What do economic resource productivities measure?

Julia K. Steinberger, Fridolin P. Krausmann
Institute of Social Ecology, 29 Schottenfeldgasse, Vienna, Austria
Contact: +43 1 522 4000 411, julias@alum.mit.edu

Presented at the International Society for Ecological Economics (ISEE) 11th BIENNIAL conference: Advancing sustainability in a time of crisis, 22–25 August 2010, Oldenburg - Bremen, Germany.

1. Extended abstract

Resource productivity (RP) is a ratio measuring the economic output per resource input: the higher the RP, the more economic wealth is produced per unit of resource use. RP is an indicator of *relative decoupling*. A high level of RP can be achieved at high levels of resource use, and progress in RP can accompany increases in resource use. It is thus meaningless to discuss progress in RP without corresponding information on economic growth: absolute dematerialization happens only when RP growth is larger than economic growth. Accordingly, since the EU Lisbon strategy calls for 3% annual economic growth, RP growth needs to be at or above that level simply to stabilize resource use levels.

Individual countries in the EU-27 have experienced growth in RP larger than their GDP growth, leading to absolute dematerialization – but in the vast majority of cases, this was for economic growth rates below 2%. In general, in Europe, high economic growth is still correlated with increases in resource use. Absolute decoupling will thus require actions beyond business as usual, and beyond the "best performance" of most countries.

There is an ongoing debate on whether higher RP is correlated to income or to competitiveness in the EU. We find that material productivity in the EU-27 is significantly correlated to income, but only weakly to competitiveness (and the correlation with competitiveness disappears when both income and competitiveness are considered). Thus countries with larger RP may simply benefit from richer economies rather than being more environmentally efficient.

At the global level, RP is strongly correlated to income. This can be explained by the "inelasticity" of resource use: the more inelastic a resource, the stronger the correlation of RP with income. The challenge of maintaining RP growth at or above economic growth rates can also be expressed in terms of the income elasticity of resource use. The resource elasticity should drop and eventually become negative at higher incomes (as in an Environmental Kuznets Curve), in contradiction with past evidence and present trends.

The conclusion of this analysis is that aggressive and ambitious measures far beyond the usual promotion of technical efficiency need to be pursued in order for reductions or even stabilization in resource use levels to be achieved.

The goal of increases in productivity which are on par or above economic growth is certainly laudable. However, it constitutes a departure from the business-as-usual of EU economies: a more significant departure than has perhaps been acknowledged to date. Increases in resource efficiency are generally translated into further economic growth through macro-economic rebound effects: effectively, increases in resource productivity constitute increases in factors of production in the economy. New sustainability measures will have to be wide-ranging indeed to overcome this normal phenomenon of market economies.

What is thus required is sweeping changes in the operation of EU economies:

- The most resource-efficient technology must be systematically implemented (and non-efficient technologies need to be phased out faster than their normal lifetime);
- Long-lasting infrastructure choices, such as urban and regional planning, transportation networks and grid/distribution infrastructure, need to be made explicitly in such a way as to reduce future resource use (denser cities, freight by rail rather than road, public transit rather than private, and so on);
- The very structure of economic transactions should be reoriented to favour resource savings. The type of economy where profits are made from resource savings rather than resource throughput is known as a "performance economy" and it requires fundamental changes in financing, insurance, legal and other regulatory and contractual frameworks for its implementation;
- Beyond these measures promoting more resource efficient technologies, infrastructure investments and economic transactions, significant reductions in resource use will likely require further measures, such as carbon taxes and quotas (possibly extended to other key resources).

2. Resource productivity as a sustainability metric

Resource productivity (shortened here as **RP**) is defined as the ratio of economic output (usually Gross Domestic Product, GDP) and resource input (usually materials or energy in tons /joules).

(Eq. 1) $$\text{RP} = \frac{\text{Economic output (GDP)}}{\text{Resource input}}$$

and its units are typically €/kg or €/MJ. RP is the inverse of resource intensity (resource/GDP), which is measured in kg/€ or MJ/€. Resource intensity is also sometimes called "resource efficiency." All of these terms (resource productivity, intensity and efficiency) are used in the literature and policy documents. In this report, we present our findings in terms of resource productivity.

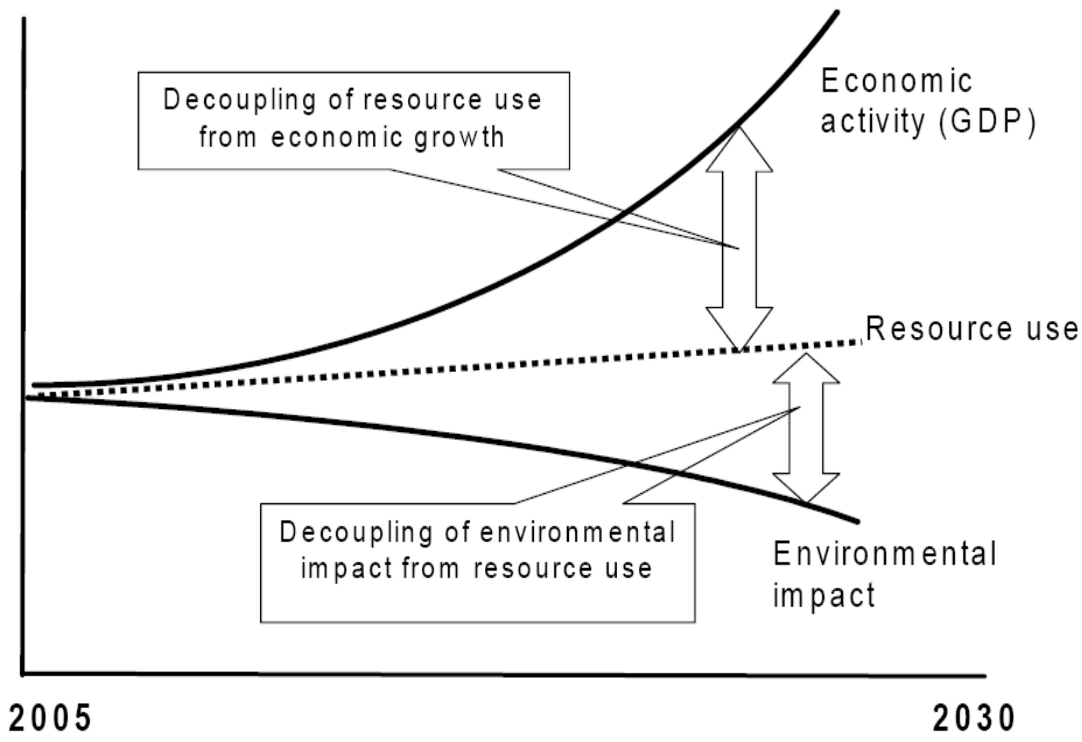
RP can be estimated for various types of resources, at various levels of the economy (product, firm, industry, economic sector, whole economy). RP studies often also consider energy productivity and carbon or greenhouse gas emissions productivity. In general, we do not expect all resources to exhibit the same behaviour with the economy, and one should be cautious in attempting to extrapolate the results from one type of RP to another. In this report, we address the macroeconomic level (whole economy GDP) and focus on material productivity: the ratio of economic output to material use.

RP combines two of the three traditional "pillars of sustainability": economic and environmental (the third pillar is concerned with social aspects) (World Commission on Environment and Development, 1987), and can thus be seen as a comprehensive sustainability measure. In the European Environmental Agency's DPSIR framework (EEA, 2000; EEA, 2002), which divides environment-society interactions into Drivers, Pressures, State, Impacts and Response, resource use is seen as a Pressure, whereas economic activity is a Driver (Stanners et al., 2007). In the context of the DPSIR framework, RP can be seen as an indicator of the balance between a society's economy and its pressures on the environment, and can measure the progress towards decoupling economic growth from negative environmental effects. It is thus understandable that RP is often considered a key indicator of sustainable development. In this interpretation, an increase in RP would be interpreted as "more sustainable," or progress towards decoupling.

RP is central to the EU's main policy document on resource use, the "Thematic Strategy on the Sustainable Use of Resources." (Commission of the European Communities, 2005). According to the Thematic Strategy, "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 environmental impact of resource use while at the same time improving resource productivity overall across the EU economy." The Thematic Strategy is based on the concept of "double decoupling": decoupling resource use from economic growth, and decoupling environmental impacts from resource use (see Figure 1). As described in Section 3.6 of this report, the decoupling of resource use from environmental impacts is far from evident, making the decoupling of resource use from the economy all the more crucial.

Figure 1: Schematic of the double decoupling concept proposed by the EU Thematic Strategy on sustainable use of resources

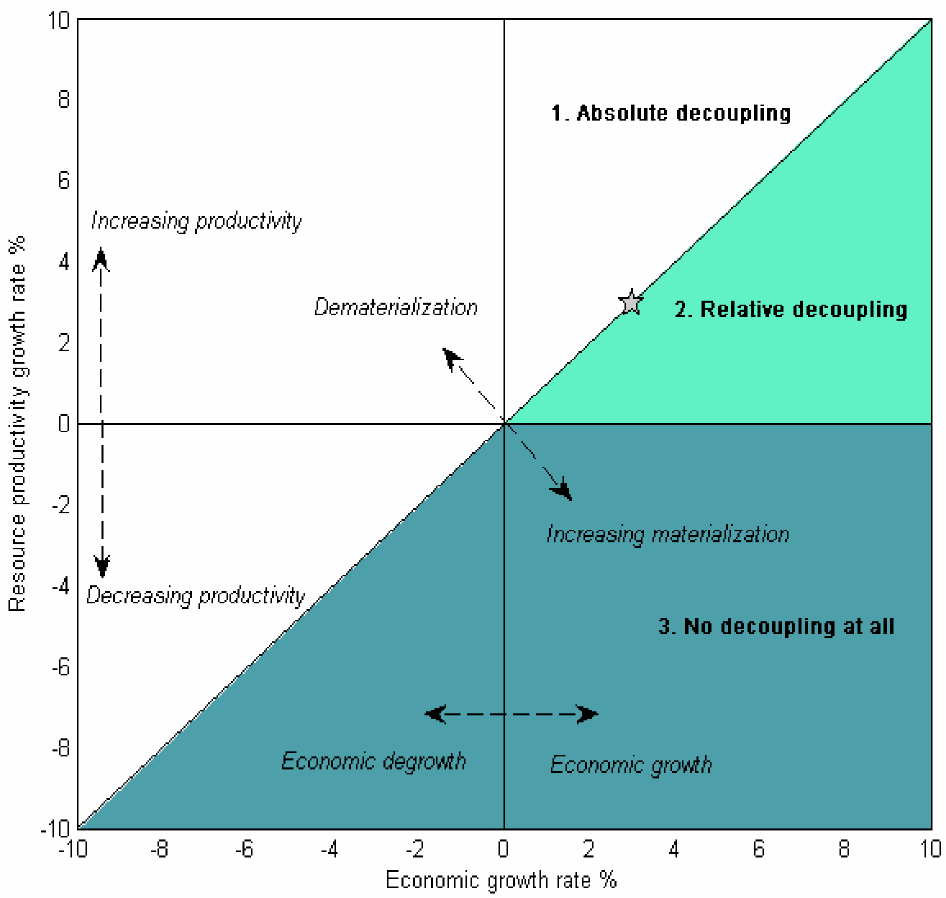


Source: Commission of the European Communities, 2005

RP is indeed an indicator of decoupling of resource use from the economy. However, as many critics have pointed out, considering RP alone provides an incomplete picture. RP effectively measures the average resource use required for an increment of economic activity. When it increases, it is a sign of *relative* decoupling of the economy from the environment: not absolute. This can be easily understood from Eq. 1. If the GDP growth rate is x% a year, and the RP growth rate is y%, the condition on total resource use decreasing is that y% > x%: that the growth rate of RP is larger than economic growth. The policy goal described in the annexes of the Thematic Strategy on the sustainable use of natural resources is of 3% economic growth and 3% productivity growth, resulting in a constant level of resource use. These growth rates are shown schematically in Figure 2, where it is clear that increases in productivity are compatible with increases in resource use – and that decreases in productivity are possible with decreasing resource use, depending on the level of economic growth they are associated with.

Figure 2: Economic growth (horizontal) and resource productivity growth (vertical) and their effect on decoupling.

If there is positive economic growth, there is only absolute decoupling in the white area (1), otherwise relative decouple in the light green area (2) or no decoupling in the dark blue area (3). The 2005 policy goal of the EU is shown as a star: 3% economic growth (Lisbon Strategy) and 3% resource productivity growth (Thematic Strategy on the sustainable use of natural resources)



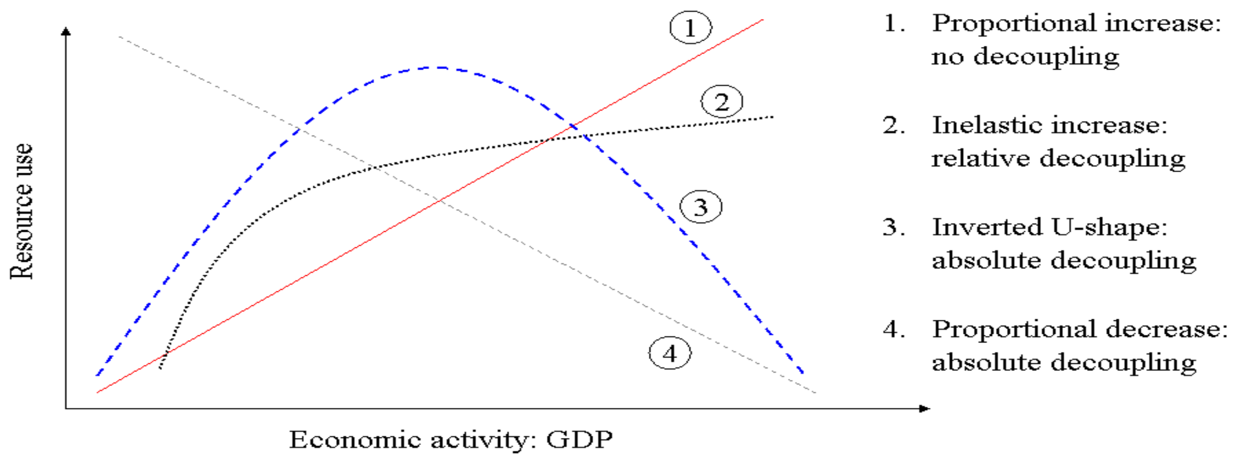
In this sense, we can see that RP growth is merely a measure of *relative decoupling*, or *weak sustainability*, if it is lagging behind economic growth. RP is an indicator of *absolute decoupling*, or *strong sustainability*, only when its growth dominates that of the economy. This distinction between absolute and relative decoupling was already made by the OECD, 2003. Mathematically, the relation between economic growth, RP and absolute vs. relative decoupling can be written as:

(Eq. 2)
$$\begin{aligned} &\text{growth(Resource use)} \approx \text{growth(GDP)} - \text{growth(RP)} \\ &\Rightarrow \text{Relative decoupling: growth(GDP)} > \text{growth(RP)} > 0 \\ &\Rightarrow \text{Absolute decoupling: growth(GDP)} < \text{growth(RP)} \end{aligned}$$

These correspond to the different regions shown in Figure 2.

In fact, RP can only be a measure of absolute decoupling if the economy is somehow in a regime where economic growth and resource use decrease go together. Figure 3 shows some of the most basic functional relations between resource use and economic activities. Curve 1 has a constant RP and no decoupling at all: resource use is simply proportional to economic growth. Curve 2 has an RP which grows with the economy, but corresponds to relative decoupling only, whereas curve 4 demonstrates absolute decoupling. Curve 3 is an Environmental Kuznets Curve (EKC): absolute decoupling occurs only above a certain economic level.

Figure 3: Basic functional relations connecting resource use and economic activity



Source: After Wilkinson et al., 2007

In fact, proportional resource decrease with economic growth (curve 4) typically corresponds to a resource which is abandoned at higher incomes (for instance dried animal dung for heating and cooking), but is replaced by a higher quality resource, like kerosene or electricity (curves 1 or 2). Thus curve 4 type behavior should be viewed with caution: it may simply correspond to the substitution of a lower quality resource by a higher one (also known as "transmaterialization" (Labys, 2002)). Moreover, curves 2, 3 and 4 can all be evidence of resource use displacement: often richer economies have apparently lower resource use and associated environmental impacts simply because the resource-intensive industries have been displaced to lower income economies. This has recently been shown to be the case for CO2 emissions of Annex B countries of the Kyoto Protocol (Peters and Hertwich, 2008).

From this brief introduction to the concept of RP, we conclude that this indicator cannot be interpreted in isolation from other information. High resource productivity coupled with a high GDP may well result in more resource consumption than lower resource productivity at a lower level of economic activity. In the following sections, we thus combine RP and other information to gain a more complete picture of the relevance and limitations of this sustainability indicator.

3. Past studies relevant to material productivity

In this section, we review the recent literature on RP, focusing on the European debate. Material productivity has been defined as an indicator of (relative) decoupling of the economy from the environment by Eurostat (Bringezu and Schütz, 2001; Eurostat et al., 2002) and the OECD (OECD, 2008). The EU-wide application of Material Flow Analysis having only been achieved in the last decade, the interpretation and true meaning of material productivity are still open questions.

Initial cross-national EU studies compared the values in RP of different EU countries (mainly the EU-15), and described the changes in material use, GDP and RP between 1980-1997 and 1980 respectively (Bringezu and Schütz, 2001; Eurostat et al., 2002). They noted the distinction between RP improvements and actual decrease in material use (Bringezu and Schütz, 2001) and investigated whether material use per capita followed an Environmental Kuznets Curve (Eurostat et al., 2002). The conclusion of the EKC investigation was that some EU countries had experienced decreases in material use per capita with increases in income, whereas others had increased their material consumption with economic growth. The EU as a whole did not exhibit any EKC behaviour. A follow-up report covering the EU-15 countries for the period 1970-2001 noted large fluctuations in RP over time, with an overall improvement for the EU-15 as whole – which, however, did not translate into absolute material decoupling (Weisz et al., 2005).

The best shape to fit the relation between material input per capita and GDP per capita was investigated for many EU countries by Bringezu et al., 2004). They did not find conclusive evidence of a particular functional shape. Perhaps this is not surprising, since it has been suggested that industrialized countries will tend to undergo phases of dematerializing and rematerializing over time (De Bruyn, 2002).

4. The current debate: resource productivity, income and economic competitiveness

A more systematic investigation of the links between RP and socioeconomic factors was conducted by van der Voet et al., 2005). They found that there were great disparities between European countries in RP, if the GDP was taken in Market Exchange Rate (MER) euros, with the eastern European and Baltic states having very low RP, but that using Purchasing Power Parity (PPP) euros reflected more comparable values of RP. As they point out, resource use should be compared to the consuming power of the economy, which is reflected by PPP rather than MER monetary values. Accordingly, we use PPP economic values throughout this report.

van der Voet et al., 2005) then proceed to investigate the socioeconomic factors underlying the variations in RP at the EU level. They find that "around half the variation in resource efficiency can be attributed to the structure of the economy and per capita GDP levels (measured in purchasing power parities)." This has significant implications for the policy relevance of RP: wealthier economies, and those with a smaller share of agriculture, extraction and industry, have higher resource productivities. Does this mean these economies are necessarily more sustainable? Many of the high RP performance countries are only demonstrating relative decoupling. Van der Voet and colleagues suggest that countries should be compared on the basis of "benchmarked" RP values, which are corrected for the influence of income and economic structure, to remove the bias favoring rich and service-dominated economies.

Recently, two significant additions to the RP literature were published. The first is an edited volume entitled "Sustainable growth and resource productivity" (Bleischwitz et al., 2009b). The chapter "Decoupling GDP from resource use, resource productivity and competitiveness: a cross-country comparison" (Steger and Bleischwitz, 2009) is of particular interest here (it is partly based on a longer report: Bleischwitz et al., 2009a). Taking data for the EU-15, EU-25, Japan, Turkey and the USA, they contrast Domestic Material Consumption (DMC) per capita in 2000, and changes in material RP (GDP/DMC) between 1980-2004 and 1992-2000. The choice of different time spans is due to insufficient data for various countries. Overall, most countries in their sample experienced growth in RP, with the exceptions of Greece, Lithuania, Portugal (for 1980-2004, not 1992-2000) and the Slovak Republic. They note that, within the EU, the higher RP of the EU-15 goes hand in hand with higher material consumption, but they still conclude that "Despite the higher consumption in the EU-15, energy and raw materials are used more efficiently in the new EU member states [...]." In this chapter, RP is thus interpreted as an indicator of the economic efficiency of material use, and higher RP to a higher efficiency which the new member states should aspire to ("potential for increasing the resource productivity"). They also point out "the need for addressing the absolute level of resource use," but without facing the apparent contradiction of attaining a high RP without the increase in material consumption. They note that that some countries achieve a high RP with lower material consumption, whereas others have high material consumption but still higher GDP.

Steger and Bleischwitz, 2009) then contrast RP values with national measures of economic competitiveness according to the World Economic Forum, and note that these are positively correlated: in general, high RP is accompanied by higher competitiveness. However, they do not consider the correlation of RP with income or economic structure as measured by van der Voet et al., 2005), which is a considerable oversight. In the longer report (Bleischwitz et al., 2009a), Bleischwitz and colleagues investigate drivers of RP, and come up with a mix of sectoral and other variables which explain differences in RP in the EU-15 from 1980 to 2000 (8 variables) and EU-27 from 1992 to 2000 (7 variables). It is not clear if they consider income as an initial variable in their model, and also unclear how this analysis ties in with either the competitiveness metric or income.

The second report is "Resource productivity, competitiveness and environmental policies" by De Bruyn et al., 2009). They first discuss the concept of resource efficiency and competitiveness at the firm level, which is known as the "Porter hypothesis": the idea that a resource efficient firm will tend to gain a competitive advantage. This hypothesis is extrapolated to the national level by De Bruyn and colleagues, but it is far from clear that the Porter hypothesis withstands the leap in scale from the firm level to the national level.

At the national level, resource use is influenced by larger and more complex forces than for a single firm. For instance, the macroeconomic "rebound effect" explains how resource efficiency improvements at the firm level may in fact translate to cheaper goods and increased aggregate demand (hence more resource throughput overall) (Hertwich, 2005; Herring and Roy, 2007). Moreover, technical efficiency improvements are a factor of economic growth (Warr et al., 2010; Ayres et al., 2007; Ayres et al., 2003): efficiency improvements overall drive economic growth (and hence a larger scale of economy-driven resource use). In this understanding, national increases in resource productivity would tend to lead to growing economies: not reduced resource use. Superficially, the economies may be more "efficient" in terms of higher RP – at a larger level of resource use.

De Bruyn and colleagues then criticize the relation between competitiveness and RP observed by Steger and Bleischwitz, 2009). They use energy productivity (GDP/primary energy) to show that a simultaneous regression taking into account both income and competitiveness finds only income to be significant. Although it is helpful to have such a direct comparison between these two hypothesized drivers of RP, it is not clear that energy productivity will behave in the same way as material productivity in this respect. Moreover, it is not clear which countries are used in comparing energy productivity, income and competitiveness.

To summarize, there is an ongoing, decade-old research effort focused on first consistently measuring material flows of European countries, and then on systematically understanding the links between the physical economy. However, there is some confusion regarding the potential links between RP and economic activity: is higher RP a competitive advantage, or simply linked to higher income levels? We will attempt to settle this question, at least for the EU-27, further on in this report.

5. Description of the data used in this study

Our productivity overview takes into account diverse datasets, which are summarized in Table 1.

Table 1: Description and sources of the datasets

Geographical area	Source	Time coverage	Material categories
EU-15	Eurostat	1970-2004	1. Total 2. Biomass 3. Fossil fuels 4. Minerals
Global *	SEVI global material flow data v2.0b http://www.uni-klu.ac.at/socec/inhalt/1088.htm	2000	
EU-27 + Norway and Switzerland	Eurostat	2000-2005	1. Total 2. Biomass 3. Fossil fuels 4. Construction minerals 5. Ores/Industrial minerals

* Note: the global dataset used here is derived purely from biophysical data and estimations (without derivations based on economic status, for instance). It is internally consistent, but not directly comparable to the other datasets. In particular, for the global dataset, construction minerals are a conservative estimate and around 30% smaller than the value measured by other methods (Steinberger et al., 2010).

Since the datasets have different geographical, temporal and material flow coverage, we will use each one of them for a specific purpose.

EU-27 + Norway and Switzerland

This dataset is the most interesting from a geographical coverage perspective for the EU, but it has very little time coverage. It will thus be used mostly to showcase cross-country differences and short-term trends.

EU-15

The EU-15 Eurostat dataset has the best time coverage, and can thus be utilized to investigate the evolution of material use, material productivity and economic performance of the EU-15 over several decades. We will also single out a few individual countries with outstanding performance in terms of their productivity growth, decline, materialization or dematerialization.

Global

The global dataset allows us to understand EU productivity in an international context.

6. Material productivity in the EU-27 + Norway and Switzerland

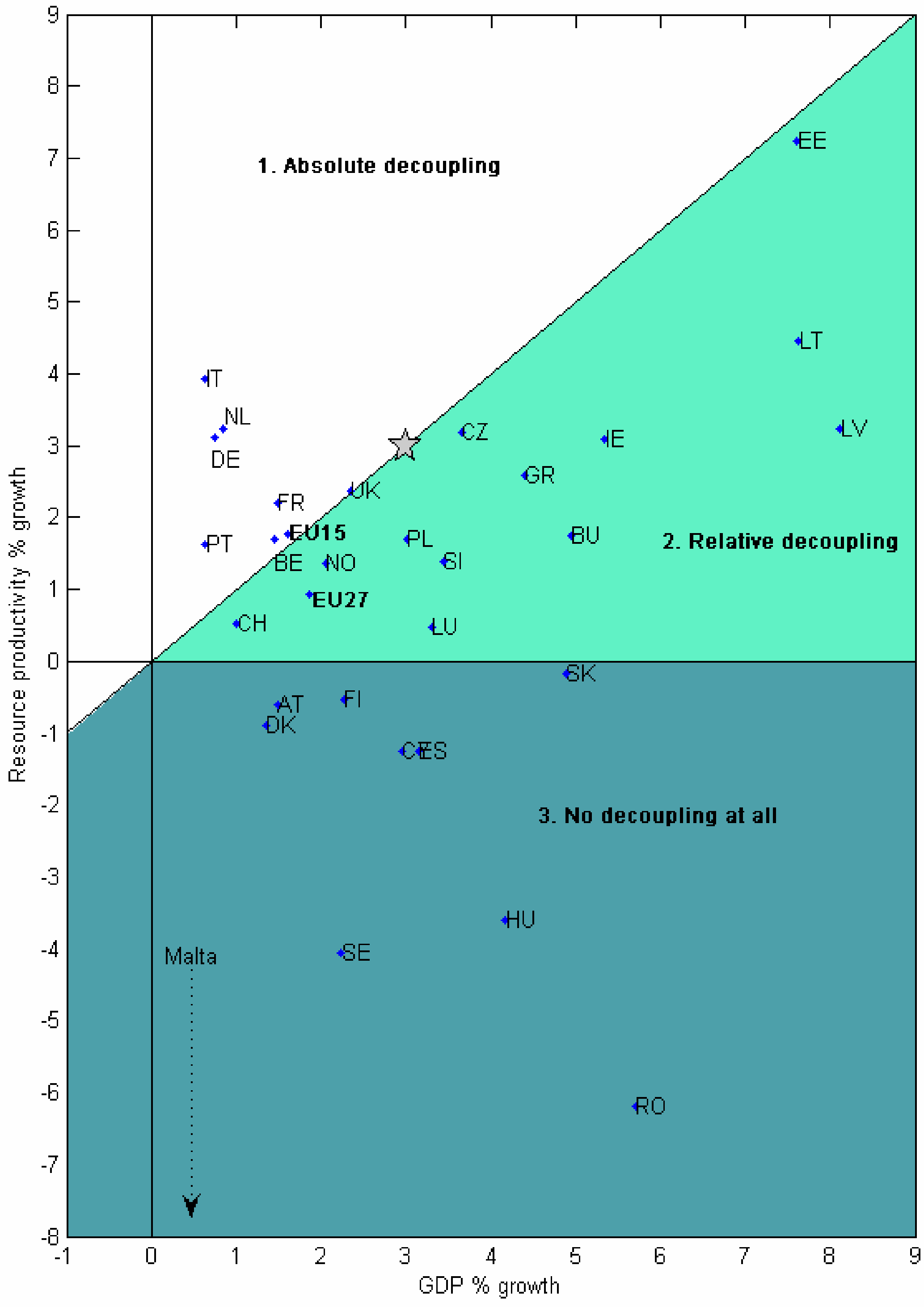
The data for the EU-27, Norway and Switzerland is only available for 2000-2005. In Table 2, we summarize some of the most important parameters. We show both total (extensive) and ratio (intensive) values, and their average yearly growth. As we explained above, for reasonable growth values (i.e. excluding Malta and Romania), growth in productivity is approximately economic growth minus DMC growth.

Economic and productivity growth factors are compared in Figure 4, which also shows the areas of increasing and decreasing material productivity, and absolute dematerialization. In the period

2000-2005, 6 countries demonstrated absolute dematerialization: Belgium, France, Germany, Italy, the Netherlands, and Portugal. The EU-15 countries as a whole experienced slight dematerialization. In contrast, 11 countries of the EU-27, the EU-27 as a whole, and Norway and Switzerland only demonstrate relative decoupling (material growth), and 10 of the EU-27 countries showed no decoupling at all, with double digit material growth seen by Romania and Malta (although Malta is so small that large fluctuations are expected simply due to scale effects).

Perhaps more troubling, there is quite a good systematic trend between economic growth and material growth (R2 = 0.49), implying that economic growth and material growth are NOT decoupled or in the process of decoupling in the EU. The dematerializing countries are also those with the smallest economic growth. This raises important, critical questions for the "double decoupling" concept on which the EU thematic strategy for sustainable resources is based (see Figure 1 above).

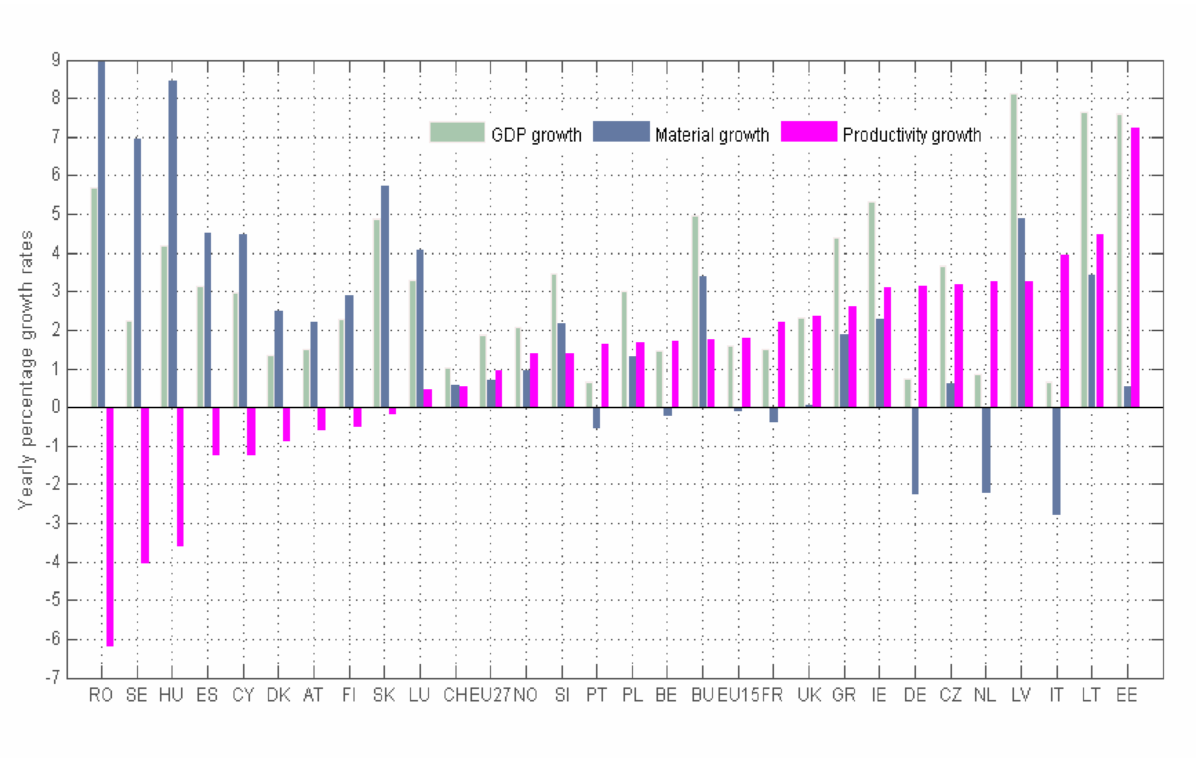
Figure 4: Productivity vs. economic growth in the EU-27 (yearly growth averages 2000-2005)



The combined economic growth and resource productivity policy goal of the EU is shown as a grey star. See Table 2 for the data and list of country codes and names.

The EU-27 countries and their GDP, material and productivity growth rates are shown as a bar chart in Figure 5, ranked by the magnitude of their productivity growth. It is clear that (1) productivity growth is just economic growth minus material growth, and that (2) the productivity growth is seldom associated with negative material growth, and that when it is, economic growth tends to be moderate.

Figure 5: EU-27 countries plus Norway and Switzerland, ranked by productivity percentage growth rates (averages 2000-2005). Romania's material growth is 16.6%, and Malta is not shown.



7. Settling the RP, competitiveness and income debate for the EU-27

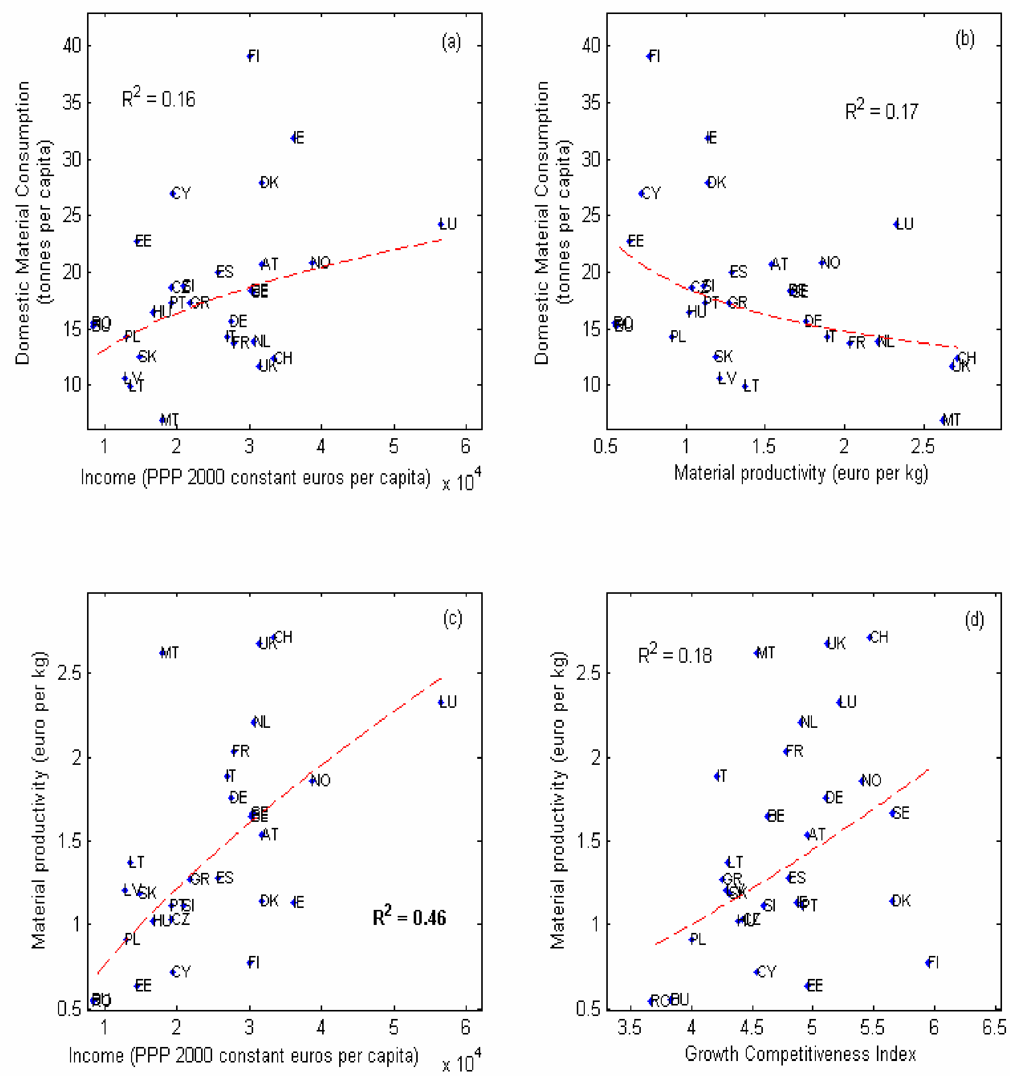
The recent debate between Steger and Bleischwitz (2009), on one hand, and de Bruyn and colleagues (2009) on the other, is a crucial one for understanding the implications of RP as a sustainability metric for Europe. Is RP linked to income, competitiveness, or both? Do material and energy productivity behave similarly in this respect? In order to bring some clarity to the discussion, we have reproduced their analysis with a set of consistent data, for the year 2005, and the countries of the EU-27 plus Switzerland and Norway, and both energy and material resource use. We have consistent time, geographical and data source coverage, and can conduct a rigorous and comparative analysis.

Our data sources are the following:

- Domestic Material Consumption (Eurostat)
- Total Primary Energy Supply (International Energy Agency)
- Purchasing Power Parity GDP (World Bank World Development Indicators)
- Growth Competitiveness Index (World Economic Forum).

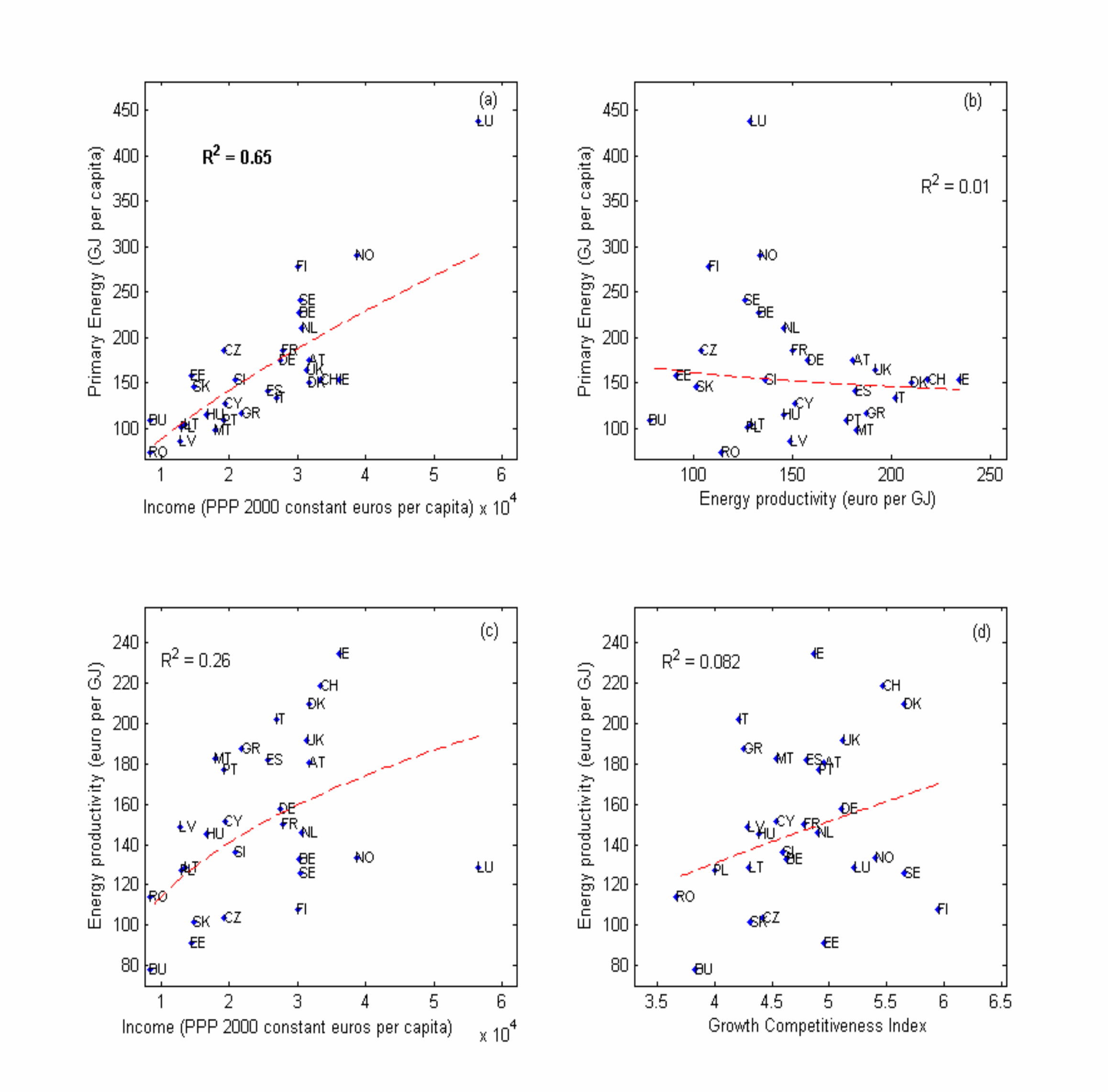
Our results for materials are shown in Figures 6 (materials) and 7 (energy). For materials, there is a weak relation between productivity and competitiveness (fig. 6 (d)), but a very strong relation between productivity and income (fig. 6 (c)), which confirms the result of Van de Voet et al. Material consumption per capita is only weakly linked to income or material productivity (fig. 6 (a) and (b)). For energy, the link between productivity and competitiveness is even weaker than for materials, which could be one source of the difference between Steger & Bleischwitz and de Bruyn et al (fig. 7 (d)). Energy productivity is weakly but significantly linked to income (fig. 7 (c)), an effect seen by de Bruyn et al for a larger sample of countries. The strongest correlation for energy is between per capita energy consumption and income (fig. 7 (a)), which is a result often seen in international and time-series studies.

Figure 6: Economic dependence of material use in the EU-27, year 2005: (a) material consumption vs. income; (b) material consumption vs. material productivity; (c) material productivity vs. income; and (d) material productivity vs. competitiveness.



The country name codes are listed in Table 2.

Figure 7: Economic dependence of energy use in the EU-27, year 2005: (a) energy consumption vs. income; (b) energy consumption vs. energy productivity; (c) energy productivity vs. income; and (d) energy productivity vs. competitiveness.



The country name codes are listed in Table 2.

Overall, the findings shown in figures 6 and 7 support the results of Van der Voet and her colleagues: the variation in material productivity among European countries can be largely explained (46% according to our regression) by income alone. These findings also support the conclusion of de Bruyn et al, despite the significant differences between material and energy productivities. Indeed, when we conduct a multivariate regression on the productivity indicator, with income and GCI as independent variables, the only significant variable is income, and GCI is insignificant (has little or no explanatory power), for both energy and material productivity.

The links we find for Europe between material and energy consumption, productivity and income, (figures 6 and 7, (a) and (c)) are in fact consistent with the results of a recent global study on material flows (Steinberger et al., 2010), which showed that fossil fuel consumption had a stronger link to the economy than material consumption as whole, and that material productivity was strongly correlated with income, but that fossil fuel productivity was not. Thus regarding the economic links of material and energy use, and material and energy productivity, the EU-27 countries, with Norway and Switzerland, are consistent with the global trends.

Table 2: Key parameters relevant to material productivity in the EU-27

	Time span	2005				2005		2000-20005			2000-20005		
		Extensive variables				Intensive		Average yearly growth: Extensive			Average yearly growth: Intensive		
		Total DMC *	Population	GDP	DMC per capita	Productivity	Income	Total DMC *	Population	GDP	DMC per capita	Productivity	Income
	Units	*1000 t*	*1000 persons*	*Million 1990 PPP €*	*t per cap*	*€ per kg*	*€ per cap*	*%*	*%*	*%*	*%*	*%*	*%*
AT	Austria	169,189	8,189	259,835	20.7	1.54	31,728	2.20	0.23	1.49	1.97	-0.61	1.26
BE	Belgium	190,772	10,398	315,185	18.3	1.65	30,312	-0.22	0.40	1.46	-0.62	1.71	1.06
DK	Denmark	151,309	5,431	172,308	27.9	1.14	31,729	2.48	0.34	1.36	2.13	-0.88	1.02
FI	Finland	205,135	5,249	157,962	39.1	0.77	30,093	2.88	0.28	2.27	2.59	-0.52	1.99
FR	France	852,441	62,312	1,732,177	13.7	2.03	27,798	-0.42	0.43	1.49	-0.85	2.21	1.06
DE	Germany	1,297,491	82,689	2,275,315	15.7	1.75	27,516	-2.26	0.08	0.74	-2.35	3.12	0.66
GR	Greece	191,799	11,120	243,130	17.2	1.27	21,864	1.87	0.26	4.40	1.60	2.59	4.13
IE	Ireland	132,393	4,148	149,973	31.9	1.13	36,156	2.28	1.76	5.34	0.51	3.09	3.52
IT	Italy	828,531	58,093	1,565,801	14.3	1.89	26,953	-2.80	0.13	0.64	-2.93	3.93	0.51
NL	Netherlands	226,002	16,299	499,523	13.9	2.21	30,647	-2.23	0.50	0.84	-2.72	3.24	0.34
LU	Luxembourg	11,067	457	25,760	24.2	2.33	56,415	4.08	0.89	3.30	3.16	0.47	2.38
PT	Portugal	180,901	10,495	201,642	17.2	1.11	19,214	-0.58	0.52	0.64	-1.10	1.62	0.12
ES	Spain	860,466	43,064	1,104,197	20.0	1.28	25,641	4.52	1.13	3.15	3.36	-1.26	2.00
SE	Sweden	165,080	9,041	274,867	18.3	1.67	30,401	6.95	0.37	2.24	6.56	-4.05	1.87
UK	United Kingdom	699,862	59,668	1,874,667	11.7	2.68	31,418	0.05	0.34	2.34	-0.29	2.38	1.99
BU	Bulgaria	118,070	7,745	65,470	15.2	0.55	8,454	3.38	-0.65	4.94	4.06	1.74	5.63
CY	Cyprus	22,511	836	16,190	26.9	0.72	19,358	4.48	1.24	2.95	3.20	-1.25	1.69
CZ	Czech Republic	190,331	10,192	196,842	18.7	1.03	19,314	0.61	-0.06	3.65	0.67	3.18	3.71
EE	Estonia	30,516	1,344	19,511	22.7	0.64	14,514	0.54	-0.38	7.60	0.92	7.24	8.00
HU	Hungary	165,980	10,086	168,964	16.5	1.02	16,752	8.45	-0.25	4.17	8.73	-3.59	4.44
LV	Latvia	24,290	2,302	29,399	10.6	1.21	12,772	4.86	-0.66	8.12	5.55	3.24	8.83
LT	Lithuania	33,864	3,425	46,345	9.9	1.37	13,531	3.43	-0.45	7.63	3.89	4.46	8.11
MT	Malta	2,764	403	7,251	6.9	2.62	18,010	40.70	0.70	0.06	39.74	-17.57	-0.63
PL	Poland	543,607	38,196	494,903	14.2	0.91	12,957	1.32	-0.12	3.01	1.45	1.69	3.14
RO	Romania	334,459	21,628	183,555	15.5	0.55	8,487	16.04	-0.47	5.70	16.58	-6.19	6.19
SK	Slovak Republic	67,558	5,387	80,068	12.5	1.19	14,863	5.73	0.00	4.88	5.73	-0.18	4.88
SI	Slovenia	37,540	1,999	41,726	18.8	1.11	20,869	2.16	0.16	3.44	2.00	1.38	3.28
NO	Norway	96,672	4,639	179,333	20.8	1.86	38,659	0.94	0.66	2.06	0.28	1.37	1.39
CH	Switzerland	91,451	7,424	248,175	12.3	2.71	33,427	0.58	0.44	1.01	0.14	0.52	0.57
	EU15	6,162,439	386,653	10,852,340	15.9	1.76	28,067	-0.13	0.38	1.60	-0.51	1.78	1.22
	EU27	7,733,929	490,195	12,202,563	20.0	1.40	24,893	0.71	0.24	1.86	0.33	0.92	1.61

*Note: DMC = Domestic Material Consumption = Extraction + Imports – Exports

8. *Productivity trends in the EU-15*

Material consumption data is available for a longer time for the EU-15 than the EU-27 (since 1970 instead of 2000). We use this data to complement our EU-27 analysis with a longer time perspective. As discussed in 3.2, the EU-15 as a whole shows stagnating material consumption, with some of the larger economies decreasing their material use over the past decades (Germany, the UK, France) and some of the others drastically increasing their material use (Greece, Spain, Portugal, Ireland).

The macro-level trends for the EU-15 and EU-27 relevant to material productivity are shown in Fig. 8 for extensive variables: total DMC, GDP and population, and in Fig. 9 for intensive variables: DMC per capita, income and material productivity.

Figure 8: Macro-trends in the EU-15 and EU-27 for extensive parameters: DMC, population and GDP. The GDP is measured in 2000 constant PPP euros.

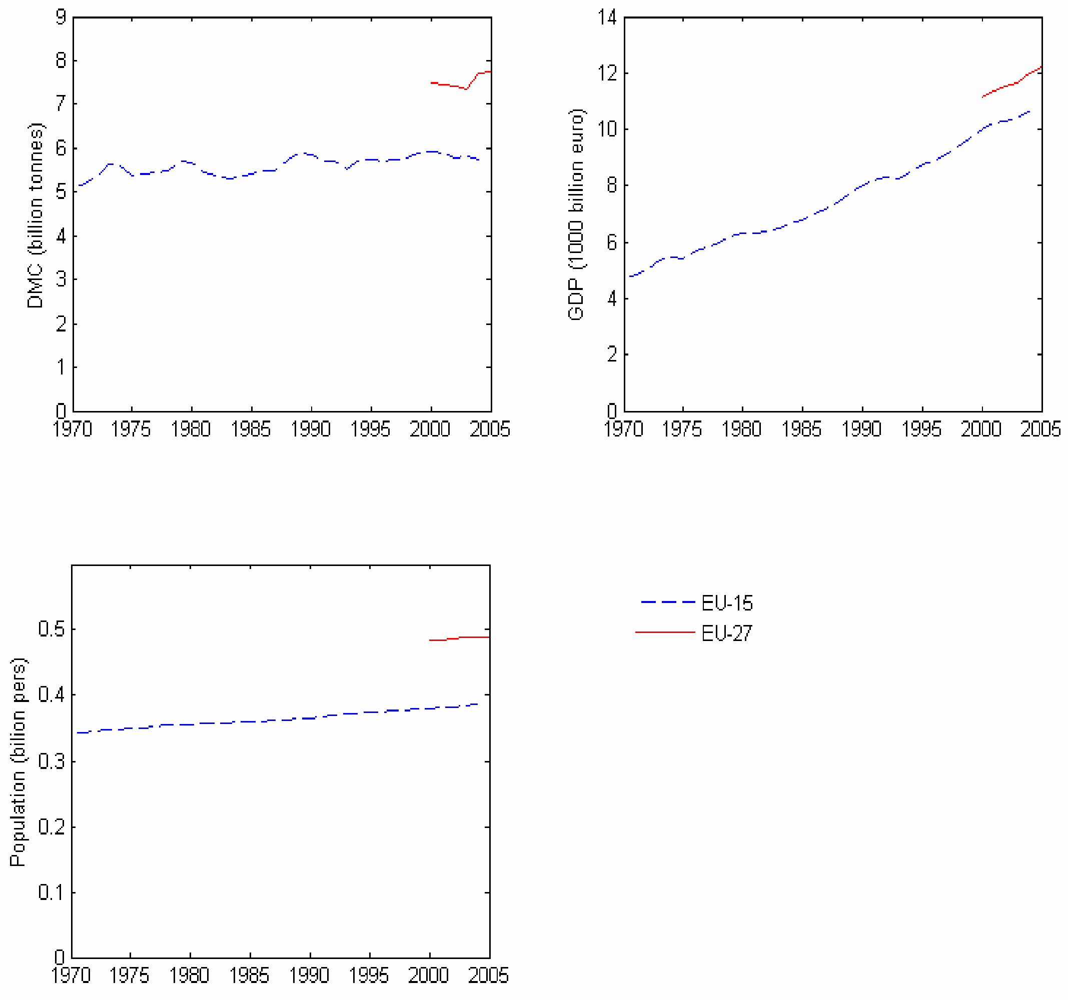
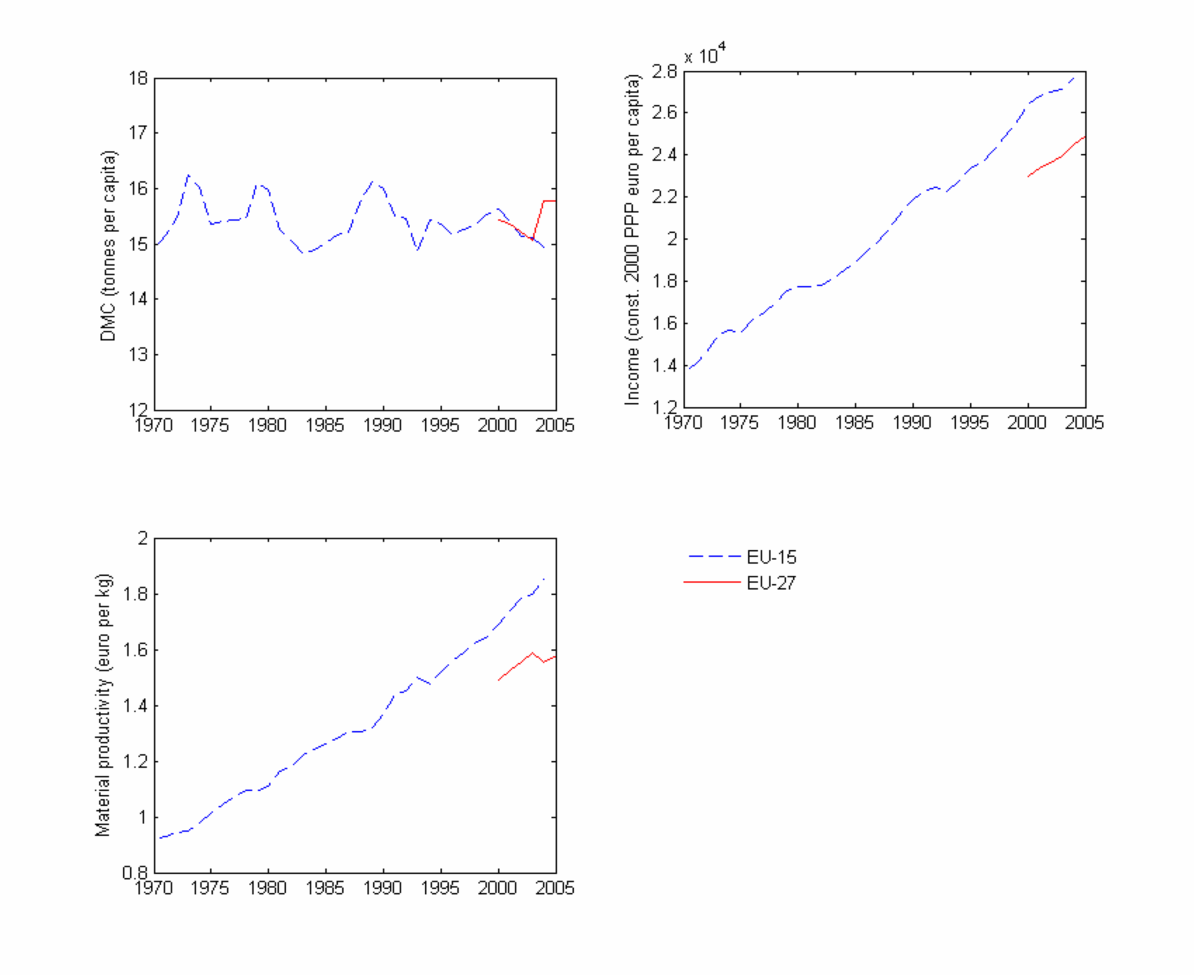


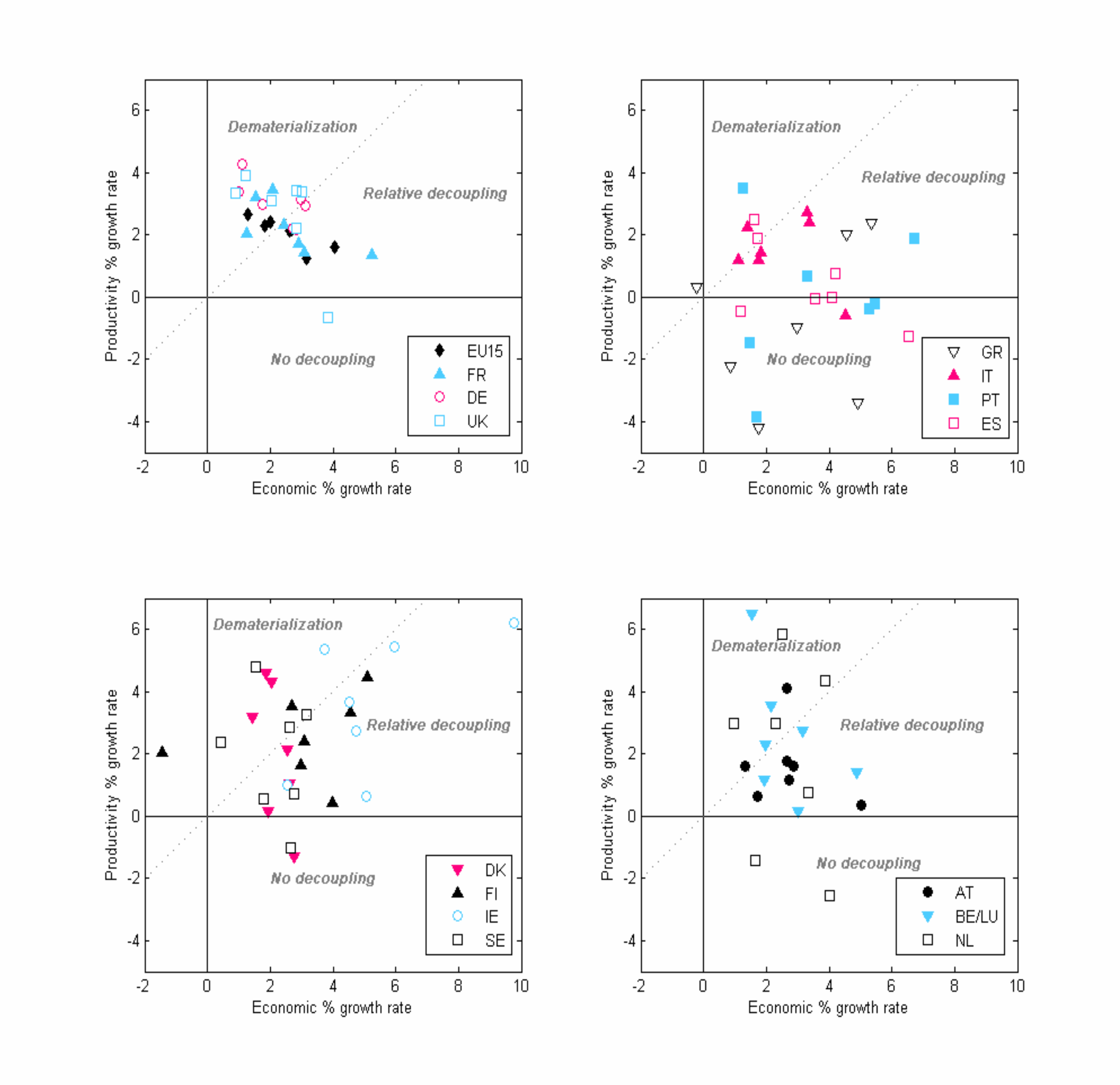
Figure 9: Macro-trends the EU-15 and EU-27 for intensive parameters: DMC per capita, income and material productivity. The GDP is measured in 2000 constant PPP euros.



As can be seen in fig. 9, the level of per capita material use in the EU-15 and EU-27 is remarkably constant, leading to increases in material productivity simply due to economic growth. In sustainability terms, the EU is exhibiting relative decoupling, not absolute dematerialization.

At the country level, the EU-15 have widely differing behaviour. As explained above, changes in RP are best understood when shown in combination with economic growth. In Figure 4, we use 5-year averaged growth rates (1970-1974, ..., 2000-2004) to examine productivity and economic growth of the EU-15. Fig 55 is analogue to Figure 4 for the EU-27 and the time span 2000-2005.

Figure 10: Productivity and economic growth rates for the EU-15 (each point represents a 5 year average: 1970-1974, ..., 2000-2004)



The largest countries, France, Germany and the UK, are often in the dematerializing upper right triangle, consistent with their overall dematerialization – but not for the periods of their largest economic growth. The Sourthern European countries, Greece, Italy, Portugal and Spain, are mostly materializing (either demonstrating relative decoupling, as is often the case for Italy, or no decoupling at all, as is most often the case for Greece and Portugal). Interestingly, Portugal was one of the few EU-27 countries showing absolute decoupling in Fig 49, marking the importance of considering longer term trends. The Northern European countries, Denmark, Finland, Ireland and Sweden, are mostly in the relative decoupling area, as are the Netherlands, Belgium/Luxembourg and Austria.

Perhaps the most interesting feature of Fig. 10 is that countries only experience absolute dematerialization when they are at the lower end of their economic growth. Apart from the Netherlands and Ireland, no country experienced economic growth rates of 3% or more while reducing material consumption – and even these two countries did not durably dematerialize. Moreover, the countries which did experience large and consistent dematerialization (France, Germany and the UK) did so by a combination of fuel shifts (moving from coal to oil and gas, or nuclear), and de-industrialization. The fuel shifts may not be available to all in a world where coal is more plentiful than either oil or gas, and the process of de-industrialization generally means that manufacturing activities are displaced overseas – not rendered more efficient. In general, the countries which were dematerializing also had economic grow rates of 2% or below. And the two countries with a period of negative economic growth, Finland and Greece, did dematerialize during that time. It appears from this analysis that resource use and economic activities are still coupled in an absolute sense in the EU-15, even though many countries and the region as a whole has been experiencing relative decoupling for decades.

9. International productivity

In this section, we show some results from an international material flow data set for the year 2000, which was constructed based solely on biophysical data and estimations, without economically-derived estimations. The data set and the analysis summarized here are described in more detail in Steinberger et al., 2010. Since the material flows are independent from economic assumptions, they can be correlated with economic parameters. In particular, this data set was used to measure the international economic elasticity of material consumption: the exponent *B* in Eq. 3 (*A* is just a scaling constant).

(Eq. 3) $$\frac{DMC}{capita} = A \cdot \left(\frac{GDP}{capita} \right)^{B}$$

The economic elasticity *B* has the following interpretation:

- if *B* = 1, DMC is *proportional* to income: when income increases by 10%, so does DMC/cap.
- if *B* >1, DMC is *elastic* with income: when income increases by 10%, DMC/cap increases by a larger amount.
- if *B* <1, DMC is *inelastic* with income: when income increases by 10%, DMC/cap increases, but by a smaller amount.
- if *B* = 0, DMC is constant with income.
- if *B* < 0, DMC decreases when income increases.

It can thus readily be seen that *B* corresponds to the slope of resource use in Fig. 3 (curve 1: *B* =1; curve 2: *B* decreasing with income, but positive; curve 3: *B* changing from positive to negative at higher incomes; curve 4: *B* = -1). Indeed, the elasticity does not have to remain constant, but can change at different income levels. However, for international material use, no strong changes in elasticity are seen as a function of income. We can thus measure a single material elasticity for each type of material use. The results are shown in Table 3. The material categories have a large range in elasticities, from very inelastic biomass (0.19) to elastic fossil fuels (1.35).

Table 3: Elasticity coefficients of international material use

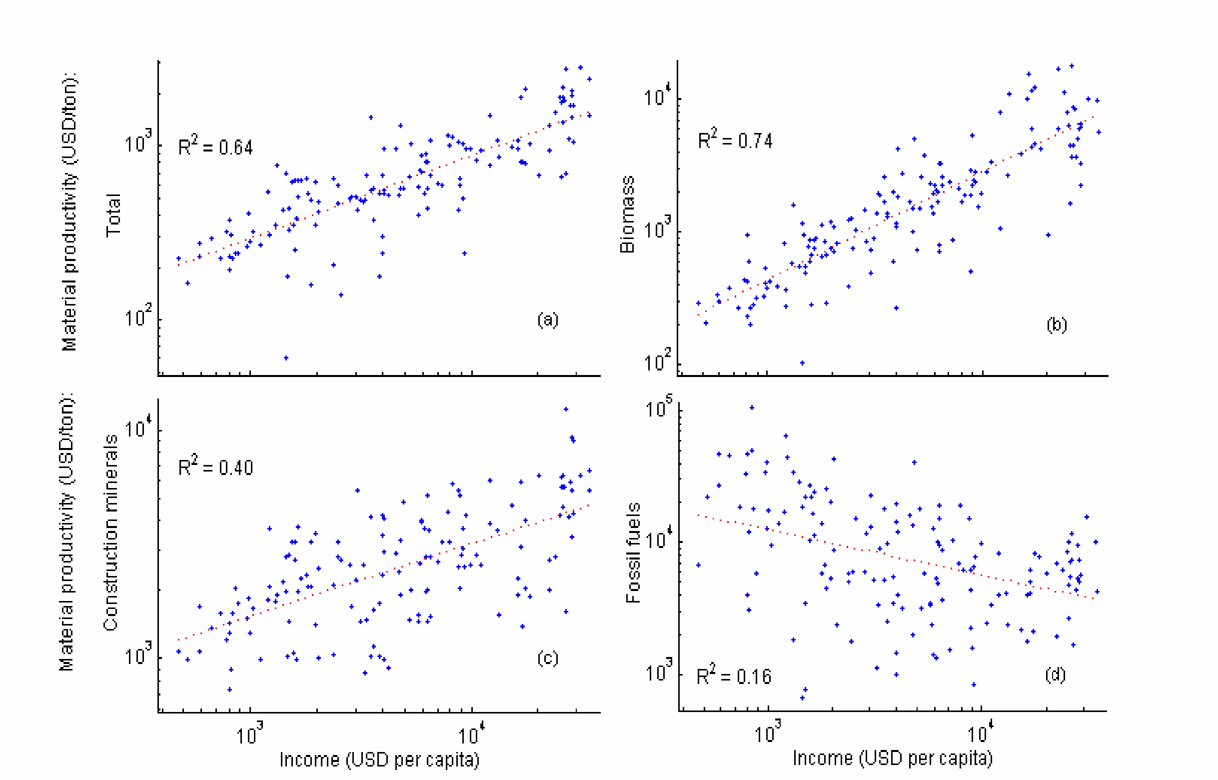
Domestic Material Consumption per capita:	B	Standard error of B
Total	0.52	0.03
Biomass	0.19	0.04
Fossil fuels	1.35	0.07
Construction Minerals	0.69	0.03
Ores/Industrial Minerals	1.01	0.10

The economic elasticity of resource use in fact has profound implications for its productivity, as can be seen from the following simple mathematical relationship (which uses Eq. 3):

(Eq. 4) $$Material\ \ Productivity = \frac{DMC}{GDP} = \left(\frac{DMC}{capita} \right) \cdot \left(\frac{GDP}{capita} \right)^{-1} = A \cdot \left(\frac{GDP}{capita} \right)^{B-1}$$

From Eq. 4, we see that material productivity will be systematically correlated with income unless the material elasticity exponent is 1. In fact, from this analysis, it is *only* in the case of material use which is proportional to income that we expect there to be no correlation of material productivity with income: from Table 3, this would be for ores/industrial minerals and possibly fossil fuels. In Figure 11, we show the correlation of international material productivity with income for 4 material categories, and indeed they behave as one would expect from Eq. 4 and the elasticities measured in Table 3.

Figure 11: International correlation of material productivity and income for different material categories



Source : from Steinberger et al., 2010

From this international perspective, the challenge of increasing RP faster than economic growth appears all the more daunting. In order for RP to grow faster than economic growth, the elasticity of material consumption would have to drop from 0.5 to 0 and below, at least for EU countries. It is hard to imagine that this large drop in income elasticity of material use could be achieved without dramatic changes in the very structures and operations of EU economies: it is certainly not going to be attained by simply promoting incremental and small increases in efficient technologies.

10. Policy implications regarding material productivity

As a conclusion to this discussion of material productivity as an indicator of sustainable economic development, we can state that the goal of increases in productivity which are on par or above economic growth is certainly laudable. However, it constitutes a departure from the business-as-usual of EU economies: a more significant departure than has perhaps been acknowledged to date.

What is required is fundamental change in the operation of EU economies:

- the most resource-efficient technology must be systematically implemented (and non-efficient technologies need to be phased out faster than their normal lifetime);
- long-lasting infrastructure choices, such as urban and regional planning, transportation networks and grid/distribution infrastructure, need to be made explicitly in such a way as to reduce future resource use (denser cities, freight by rail rather than road, public transit rather than private, and so on, as described in Jaccard et al., 1997);
- the very structure of economic transactions should be reoriented to favor resource savings. The type of economy where profits are made from resource savings rather than resource throughput is known as a "performance economy" (Stahel, 2006) and it requires fundamental changes in financing, insurance, legal and other regulatory and contractual frameworks for its implementation (Steinberger et al., 2009).

11. Acknowledgements

This work was supported through the GLOMETRA project (P-21012-G11) funded by the Austrian Science Fund (FWF) and by the European Commission DG Environment "Preparatory study for the review of the Thematic Strategy on the Sustainable Use of Natural Resources."

12. References

Ayres, R.U., Turton, H., Casten, T., 2007. Energy efficiency, sustainability and economic growth. Energy, 32 (5), 634-648.

Ayres, R.U., Warr, B., Ayres, L.W., 2003. Exergy, power and work in the US Economy, 1900-1998. Energy, 28 (3), 219-273.

Bleischwitz, R., Bahn-Walkowiak, B., Onischka, M., Röder, O., Steger, S., 2009a. The relation between resource productivity and competitiveness. Wuppertal Institute,

Bleischwitz, R., Welfens, P.J.J., Zhang, Z., 2009b. Sustainable Growth and Resource Productivity. Greenleaf Publishing Limited, Sheffield.

Bringezu, S., Schütz, H., 2001. Material use indicators for the European Union, 1980-1997. Economy-wide material flow accounts and balances and derived indicators of resource use. Eurostat, Luxembourg.

Bringezu, S., Schutz, H., Steger, S., Baudisch, J., 2004. International comparison of resource use and its relation to economic growth: The development of total material requirement, direct material inputs and hidden flows and the structure of TMR. Ecological Economics, 51 (1-2), 97-124.

Commission of the European Communities, 2005. Thematic strategy on the sustainable use of natural resources (Communication and Annexes). Commission of the European Communities (CEC), COM (2005) 670 final, SEC 1684, Brussels.

De Bruyn, S., Markowska, A., De Jong, F., Blom, M., 2009. Resource productivity, competitiveness and environmental policies. CE Delft,

De Bruyn, S.M., 2002. Dematerialization and rematerialization as two recurring phenomena of industrial ecology. In: Ayres, R.U. and Ayres, L.W. (Eds.), A Handbook of Industrial Ecology. Edward Elgar, Cheltenham, Northampton, pp. 209-222.

EEA, 2000. Environmental signals 2000. European Environment Agency (EEA), Copenhagen.

EEA, 2002. Environmental Signals 2002 - Benchmarking the Millenium. European Environmental Agency, Copenhagen.

Eurostat, Weisz, H., Fischer-Kowalski, M., Amann, C., Eisenmenger, N., Erb, K.-H., Hubacek, K., Krausmann, F., 2002. Material Use in the European Union 1980-2000. Indicators and Analysis. Eurostat working paper. Office for Official Publications of the European Communities, Luxembourg.

Herring, H., Roy, R., 2007. Technological innovation, energy efficient design and the rebound effect. Technovation, 27, 194-203.

Hertwich, E.G., 2005. Consumption and the Rebound Effect: An Industrial Ecology Perspective. Journal of Industrial Ecology, 9 (1-2, Special Issue on Consumption and Industrial Ecology), 85-98.

Jaccard, M., Failing, L., Berry, T., 1997. From equipment to infrastructure: community energy management and greenhouse gas emission reduction. Energy Policy, 25 (13), 1065-1074.

Labys, W.C., 2002. Transmaterialization. In: Ayres, R.U. and Ayres, L.W. (Eds.), A Handbook of Industrial Ecology. Edward Elgar, Cheltenham, Northampton, pp. 202-208.

OECD, 2003. Environmental Indicators: Development, Measurement, and Use. OECD, Paris.

OECD, 2008. Measuring Material Flows and Resource Productivity. Synthesis Report. OECD, Paris.

Peters, G.P., Hertwich, E.G., 2008. CO2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science & Technology, 42 (5), 1401-1407.

Stahel, W.R., 2006. The Performance Economy. Palgrave Macmillan, New York.

Stanners, D., Bosch, P., Dom, A., Gabrielsen, P., Gee, D., Martin, J., Rickard, L., Weber, J.-L., 2007. Frameworks for environmental assessment and indicators at the EEA. In: Hak, T., Moldan, B. and Dahl, A.L. (Eds.), Sustainability Indicators. A Scientific Assessment. SCOPE 67. Island Press, Washington, Covelo, London, pp. 127-144.

Steger, G., Bleischwitz, R., 2009. Decoupling GDP from resource use, resource productivity and competitiveness: a cross-country comparison. In: Bleischwitz, R., Welfens, P.J.J. and Zhang, Z. (Eds.), Sustainable growth and resource productivity. Economic and global policy issues. Greenleaf, Sheffield, pp. 172-194.

Steinberger, J.K., Krausmann, F., Eisenmenger, N., 2010. Global patterns of material use: a socioeconomic and geophysical analysis. Ecological Economics, 69 (5), 1148-1158.

Steinberger, J.K., van Niel, J., Bourg, D., 2009. Profiting from negawatts: reducing absolute consumption and emissions through a performance-based energy economy. Energy Policy, 37 (1), 361-370.

van der Voet, E., van Oers, L., Moll, S., Schütz, H., Bringezu, S., De Bruyn, S.M., Sevenster, M., Warringa, G., 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. Universitair Grafisch Bedrijf, Leiden.

Warr, B., Eisenmenger, N., Ayres, R.U., 2010. Natural resource exergy, useful work and economic growth through the 20th century: The Austrian case. Ecological Economics, forthcoming.

Weisz, H., Krausmann, F., Eisenmenger, N., Amann, C., Hubacek, K., 2005. Development of Material Use in the European Union 1970-2001. Material composition, cross-country comparison, and material flow indicators. Eurostat, Office for Official Publications of the European Communities, Luxembourg.

Wilkinson, P., Smith, K.R., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. The Lancet, 370 (9591), 965-978.

World Commission on Environment and Development, 1987. Our Common Future, The Brundtland-Report. Oxford University Press, Oxford.