschen Wirtschaft Köln*, Köln
- Bleischwitz, R. (1998), *Ressourcenproduktivität. Innovationen für Umwelt und Beschäftigung*, Springer Verlag, Berlin / Heidelberg et. al. 1998.

- Bleischwitz, R. (2005), *A Triple-I Strategy for the Future of Europe*. Inaugural Speech as Toyota Chair for Industry and Sustainability, in: College of Europe, Bruges *European Economic Policy Papers BEEP* No. 10/2005.
- Bleischwitz, R. (Ed.) (2007), *Corporate Governance of Sustainability: A Co-Evolutionary View on Resource Management*. Edward Elgar Publisher.
- Bleischwitz, R. / Bahn-Walkowiak 2007: Aggregates and construction markets in Europe – towards a sectoral action plan on sustainable resource management, in: 'Minerals and Energy' H 3-4/ 2007, pp. 159–176
- Bleischwitz, R. / Bahn-Walkowiak, B. (2008), *Aggregates and construction markets in Europe – towards a sectoral action plan on sustainable resource management*, in: 'Minerals and Energy' H 3-4, pp. 159–176.
- Bleischwitz, R. / Fuhrmann, K. / Huchler, E. (2007), *The Sustainability Impact of the EU Emissions Trading System on the European Industry*, in: College of Europe, Bruges *European Economic Policy Papers BEEP* No. 17/2007.
- Bleischwitz, R. / Fuhrmann, K. Huchler, E. (2007): The Sustainability Impact of the EU Emissions Trading System on the European Industry, in: College of Europe, Bruges *European Economic Policy Papers BEEP* No. 17/2007.
- Bleischwitz, R. / Fuhrmann, K. Huchler, E. (2007): The Sustainability Impact of the EU Emissions Trading System on the European Industry, in: College of Europe, Bruges *European Economic Policy Papers BEEP* No. 17/2007.
- Bleischwitz, R. / Hennicke, P. (Eds.) (2004), *Eco-Efficiency, Regulation, and Sustainable Business. Towards a Governance Structure for Sustainable Development*, Edward Elgar Publisher.
- Bleischwitz, R., (2001), *Rethinking Productivity: Why has Economic Analysis Focused on Labour Instead of Natural Resources?*, in: *Environmental and Resource Economics (EARE)*, 19 (1), pp. 23 - 36.
- Bolwerk, G. et al. German Contribution to the Review of the Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries - Part II: Cement Manufacturing Industries, 2006..  
<http://www.bvt.umweltbundesamt.de/archiv-e/Part-II-Cement-Manufacturing-Industries.pdf>
- Boston Consulting Group (2006): innovationsstandort Deutschland - quo vadis?, München
- Bratzel, S. / Tellermann, R. (2007): Die Umweltstrategien der Automobilhersteller: AutomotiveMARKETS 2007 - Eine Analyse der Fahrzeugsegmente und Umweltinnovationen, FHDW Center of Automotive, Bergisch Gladbach
- Bringezu S. (2002), *Industrial Ecology: Analyses for Sustainable Resource and Materials Management in Germany and Europe*, Ayres R., Ayres L. (eds.) (2002), *A Handbook of Industrial Ecology*, Cheltenham / Northampton, Edward Elgar, pp. 288 - 300.
- Bringezu S., Schütz H. (2001a), *Total Material Resource Flows of the United Kingdom*, A Study of the Wuppertal Institute for the Department for the Environment, Transport and the Regions. Final report 6/01.
- Bringezu, S. (2004), *Erdlandung: Navigation zu den Ressourcen der Zukunft*, Stuttgart, Leipzig, Hirzel.
- Bringezu, S. et al. (2004), *International Comparison of Resource Use and its Relation to Economic Growth: the Development of Total Material Requirement, Direct Mate-*

- rial Inputs and Hidden Flows and the Structure of TMR*. In: Ecological Economics (51), S. 97-124.
- Bringezu, S., Schütz, H., Moll, S. (2003), *Rationale for and interpretation of economy-wide Materials Flow Analysis and derived indicators*. In: *Journal of Industrial Ecology*, 7 (2), pp. 43 - 64.
- Brunner, M. (2006): Strategisches Nachhaltigkeitsmanagement in der Automobilindustrie: eine empirische Untersuchung Berlin.
- Buck, Christian (2008): Die Industrie fürchtet Pläne aus Brüssel, in: Handelsblatt Nr. 188, 26.9.2008, S. B1 – B4, Düsseldorf 2008.
- Busch T., Liedtke C., Beucker S. (2006), *The concept of corporate resource efficiency accounting: a case study in the electronic industry*, Schaltegger S. (ed.), Sustainability Accounting and Reporting, Dordrecht, Springer.
- Canas, A. et al. (2003), *A New Environmental Kuznets Curve? Relationship between Direct Material Input and Income per Capita: Evidence from Industrial Countries*. In: Ecological Economics (46), S. 217-229.
- Carbon Trust, Brand value at Risk from climate change, London 2005
- CCIC - Consultative Commission on Industrial Change, Hearing on the evolution of the european cement industry, Brussels 2007  
[http://www.eesc.europa.eu/sections/ccmi/docs/documents/16\\_05\\_20Juli\\_Athens/Mission\\_report\\_EN.pdf](http://www.eesc.europa.eu/sections/ccmi/docs/documents/16_05_20Juli_Athens/Mission_report_EN.pdf)
- CD4CDM, <http://cd4cdm.org/>
- CEC [Commission of the European Communities] (2005), *Thematic Strategy on the sustainable use of natural resources*, COM(2005) 670 final, Brussels.
- CEC [Communication from the Commission to the European Parliament and the Council] (2008), *The Raw Materials Initiative – Meeting Our Critical Needs for Growth and Jobs in Europe* {SEC(2008) 2741}, COM(2008) 699, Brussels
- Cembureau. 2008. Activity Report 2007, Brussels 2007  
<http://www.cembureau.eu/Documents/Publications/Activity%20Report%202007.pdf>
- Cembureau. Alternative fuels in cement manufacture – technical and environmental review. Brussels 1997.  
[http://www.cembureau.be/Documents/Publications/Alternative\\_Fuels\\_in\\_Cement\\_Manufacture\\_CEMBUREAU\\_Brochure\\_EN.pdf](http://www.cembureau.be/Documents/Publications/Alternative_Fuels_in_Cement_Manufacture_CEMBUREAU_Brochure_EN.pdf)
- Cembureau. Competitiveness of the european cement industry. Brussels 2000.
- Cleveland, C. J., Ruth, M. (1998), *Indicators of Dematerialization and the Materials Intensity of Use*. In: *Industrial Ecology*, 2: 13-49.
- Crotty, J. / M. Kandlikar (2007): 'Is European end-of life vehicle legislation living up to expectations?', *Journal of Cleaner Production*, Vol. 15, pp. 17-27.
- Dahlström K., Ekins P. (2005), *Eco-Efficiency Trends in the UK Steel and Aluminum Industries*, in: *Journal of Industrial Ecology*, 9 (4), p. 175.
- Deutsche Bank (2002): The Drivers - How to navigate the auto industry?, Frankfurt am Main
- Diez, W. (2001): Die Automobilindustrie im Zeichen der Globalisierung. In: Diez, W.: *Grundlagen der Automobilwirtschaft*, Ottobrunn, pages 97-118

- ECTP, Vision 2030 & Strategic Research Agenda – Focus Area Materials, Brussels 2005. <http://www.ectp.org/documentation/FA-MATERIALS-Vision2030-and-SRA-Version1-2005-09-02.pdf>
- EEA (1998), *Guidelines for Data Collection and Processing* - EU State of the Environment Report, Copenhagen.
- EEA (2003), *Europe's environment: the third assessment*. Environmental assessment report No 10, Copenhagen.
- EEA (2006), *Using the market for cost-effective environmental policy, Market-based instruments in Europe*, EEA Report No 1/2006. Copenhagen.
- EEA (2008), *Effectiveness of environmental taxes and charges for managing sand, gravel and rock extraction in selected EU countries*, EEA report 2/2008, Copenhagen.
- Eikmeier, B., Gabriel, J. und Pfaffenberger, W. Gutachten - Perspektiven für die energieintensive Industrie in europäischen Strommarkt unter Berücksichtigung der Regulierung der Netzentgelte, Bremen 2005 [www.bei.uni-bremen.de/pdf/projekt/gutachten\\_0222.pdf](http://www.bei.uni-bremen.de/pdf/projekt/gutachten_0222.pdf)
- Environment Agency. Measuring environmental performance - Sector report for the cement industry, Bristol 2005. [http://publications.environment-agency.gov.uk/pdf/GEHO1105BJVK-e-e.pdf?lang=\\_e](http://publications.environment-agency.gov.uk/pdf/GEHO1105BJVK-e-e.pdf?lang=_e)
- Environment and Development (1997), Special Issue to EKC, 1997-2.
- Ernst & Young (2007): Entwicklung der weltweiten Pkw-Produktion: Herausforderungen für den Automobilstandort Deutschland, Frankfurt am Main
- ESTEP - European Steel Technologie Platform (2005): Strategic Research Agenda: A vision for the future of the steel sector, Belgien; Download unter: [ftp://ftp.cordis.europa.eu/pub/estep/docs/sra\\_en.pdf](ftp://ftp.cordis.europa.eu/pub/estep/docs/sra_en.pdf)
- ETC-WMF (2003), *Zero Study: Resource Use in European Countries*. An Estimate of Materials and Waste Streams in the Community, including Imports and Exports using the Instruments of Material Flow Analysis, ETC-WMF, by Moll S., Bringezu S., Schütz H., Copenhagen, ETC-WMF/EEA.
- EUROFER (2006): ESTEP: From a strategic research Agenda to implementation, Brussels 2006.
- EUROFER (2007): The European Steel Industry's Contribution to an integrated product policy – final report, Brussels 2007, URL: [www.eurofer.be/publications/pdf/2007-IPP\\_Final\\_Report.pdf](http://www.eurofer.be/publications/pdf/2007-IPP_Final_Report.pdf)
- EUROFER (2008), Annual Report 2007, Brussels 2008.
- Europe Innova (2008), *What is the right strategy for more innovation in Europe? Drivers and challenges for innovation performance at the sector level*. Synthesis Report, Systematic Innovation Watch (SIW), prepared by Andreas Reinstaller, Fabian Unterlass, Austrian Institute for Economic Research (WIFO).
- European Commission (2004): European Competitiveness Report 2004. Competitiveness and Benchmarking, Brussel.
- European Commission (2006): Analysis of economic indicators of the EU metals industry: the impact of raw material and energy supply on competitiveness. SEC (2006) 1069, Brussels 2006.
- European Commission (2007): Eine Leitmarktiniziative für Europa; KOM (2007) 860 endg., Brussels.

- European Commission (2008): Mitteilung der Kommission an den Rat und das Europäische Parlament über die Wettbewerbsfähigkeit der Metallindustrie. KOM(2008) 108 final, Brussels 2008.
- European Commission, Cars21 – A competitive Automotive regulatory System for the 21st century, Brussels 2006
- European Commission. Integrated Pollution Prevention and Control (IPPC) - Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries. Draft September 2007, Brussels 2007.  
<http://eippcb.jrc.es/pub/english.cgi/d1306713/03%20Reference%20Document%20on%20Best%20Available%20Technique%20for%20the%20Cement%20and%20Lime%20Manufacturing%20Industry%20%28revised%20Draft%20one%29>
- Eurostat (2001), *Economy-wide material flow accounts and derived indicators. A methodological guide*, Luxembourg, EC.
- Eurostat (2007), *Measuring progress towards a more sustainable Europe: 2007 monitoring report of the EU sustainable development strategy*, Luxembourg; EC, [http://ec.europa.eu/sustainable/docs/estat\\_2007\\_sds\\_en.pdf](http://ec.europa.eu/sustainable/docs/estat_2007_sds_en.pdf), 2008-10-30.
- Eurostat (2008), *Eurostat Quality Profile, Gross Domestic Product (GDP) per capita in Purchasing Power Standards (PPS)*,  
[http://circa.europa.eu/Public/irc/ds/structind/library?l=/general\\_information/quality\\_profiles/economic\\_background/eb011\\_capitapdf/EN\\_2.0\\_&a=d](http://circa.europa.eu/Public/irc/ds/structind/library?l=/general_information/quality_profiles/economic_background/eb011_capitapdf/EN_2.0_&a=d), 2008-11-03.
- Eurostat (2008), *Eurostat Quality Profile, Resource Productivity and Domestic Material Consumption*,  
[http://epp.eurostat.ec.europa.eu/pls/portal/docs/PAGE/PGP\\_DS\\_SUSTDEVIND/PGE\\_DS\\_SUSTDEVIND\\_01/TAB68079609/RESOURCE%20PRODUCTIVITY.PDF](http://epp.eurostat.ec.europa.eu/pls/portal/docs/PAGE/PGP_DS_SUSTDEVIND/PGE_DS_SUSTDEVIND_01/TAB68079609/RESOURCE%20PRODUCTIVITY.PDF), 2008-11-03.
- Eurostat, <http://epp.eurostat.ec.europa.eu>
- Eurostat/IFF (2004), *Economy-wide Material Flow Accounts and Indicators of Resource Use for the EU-15: 1970-2001*, Luxembourg, Eurostat.
- Ferrao, P, J. Amaral, (2006): 'Assessing the economics of auto recycling activities in relation to European Union Directive on end of life vehicle', *Technological Forecasting & Social Change*, Vol. 73., 2006.
- Fischedick, Manfred et al. (2008): *Ecological, Economic and Structural Comparison of Renewable Energy Technologies with Carbon Capture and Storage – an integrated approach*. Wuppertal 2008.  
[http://www.wupperinst.org/uploads/tx\\_wiprojekt/RECCS\\_final\\_report\\_long.pdf](http://www.wupperinst.org/uploads/tx_wiprojekt/RECCS_final_report_long.pdf)
- Fischedick, Manfred et al: *Ecological, Economic and Structural Comparison of Renewable Energy Technologies with Carbon Capture and Storage – an integrated approach*. Wuppertal 2008.  
[http://www.wupperinst.org/uploads/tx\\_wiprojekt/RECCS\\_final\\_report\\_long.pdf](http://www.wupperinst.org/uploads/tx_wiprojekt/RECCS_final_report_long.pdf)
- Floßdorf, F.-J.; Wieland, H.-J. (2003): *Stahlanwendung durch nachhaltige technische Lösungen*, Vortrag bei Format – Technologie und Wandel, 25.03.2003
- Gielen, Dolf. Western European Materials as Sources and Sinks of CO<sub>2</sub> – a Material flow Analysis Perspective. In: *Journal of Industrial Ecology*, Vol.2 No.2, 1998, p.43-62.
- Goossens, Y., A. Mäkipää, P. Schepelmann, I. van de Sand, I., Kuhndt M., Herndorf, M. (2007), *Alternative progress indicators to Gross Domestic Product (GDP) as a means towards sustainable development*, Luxembourg, European Parliament / Policy Department Economic and Scientific Policy.

- Government of Japan (2003), *Fundamental Plan for Establishing a Sound Material-Cycle Society*, (Tentative Translation by Ministry of the Environment), Tokyo.
- Gromer, S. (2006): Die Automobilindustrie in Deutschland. Eine Untersuchung auf Basis des Konzepts zur Koodinierungsmängeldiagnose, Hamburg.
- Harrison, John, Sustainability in cement and concrete industry. In: ZKG International, Vol. 60, No 2-2007
- Hennes, Markus (2008): Mittal glaubt an den Boom. In: Handelsblatt Nr. 182, 18.9.2008, S. 17, Düsseldorf 2008.
- Hesse, A. (2006): Climate and corporations - Right answers or wrong questions? Carbon Disclosure Project data - Validation, analysis, improvements, Bonn, Berlin
- Hessling et al: Entwicklung neuer Stähle, Aachen 2007: [http://www.ihk-niederrhein.de/downloads/Vortrag\\_Goetz\\_Hessling\\_RWTH\\_IHK\\_Automotive.pdf](http://www.ihk-niederrhein.de/downloads/Vortrag_Goetz_Hessling_RWTH_IHK_Automotive.pdf)
- Hinterberger F., Moll S., Femia A. (1998), *Arbeitsproduktivität, Ressourcenproduktivität und Ressourcenintensität der Arbeit : makroökonomische und sektorale Analyse*, Gelsenkirchen, Institut Arbeit und Technik, (Graue Reihe des Instituts Arbeit und Technik; 02).
- Hoekstra, R., van den Bergh, J.C.J.M. (2002), *Structural Decomposition Analysis of Physical Flows in the Economy*, in: Environmental and Resource Economics 23, pp. 357 - 378.
- IISI - International Iron and Steel Institute (ed.) (1998): Worldwide LCI Database for Steel Industry Products; Technical Report No. 1, Brussel.
- IISI - International Iron and Steel Institute (ed.) (2007): World Steel in Figures 2007; Web/pdf version; 4 September 2007, Brussel
- IISI - International Iron and Steel Institute (ed.) (2008): World crude steel output increases by 7.5% in 2007; Media Release vom 23.01.2008; URL: <http://www.worldsteel.org/pictures/newsfiles/2007%20Summary.pdf>
- IKB (2007), IKB Branchenbericht Rohstoffmärkte, Düsseldorf 2007.
- IKB Deutsche Industriebank (2003): Automobilzulieferer - Unveränderte hoher Effizienz- und Innovationsdruck, IKB Informationen, Düsseldorf
- IKB Deutsche Industriebank (2007): Rohstoffmärkte, IKB Branchenberichte, Düsseldorf
- International Energy Agency (IEA) (2007): Tracking Industrial Energy Efficiency and CO2 Emissions. Paris 2007.
- International Energy Agency (IEA): Tracking Industrial Energy Efficiency and CO2 Emissions. Paris 2007.
- IPCC, The Fourth Assessment Report on Climate Change, Genueva 2007.
- JEMAI [Japan Environmental Management Association for Industry] (2004), *Eco-Efficiency and Factor. Handbook for Products – Creation of Indicator for “Sustainable Society”; Toward a greater value and reduced environmental load*, JEMAI/METI.
- JSCE – Japan Society of Civil Engineers, Ecocement New recycling resources reborn for an affluent future. Newsletter. Tokio 2008.  
<http://www.jsce.or.jp/committee/concrete/e/newsletter/newsletter08/Ecocement.pdf>
- Kendall et al. (2008): Materials design for sustainability through life cycle: modeling of engineered cementitious composites, in: Materials and Structures (2008) 41:1117–1131.



- Kerkhoff, Hans Jürgen: Stahlindustrie vor neuen Herausforderungen, WV Stahl, IISI-42-Jahrestagung, Washington 2008, <http://www.stahl-online.de/stahltag/PM05102008.pdf>
- Konrad / Nill, Innovationen für Nachhaltigkeit., Schriftenreihe des IÖW, Institut für ökologische Wirtschaftsforschung, Nr. 157/01, Berlin 2001
- KPMG (2008): Momentum - 2008 KPMG Global Auto Executive Survey, München.
- Kristof, K. / Liedtke, C. / Baedeker, C. / Lemken, T. (2007): Erfolgsfaktoren für eine erfolgreiche Ressourcenpolitik: Kostensenkung, Rohstoffsicherheit, Arbeitsplätze und Umweltschutz. Hintergrundpapier für die Innovationskonferenz II „Ressourceneffizienz“. Wuppertal
- Kristof, Kora et al. Developing Sustainable Markets for Building with Wood. Wuppertal 2008.  
[http://www.holzwende2020.de/custom/user/Allgemein/Holwende\\_Netz\\_englisch.pdf](http://www.holzwende2020.de/custom/user/Allgemein/Holwende_Netz_englisch.pdf)
- Kurek, R. (2004): Erfolgsstrategien für Automobilzulieferer - Wirksames Management in einem dynamischen Umfeld, Berlin.
- Lafarge. Lafarge – Annual Report 2006, on from 20-F, 2006 [www.lafarge.com](http://www.lafarge.com)
- Lemken, Thomas, et al. (2008): Stahl – ein Werkstoff mit Innovationspotenzial, Wuppertal 2008. Studie für das Umweltbundesamt; vgl.: [www.ressourcenproduktivitaet.de](http://www.ressourcenproduktivitaet.de)
- Liljy, R. (2008): *Negotiated Environmental Agreements in Promoting Material Efficiency in Industry - first Steps in Finland*, revised manuscript submitted to 'Journal of Cleaner Production'.
- Löwer (2008), Handelsblatt Nr. 187, 25.9.2008, S. 18
- Mäenpää I. et al. (2001), *Material Flows in Finland: Resource Use in a Small Open Economy*, in: Journal of Industrial Ecology, Vol. (5), pp. 33 - 48.
- Malenbaum, W. (1978), *World Demand for Raw Materials in 1985 and 2000*. New York.
- Malerba, F. (2007), *Innovation and the dynamics and evolution of industries. Progress and challenges*, in: International Journal of Industrial Organization 25, pp. 675-699.
- Maurer, A. / Dietz, F. / Lang, N. (2004): Beyond Cost Reduction. Reinventing the Automotive OEM-Supplier Interface, Boston Consulting Group Report, Boston
- McKinsey, Ecofys. EU ETS Review - Report on International Competitiveness, Brussels 2006.
- Merten, T.; Liedtke, C.; Schmidt-Bleek, F.: Materialintensitätsanalysen von Grund-, Werkund Baustoffen - Die Werkstoffe Beton und Stahl- Materialintensitäten von Freileitungsmasten, Wuppertal Paper Nr. 27, Wuppertal 1995
- Moll, S., Bringezu, S. (2005), *Aggregated Indicators for Resource Use and Resource Productivity*. Their meaning, cross-country comparability, and potential driving factors. European Environment Agency, Copenhagen.
- Moll, S., Gee D. (eds.) (1999), *Making sustainability accountable: Eco-efficiency, resource productivity and innovation*; Proceedings of a workshop on the occasion of the Fifth Anniversary of the European Environment Agency (EEA) 28 - 30 October 1998 in Copenhagen, Topic report No 11/1999, Copenhagen, European Environment Agency

- Moll, Stephan; Acosta, Jose; Schütz, Helmut (2005): Iron and steel – a materials system analysis: A study examining the material flows related to the production and consumption of steel in den EU. ETC/RWM. Copenhagen 2005.
- Moody's Investor Service, European Auto Original Equipment Manufacturers, London 2008
- Moriguchi Y. (2002), *Material Flow Analysis and Industrial Ecology Studies in Japan*, in: Ayres, R.U., Ayres, L. (eds.) (2002), *A Handbook of Industrial Ecology*, Cheltenham / Northampton, Edward Elgar, pp. 301 - 310.
- Mütze, Stefan (2008): *Stahlindustrie vor Abschwächung*, Branchenfokus Helaba Volkswirtschaft/Research, Frankfurt 2008
- Nieuwenhuis, P. / Wells, P. (2003): *The automotive industry and the environment - A technical, business and social future*, Cambridge.
- Nitschke-Pagel, T. (2007): *Schweißnachbehandlung bei hochfesten Stählen*. Konferenz Tagungsband: Hochfester Stahl- im Stahl- und Maschinenbau – Neues aus Forschung und Anwendung am 13.12.2006 in Wallerfangen; Forschungsvereinigung Stahlanwendung e.V., Düsseldorf.
- Ochel, W., Röhn, O. (2008), *Indikatorenbasierte Länderrankings*, In: *Perspektiven der Wirtschaftspolitik* 9 (2), pp. 226 - 251.
- OECD (1994), *Environmental Indicators - OECD Core Set*. Paris
- OECD (2008a), *Measuring Material Flows and Resource Productivity*. Vol. I. The OECD Guide, Paris, Organisation for Economic Development and Co-operation.
- OECD (2008b), *Measuring Material Flows and Resource Productivity*. Vol. II. The Accounting Framework, Paris, Organisation for Economic Development and Co-operation.
- OECD (2008c), *Measuring Material Flows and Resource Productivity*. Vol. III. Inventory of Country Activities, Paris, Organisation for Economic Development and Co-operation.
- OECD (2008d), *OECD Key Environmental Indicators 2008*, Paris, Organisation for Economic Development and Co-operation.
- OECD (2008e), *Recommendation of the Council on Resource Productivity*, Meeting of the Environment Policy Committee (EPOC) at Ministerial Level Environment and Global Competitiveness, 28-29 April 2008, Adopted by the OECD Council on 28 March 2008, Paris, Organisation for Economic Development and Co-operation.
- OECD, *Environmental Outlook to 2030*, Paris 2008.
- Oliver Wyman Consulting (2008): *Auto & Umwelt 2007 - Klimadebatte verändert Kaufverhalten*, München
- Oliver Wyman Consulting, *Car Innovation 2015*, Frankfurt / M. 2007
- Onischka, Mathias ; Schwenke, Martina. *Messung und Anwendung von Risikoinformationen in der Finanzanalyse, Portfoliomanagement und Risikomanagement : Diskussionspaper*. - Wuppertal : Wuppertal Inst. für Klima, Umwelt, Energie, 2008
- Oss van Hendrick; Padovani Amy. *Cement Manufacture and the Environment*. *Journal of Industrial Ecology*, Vol 6., No.2, 2002, p.89-105.
- Oss van Hendrick; Padovani Amy. *Cement Manufacture and the Environment – Environmental Challenges and Opportunities*. *Journal of Industrial Ecology*, Vol 7., No.1, 2003, p.93-126.

- Pearce D. (2001), *Measuring resource productivity*: a background paper by David Pearce for the Department of Trade and Industry & Green Alliance conference "Revolutionising resource use: measuring radical improvements in resource productivity", London, 14 February 2001, London, DTI / Green Alliance.
- Radtke, P. / Abele, E. / Zielke, A. E. (2004): *Die smarte Revolution in der Automobilindustrie*, Frankfurt am Main, Wien.
- Renault, 2008 :  
[http://www.renault.com/renault\\_com/en/images/16929%2016929\\_Alliance\\_FCV\\_pressrelease\\_may08\\_\\_GB\\_tcm1120-762783.pdf](http://www.renault.com/renault_com/en/images/16929%2016929_Alliance_FCV_pressrelease_may08__GB_tcm1120-762783.pdf)
- Reuters, Congress Approves \$25 Billion in Loans to U.S. Auto Makers, 27.09.2008:  
<http://www.reuters.com/article/newsOne/idUSTRE48Q2WI20081001>
- Reuters, Ranking of world's top 10 auto groups by sales, 01.09.2008:  
<http://www.reuters.com/article/ousivMolt/idUST8934920080901>,
- Ritthoff M., Rohn, H., Liedtke C. (2002), *MIPS berechnen: Ressourcenproduktivität von Produkten und Dienstleistungen*, Wuppertal, Wuppertal Inst. for Climate, Environment, Energy.
- Ritthoff, M. (2006): Relevance of region of origin of a technology on material intensity; Workshop on Material Flows and Environmental Impacts associated with Massive Consumption of Natural Resources and Products, November 17, 2006, Tsukuba, Japan
- Ritthoff, Michael (2007): *Der Werkstoff Stahl und seine Anwendung*. Hintergrundpapier für die Veranstaltung "Zukunftsdialog Rohstoffproduktivität und Ressourcenschonung", Wuppertal 2007.
- Roeder, Oliver: *Ressourcenproduktivität und Wettbewerbsfähigkeit: Konzeptionelle Überlegungen am Beispiel der Automobilindustrie*, Wuppertal 2009 (Forthcoming)
- Roeder, Oliver; Liedtke, Christa: *Ressourceneffizienzpolitik zur Steigerung der Wettbewerbsfähigkeit*, Wirtschaftspolitische Blätter, 4/2006, S. 523-540
- Rogich D., Matos G.R. (2002), *Material Flow Accounts: the United States and the World*, in: Ayres, R., Ayres, L. (Eds.) (2002), *A Handbook of Industrial Ecology*, Cheltenham / Northampton: Edward Elgar, pp. 260 - 287.
- Romer, P. M. (1990), *Endogenous Technological Change*, In: *Journal of Political Economy*, University of Chicago Press, vol. 98(5), pages 71-102.
- RWI / ISI / BGR (2006): *Trends der Angebots- und Nachfragesituation bei mineralischen Rohstoffen*, Essen 2006
- RWI, *Trends der Angebots- und Nachfragesituation bei mineralischen Rohstoffen*, Essen 2006
- SAM/WIR: *Changing Drivers: The Impact of Climate Change on Competitiveness and Value Creation in the Automotive Industry*, Zurich 2004.
- Scasny M. et al. (2003), *Material Flow Account, Balances and derived Indicators for the Czech Republic during the 1990s: Results and Recommendations for Methodological Improvements*, in: *Ecological Economics*, 45 (1), pp. 41 - 57.
- Schepelmann, P. / Schütz, H. / Bringezu, S. (2006): *Assessment of the EC Thematic Strategy on the Sustainable Use of Natural Resources*. Commissioned by the European Parliament, DG Internal Affairs, Department A - Environment and Food safety, IP/A/ENVI/ST/2006-99, WI-Stellungnahme.  
[http://www.europarl.europa.eu/comparl/envi/pdf/externalexpertise/ieep\\_6leg/sustainable\\_use\\_of\\_natural\\_resources.pdf](http://www.europarl.europa.eu/comparl/envi/pdf/externalexpertise/ieep_6leg/sustainable_use_of_natural_resources.pdf)

- Schmidt-Bleek, F. (1994), *Wieviel Umwelt braucht der Mensch? MIPS - das Maß für ökologisches Wirtschaften*, Berlin, Birkhäuser.
- Schütz, H., Bringezu, S. (2008), *Resource consumption of Germany - indicators and definitions*, Dessau-Roßlau, Federal Environment Agency.
- Schütz, H., Ritthoff, M. (2006), *Informationssysteme zur Erhöhung der Ressourcenproduktivität: Ansätze auf Mikro-, Meso- und Makro-Ebene*. Wuppertal, Wuppertal Institute for Climate, Environment, Energy.
- Shen, Weiguo et al: A new kind of Eco-cement made of cement kiln dust and granular blast furnace slag. In: Journal of Wuhan University of Technology. Vol. 21 No 1. ISSU 71, p 143-146.
- Stagl, S. (1999), *Delinking Economic Growth from Environmental Degradation? A Literature Survey on the Environmental Kuznets Curve Hypothesis*, Working Papers geewp06, Vienna University of Economics.
- Steger, S., Bleischwitz, R. (2007), *Entkoppelung der Ressourcennutzung vom Wachstum : wie erfolgreich ist Europa bei der Erhöhung der Ressourcenproduktivität und einer Dematerialisierung?*. In: Rudolph, Sven (Hrsg.): *Wachstum, Wachstum über alles? : Ein ökonomisches Leitbild auf dem Prüfstand von Umwelt und Gerechtigkeit*. - Marburg : Metropolis-Verl., S. 101-129.
- Steger, U. (2004): *Nachhaltigkeits-Orientierung der Automobilhersteller - Wege aus dem Dilemma?* In: Ebel, B. / Hofer, M. B. / Al-Sibai, J.: *Automotive Management: Strategien und Marketing in der Automobilwirtschaft*, Berlin, Heidelberg, New-York, pages 50-60
- Stockmar, J. (2004): *Erfolgsfaktoren für Automobilzulieferer - Strategien für 2010*. In: Ebel, B. / Hofer, M. B. / Al-Sibai, J.: *Automotive Management: Strategien und Marketing in der Automobilwirtschaft*, Berlin, Heidelberg, New-York, pages 61-77
- Sturbeck, Werner: *Klimaschock*, in: Handelsblatt, 20.10.2008, S. 21. Düsseldorf 2008.
- Taufetter, Gerald. *Kitt für das Klima*. In: Der Spiegel, 25.08.2008.
- TecCement, TecEco Cement Concretes – Abatement, Sequestration and Waste Utilization in the Built Environment, Glenorchy 2006.  
[http://www.tececo.com/files/conference\\_papers/TecEcoTechnologyAbatementSequestrationandWasteUtilisation110506.pdf](http://www.tececo.com/files/conference_papers/TecEcoTechnologyAbatementSequestrationandWasteUtilisation110506.pdf)
- ThyssenKrupp Steel (Hg.) (2007): *Produktinformation höherfeste IF-Stähle HX; Für hohe Streck- und Tiefziehbeanspruchung*; Duisburg; URL: <http://www.thyssenkrupp-steel.com/auto>
- Tukker, A. et al. (2005), *Environmental Impacts of Products. Analysis of the Life Cycle Environmental Impacts related to the Total Final Consumption of the EU25*. Sevilla, ESTO/IPTS.
- UBS. UBS research focus - Klimawandel: Ein heißes Thema. Zurich 2007.
- UN [United Nations], EC [European Commission], IMF [International Monetary Fund], OECD [Organisation for Economic Co-operation and Development], World Bank (2005), *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003*, Studies in Methods, Series F, No.61, Rev.1, Glossary, United Nations, New York, para. 10.203.
- van der Sand et al, *Abschätzung von Potenzialen zur Verringerung des Ressourcenverbrauchs im Automobilsektor*, Wuppertal 2007,  
[http://www.ressourcenproduktivitaet.de/download.php?datei=src/downloads/AP\\_42\\_Automobilsektor.pdf](http://www.ressourcenproduktivitaet.de/download.php?datei=src/downloads/AP_42_Automobilsektor.pdf)

- VDA, Jahresbericht 2006, Frankfurt /M 2006
- VDA, Jahresbericht 2006, Frankfurt/M. 2006
- VDA, Jahresbericht 2007, Frankfurt/M. 2007
- VDA, Tatsachen und Zahlen aus der Automobilindustrie, Frankfurt / M. 2008
- VDZ - Verein Deutscher Zementindustrie. Position der deutschen Zementindustrie zur Weiterentwicklung des Europäischen Emissionshandelssystems (EU-ETS) für den Zeitraum 2013 bis 2020, 2008 [http://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/UmweltundRessourcen/emissionshandel/Position\\_Zementindustrie\\_EU\\_ETS\\_2013.pdf](http://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/UmweltundRessourcen/emissionshandel/Position_Zementindustrie_EU_ETS_2013.pdf)
- Velikonja, D. (2004): Visionen und innovative Lösungen in der Umformtechnik, Stahl und Eisen 124 (2004) Nr. 8, S. 36-38
- Voet, E. van der et al. (2005), *Policy Review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries*, Leiden/Wuppertal/Delft, Institute of Environmental Sciences (CML)/Wuppertal Institute for Climate, Environment and Energy/CE Solutions for Environment, Economy and Technology.
- Volkswagen AG, Werkstoffverteilung VW Passat B6 1,9 TDI, Internet: [http://www.volkswagenag.com/vwag/vwcorp/content/de/sustainability\\_and\\_responsibility/Umwelt/Ressourceneffizienz/Materialeffizienz.html](http://www.volkswagenag.com/vwag/vwcorp/content/de/sustainability_and_responsibility/Umwelt/Ressourceneffizienz/Materialeffizienz.html)
- Wagner, Katrin. Appendix C1 -The European Cement Industry, Background Assessment Institute for Prospective Technological Studies, JRC, European Commission, Seville 2001. <ftp://ftp.jrc.es/pub/EURdoc/AppendixC1.pdf>
- WBCSD, Mobility 2030: Meeting the challenges to sustainability, Geneva 2004.
- WBCSD. CO2 Accounting and Reporting Standard for the Cement Industry. Chonches-Geneva 2005b.
- WBCSD. Guidelines for the Selection and Use of Fuels and Raw Materials in the Cement Manufacturing Process. Chonches-Geneva 2005a.
- Weisz, H. et al. (2002), *Development of Material Use in the European Union 1970 – 2001. Material Composition, Cross-Country Comparison, and Material Flow Indicators*. Eurostat Working Papers. Luxembourg.
- Weisz, H. et al. (2006), *The Physical Economy of the European Union: Cross-Country Comparison and Determinants of Material Consumption*. In: Ecological Economics 58 (1), S. 676-698.
- Weisz, H., Duchin, F. (2004), *Physical and Monetary Input-Output Analysis: What Makes the Difference?* Rensselaer Working Paper in Economics, No. 0422, Troy, NY.
- Wirtschaftsvereinigung Stahl (2003): Statistisches Jahrbuch der Stahlindustrie 2003-2004 (CDROM).Düsseldorf
- World Economic Forum (2002), *Global Competitiveness Report 2001/2002*, New York, Oxford, Oxford University Press.
- ZEW, Innovationsreport: Fahreugbau, Branchenreport, Jg. 15, Nr. 5, 2008

## **7. Annex**

Table 7-1: Overview of variables and expected signs:

Variable	Description	Unit of measurment	Expected Sign
DMlcap	Direct Material Input per cap	in Tonnes per cap	
DMCcap	Direct Material Consumption per cap	in Tonnes per cap	
DMI_RI	Direct Material Input per 1000 US\$ in ppp	in kg per 1000 US\$ in ppp	
DMC_RI	Direct Material Input per 1000 US\$ in ppp	in kg per 1000 US\$ in ppp	
TMRcap	Total Material Requirement per cap	in Tonnes per cap	
TMR_RI	Total Material Requirement per 1000 US\$ in ppp	in kg per 1000 US\$ in ppp	
TMIcap	Total Material Input per cap	in Tonnes per cap	
bevdict	Population density	in persons per qkm	-
arbeitsl	Unemployment rate	in % of total labor force	+
equote	share of labour force on total population	in % of total population	?
landwira	share of employees in the agriculture sector on total employess	in %	-
industria	share of employees in the industry sector on total employess	in %	+
baua	share of employees in the construction sector on total employess	in %	+
dienstla	share of employees in the service sector on total employess	in %	-
bipcapppp	Gross Domestic Product in Purchasing Power Parity per cap	in US\$ per cap EKS	+
bipccap	Gross Domestic Product in real prices per cap	in Euro per cap	+
aninccap	Gross fixed capital formation constant per cap	in Euro per cap	+
konccap	Consumption expenditure of privat households per cap	in Euro per cap	+
kon2	share of consumption expenditure of private households on GDP	in % of GDP	+
bwsc1cap	Gross Value Added agricultural sector per cap	in Euro (constant prices) per cap	-
bwsc2cap	Gross Value Added industry sector per cap	in Euro (constant prices) per cap	+
bwsc3cap	Gross Value Added construction sector per cap	in Euro (constant prices) per cap	+
bwsc4cap	Gross Value Added service sector per cap	in Euro (constant prices) per cap	-
bwscan1	share of GVA agricultural sector on total GVA	in %	-
bwscan2	share of GVA industry sector on total GVA	in %	+
bwscan3	share of GVA construction sector on total GVA	in %	+
bwscan4	share of GVA service sector on total GVA	in %	-
arprodc1	labour productivity agricultural sector per employee	in Euro (constant prices) per employee	?
arprodc2	labour productivity industry sector per employee	in Euro (constant prices) per employee	?
arprodc3	labour productivity construction sector per employee	in Euro (constant prices) per employee	?
arprodc4	labour productivity service sector per employee	in Euro (constant prices) per employee	?
ausgoeff	public spending on education	in % of GDP	-
ausgbip	expenditure in R&D	in % of GDP	-
patenteu	patent application in the European Patent Office (EPA)	per Mio. Persons	-
patentus	patent application in the United States Patent and Trademark Office (USPTO)	per Mio. Persons	-
tertiaer	university degrees in natural science and engineering disciplines	in % of population, age 20-29	-
expcap	Exporte per cap	in Euro	?
expan	share of Exports on GDP	in % of GDP	-
impcap	Importe per cap	in Euro	?
impan	share of Imports on GDP	in % of GDP	-

Variable	Description	Unit of measurment	Expected Sign
anlinvc2	Gross fixed capital formation in Metal products and machinery	in Euro (constant prices) per cap	+
anlinvc3	Gross fixed capital formation in Transport equipment	in Euro (constant prices) per cap	+
anlinvc4	Gross fixed capital formation in Construction work housing	in Euro (constant prices) per cap	+
anlinvc5	Gross fixed capital formation in Construction work other constructions	in Euro (constant prices) per cap	+
anlinvc6	Gross fixed capital formation in Other products	in Euro (constant prices) per cap	+
anbip2	share of Gross fixed capital formation in Metal products and machinery on GDP	in % of GDP	+
anbip3	share Gross fixed capital formation in Transport equipment on GDP	in % of GDP	+
anbip4	share Gross fixed capital formation in Construction work housing onGDP	in % of GDP	+
anbip5	share Gross fixed capital formation in Construction work on GDP	in % of GDP	+
anbip45	share Gross fixed capital formation in Construction work other constructions on GDP	in % of GDP	+
anbip6	share Gross fixed capital formation in Other products on total gross fixed capital formation	in % of GDP	+
heat	annual heating degree days	average daily difference between medium temperature and 18°C	+
cool	annual cooling degree days	average daily difference between medium temperature and 18°C	+
abfges	municipal solid waste (collected) per cap	in kg per cap/year	?
deponie	municipal solid waste (landfilled) per cap	in kg per cap/year	?
verbran	municipal solid waste (burned) per cap	in kg per cap/year	?
renew	share renewable energy on total energy use	in % of total energy use	-
intens	Energy intensity (Gross domestic energy use per Unit BIP)	kg in oil equivalent per 1000 Euro	-
peecap	Primary Energy Generation per cap	in toe per cap	+
bivcap	Gross Domestic Energy Use per cap	in toe per cap	+
eendvcap	Final Energy Consumption per cap	in toe per cap	+
eendvgcap	Final Energy Consumption Industry per cap	in toe per cap	+
eendvhcap	Final Energy Consumption private households per cap	in toe per cap	+
super	price of petroleum (super)	in Euro per 1000 liter	-
bleifrei	price of petroleum (unleaded)	in Euro per 1000 liter	-
diesel	price of petroleum (diesel)	in Euro per 1000 liter	-
heizen	price of petroleum (light oil)	in Euro per 1000 liter	-
dwelling	Dwelling Stock	Dwellings per 1000 capita	+
tkmcap	transport-km per cap	in tkm per cap	+
pkmcap	passenger kilometers per cap	in pkm per cap	+
mw	motorways per cap	in meters per cap	+
roads	streets per cap (without motorways)	in meters per cap	+
railcap	railway per cap	in meters per 1000 cap	+
car	car possession	numbers of cars per 1000 cap	+
dwellingcom	dwellings completed	per 1000 cap	+



Figure 7-1: Correlation-matrix EU15 1980-2000, limited variables

	dmcca	bevdic	equote	industra	baua	bipcpp	kona	bwsca1	bwsca2	bwsca3	bwsca4	arprod2	arprod3	ausgbip	patenteu	impcap	impan	anbip2	anbip3	anbip4	heat	cool	abfges	renew	peecap	eendvcap	super	diesel	dwelling	tkmcap	mw	rail	car	dwelcom
dmccap	1,00																																	
bevdicht	0,18	1,00																																
equote	0,07	0,32	1,00																															
industra	-0,01	-0,61	-0,07	1,00																														
baua	-0,01	-0,52	-0,37	0,66	1,00																													
bipcppp	0,43	0,57	0,33	-0,64	-0,69	1,00																												
kona	-0,56	-0,60	-0,14	0,43	0,24	-0,64	1,00																											
bwsca1	-0,34	-0,50	-0,38	0,07	0,46	-0,72	0,46	1,00																										
bwsca2	-0,06	0,30	0,46	0,33	-0,12	0,12	0,07	-0,65	1,00																									
bwsca3	-0,15	-0,42	-0,41	0,52	0,87	-0,74	0,39	0,55	-0,06	1,00																								
bwsca4	0,36	0,36	0,10	-0,62	-0,73	0,79	-0,49	-0,42	-0,31	-0,86	1,00																							
arprod2	0,37	0,75	0,13	-0,79	-0,62	0,88	-0,80	-0,53	-0,06	-0,65	0,75	1,00																						
arprod3	0,49	0,58	0,04	-0,59	-0,67	0,88	-0,63	-0,70	0,08	-0,63	0,77	0,86	1,00																					
ausgbip	0,39	0,49	0,39	-0,48	-0,64	0,89	-0,60	-0,71	0,14	-0,73	0,77	0,80	0,84	1,00																				
patenteu	0,48	0,56	0,48	-0,43	-0,56	0,86	-0,61	-0,69	0,21	-0,65	0,67	0,78	0,77	0,94	1,00																			
impcap	0,48	0,82	0,06	-0,52	-0,50	0,64	-0,69	-0,54	0,12	-0,53	0,57	0,77	0,70	0,47	0,52	1,00																		
impan	0,25	0,76	0,02	-0,36	-0,34	0,33	-0,44	-0,36	0,19	-0,35	0,30	0,49	0,38	0,12	0,18	0,90	1,00																	
anbip2	0,06	0,29	0,18	0,07	-0,41	0,28	0,10	-0,57	0,53	-0,41	0,22	0,08	0,25	0,12	0,15	0,47	0,57	1,00																
anbip3	0,20	0,41	0,35	-0,26	0,03	0,16	-0,32	0,02	-0,05	-0,13	0,07	0,23	-0,09	0,01	0,09	0,37	0,49	0,12	1,00															
anbip4	0,05	-0,20	-0,15	0,48	0,87	-0,57	0,09	0,41	-0,02	0,85	-0,72	-0,43	-0,55	-0,46	-0,31	-0,37	-0,26	-0,49	0,13	1,00														
heat	0,53	0,73	0,48	-0,49	-0,70	0,86	-0,64	-0,76	0,29	-0,71	0,70	0,80	0,85	0,87	0,91	0,72	0,44	0,34	0,14	-0,45	1,00													
cool	-0,30	-0,72	-0,65	0,35	0,72	-0,73	0,54	0,78	-0,43	0,80	-0,61	-0,65	-0,64	-0,78	-0,78	-0,66	-0,51	-0,48	-0,27	0,52	-0,89	1,00												
abfges	0,38	0,44	0,53	-0,47	-0,45	0,85	-0,51	-0,59	0,19	-0,49	0,50	0,65	0,60	0,73	0,75	0,40	0,17	0,14	0,26	-0,27	0,68	-0,59	1,00											
renew	-0,33	-0,77	-0,24	0,59	0,60	-0,69	0,35	0,56	-0,26	0,44	-0,50	-0,68	-0,74	-0,58	-0,63	-0,70	-0,54	-0,38	-0,15	0,35	-0,80	0,61	-0,54	1,00										
peecap	-0,08	0,63	0,64	-0,72	-0,71	0,68	-0,30	-0,41	0,20	-0,57	0,44	0,62	0,50	0,63	0,61	0,31	0,15	0,10	0,23	-0,46	0,65	-0,65	0,66	-0,63	1,00									
eendvcap	0,53	0,79	0,19	-0,61	-0,65	0,88	-0,72	-0,71	0,16	-0,67	0,75	0,91	0,91	0,80	0,81	0,89	0,65	0,37	0,21	-0,47	0,92	-0,78	0,64	-0,81	0,53	1,00								
super	0,02	0,46	0,47	-0,43	-0,54	0,68	-0,36	-0,49	0,11	-0,73	0,63	0,60	0,42	0,66	0,70	0,43	0,28	0,37	0,29	-0,45	0,59	-0,68	0,59	-0,39	0,58	0,56	1,00							
diesel	-0,18	0,25	0,48	-0,29	-0,60	0,56	0,09	-0,53	0,36	-0,60	0,41	0,28	0,33	0,42	0,43	0,19	0,13	0,62	0,00	-0,62	0,44	-0,51	0,50	-0,45	0,62	0,34	0,73	1,00						
dwelling	0,20	-0,39	-0,25	-0,24	0,06	0,33	-0,04	0,09	-0,44	0,03	0,26	0,19	0,27	0,27	0,20	-0,29	-0,56	-0,44	-0,29	-0,04	-0,02	0,33	0,34	0,02	0,07	0,01	0,00	0,05	1,00					
tkmcap	-0,11	-0,08	0,27	-0,16	-0,30	0,51	0,15	-0,44	0,30	-0,28	0,21	0,16	0,29	0,38	0,37	-0,14	-0,29	0,27	-0,22	-0,37	0,23	-0,15	0,56	-0,25	0,44	0,14	0,45	0,77	0,52	1,00				
mw	0,48	-0,05	-0,47	-0,04	0,41	0,22	-0,53	-0,10	-0,26	0,23	0,06	0,29	0,25	0,05	0,03	0,23	0,10	-0,24	0,09	0,27	-0,03	0,25	0,23	0,02	-0,31	0,21	-0,17	-0,35	0,48	-0,01	1,00			
rail	0,37	-0,47	-0,08	0,31	0,00	0,23	-0,11	-0,25	-0,12	-0,24	0,37	0,03	0,26	0,45	0,37	-0,21	-0,49	-0,09	-0,42	-0,13	0,16	-0,07	0,13	0,23	-0,26	0,06	0,14	-0,01	0,49	0,24	0,19	1,00		
car	0,44	0,20	0,03	-0,19	-0,20	0,76	-0,44	-0,70	0,21	-0,34	0,47	0,58	0,71	0,73	0,70	0,32	0,02	0,15	-0,10	-0,18	0,56	-0,37	0,70	-0,42	0,25	0,61	0,43	0,33	0,54	0,59	0,50	0,52	1,00	
dwelcom	0,04	-0,25	-0,27	0,35	0,77	-0,44	0,09	0,40	-0,10	0,70	-0,59	-0,36	-0,51	-0,50	-0,41	-0,24	-0,05	-0,31	0,30	0,76	-0,55	0,55	-0,09	0,42	-0,53	-0,40	-0,38	-0,57	0,03	-0,27	0,45	-0,16	-0,07	1,00

Figure 7-2: Correlation-matrix EU27 1992-2000, limited variables

	dmcca	bevdic	equote	industra	baua	bipcpp	kon2	bwsca1	bwsca2	bwsca3	bwsca4	arprod2	arprod3	ausgbip	patenteu	impcap	impan	anbip2	anbip3	anbip4	heat	cool	abfges	renew	peecap	eendvcap	bleifrei	diesel	dwelling	tkmcap	mw	rail	car	dwelloc	
dmccap	1,00																																		
bevdicht	-0,26	1,00																																	
equote	0,44	0,15	1,00																																
industra	0,06	-0,42	-0,27	1,00																															
baua	-0,05	-0,37	-0,35	0,57	1,00																														
bipcppp	0,41	0,37	0,62	-0,62	-0,62	1,00																													
kon2	-0,57	-0,35	-0,39	0,43	0,26	-0,68	1,00																												
bwsca1	-0,21	-0,34	-0,40	0,00	0,34	-0,59	0,33	1,00																											
bwsca2	-0,14	0,07	0,11	0,23	0,02	-0,03	0,20	-0,62	1,00																										
bwsca3	-0,11	-0,34	-0,23	0,24	0,80	-0,50	0,37	0,31	0,12	1,00																									
bwsca4	0,29	0,34	0,25	-0,35	-0,69	0,64	-0,49	-0,21	-0,52	-0,82	1,00																								
arprod2	0,23	0,45	0,38	-0,81	-0,48	0,82	-0,73	-0,44	0,06	-0,28	0,37	1,00																							
arprod3	0,46	0,21	0,38	-0,53	-0,50	0,80	-0,56	-0,62	0,10	-0,20	0,41	0,79	1,00																						
ausgbip	0,38	0,26	0,43	-0,31	-0,58	0,74	-0,59	-0,66	0,25	-0,62	0,54	0,66	0,65	1,00																					
patenteu	0,43	0,30	0,56	-0,26	-0,37	0,73	-0,58	-0,59	0,23	-0,44	0,42	0,63	0,56	0,86	1,00																				
impcap	0,39	0,56	0,44	-0,62	-0,41	0,74	-0,71	-0,40	-0,05	-0,28	0,44	0,80	0,67	0,43	0,53	1,00																			
impan	0,04	0,65	0,20	-0,53	-0,29	0,41	-0,42	-0,25	0,04	-0,16	0,20	0,57	0,34	0,08	0,19	0,86	1,00																		
anbip2	0,07	0,13	0,29	-0,04	-0,41	0,34	0,11	-0,55	0,43	-0,30	0,15	0,13	0,26	0,21	0,22	0,37	0,45	1,00																	
anbip3	0,22	0,31	0,50	-0,32	-0,01	0,39	-0,43	0,07	-0,35	-0,12	0,28	0,30	0,05	0,00	0,19	0,53	0,51	0,08	1,00																
anbip4	0,01	-0,07	-0,04	0,29	0,83	-0,34	0,10	0,16	0,09	0,84	-0,63	-0,16	-0,19	-0,38	-0,10	-0,14	-0,10	-0,42	0,14	1,00															
heat	0,62	0,30	0,70	-0,44	-0,57	0,82	-0,67	-0,65	0,20	-0,42	0,46	0,74	0,81	0,81	0,80	0,71	0,37	0,36	0,20	-0,24	1,00														
cool	-0,35	-0,51	-0,71	0,35	0,68	-0,76	0,57	0,73	-0,24	0,63	-0,57	-0,61	-0,62	-0,76	-0,68	-0,65	-0,46	-0,48	-0,31	0,38	-0,86	1,00													
abfges	0,42	0,35	0,68	-0,35	-0,42	0,85	-0,57	-0,51	-0,03	-0,40	0,52	0,53	0,54	0,61	0,67	0,52	0,23	0,24	0,45	-0,16	0,65	-0,65	1,00												
renew	0,21	-0,53	0,21	-0,22	0,24	0,06	-0,05	0,04	0,17	0,52	-0,45	0,29	0,28	-0,05	0,00	0,12	0,02	0,02	0,03	0,32	0,17	0,09	-0,13	1,00											
peecap	0,02	0,49	0,55	-0,52	-0,75	0,60	-0,36	-0,26	-0,05	-0,68	0,56	0,39	0,26	0,53	0,41	0,33	0,19	0,22	0,23	-0,58	0,51	-0,63	0,61	-0,37	1,00										
eendvcap	0,41	0,55	0,38	-0,56	-0,62	0,80	-0,72	-0,63	0,17	-0,53	0,54	0,84	0,78	0,79	0,70	0,82	0,60	0,35	0,19	-0,36	0,86	-0,80	0,58	-0,05	0,49	1,00									
bleifrei	0,03	0,30	0,48	-0,40	-0,47	0,67	-0,34	-0,36	-0,04	-0,56	0,54	0,50	0,27	0,53	0,59	0,44	0,29	0,43	0,37	-0,36	0,46	-0,58	0,57	-0,05	0,54	0,45	1,00								
diesel	-0,12	0,21	0,44	-0,30	-0,57	0,53	0,05	-0,44	0,22	-0,47	0,34	0,26	0,23	0,35	0,35	0,24	0,19	0,70	0,07	-0,50	0,36	-0,49	0,45	-0,08	0,58	0,30	0,80	1,00							
dwelling	0,28	-0,38	-0,15	0,03	-0,05	0,20	-0,14	0,12	-0,30	-0,22	0,30	-0,01	0,09	0,31	0,23	-0,27	-0,59	-0,33	-0,22	-0,22	0,01	0,23	0,27	-0,16	0,13	-0,01	0,06	-0,02	1,00						
tkmcap	-0,09	0,02	0,05	0,14	-0,27	0,22	0,11	-0,42	0,40	-0,40	0,15	-0,02	0,01	0,43	0,39	-0,21	-0,30	0,29	-0,30	-0,35	0,14	-0,17	0,31	-0,34	0,35	0,15	0,35	0,51	0,46	1,00					
mw	0,49	-0,24	-0,06	-0,12	0,40	0,24	-0,55	-0,05	-0,15	0,37	-0,12	0,36	0,37	0,03	0,08	0,32	0,13	-0,22	0,20	0,35	0,14	0,16	0,17	0,48	-0,36	0,18	-0,13	-0,36	0,27	-0,25	1,00				
rail	0,57	-0,56	0,25	0,01	-0,03	0,27	-0,27	-0,29	0,27	0,01	-0,05	0,33	0,45	0,53	0,48	0,09	-0,22	0,10	-0,21	-0,02	0,51	-0,21	0,10	0,66	-0,17	0,28	0,12	0,01	0,29	0,13	0,38	1,00			
car	0,19	0,05	0,14	-0,07	-0,01	0,53	-0,25	-0,72	0,47	0,04	0,01	0,50	0,64	0,58	0,58	0,24	0,00	0,20	-0,11	0,17	0,45	-0,32	0,44	0,26	-0,10	0,45	0,27	0,20	0,25	0,38	0,39	0,50	1,00		
dwelloc	-0,13	-0,14	-0,30	0,25	0,80	-0,40	0,20	0,28	0,04	0,78	-0,63	-0,22	-0,29	-0,52	-0,37	-0,20	-0,02	-0,32	0,18	0,81	-0,49	0,55	-0,20	0,28	-0,65	-0,42	-0,41	-0,52	-0,15	-0,31	0,43	-0,13	0,14	1,00	

