CLIMATE CHANGE

SCIENTIFIC ASSESSMENT AND POLICY ANALYSIS

Assessment of the interaction between economic and physical growth

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This study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis (WAB) Climate Change

Wetenschappelijke Assessment en Beleidsanalyse (WAB) Klimaatverandering
Het programma Wetenschappelijke Assessment en Beleidsanalyse Klimaatverandering in opdracht van het ministerie van VROM heeft tot doel:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

De analyses en assessments beogen een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. De activiteiten hebben een looptijd van enkele maanden tot maximaal ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse en zonodig buitenlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van de deelnemers van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Doelgroep zijn met name de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid.
De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit MNP, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het MNP is hoofdaannemer en fungeert als voorzitter van de Stuurgroep.

Scientific Assessment and Policy Analysis (WAB) for Climate Change
The Netherlands Programme on Scientific Assessment and Policy Analysis Climate Change has the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

We are concerned here with analyses and assessments intended for a balanced evaluation of the state of the art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to a maximum of one year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic. The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency, the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of the Wageningen University and Research Centre (WUR), the Netherlands Energy Research Foundation (ECN), the Netherlands Research Programme on Climate Change Centre of the Vrije Universiteit in Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute of the Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency as main contracting body is chairing the steering committee.

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Preface

The initiative for this project was taken by prof. K. Blok and prof. H.J.M. de Vries, and builds upon the expertise available at Utrecht University, MNP, Ecofys, and ECN in the area of sustainable development, economic modelling and scenario analysis. The essay by prof. de Vries on “Matter and Money” formed the starting point of the study, deepening the thinking process on the relationship between economic and physical growth. During the final workshop the partners have also benefited from the contribution by Dr. S. Bringezu of Wuppertal Institute (Wuppertal, Germany) and by the constructive remarks on the sector studies by prof. J. van den Bergh of VU Amsterdam, and his questioning of the importance of GDP.

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Abstract

Computer model results of possible future greenhouse gas (GHG) emissions represent an important starting point for climate policy. This is especially true for medium and long term emission scenarios such as those published by the Intergovernmental Panel on Climate Change (IPCC). In such scenarios, economic growth is a crucial input parameter because even moderate growth rates - if sustained over several decades – typically lead to high GDP values. For the discussion about future GHG emissions key questions are therefore whether the economic projections are realistic at all and, if so, whether they will show similar dynamics as observed in the past and also lead to an increase of activity in physical terms.

The central question for this project therefore was: To what extent does increased economic activity lead to increased activity in physical terms? The so-called “saturation hypothesis” assumes that with increasing GDP, human activity in physical terms will initially grow on a per capita basis, and then level off to a constant level per capita. The project focused on three main sectors: industry, transport and households.

One of the main findings of the project is that the saturation hypothesis holds in specific sectors, but in general does not hold. We found a levelling-off for some types of human activity, e.g. for steel consumption, cement consumption, and household living area. But in other cases, we rather found a development where the level of human activity continues to grow with GDP growth, e.g. for freight transport, and for the consumption of plastics and paper. It should be mentioned, though, that in most cases we have studied time series of 30 to 40 years in the past, and that saturation still may occur in the future.

Given these results two different ways forward are proposed. The first approach is to deepen the current analysis by gathering more data for more countries and for more categories, and to find a theoretical basis for the developments observed. The second and more extended approach would take into account the intersectoral interactions, because it is clear that the three sectors studies are interrelated.

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Conclusions of the project

One of the main findings is that the saturation hypothesis holds in specific sectors, but in general does not hold. The saturation hypothesis assumes that with increasing GDP, human activity in physical terms will initially grow on a per capita basis, and then level off to a constant level per capita. We found a levelling-off for some types of human activity, e.g. for steel consumption, cement consumption, and household living area. But in other cases, we rather found a development where the level of human activity continues to grow with GDP growth, e.g. for freight transport, and for the consumption of plastics and paper. It should be mentioned, though, that in most cases we have studied time series of the past 30 to 40 years, and that saturation may occur in the future. This also because there are obvious limitations, such as maximum per capita car ownership or minimum number of persons per household, that in the end will affect the future development of the related activity levels.

For the total of 19 OECD countries, we found the share of **industry** on the total GDP to decrease from roughly 27% in 1979 to 18% in 2002. This indicates that industrialized countries develop towards service economies with both the service and transport sector growing faster than GDP per capita. However, this finding does not mean that the absolute value added of the industry declines. Rather the opposite is true, as value added of the industrial sector continues to increase but at slower rates than the total economic growth.

Our analysis of the industrial sector revealed a trend towards re-coupling between physical output and value added for paper and paperboard production and for cement production in South Asia and China. We furthermore identified a trend towards decoupling (i) between cement production and value added of the non-metallic minerals industries of North America and Europe and (ii) for aluminium production in the non-ferrous metals industry of China. For all other bulk material industries analyzed (i.e. wood production, feedstock use in the chemical industry, production of bricks, iron and steel, and aluminium production in the non-ferrous metals industry of North America, Europe, and South Asia) we were not able to identify robust trends towards either decoupling or re-coupling between monetary and physical activity. Based on this semi-qualitative data analysis, we find therefore no indication for a general trend towards decoupling between physical and economic growth in industry.

Unlike the industrial sector, both passenger and freight **transport** have been growing faster than GDP over the past decades. With rising income levels we observe (i) a trend towards faster passenger transport modes and (ii) a trend to specialized high-speed logistic freight chains (just- in-time delivery), along with reduced load factors, compared to traditional bulk oriented logistics. Although the energy efficiency of all transport modes for passenger and freight transport has increased over the past decades (partly as a consequence of energy conservation policies), the transport volumes have been growing substantially faster, resulting in an overall increase of energy use and CO_2 emissions.

For the total transport sector, we conclude that decoupling between passenger and freight transport and per capita GDP cannot be observed and is unlikely to occur in the near future as saturation in both passenger and freight transport is not yet occurring. The energy use of the transport sector will continue to increase. It is therefore likely that the transport sector becomes the major CO_2 emitter of all economic sectors in the next decades.

Next to the increasing demand for transportation also the need for other **services** increased markedly. The increasing complexity of modern economies stimulates activities in the service sector, i.e. health, education, finances, government. Linking the monetary growth of the service sector to physical activities is, however, complicated by the fact that data about physical activities in the service sector are scarce. In absolute terms, the number of employees in the service sector as a whole rose in all studied IEA-countries in the period of 1970-2000, while the amount of office space per employee (in m^2) appears to be relatively stable over time. Regarding the amount of office space per employee versus value added of the service sector no clear trend could be identified. The use of office equipment has increased significantly in the last ten to fifteen years. Based on limited available information, it is expected that the amount of office equipment did not reach saturation yet. Demand for more comfort (indoor climate, electronic devices) and developments in the area of communication technology might further increase the amount of office equipments and as a consequence the energy demand of the service sector.

The data of developed countries indicate a trend towards re-coupling between the number of employees and the use of office equipment with the value added generated in the service sector. No general trends are observed regarding the development of floor area per employee and increasing value added in the service sector.

Households account for almost one third of the total worldwide final energy consumption. Next to economic and demographic growth, the average dwelling area, number of persons per dwelling, average living area per capita and appliances per capita are the main drivers for energy consumption in households. In our analysis, we found evidence that total energy demand will level off at higher living standards, and that a decoupling of economic growth and total energy consumption in households is occurring. However, we could not find a uniform trend towards decreasing per capita total energy use in households.

For most countries the space heating energy intensity declines rapidly, and has a major impact on the total energy use. Declining energy use for space heating is caused by increased energy efficiency (e.g. insulation, energy efficient heating systems). As of 1970 the continued growth in absolute dwelling area with increasing GDP per capita is striking, despite large differences between individual countries regarding per capita dwelling area. However, as the average dwelling area per capita grows slower than per capita GDP, we observe a trend towards weak decoupling between growth of absolute dwelling area and GDP. We furthermore identified a general trend towards increasing living area per person as household occupancy decreases with increasing per capita GDP. The current trend in dwelling area development shows that although average dwelling size per capita is still growing, the growth is slowing or even stabilising in several developed countries. With potentially slowing or even declining population a stabilisation of total living area can be expected in the future. In most developed countries the increase of energy consumption in households over the last decades is due to the increased electricity consumption of new appliances (even when some of it is offset by increased efficiency of major energy consuming appliances). The physical indicator ownership of electric appliances shows a re-coupling trend with GDP per capita.

Given the above results two different **ways forward** are proposed. The first approach is to deepen the current analysis by gathering more data for more countries and for more categories, and to find a theoretical basis for the developments observed. The second and more extended approach would take into account the intersectoral interactions, because it is clear that the three sectors studies are interrelated.The ongoing discussion about the role of GDP as a proper (or improper) indicator for well-being, should be included in further research in the area of the relationship between physical and economic growth.

Final remarks: The main objective of the essay “Matter and Money”, which was written at the start of the project, was to enrich the ways in which we think about our future, the future of the human race and of the earth. Models can help in this thinking process but they have to be improved to deal better with real-world complexity. They can be used in telling richer and more varied stories. In this way, also our perspective on what sustainable development pathways can and should be will be broadened, for instance vis-à-vis the matter-and-money issue. A few roads seem particularly promising for further research. First, obtaining a better understanding of the functioning of subsistence economies and the conditions for development, using both earth science and social science theories and tools. Next, the analysis of what drives economic growth and which forces influence the (de)coupling of monetary growth from materials flows has to be strengthened. The role of services, including the ICT-sector, deserves more attention, as part of this analysis. Finally, the link between economic growth - and in particular GDP-growth - and the experience of well-being has to be investigated and debated much more thoroughly if we are serious about the quest for sustainable development.

Executive Summary

Decoupling between physical and monetary growth of the economy has been identified as one of the key strategies towards sustainable development. The extent to which economic and physical activity are decoupled from each other has important implications for long-term energy and emissions scenario modelling. This is especially true for greenhouse gas (GHG) emission scenarios such as those published by the Intergovernmental Panel on Climate Change (IPCC, 2000). In such scenarios, economic growth (expressed in monetary terms) is a crucial input parameter. Even moderate growth rates - if sustained over two or more decades – typically lead to high to very high GDP values, indicating that also energy consumption and hence CO_2 emissions might reach tremendous levels.

This assessment project aims therefore at analyzing the relationship between physical activity and economic growth in three economic key sectors, i.e., (i) industry, (ii) transport, and (iii) households and services. Our research activities are mainly based on a literature review and were complemented by own data analyses. The report sets out with an overview chapter, providing the conceptual background for three sector studies (Chapter 2), which are presented in the subsequent three chapters (Chapter 3–5). In the final Chapter 6, we provide a summary and conclusions and we identify future research needs.

In order to assess the consequences of different trajectories of economic, technological and societal developments on energy use and greenhouse gas emissions, computer-based scenario analyses are being performed. Depending on the storyline, these make use of various 'stylized relationships', which are sometimes discussed explicitly, while they often remain implicit. As discussed in Chapter 2, more in-depth analysis is needed, adding bio-geographical, techno-economic and institutional heterogeneity. This would also allow broaden our perspective of what sustainable development pathways can be. Few directions, which seem particularly promising for research, are (see Chapter 2):

(i) to gain a better understanding of the functioning of subsistence economies and the conditions for development, using both earth science and social science theories and tools,
(ii) to analyze the drivers of economic growth and the forces that influence the (de)coupling of monetary growth from materials flows
(iii) to pay special attention to information and communication technologies (ICT) and
(iv) to investigate thoroughly the link between economic growth - and in particular GDP-growth - and the experience of well-being and to debate this issue much more.

This report, which is primarily related to point (ii), studies the relationship between physical and monetary flows for the industry sector (Chapter 3), transport (Chapter 4) and households and services (Chapter 5).

The **industry sector's** share of the total GDP decreased for the total of 19 OECD countries from roughly 27% in 1979 to 18% in 2002. This result indicates that industrialized countries develop towards service economies with both, the total service sector and the transport sector growing faster than per capita GDP. However, this finding does not mean that the absolute value added of the industry declines. Rather the opposite is true, as the value added of the industrial sector continues to increase but at slower rates than the total economy.

This development is also reflected by the consumption of various bulk materials: While we find a general trend towards declining intensity of use with increasing per capita GDP, we also identify a trend towards increasing absolute per capita materials consumption. These results show that the shift towards the service economy can lead to weak decoupling between physical and monetary growth but not to absolute dematerialization, i.e. an absolute decline of materials consumption.

Based on the analysis of physical production and value added data of selected *bulk* material industries we find no indication for a general trend towards decoupling between physical and economic growth. For scenario projections, this means that each percentage growth of value

added in the *bulk* material sectors can roughly be expected to lead to at least a comparable growth in physical output.

Unlike the industrial sector, both **passenger and freight transport** have experienced high growth rates over the past decades. With rising income levels we observe (i) a trend towards faster and long-disctance passenger transport modes and (ii) a trend to specialized high-speed logistic freight chains (just in time delivery), along with reduced load factors and longer transport distances as compared to traditional bulk oriented logistics. This development has overcompensated the energy efficiency gains and ultimately results in an overall increase of energy use and CO_2 emissions. We would therefore conclude that decoupling between passenger and freight transport and per capita GDP cannot be observed and is unlikely to occur in the near future as saturation in both passenger and freight transport is not yet occurring.

Next to the increasing demand for transportation also the need for other **services** increased markedly. In absolute terms, the number of employees in the service sector as a whole rose in all studied IEA countries in the period of 1970-2000, while the amount of office space per employee (in m^2) appears to be relatively stable over time. Regarding the amount of office space per employee versus value added of the service sector no clear trend could be identified. The use of office equipment has increased significantly in last ten to fifteen years. Based on limited available information, it is expected that the amount of office equipment did not reach saturation yet. As a consequence energy demand of the service sector will continue to increase.

In our analysis of households, we found evidence that total energy demand will level off at higher living standards, and that a decoupling of economic growth and total energy consumption in households is occurring. However, we could not find a uniform trend towards decreasing per capita total energy use in households, as countries that start at a relatively high (historical) level of energy use per capita tend to reduce their per capita energy demand with increasing per capita GDP (e.g. Denmark and Germany) while countries that have a relatively low residential energy use per capita at low GDP level like Japan, Finland and Norway continue to increase their energy use per capita. While developed countries show very large differences in per capita energy use, a convergence towards similar levels of residential per capita energy use is hence observed.

For most countries, the space heating energy intensity declines rapidly and has a major impact on the total energy use. As of 1970 the continued growth in absolute dwelling area with increasing GDP per capita is striking, despite large differences between individual countries regarding per capita dwelling area. However, as the average dwelling area per capita grows slower than per capita GDP, we observe a trend towards weak decoupling between growth of absolute dwelling area and GDP. We furthermore identified a general trend towards increasing living area per person as household occupancy decreases with increasing per capita GDP.

Our findings for the three sectors are, however, subject to uncertainties, partly due to dubious data quality. The identified trends have not been subject to a sound quantitative statistical testing. To that end, a more rigorous statistical hypothesis testing via regression analysis should be applied.

Combining these empirical findings with GDP **projections** for Western Europe (see Chapter 6.2), we conclude that in the high scenario (scenario IPCC-A1) and the medium growth scenario (scenario ‘Strong Europe’) the physical flows of bulk materials are likely to increase by a factor of around 2.0 to 2.5 in the period 2000 to 2020. For transport (commercial transport only), the physical flows (ton kilometres and passenger km) may increase by a factor of approximately 2 to 3 between 2000 and 2020, while, in contrast, the changes expected for the service sector (without transportation) are rather moderate, with *mean* estimates for absolute floor space growth between 1.2 and 1.5.

These results seem implausibly high for bulk materials, while they seem rather acceptable for transportation and services. This leads to the following interesting new insights for these two scenarios:

(i) The results indicate that the economic projections for industry tend to be too high, while the economic projections for transport and for services seem to be in the right range.

(ii) Only weak decoupling between physical and monetary growth seems in sight, while the physical flows in absolute terms are expected to increase very substantially and absolute decoupling seems unlikely.

The report concludes by summarizing the remaining information gaps and by providing recommendations for further research, for which numerous opportunities exist (Chapter 6.3).

1 Introduction

Decoupling between physical and monetary growth of the economy has been identified as one of the key strategies towards sustainable development (Schmidt-Bleek, 1994, von Weizsäcker et al., 1997, de Bruyn, 1999). For more than 15 years, the sustainability discussions have been dealing with the unresolved controversy, to which extent increasing economic wealth translates into enhanced consumption of resources, materials, and energy. According to several authors (e.g., Cleveland and Ruth, 1999, Bringezu et al., 2004) there is still no compelling empirical evidence that economic development has decoupled from material and energy consumption for the economy as a whole. At the same time, according to numerous qualitative and quantitative studies, material and energy intensity in industrialized countries could be reduced by a factor of 4 to 10, leading to absolute decoupling between physical and monetary growth in the future (Schmidt-Bleek, 1994, von Weizsäcker et al., 1997).

This controversy has important implications for long-term energy and emission models, the results of which represent one of the starting points for energy policy and environmental policy. This is especially true for greenhouse gas (GHG) emission scenarios such as those published by the Intergovernmental Panel on Climate Change (IPCC, 2000). In such scenarios, economic growth is a crucial input parameter. Hence, even moderate growth rates - if sustained over two or more decades – typically lead to high to very high GDP values. In spite of a growing world population (rising from over 6 billion nowadays to nearly 9 - 10 billion by 2050) economic growth scenarios result in a substantial increase of per-capita-income (e.g., from around 4,000 US$/cap nowadays to values in excess of 45.000 US$/cap by 2050). Key questions are therefore:

- whether such economic projections are at all realistic or whether they might be overoptimistic by (wrongly) assuming that similar dynamics as observed in the past will also be experienced in the future (especially in developing countries) and that environmental feedbacks will not interfere (as was the assumption in the IPCC-scenarios), and
- to which extent the increased economic wealth will translate into physical growth, energy use and emissions, and whether feedbacks from the resource supply system have to be accounted for.

A deeper insight into the latter question (especially concerning the relationship between economic and physical growth) could be key for answering the first question. Improving the understanding of the relationships and dynamics regarding economic growth and physical activity may subsequently allow bringing in new arguments into the controversial discussions around the IPCC emission scenarios in the recent past (e.g. Nakicenovic et al., 2003). Ultimately, this could offer a first basis for a renewed discussion about the extremely wide ranges of scenario results and their plausibility.

The relationship between monetary growth and GHG emissions can be broken down into two factors, i.e., the relationship between

- monetary and physical growth (or: flows)

and between

- physical flows on the one hand and energy use and GHG emissions on the other.

The latter relationship is subject to technology choices (e.g. standard versus highly efficient technology) and to the fuel mix (overall carbon content of fuel). The analysis of these aspects is not the primary aim of this study, although they cannot be completely neglected when reviewing existing work. Instead, it is the primary goal of this assessment study to compile and interpret all available analyses on the relationship between monetary and physical growth. While being set up in this fashion, it became clear during the collection of the relevant literature that the amount of work addressing this specific question is very limited, even if implicit coverage is included. It was therefore decided to conduct, within the means of this project, own data analyses with readily available data in order to firstly obtain a better understanding of the relationships and secondly to explore possibilities of conducting more thorough investigations. The extent to which this has been possible differs across the various sectors covered by this report.

Following this introduction, the study is composed of three parts: the first part, represented by Chapter 2, provides an overview of generally accepted versus unclear relationships ('stylized facts') which are implemented in large energy-economy-emission models such as the used for IPCC scenario projections; furthermore missing elements and links are identified. The second part consists of three chapters, which discuss the relationships between physical and monetary flows in the three sectors industry (Chapter 3), transport (Chapter 4) and households (Chapter 5). Finally, in Chapter 6, we summarize our findings and draw conclusions about the current understanding and possible future developments regarding physical and monetary growth. We finally identify possible steps to be taken by further research.

2 Setting the Stage: Matter and Money, long-term prospects for world development

Bert de Vries, MNP/Utrecht University

2.1 Introduction

In exploring the causes of human-induced climate change and the options of mitigation and adaptation, it is necessary to analyse the forces behind societal development. The climate change debate is thus intricately interwoven with the aspiration for a decent life for the larger part of the human population, that is: with development. It also signals, with other signs of environmental deterioration, the need to develop within the constraints posed by the natural environment, that is: the need for sustainable development. Four global analyses of the last decade bring these threads together:

- The Special Report on Emissions Scenarios (SRES) presented to the IPCC in 2000, which explored possible greenhousegas emission trajectories (Nakicenovic *et al.,* 2000);
- The Millennium Development Goals (MDG) as formulated by the UNDP and accorded by the UN in 2000 (www.undp.org/mdg); which expresses the political intention to increase quality of life for the millions of people living in destitute circumstances [1];
- The Global Environment Outlook (GEO) of UNEP (http://www.unep.org/geo) which is published since 1997 on a bi-annual basis and addresses the major regional and global environment problems, both current and emerging, and explores possible and desirable directions towards sustainable development; and
- The Millennium Ecosystem Assessment (MA) which evaluated the role and future of ecosystem services and the consequences of their misuse and options for sustainable management (www.millenniumassessment.org).

From these reports one may conclude that, in this first decade of the 21st century, humanity has the relevant knowledge and the good intentions for global sustainable development. Yet, the path towards it looks bumpy and full of possible sidetracks, some of them outright catastrophic.

Statement: The rationale for the IPCC-SRES economic growth – energy demand scenarios is scientifically weak

In this essay I will try to shed light on some controversies surrounding the interpretation of our predicament and on strategies for a more sustainable development path. I call it an essay because it will be a mixture of personal valuations and scientific observations. The focus is on the interface between the earth/life sciences with their physical orientation and the social sciences with their monetary as well as socio-cultural orientation. I use the shorthand title Matter and Money. The dominant context is climate change as analysed in the SRES analysis, reflecting my own involvement (De Vries, 2006). The essay is meant to provide constructive criticism in order to improve the next round of long-term global change forecasts, for the IPCC and other organizations.

First, I give a brief description of some of the assumptions on economic growth and energy use in the SRES and discuss briefly their validity. In paragraph 3, the process of agricultural development in the low-income regions is explored, with an emphasis on energy use. In paragraph 4, the forces behind economic growth as a process of adding value are investigated, with some suggestions how to get more insight into the dynamics of dematerialization. Next, some reflections on the service sector are given, after which I finalize with a discussion of the relationship between economic growth and happiness.

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[1] It is worth noting that energy is not mentioned explicitly in the MDGs.

2.2 The IPCC-SRES scenarios: economic growth and energy use

2.2.1 'Stylized fact' assumptons in SRES

De Mooij and Van den Bergh (2002) conclude that 'it is difficult, if not impossible, to draw general conclusions about the reconciliation of environmental preservation and growth' and suggest to think in terms of different perspectives (or worldviews). This has also been the approach in the construction of greenhousegas emission scenarios (SRES) and advocated more in general in investigating complex socio-ecological systems (De Vries, 2001). In this essay I will use the notion of generic relationship - or metamodel, hypothetical law, 'stylized facts', or 'logic' - to refer to rather general, abstract correlations which often represent such perspectives and suggest causal mechanisms within confined domains of validity. Indeed, different (scientific) perspectives upon the growth-environment nexus and the associated storylines or narratives can be understood quite well in terms of such generic relationships.

The rationale for the IPCC-SRES population and economic activity scenarios was predominantly based on a few stylized facts (Nakicenovic et al., 2000, De Vries et al., 2000):

1. Population growth will decline with rising income (GDP/cap) and economic growth will be bell-shaped as a function of income (GDP/cap);
2. Economic growth (cq. its driving force: factor productivity growth) will correlate positively with globalization = 'free' trade, and globalization = 'free' trade will speed up income convergence between rich and poor countries/regions; for both, technological developments are crucial;
3. Economic activity related indicators (Value Added VA and employment) will follow structural change, i.e. the dominant share will change from agriculture to manufacturing/industry and then to services;
4. With rising income, resource intensity declines ('dematerialization' - Appendix B) and environmental stress decreases ('environmental Kuznets curve' - Appendix C).

These metamodels have not all been introduced explicitly; some entered the scenario construction via the relationships used in the models and/or via the criteria used for model result evaluation. All of these metamodels are contingent upon underlying assumptions about choice of countries, periods, concepts and aggregation levels. Most of them conceal such underlying uncertainty and diversity in explanatory mechanisms that they should only be used in the context of a qualitative storyline or narrative - as the IPCC-SRES team did. In this way they are not so much a scientific truth as a mental model dominating the actions in a particular world future. Let us briefly look at the evidence for these 'stylized facts' assumptions.

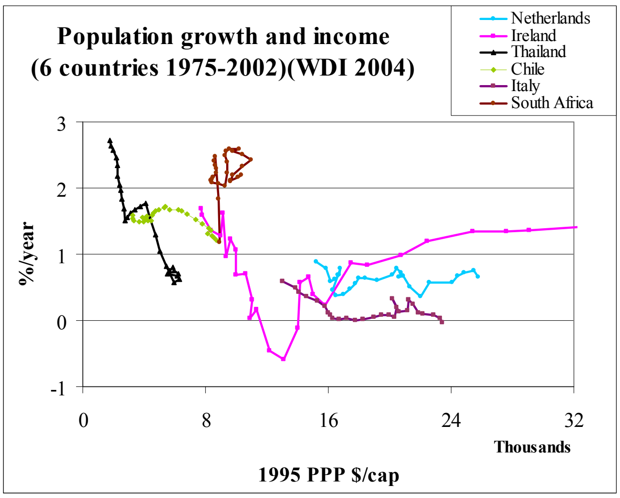


Figure 2.1. Relationship between population growth and income for 6 countries 1975-2002

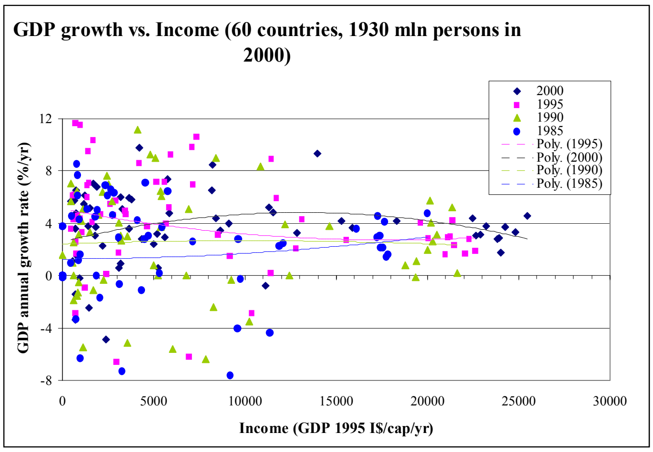


Figure 2.2. Relationship between GDP growth rate and income for 6 countries 1975-2002

Population and economy. There has been a consistent fall in nearly all countries in the world in the population growth rate since the second half of the 20th century, as part of the demographic transition (Rotmans and De Vries 1997; Figure 2.1). In the same period, income measured as GDP/capita has risen - so on the average the relationship appears to hold. But significant exceptions have been observed. For instance, fertility rates in low-income regions drop faster than had been expected only a decade ago – an acceleration. In some regions and periods, such as Russia, an (expectation of) lower income or political instability has caused a decrease in fertility - a reversal. South Africa has experienced a period of large socio-political change and the rise of HIV-AIDS. Saudi Arabia's population and income growth reflect its culture as well as its oil wealth. The reproductive behaviour of the Irish population has not kept pace with the fast rise in income.

As to the relationship between economic (GDP) growth vs. income (GDP/cap), the relationship is spurious: for a total of 60 countries between 1985 and 2000, no meaningful aggregate relationship is found (Figure 2.2). Possible explanations of lower growth rates in the high-income (OECD-) regions are saturation, ageing, a lower savings rate and a labour-leisure trade-off. However, for low-income countries there is a wide variety in GDP-growth rates and other explanatory variables than income have to be identified. Most macro-economic models tend to capture such factors by linking GDP-growth to the labour force and the capital stock (growth). The slowdown in productivity growth with income growth is then imputed by a declining total factor productivity (tfp) growth. In this way the WorldScan model has been used for the forward extrapolation of regional economic growth paths (Figure 2.3; De Vries *et al.,* 2000).

Trade. The causal mechanisms between economic (GDP) and (global) trade are in the aggregate more a matter of belief and hope than of historical evidence. I have not carefully searched the economic literature but the issue is notoriously difficult to measure and controversial. Trade is assumed to be beneficial as the comparative advantages in cheap labour and resources are realized by globally orchestrated capital flows - but transaction costs are not considered and the cheap transport costs of the last decades are an explicit condition. Here, too, macro-economic models reproduce the benefits of trade in an 'open world' as an outcome of input assumptions. In combination with a faster growth in labour productivity through education and in total factor productivity (tfp), the simulations generate income convergence - in the 'open world' scenarios more than in the 'closed world' ones[2]. As a result,

[2] The income convergence in the SRES has been introduced explicitly in the two globalizing scenarios as something which would occur as a side-effect of open market dynamics (A1) or as a globally formulated and supported objective (B1). It has led to the still inconclusive debate about the use of mer or ppp in comparing income across regions (Nakicenovic *et al.,* 2003). Income convergence is less in the non-globalizing futures, but it may be thought to be compensated for by more pluralism in cultural identity and socio-political organization and hence acceptance.

models such as the WorldScan model generate high GDP-growth in the low-income regions, which is for over 80% accounted for by capital accumulation and technological innovations (Figure *2.3*; cf. De Vries *et al.* 2000).

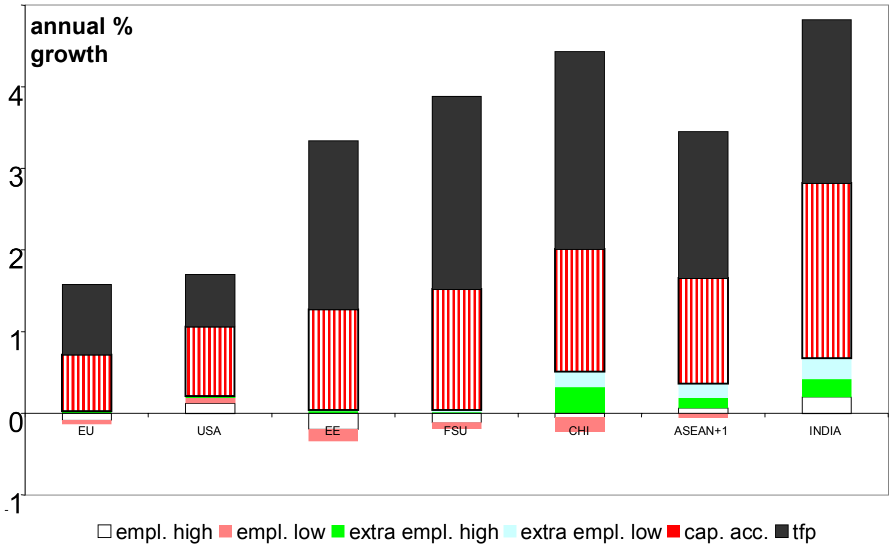


Figure 2.3. Growth accounting: contribution of various factors to GDP-growth in 7 regions in the B1-scenario (De Vries et al., 2000); the black parts indicate growth from increase in total factor productivity (ftp), the striped ones from capital accumulation; rising capital-labour ratios and the other from increase in labour force size and skill level

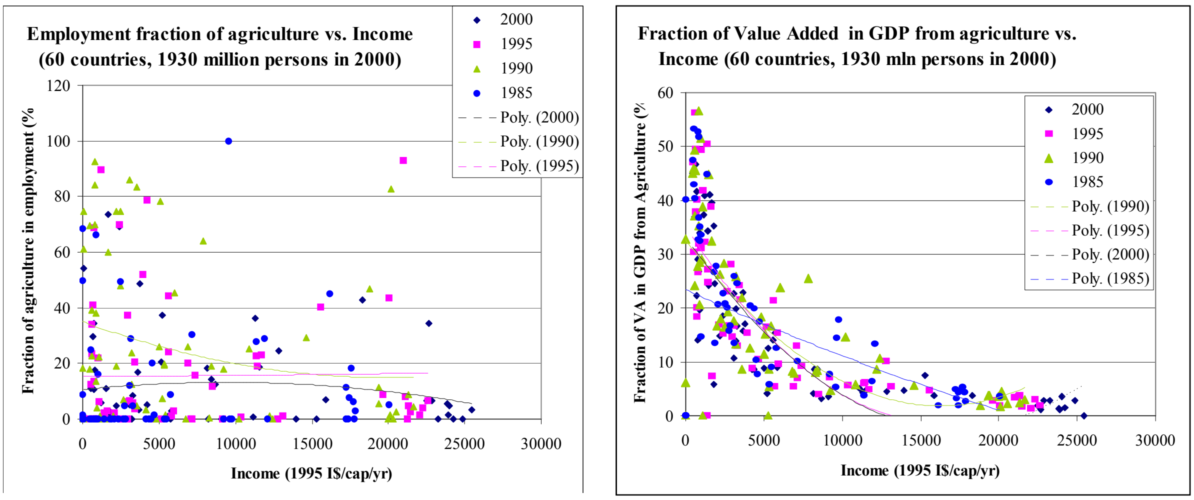


Figure 2.4. Fraction of agriculture in employment (left) and Value Added (right) as function of income

Structural change. The cross-country and time-series data confirm the consistent decline of the share of agriculture in total Value Added (VA) with rising income (GDP/cap) - but for the share in total employment the situation is less clear (Figure 2.4). Apparently, the growth in the non-agricultural sectors is not always and/or rapidly absorbing the rural unemployed. The data also seem to confirm the initial rise of the fraction of manufacturing in total VA, followed by a decline with a concomitant rise in the service sector fraction. Yet, as with so many intercountry comparisons, there are large variations in the trend (Figure 2.5). For instance, Thailand has a disproportionately large fraction of the population working in the (formal) services sector - which highlights its role as tourist place. The Czech Republic has a rather high service sector employment in view of its pre-1989 socialist industry-orientation - there are still large uncertainties about the direction the Eastern European economies will go.

Several hypotheses for structural economic change have been advanced as an explanation. Yet, even the empirical evidence is less solid than it seems. A recent reconstruction indicates that the private and public services sector (excluding transport and communication) in Sweden 1800-1990 has *not* increased its share in VA in real terms - it remained at roughly 30% (Kander, 2005). It also shows the notorious problem of measuring service sector output and VA adequately.

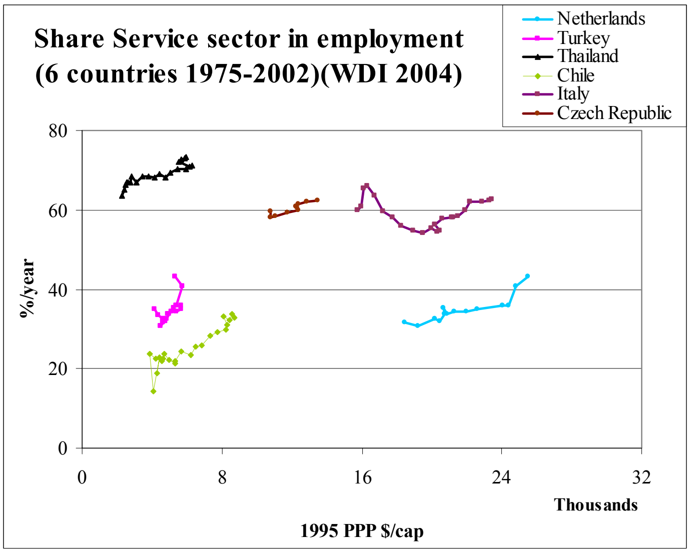


Figure 2.5. Fraction of service sectors in Value Added and Employment as function of income

Economy, resources and environment. Will economic and physical flows decouple upon further economic growth and alleviate the problems of resource scarcity and environmental deterioration? Does a theory of dematerialization, i.e. a reduction in (raw) material intensity of economic activities, hold (Appendix B)? A first question: Did dematerialization cq., decoupling happen? The conventional economic indicators show that the energy (and material) intensity measured as commercial energy per unit GDP have declined. Why? The major factor has been the continuous drive to reduce production costs and hence energy costs cq., use - a drive which was accelerated by the oil price hikes in the 1970s and early 1980s and the subsequent wave of innovations. Another explanation has been the transition to a service economy, because the service sectors tend to be less energy-intensive. This explanation may be overstated in the aggregate for two reasons:

- An analysis of Danish economic trends suggests that private and public services should be separated, as the former is linked to manufacturing and has an energy productivity significantly higher than for the latter - reflecting the role of transport and the higher labour productivity in the private service sector (Jespersen, 1997);
- The share of the service sector may in real terms not have increased (see above - Kander 2005). Instead, a more convincing hypothesis might be that ICT/microelectronics have led to a dematerialization of the industrial production and of consumption activities (cf. paragraph 4). In other words, the decrease in industrial energy-intensity at the margin mattered more than the switch to service sector activities [3].

Unfortunately, the issue is confused by ambiguities about the concept and measurement of service sector output and its relation to other economic activities, in particular for the non-market public sector. Hence, several other explanations for the decoupling of physical and monetary growth have been put forward - and the debate continues.

New ways of investigating the activities in what is called 'the service sector' are needed. For instance, the final demand for services tends to grow faster with rising income - an observation

[3] The effect may have slowed down somewhat due to reduced economic growth as a response to rising oil prices and hence a slower turnover rate of capital stocks (De Vries *et al*., 2000).

which asks for a conceptual redefinition of services as an activity which adds value to commodities when these are used by individuals and organizations as agents of knowledge and information (Parrinello 2004). It may then be argued, for instance, that dematerialization happens because consumers substitute services for commodities - and not because of, for instance, environmental behavioural change. Evidently, an adequate evaluation would have to include the accumulation of human capital - its omission underestimates the VA of the (public) service sector - and to consider the role of time use and time constraints in consumption activities (Cogoy, 2004, Jalas, 2002).

More generally: is there any evidence that environmental stress will recede automatically when income rises? The so-called Environmental Kuznets Curve (EKC; Appendix C) has been formulated to express the observation that the emission-intensity of certain pollutants (such as SO_2 and NO_x) has a bell-shaped form as a function of income across a large group of countries and over time. One explanation is that, particularly at high population and economic and hence emission density, a rising middle-income class starts to appreciate increasingly a clean and healthy environment as part of their quality of life - and hence emission reduction measures are taken. In combination with technological developments - the cost to reduce one unit of emission has declined significantly for many pollutants - this has led to the bell-shaped curve. However, the EKC has to be refuted as an aggregate phenomenon because it may not occur for more persistent and essential substances (such as CO_2) and it may hide the shift from the more visible and easy-to-reduce substances to more insidious ones with difficult-to-prove and long-term effects.

Despite these caveats, most economy-energy-environment models use the above stylized facts in one form or another to generate (carbon) emission scenarios, using a variety of mechanisms to simulate energy demand. Among these are demand saturation, autonomous and price-induced innovations, technology transfer, resource depletion and substitution to new energy carriers and technologies. The resulting energy use implies in almost any scenario a reduced energy-intensity measured in GJ/$. It is also assumed that higher income leads to more severe environmental policies - and as a result emissions of for instance SO_2 decrease in almost any scenario and the fastest in the high-growth ones [4].

2.2.2 Other assumptions in SRES

Evidently, quite a few assumptions entered the storylines and modeling without any explicit consideration or argumentation. I suggest the following:

1. The emergence of a welfare state with democratic rights, social security arrangements and taxation goes along with the population and economic growth pathways;
2. Collective goods and services needed for a well-functioning health, educational and transport system (infrastructure) will be provided by some mixture of public and private activities;
3. Importantly in the present context: environmental feedbacks can be accommodated throughout the scenario period without major (voluntary or forced) changes in the extent and nature of economic growth [5].

Behind each of these assumptions, various metamodels - or even social science schools – do exist to justify them in terms of an underlying logic. I will briefly discuss each.

The welfare state. It is a key question - and uncertainty - whether governments in low-income countries can get and maintain the legitimacy and develop the required effectiveness needed for the transition to a welfare state, with extensive collective arrangements in the form of infrastructure (health, education, transport) and social security arrangements (unemployment,

[4] A recent comparison of SRES with historical data indicates an underestimation of the reduction rate of sulphur dioxide emissions (Van Vuuren and O'Neill, 2006).

[5] This is at least partly the result of a limited mandate of the IPCC to SRES (cf. Nakicenovic *et al.,* 2000).

pensions) [6]. Proven concepts of public and private arrangements as in the European welfare state are no longer self-evident, with globalizing capital and goods and services markets and at the same time increasing pressure to constrain migration. The build-up of 'human capital' is a necessity for economic growth - but how large a fraction of the population is going to participate in it? Will people in Africa, Asia and South-America be confronted with highly labour-productive manufacturing and services, with large parts of the population becoming the servants of those who succeed? Is there hope that novel, community-based pathways are found to decent prosperity for these large populations? In SRES these issues have been dealt with in the form of narratives, assuming that in the globalizing futures (A1 and B1) the forces of 'modernity' would prevail and enable some kind of 'welfare world'. If these forces fail, this utilitarian utopia will not emerge, or later.

Legitimacy of governments. It is evident that the legitimacy of government is in quite a few countries either absent or under threat. In some places this is part of the longer term transition from tribal oriented governance to the more 'modern' forms of the nation-state and the welfare state. Inevitably, this is a slow process with all kinds of conflicts and possibly novel outcomes. The colonial past, cultural traditions, growing populations and rising expectations – excited by the fast dissemination of images and information across the world - make governance in many countries a very difficult task. Some elites simply stick to authoritarian rule, using their resource wealth to suppress their populations or buy their consent. This is the so-called *resource curse:* a state's reliance on either oil or mineral exports tend to make it less democratic (Ross, 2002; Figure 2.6). In other countries the emergence of 'westernized' elites leads to a variety of conflicts with the more traditionally oriented parts of the population – as is splendidly described by Castells (1997) in his book The Power of Identity.

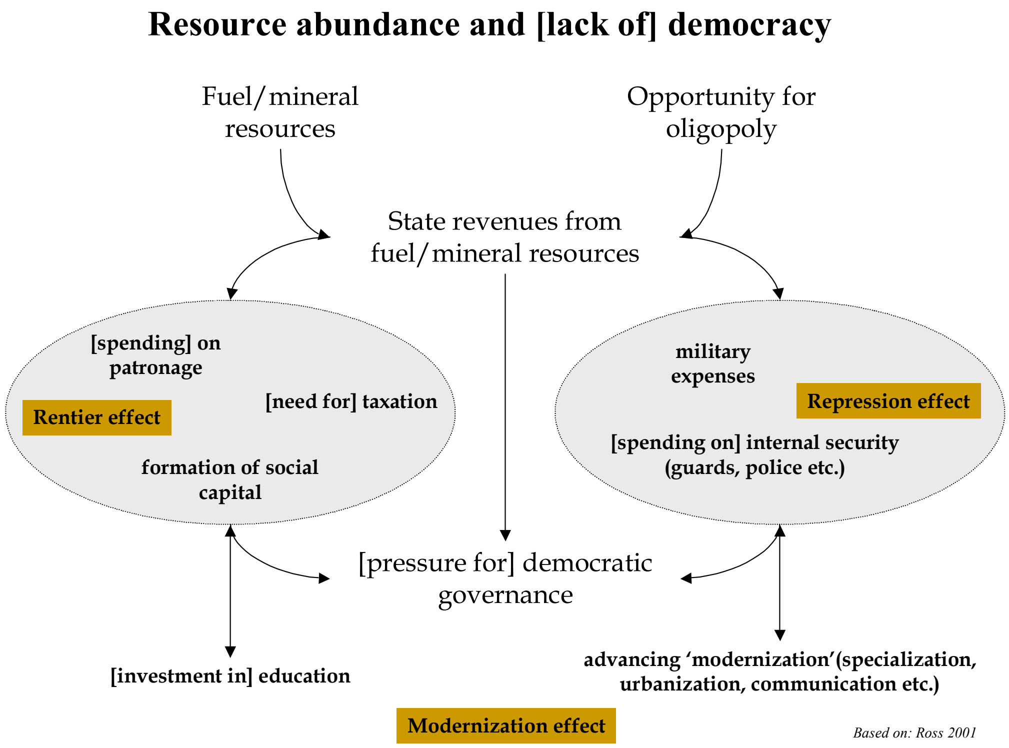


Figure 2.6. The resource curse: mechanisms, which tend to obstruct democratic governance in resource-wealthy countries

In the present context, the issue really is whether governments can gain legitimacy by their ability to guide the process of economic development and provide basic goods and services, as

[6] See for instance the recent report India Infrastructure Report 2006 / Urban Infrastructure, Oxford University Press New Delhi, for an overview of the huge challenges posed by the need for infrastructure.

is implicit in most macro-economic projections. This requires careful navigating, in search of the right balance between preserving one's own culture and opening up to the 'western' world, between dictatorship and democracy, between 'command-and-control' government and 'free' markets. Too much market may cause income inequalities, which cause social and political instabilities and frustrate economic growth - sufficient wealth has to 'trickle-down' to the poor [7]. Too much government, with regulation in association with nationalism and economic and cultural protectionism, may lead to centralized political control and stifle the innovation needed for economic growth. Scientific knowledge and models play a quite limited role in exploring these issues – which is why model-based narratives were constructed in SRES. If the forces of local and regional governance and culture prevail, as in two of the four SRES (A2 and B2), even the very attempt to find universal mechanisms is bound to fail.

(Over)exploitation of natural capital stocks. Past rise and fall of civilizations indicate that human groups have often risen in a spiral of opportunities on the one hand and threats from the extra-human world (droughts and floods, wild beasts and pests, earthquakes and volcanic eruptions), from inter-human relationships (hostile neighbours, invading warriors) and from mismanagement due to intra-human nature – negligence, ignorance, lack of self-restraint or discipline (De Vries and Goudsblom, 2004). Overexploitation of the local natural resources has often played a role, though not a simple one, in decline or collapse of societies. Despite increased understanding of socio-ecological systems and better technical and organizational skills to manage them, there is widespread overexploitation going on and it probably gets worse in parts of the world. It manifests itself in various forms, as the syndrome approach highlights (Petsch-Held *et al.,* 1999).

In most long-term scenarios – such as SRES – the cost of environmental deterioration and the measures to restore and replaces lost ecosystem services and of the associated cost in human health are considered to be implicit in the economic growth dynamic. This is, indeed, the assumption behind the postulated EKC discussed in the previous paragraph. However, this may be a dangerous mistake. Water shortages and conflicts about water, harvest failure from eroding soils in combination with climate change, depletion of locally essential stocks of fish and wood etc. may cause irreversible damage which destroys the prospect for economic development. Adaptation to the new circumstances, if possible at all, may be so costly as to absorb most of the resources needed for development. The larger connectedness of the world may make such developments less catastrophic, but food aid may aggravate the situation as dependency increases whereas migration to urban centres is merely displacing the problems. At the global scale, the room for migration to new relatively pristine continents has also narrowed down considerably and migration to affluent regions is becoming more difficult every day.

Urban-rural divide. "A survey… shows that the income gap between rural and urban residents in China has kept growing in the past five years [since 1998], and China has become one of the countries with the largest urban-rural gap… income per capita of urban residents was 3.1 times higher than that of farmers in 2002, much higher than 2.8 in 1995… However, even this does not tell the real disparity between urban and rural citizens. The income of urban citizens concerned does not count the welfare they have access to, including the medical care, unemployment insurance and minimum living relief. Most farmers have no access to these. What's more, they have to pay the educational cost themselves while the government covers most of such costs for urban residents." (TUC, 2006). On the other hand, it would be worthwhile to investigate whether urban life brings additional expenses with it and whether certain quality of life aspects of rural life which are absent in urban life, such as esthetics and quietness, should be accounted for.

The above assumptions - and many others - are about far more complex parts of socio-ecological systems than the aspects usually dealt with in economy-energy-environment analyses. To deal with this complexity and the associated uncertainties is why storylines or

[7] In north-east Brazil, for instance, an intentional class structure kept the poor 80% of the population poor through much higher fertility rates, with a subsequent labour surplus and thus low wage level and reduction in savings capability and job opportunities for women - and vice versa (Daly, 1996, Ch. 9).

narratives are used in SRES [8]. It may help to bring in the requisite variety in possible world futures. For this very reason one cannot and should not assign probabilities to the corresponding energy use and emissions pathways. It may only be concluded that particular energy and emission trajectories are compatible with a rather wide variety of developments in technology, governance, economy and trade.

Can we do better than SRES, in particular with regard to the matter and money issue? Demographers are usually forecasting several generations into the future because population dynamics is rather robust - and yet, the recent fall in fertility has been unexpectedly fast. Most macro-economic modelers refrain from forward projections more than 5 à 10 years ahead, because the underlying dynamics is too complex - and subsequently some exponential GDP-growth path is proposed for further use. Technology assessments are usually further into the future, as large capital investments and infrastructure development cover periods of 30 years and more. Although revealing, especially if rooted in historical analysis (see e.g. Geels 2000), such analyses show the many inherent uncertainties. Long-term analyses of economic growth and technological dynamics have led to, amongst others, models of Kondratiev-cycle dynamics (see e.g. Tylecote 1992). However, such attempts to link long-term productivity growth to novel technologies (info-, nano-, bio-, robotics, psychofarmaca) and new waves of goods and services are still at their infancy (Kohler 2002). Long-term modeling of the effects of resource depletion and environmental service decay on economic development and quality of life for humans is also quite limited (Bouwman and Costanza 2004)). Incorporating the insights from sociology and psychology is even further away, although promising avenues are emerging with novel methods like multi-agent simulation (MAS) and complex adaptive systems (CAS) approaches [9].

Nevertheless, we can and should do better than the IPCC-SRES effort. The Millennium Ecosystem Assessment (MA) has re-applied and refined the scenario methodology, with the notion of ecosystem services a central one. The Millennium Development Goals (MDG) is widening the narrow outlook of most economists and politicians, offering the possibility to bring in cultural and ethical dimensions. In the following paragraphs I will indicate some promising areas for further research.

2.3 Development of agricultural populations: past and present

2.3.1 Agricultural development

Food is the human-environment interaction *par excellence.* For the last 5 to 10 millennia, most human beings have been member of an agricultural society characterized by small family units, which worked the land and kept animals for food. They depended for their livelihood on agriculture and forms of hunting and gathering. Besides, there was small-scale resource use: stones from quarries, wood from forests, skins and bones from animals, and later metals from rich ores. Food was the essential numeraire for transactions and human and animal labour and soils the essential primary production factors. Gradually, the role of the non-farming

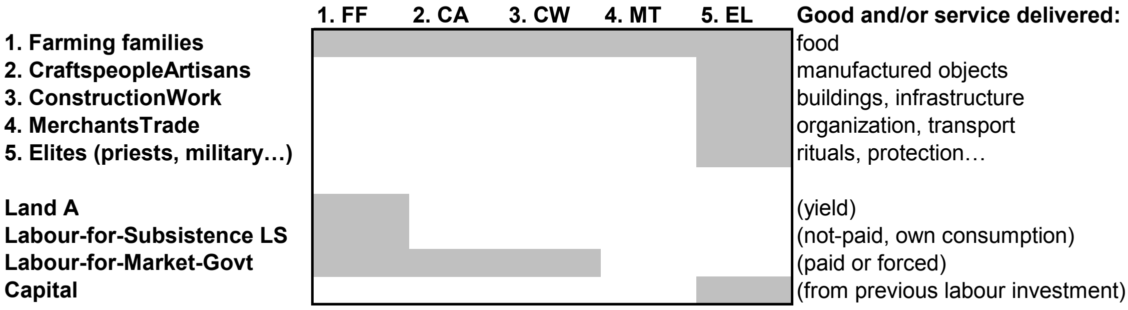
Statement: The role of agriculture in the economic development process is [in IPCC-SRES] neglected and badly understood

[8] It should be added that it was not permitted to incorporate large-scale catastrophes in the scenario narratives, although the protectionist materialist future (A2) was felt by most participants to be full of mishaps.

[9] Whether insights from sociology and psychology are needed for futures exploration is controversial in itself: the profit- and market-driven process of scientific and technological change may simply mold socio-cultural aspects according to its needs and provisions This leads to the question of steering scientific and technological change in politically desirable directions - a question which is largely suppressed by the rhetoric of consumers and markets.

population increased: artisans, priests, soldiers. They got part of the food by exchange or extortion and provided in return ‘goods’ such as houses or boats or jewelry and ‘services’ such as rituals and protection.

There was hardly any ‘consumption’ in the present-day sense. Within a given period (day, month, season, year) people would produce food, part of which was eaten and the remainder stored and/or traded. There was a ‘capital’ account in the sense that labour had to be invested into structures, which had to be sustained for longer periods. The capital took the form of infrastructural works (dikes, palaces, roads etc.) and of acquired skills (education). Both required the effort of skilled labourers and craftsmen and thus of food for payment.



Such a simple economy can be represented in an input-output (I-O) framework as in the scheme below. If food is the numeraire, one may call it a Food Input-Output Table (FIOT), where the grey cells indicate the place of important transactions. In such a *subsistence economy* it is useful to use food energy, in kcal/person/period of food supplied and required, as a numeraire to establish a measure of quality-of-life. Such an approach can be rooted in metabolism analyses of non-human species and of early human groups (Fischer-Kowalski and Haberl 1998).

2.3.1.1 Input-Output framework for a subsistence economy

The surplus is presumedly accumulated among the elites (column 5. EL), but the growth of capital in the other sectors (row Capital) is important in raising the labour productivity and the very possibility of other activities such as building canals and dikes for agriculture, quarries and mines for craftspeople, ships and roads for traders. The dynamics of these growth processes were largely determined by two processes:

- The gradual expansion into non-cultivated land and the intensification of land use, in order to raise food; and
- The organization of labour for construction and manufacturing and trading, in order to build up the stock of capital.

The dynamic interplay between available food, population growth and working hours is not a simple one, as the debate on the ideas of Malthus, Sahlins and Boserup has shown (De Vries and Goudsblom, 2004).

The relationship of these early societies to the formal economic descriptions en vogue nowadays is not simple either. The input of land, labour and capital can abstractly be conceived of as the production function, which postulates a production frontier indicating the available best combinations of various substitutable production inputs (or factors). However, the valuation of the production factors was different from today. Much was produced and consumed within the confines of the family, much exchange on markets may have been *in natura*; and much use of labour was coercive or *in natura* exchange for protection[10]. Hence, it is not easy to monetarize the activities in pre- and early-industrial societies as a basis for comparison (Maddison, 2001).

[10] See for instance Grapperhaus (2002) for a fascinating account of the history of taxation.

The European Miracle. Many books have been written about the reasons for Europe's ascendancy in the last 300 years, among them The European Miracle by Jones (1981; 2003) 'A study of a historian on Europe's comparative advantage in becoming the world's first and leading industrialist region'. Jones argues that environment, market and state have to be analysed to understand the reason. Certainly, the roots of Europe's industrialization are much earlier than Britain's rise. He rejects the idea that it mostly derived from exploiting colonies. In his view it is a mix in which the relatively small scale, political decentralization, markets for land and labour and rather small income differences makes the difference with the steppe imperia (Mongol, Moghul, Ottoman) being command hierarchies imposed upon customary agriculture. Also, European 'governments' had more concern about public goods such as disaster relief and incentives for private investment. *"A relatively steady environment and above all the limits set to arbitrariness set by a competitive political arena do seem to have been the prime conditions of growth and development. Europe escaped the categorical dangers of giant centralized empires as these were revealed in the Asian past. Beyond that, European development was the result of its own indissoluble, historical layering."* (Jones, 2003, pp. xxxvii).

It took millennia of social, cultural and political developments for Europe to reach the situation which is associated with an 'industrialized nation based upon market capitalism'. The landowning, clerical, business and trade elites became part of an increasingly organized society, in which the government exerted several monopolies (e.g. on violence and taxation) and formulated, implemented and enforced all kinds of regulations (Jones, 2003). More and more activities of people were incorporated in the monetary economy – and with it their assets and time. Food became a declining part of consumption expenditures. Criteria for happiness broadened from basic needs such as food (and shelter and clothing) to – an ever widening mix of goods and services, valued not only for their intrinsic and exchange value but also for their comparative and innovative features. Monetary flows, assets and income became the numeraire and yardstick par excellence in the industrial era.

The historical process of agrarianization is not over. Almost half of of human beings live anno 2000 still largely an agricultural life which is dominated by production of and access to food and soil – the agricultural stage. The material fluxes are relatively small and low-density, although they are increasing and start to cause local overexploitation in ever more places [11]. Food flows are largely in and between the farming families on local food markets. Energy stems for a large part from human and animal power, biomass (photosynthesis) and sometimes water and wind, at the level of 1 to 2 horsepower per person (25-50 GJ/cap/yr). Figure 2.7 shows the energy use distribution pyramid for energy for the world population in the year 2000 with and without 'traditional' (or 'non-commercial') biomass-based energy carriers (De Vries, 2004; World Bank data). As in ecological foodwebs, the large bottom of the pyramid is the millions of people who live a subsistence life. Part of the upper strata prey upon these lower strata in the form of surplus extraction. The lower strata may, however, still be the most resilient in the long term.

[11] See, among others, the Global Environmental Outlook 2002 (UNEP) and the syndrome approach enumerating various forms of stress situations resulting from population and economic activity pressure (Petschl-Held *et al.,* 1999).

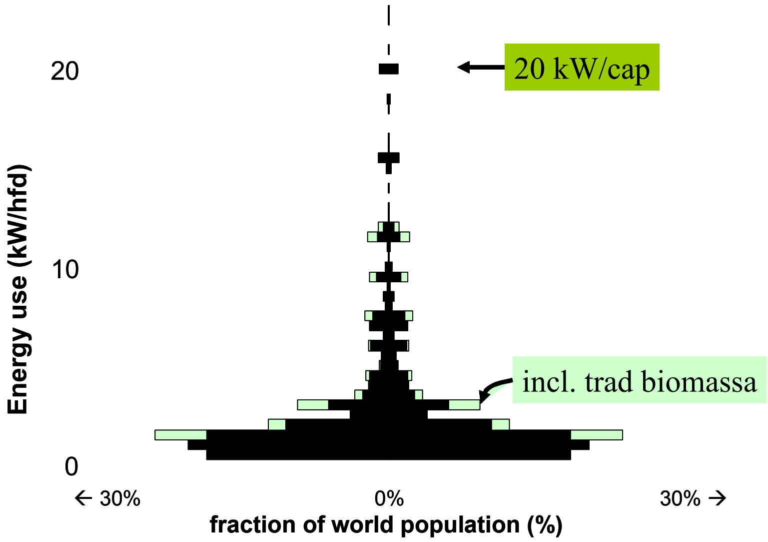


Figure 2.7. The world population (%) divided according to energy use (kW/cap) classes; the white bars are with inclusion of traditional biomass use

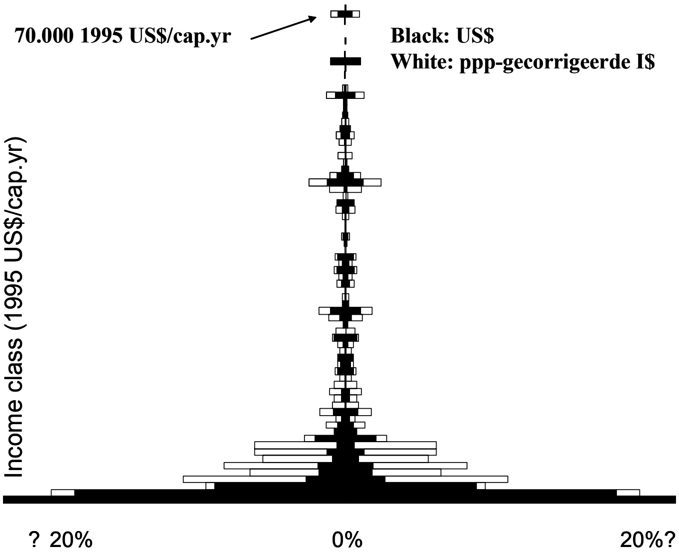


Figure 2.8. The world population (%) divided according to income (GDP/cap/yr) classes; the white bars are valid when purchasing power parity (ppp) factors are applied

Formally, the size of an economy is calculated from the value added in transactions between the groups identified i.e. the rows of labour for market-government and the rewards of capital (Appendix D). For this formal part of the economy, one can construct the monetary income pyramid. It is shown in Figure 2.8 above, for the world in the year 2000, and is seen to be more unequal than the energy use pyramid (De Vries, 2004; World Bank data). In subsistence economies such monetary flows are of course underestimating the actual human-induced resource flows in comparison with equal monetary flows in high-income regions. It is estimated that in large parts of rural India over 90% of human activities are in the informal economy i.e. not recorded in monetary balances (Dasgupta and Singh, 2005). Also in the more developed economies the informal sector is still significant[12]. The use of purchasing-power-parity (ppp) correction factors stems partly from this consideration and. decreases the income differences

[12] The size of the informal sector is difficult to estimate, even if well-defined. Schneider and Enste (2000) found that around 1990 it accounted in most LDC for more than 15% and in OECD-countries for 10-20% of GDP. They estimated that it had changed with up to 15% point in OECD-countries during the 1970-1990 period.

(cf. Van Vuuren and Alfven 2006). Here, even more than in the energy use pyramid, the upper strata extract surplus from the lower strata by their superior knowledge and information structures and access to capital and other resources.

> *"Chotu Ram knew that 'development' was not necessarily to the advantage of everyone… Chotu Ram was a Kumhar, or potter, by caste but nowadays the farmers were cash-conscious and unwilling to spare any of their land for his caste to dig clay. What's more, clay cups and pots were today considered inferior - stainless steel, plastic and, among the wealthier, china had taken over. When the service of potters had been as essential to [the village] Thakurdwara as that of barbers or washermen, Chotu Ram's family had been reasonably well looked after. They had received grain and other gifts that at least provided their basic requirements. Now Chotu Ram had become a modern man, he'd entered the cash economy, but the wages he received barely allowed him to buy anything beyond the grain his family ate, and they certainly did not cover the emergencies that every family in the village had to face from time to time. "* (Mark Tully, The Heart of India, 1995 pp. 22-23).

In early times, one may presume, people's happiness was for many linked to the absence of disease, hunger and war. For many this is still true. Absence of disease, hunger and war is in complicated ways connected to resource availability, organizational and other skills and institutional and governance arrangements. 'Modern' development theories suggest that a process of modernization as the high-income regions of the world have experienced is the road to progress. The Millennium Development Goals (MDGs) are an expression of such a development creed. Yet, the road will be different.

Can the development path of the present high-income regions be imitated? History never repeats itself. In particular:

- present-day low-income regions have to develop in a socio-cultural and economic situation totally different from that of 50-100 years ago - for instance, in terms of communications and travel and of agricultural and industrial competitiveness;
- much of the available resource base: land, fossil fuels, fishing areas, forests, has been or in being depleted - so instead of the advantages squeezed out of populations during colonialism, there are the disadvantages of less access to lower-quality resources.

The intrusion of new goods and services, which equally attract the unscrupulous rich and the adventurous young, are pushing development in consumer directions, which cannot easily be accommodated by their own populations. At the same time, it offers consumer and entrepreneurial opportunities unknown to any previous generation. Examples are seen all over the world: the penetration of the private car driving out the bicycle, the change in food diet, the rapid introduction of the Internet and the mobile phone etc.. The development process is thus partly the result of unsatisfied basic needs (poverty-driven) and partly of the aspiration to become 'modern' (supply- and imitation-driven). Its unfolding in the course of this 21st century will probably be some mixture of 'dynamics-as-usual', anticipated novel trends and unknown and unknowable surprise events.

2.3.2 Energy for agriculture

What can be said about the prospects for the world agricultural population - at least two billion people - to develop themselves to what often is called 'a decent life' and at the same time remain within the constraints set by longer-term continuity: what are their prospects for sustainable development? In my view the role of agriculture in the economic development process is (in IPCC-SRES) badly understood and, maybe for that reason and/or because agriculture is minor in monetary terms, neglected.

A take-off for development – which is usually equated with economic growth – has to come from the organized use of the means at one's disposal, that is, the available resources. This supply side consists of the 'primary production factors': land, (renewable and non-renewable) energy, labour and capital, which are mutually connected via engineering and economic production processes. In the modern world, the quality and value of these production factors is a complex function of local as well as global determinants such as capital and knowledge availability, soil and climate, food demand and others.

What gets such a take-off going? Most research indicates that the labour surplus, which occurs upon productivity increase looks for job opportunities in the towns and cities. Driven by a perceived differential in quality of life - among it: income - an enormous urbanization process unfolds. In the present world where there are less barriers to the trade in primary resources and manufactured goods but also in production factors (labour but especially capital and knowledge), the development process appears to be characterized by:

a) Globalization of food production-trade-consumption, which gives (export) opportunities for certain groups in low-consumption regions but can also disrupt the food supply system for the indigenous population;
b) Rising though often latent unemployment in agriculture leads to migration to urbanized regions, where labourers compete at low wages for few jobs in capital-intensive world-market oriented industries;
c) Part of the educated population manages to create value-added in the service sector (banking, ITC, tourism) but the larger part of the urban populations have to survive in a largely informal economy with, a.o., providing low-skilled services (cleaning, laundry, childcare etc.) to the urban elites.

How this process will unfold will depend on local/regional opportunities but also on socio-cultural and political values and trends. Because of the large uncertainties involved - will the elites mimick western life-styles, will food security be a major concern etc. - it is best to use scenarios, that is, models within a narrative context (De Vries, 2006). I focus for a moment on energy inputs.

Farming families had, and largely still have three options to create surplus (‘value added’) and participate in economic growth:

- • increase labour productivity: this requires usually machinery such as tractors (diesel) and infrastructure (indirect energy) i.e. energy- and capital-intensity rise;
- • increase land productivity: requires usually additional inputs such as fertilizers (indirect energy) and pumps (electricity) i.e. energy-intensity and possibly labour-intensity rises;
- • put new land into cultivation (extensification) – often at a lower marginal yield.
- In practice, a combination of the three happened and happens. World acreage used for food production was 6% of the land area in 1700 and 37% by 2000. In the high income countries land and labour productivity are a factor 10 and 50 respectively higher than in earlier and present-day subsistence economies (Giampietro, 2002, pp. 327).

An enormous increase has occurred in the capital-labour ratio, with capital (tractors etc.) and energy being complements (Figure 2.9). Past developments in the industrialized countries suggest a route of increasing fossil-fuel intensity as a substitute for human and animal labour (Figure 2.10). In most countries the agricultural labour force has declined to a few percent only of the total labour population, but the huge expansion of the food processing industry (including packaging and transport) has kept the food industry an important economic sector.

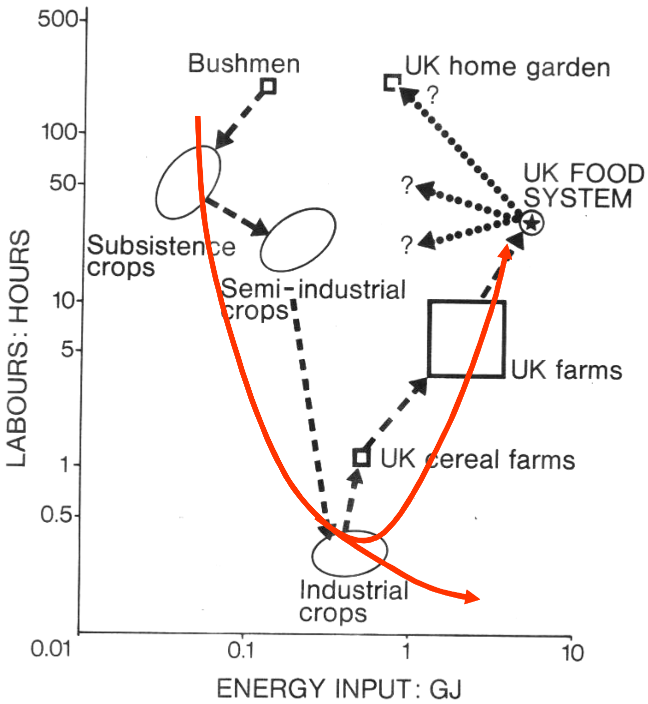


Figure 2.9. Normalized inputs of labour and capital in agriculture, Belgium and USA 1885-1995 (Shankar et al., 2003)

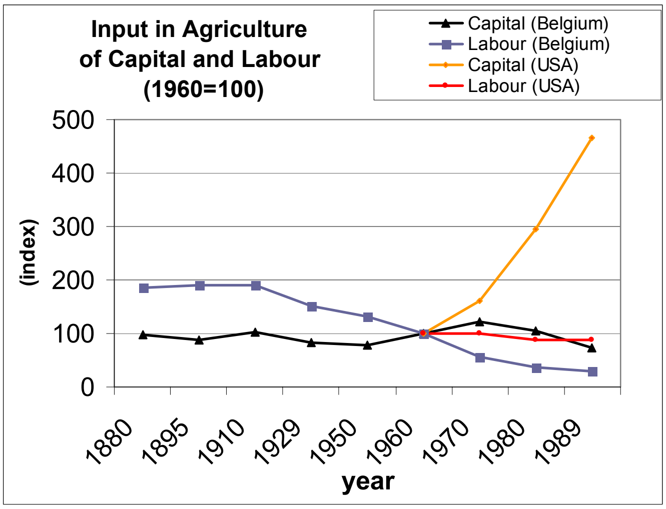


Figure 2.10. Inputs of labour and energy per unit of food in various farming systems (Leach, 1976)

In both globalizing IPCC-SRES scenarios (A1, B1) it is assumed that the skills and resources are available to increase food production in non-OECD regions (IMAGE-team, 2001). Because the cultivation of new land is limited, this will inevitably mean a further intensification of agriculture, in the form of irrigation, increased use of fertilizer etc.

It is unclear whether the large rural populations of the low-income regions will have the purchasing power to buy the necessary inputs to produce sufficient surplus food and to make the transition to producing for and working in the formal economy. It will happen in some regions, probably under intense global competition and in combination with food processing as the value-adding part of the food chain. Here, the risks of pesticides and other chemicals and of biotechnological techniques may become a paramount issue ('biosafety'). In other regions it may not succeed, simply because the conditions for such a take-off are not fulfilled. For instance, there may be serious and increasing water shortages and stagnation in the transition to more water-efficient techniques due to lack of capital and skills. In these areas outmigration and food aid may become inevitable ingredients of the future. Climate change may for them become the final blow.

Will the expansion of food supply for the 2 à 3 billion people who are still aspiring for a more healthy and complete diet be thwarted by high costs of and limited access to energy carriers [13]? A quick calculation: the total primary energy use over the food supply chain (agriculture, fertilizers, transport and food processing) in the EU-13 between 1970 and 2002 has increased on average with 1,6 %/yr to about 3960 PJ/yr (or 7% of the total final energy use) (Ramirez 2005). The energy-intensity measured as energy use per unit of economic value added (GJ/€) has been declining with an average 2.7 %/yr. Thus, some 340 10^9 1995-ppp € of value added (or 5% of EU-13 GDP) was produced in the EU-13 food chain with some 7% of the total labour force. To raise 2,5 billion people from the present 40 GJ/cap/yr level of mostly renewable biomass input to the average 11 GJ/cap/yr of mostly fossil fuel (2002) for the EU-13 agriculture and food processing would require an additional fossil fuel use of 27500 PJ/yr. This 1/6th of present (2005) world oil production or less than the 1990-2000 growth of oil use for additional private cars [14]. The equivalent economic value added of 945 1995-ppp €/cap/yr would imply a 5-10% rise in present (2005) world GDP - but part of it would simply be a formalization of activities already performed.

Thus, technically speaking and from an energy point of view, it appears a rather easy task to ban large-scale food deficiency in the world. But, let us suppose that rural populations are able to organize such an agricultural development process. The limits they face will have to do with:

- *Land*: many of the low-consumption regions are close to the carrying-capacity for humans - if these are exceeded by population growth and/or lifted with the help of intensification (more inputs, new technologies), survival risks will increase or shift;
- *Energy*, notably oil: will they have a chance on the world energy market with ever more competition to get the depleting stocks of cheap oil and gas? Probably not, which implies the use, at least partly, of indigenous energy sources such as indigenous coal-based electricity or biomass-derived fuels;
- *Water*: large human populations are living in semi-arid regions where water supply is fluctuating and/or scarce; this may put serious constraints on the sustainable development of food provision;
- *Infrastructure*: to get agricultural production and processing going, there will also be a need for adequate roads and/or railways, for financial services and education etc. - which presumes well-functioning institutions, government and other, at various levels;
- *Environmental change*, among it deforestation and soil erosion and in the longer term climate change and its impacts on land, water and other ecosystem services; although they hardly contribute themselves to greenhousegas emissions, the large rural populations may also be the more vulnerable ones if climate change is to occur in the form of more intense storms, sea level rise etc [15].

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13 The answer will of course depend on many aspects, as has been worked out for four scenarios in the Sustainability Outlook (RIVM, 2004).

14 Assuming EU-13 about 360 mln people with an average income of 22000 1995-ppp €/cap/yr.

15 Also eutrophication and deforestation related erosion are posing increasingly serious risks (see e.g. RIVM, 2004).

Food trade may help some populations for some periods, but there are risks too. Food aid may erode the local farmer's capability to produce food and lead to a food dependency lock-in. Food dependency, directly via imports or indirectly via patents as with GMOs may cause food price volatilities which can trigger a spiral of social unrest and declining food production. In my view, the best way to address these threats is to emphasize to a much larger extent the opportunities for local self-reliance and resilience - with micro-credits, locally grown energy crops, appropriate transport means etc. The emergence of ICT and in particular internet can give a totally new impetus in this respect.

Although much local and anecdotal evidence is around, it seems there is not yet a comprehensive and transdisciplinary framework available to investigate these issues and formulate effective policies around it. Clearly, more energy will be needed - but will those in need of it get it? Will enough land be available? Can we enhance the resilience of these populations for external disturbances such as more intense weather events or global trade shocks? This part of the global change future has to be explored in more depth and more systematically than has occurred in either the IPCC-SRES or the MA scenarios. It is particularly important to acknowledge the diversity and heterogeneity in biogeography and social and cultural circumstances, instead of pushing a single image of the world-to-be. More specifically, it is of prime importance to **collect the numerous bottom-up models about low-income populations and their (agricultural) activities and construct a generic model which can be used to simulate the onset of (formal) economic development against the local/regional biogeographical background.** Examples of such models abound in the literature, for instance the SALU model (Stephenne and Lambin, 2001) on the Sahel, the CLUE-model (Verburg, 2002), the FALLOW model and others (http://www.worldagroforestry.org/sea/Products/AFModels/fallow/download.htm). Most of these models are not (yet) connected to a larger I-O-based macro-economic framework. A more integrating framework is the Geonamics software tool, which has been applied in for instance Sulawesi; this approach uses cellular automata and macro-level dynamic models against a background of biogeographical information (Engelen *et al.*, 1995; www.riks.nl).

2.4 Economic growth: the process of adding value

2.4.1 Economic growth and the role of matter and energy

Statement: Without addressing the nature of economic [value-added] growth, the money-material link will remain ill-understood

Over the last decades, the neoclassical formulation of economic theory has suffered increasingly from attacks on its ideological and abstract-theoretical content. The search for a more sustainable development pattern, which received a boost with the publication of the UN-report *Our Common Future* (1986), has been one of the sources of discontent and has given birth to such disciplines as ecological and evolutionary economics. Critical new streams of thought in these disciplines have pointed out that the conventional theory has serious shortcomings, such as the neglect of the laws of thermodynamics and unacceptably simple notions of complex ecosystem and innovation dynamics. The simplistic formalisms of neoclassical economic growth theory are slowly refined and extended. Nevertheless, the modern economic world system is of such a complexity that one should not hope for a single comprehensive explanatory theory. Moreover, attempts to improve existing concepts and hypotheses are hampered by outdated ideas and data. I discuss a few interesting ideas in the matter-and-money context and as a sequel to paragraph 2.

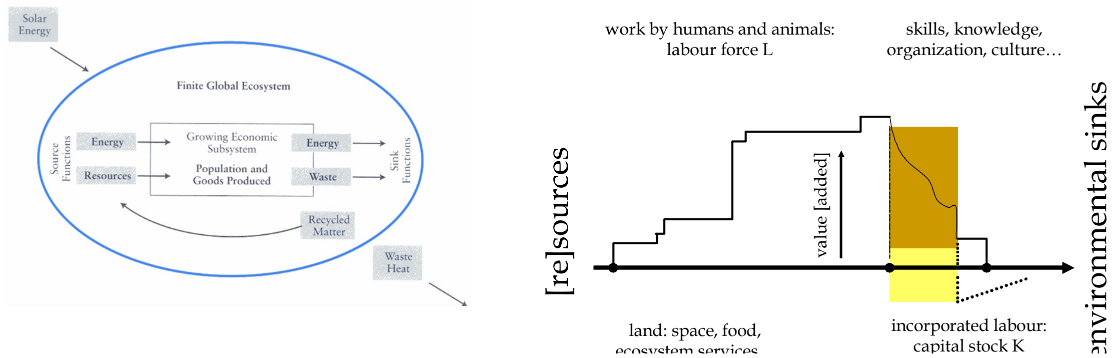

Figure 2.11. The economic process within the larger confines of the global ecosystem and as a chain of value adding and eroding processes

What, then, is the economic growth process about? I suggest Figure 2.11 as expressing the three most important 'textbook' notions:

a) an economy is the subset of processes which interfere with natural stocks and flows of matter and energy, in order to satisfy human needs and aspirations (Figure 2.11 left; Meadows *et al.,* 1991, Hart, 1996);
b) an economic process is thus a process in which value is added to parts of the natural system, by human labour and skills and ingenuity (production), and subsequently value is lost (consumption) (Figure 2.11 right);
c) in the process the natural system dynamics will be influenced in a variety of ways, such as ore quality decline and metal dispersion etc. – loss of available potential to do work (exergy) being the one common feature across all these changes.

The first point makes it clear that economic activities happen in-between natural sources and sinks of matter and energy which obey the laws of thermodynamics - as Georgescu-Roegen (1979) as one of the first economists discussed from an economic point-of-view. It is now a scientifically well-established but not widespread understood fact that what we call economic activity can only occur with the use of exergy i.e. some degradation of a high-quality to a low(er) quality energy flux. Such a potential of useful work can be in the form of flows such as solar irradiation, strong ocean or air currents and photosynthesis, or of stocks such as high-grade metal ores and past accumulations of carbon ('fossil fuels').

Energy as an input is in most economic analyses considered as one of the subordinate production factors, labour and capital being the more important ones. This is understandable for a period in which fossil fuels were abundant and becoming cheaper every year. This has changed in the second half of the 20th century. Moreover, it was found that labour and capital - the rewarding of which has been and is one of the big issues in economic history - explain only a small part of historical growth in GDP – the residue has to be ascribed to 'technological change' (Solow 1957). Energy has been undervalued in economic analyses because the coal and later the oil and gas which fuelled the industrialization process were considered to be available 'for free' [16]. In fact energy inputs, if properly measured, are besides labour and capital the key explanatory factor behind economic growth. For the USA, for instance, the input of energy in the form of useful work ('exergy services') yields an almost perfect explanation of GDP-growth for the period 1900-1975 on the basis of the so-called LINEX production function (Ayres, 2003, Ayres and Warr, 2005):

$$Y = A \cdot U \cdot \exp\left(\frac{aL}{U} - \frac{b(U+L)}{K}\right)$$

[16] Unlike in pre-industrial societies where people are well aware of the time used to gather fuelwood or the land required for feeding animals.

with labour input L, capital input K, useful work input U and A, a and b parameters [17]. Two points are remarkable. First, useful work (or exergy services) may well be a *sine qua non* for the kind of GDP-growth the high-income regions have realized in the past. Secondly, after 1975 the US-economy has experienced another source of value added - possible candidates are the oil price hike induced efforts to increase energy productivity and the rise of ICT. This strongly suggests that GDP-growth in the low-income regions of the world will inevitably concur with an increase in the use of exergy services - notably of the high-quality carrier electricity. Or, stated differently, it suggests a clear lower bound on the energy-intensity defined as useful work per unit of value added (GJ/€).

Depletion and degradation. While adding value to natural resources in order to extract economic value or 'utility' from it, human societies are degrading the stocks of high-quality energy and minerals and the stocks and flows in renewable resource systems such as fisheries and forests. Degradation of non-renewable resource stocks has so far largely been offset by human ingenuity: discovering new or previously unusable stocks (coal, oil, gas, uranium) has led to a long-term decline in the labour and capital required to get one unit of energy [18]. However, with the ongoing depletion of the world's low-cost high-quality exergy stocks, the cost of exergy service provision will inevitably rise. In fact, the transition to lower-quality stocks (tar sands, oil shales) and more capital- and knowledge-intensive alternatives (nuclear, wind, solar, biomass) is at the very heart of the abovementioned IPCC-SRES scenarios. Regarding renewable resources such as soils, forests and fish, here too the ongoing overexploitation degrades the resource base and forces a switch to more costly and lower-quality alternatives.

More recently, the attention has been drawn to the more general and widespread effects of economic growth (Y) on ecosystem services (www.millenniumassessment.org). Their role in providing necessary but often non-priced inputs for economic processes is becoming more clear, now that productive soils, unpolluted water flows and clean air become more scarce. Yet, it is not easy to assess their role as they are in multiple ways connected to human activities[19]. Their valuation is also contentious, not in the least because it usually is a common resource for which adequate exploitation regimes have to be established lest they are not degraded or even destroyed. A difficulty here is - a major topic in environmental and ecological economics at which level the quality of ecosystem services should be sustained. This, of course, depends not only on the ‘utility’ in a broad sense derived from it but also on the effort, or utility’ forgone, by maintaining the quality.

One approach is to assess the economic value of the ecosystem services lost. A practical solution is to count the inputs needed to restore the environmental quality, c.q., ecosystem services to the desired level as the value added which should be assigned at the very beginning to the natural resources, together with the lost resource value due to size and quality decline. Of course, there will never be an absolute reference point in complex socio-ecological systems: humans have been altering many ecosystems already for centuries or even millennia. In its most simplistic form solved with (marginal) abatement cost curves and the various methods to evaluate the (implied, long-term, discounted) costs of ecosystem damage against the (short-term, discounted) costs of reducing ecosystem interference. As has been argued in the Sustainability Outlook (RIVM, 2004) a more strategic and comprehensive approach is to use cultural perspectives and value orientations. For instance, one can distinguish the extremes of a risk-taking entrepreneurial attitude ('nature robust', risk of lost business opportunities) and of a risk-averse conservationist attitude ('nature fragile', risk of irreversible loss) (see e.g. De Vries, 2001a). Recently, the notion of synergy or co-benefits, that is: of policy measures, which simultaneously support the quality of various sources and sinks, is gaining prominence.

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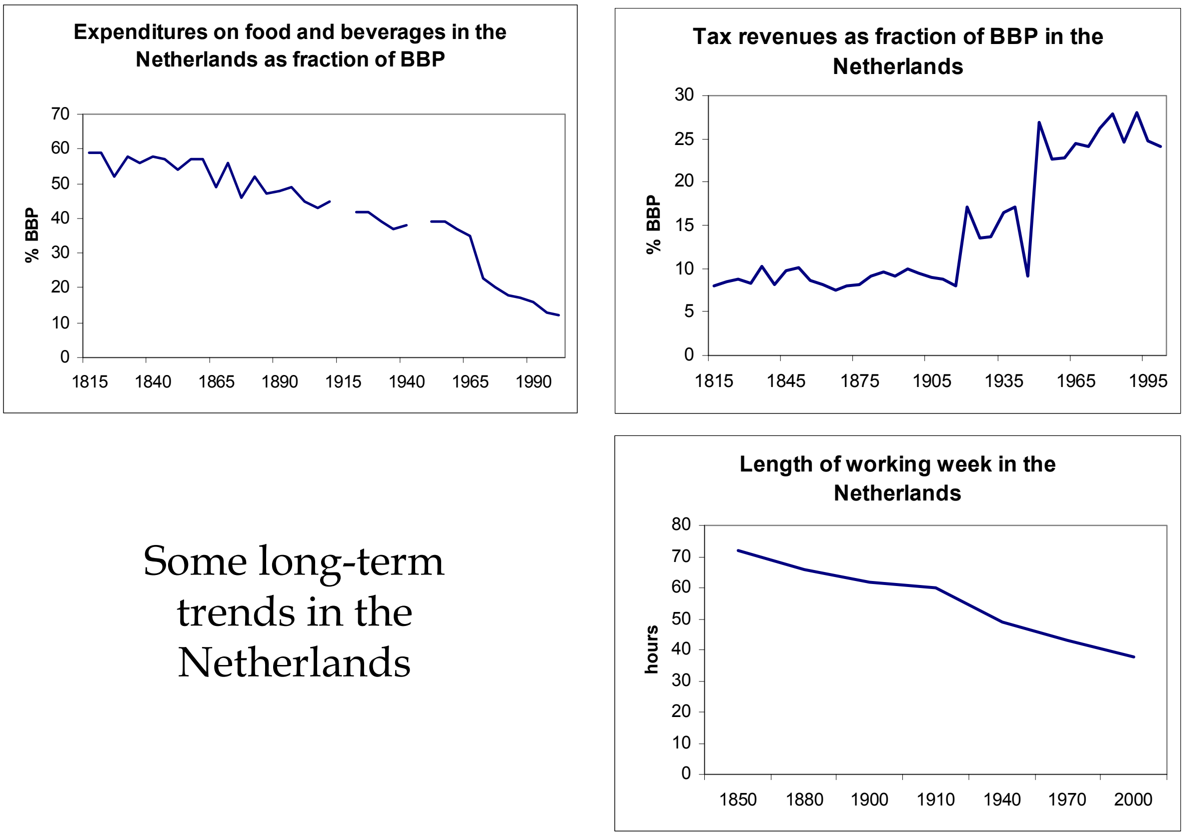
17 If commercial energy use is used for U instead of useful work, the explanation fails. It highlights the important role of electric power.

18 Not necessarily per unit of useful work. It would be interesting to analyse the useful work per unit GDP at sectoral level to deepen our understanding.

19 For instance the research done in the Resilience Alliance (www.resalliance.org) on the dynamics of socio-ecological systems gives novel perspectives on this issue.

2.5 Forces of economic growth

People are motivated by complex needs and desires (Douglas *et al.* 1999). Often, it is assumed that at low income levels the needs are rather straightforward: food, shelter and clothing as basic needs. Such a view, inspired by amongst others Maslow's hierarchy of needs, may be far too simplistic. In low income populations needs are to a large extent socially constructed (Max-Neef 1991, 1995). This is even more true at higher income levels. At the income levels prevailing nowadays in most European nations, North-American states and Japan, the consumerist culture has developed its own mechanisms to channel peoples' energy and serve the needs of various societal groups. Neo-classical economic theory with its emphasis on a individual utility curve and its utility maximizing agent with perfect foresight looses its relevance as a tool for insight and policy. **One important challenge for a next round of (emission) scenarios is to acquire a more in-depth understanding of the forces behind the activities of people as producer (labourer, employee), consumer – and citizen.** In the last decade, a lot of novel and creative work has been done in this direction – for instance, on the balance between competition and cooperation, on the dynamics of innovation and on the role of comparison and imitation in consumer behaviour.
To trace and explain longer-term economic development processes, one has to come up with stylized facts about a series of phenomena (cf. paragraph 2). The graphs in Figure 2.12 show some long-term trends for the Netherlands:



Bronnen

CBS: Nationaal goed, Feiten en cijfers over onze samenleving (ca.) 1800-1999

CBS en RUG: Tweehonderd jaar statistiek in tijdreeksen (1800-1999)

Figure 2.12. Some long-term trends in the Netherlands

- the persistent decline in expenditures on food and beverages as fraction of GDP;
- the continuous rise in tax revenues as fraction of GDP, reflecting the rise of the welfare state with its collective organization of health and education, infrastructure, social security etc.;
- and the halving of the working week since the mid-19th century.

Such long-term trends are evident in most of the presently ‘high-income’ (OECD) countries of the world. They are associated with the process of ‘modernization’ and ‘westernization’. Other trends can be added, such as population growth, throughput of energy and materials, fraction of women working in the formal economy etc. What matters here is that these trends have an underlying robustness: they have not been broken by major events like the 1st and 2nd (European) World Wars, the breakdown of colonialism and two oil prices crises.

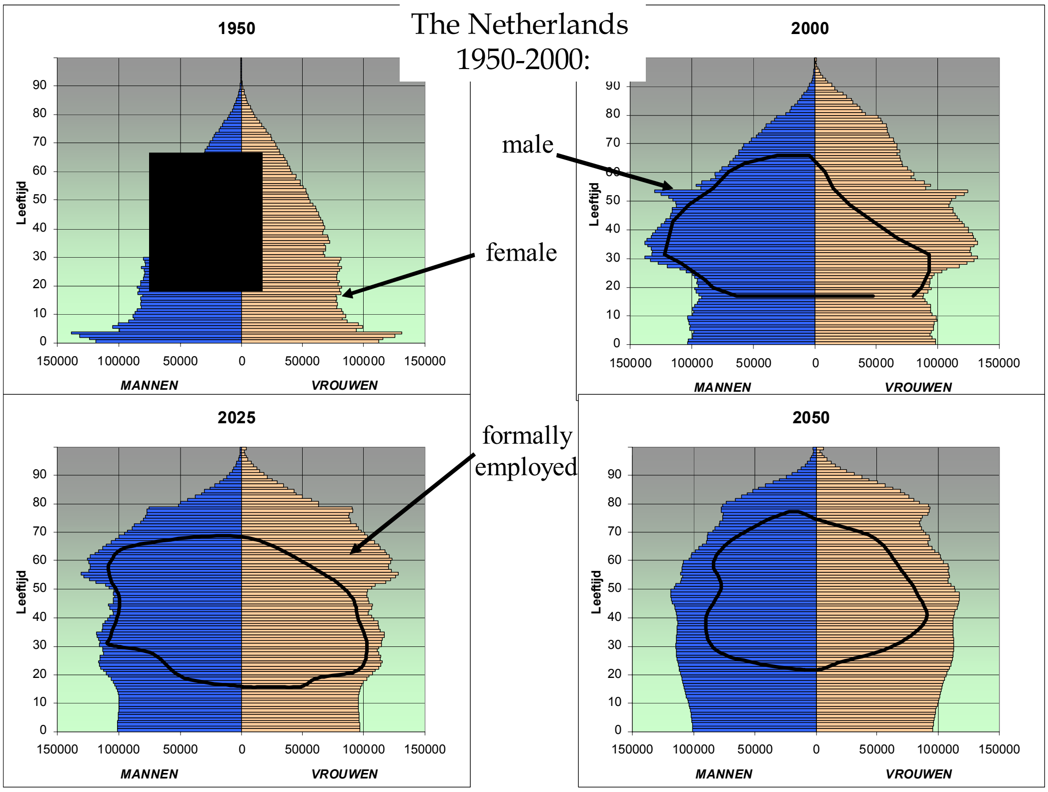


Figure 2.13. The population pyramid in The Netherlands, 1950-2050 (De Jong and Hilderink, 2004)

It appears that part of the robustness stems from a single key factor: human population dynamics. Populations have an inherent inertia, referred to as the population momentum. It is a rather robust phenomenon, although there may be surprises e.g. in migration (see e.g. Hilderink 2000; http://www.mnp.nl/image/model_details/population/). The graphs in Figure 2.13 show a reconstructed population pyramid for the Dutch population between 1950 and 2000 and a forward projection for 2025 and 2050. These pyramids indicate not only people as consumers and citizens but also people as labourers and employees - two key variables for the size and nature of economic (GDP) growth. The bars show how many male (left) and female (right) individuals were living in the Netherlands. The grey areas indicate, in a crude fashion, the part of the population which was/is formally employed. Since 1950, the population has almost doubled. In the future, the increase in number of persons will be much smaller – a rather solid prediction. Since 1950, many activities (household work, child and personal care, educating, enjoying nature) have become part of the formal monetary economy – and are measured as GDP-growth. At the same time, the number of working hours has declined, periods of education are longer, there is more part-time employment and early retirement is on the rise. The increase in labour/employment is less easy to forecast, as it involved more complex dynamics and value aspects. Dutch and European populations, for instance, are becoming older on average and should for that reason work beyond 65 years 'to keep the system financially viable' – according to the conventional economic view. This in itself will generate GDP-growth - but one has to speculate, as is done in scenarios, about the nature of the additional activities and their consequences for matter and energy flows. Will they be in the formal economy? Will older people become even more avid car users, travel ever more often to their second home with cheap carriers? Or are they the green 'health food' and 'slow food' oriented consumers of the future, decide to invest responsibly in energy efficient houses and cars and give the local craftspeople new prospects? Or both?

There are, of course, other forces at work to keep economic activities (and GDP) growing:

- the inherent sense of ambition, excitement and entrepreneurship will cause (young) (parts of) populations to develop *new desires and needs* and aspire to satisfy these; this process is reinforced by increasingly commercially driven science and technology;
- *capital* and the financial elites behind it are roaming around the world in search for high returns and are as such a, if not the, major force behind economic expansion; the resulting financial imbalances pose serious risks to economic stability;
- labour, losing power in the process of globalization, bargains with national/regional governments to safeguard fair income distribution - thus, the breakdown of the welfare state as part of international ('cowboy') capitalism is counteracted by the attempts to create *employment* despite labour productivity increases and outmigration to low-wage areas [20];
- *political elites* have to gain from economic growth as their spending power is directly related to it; it also explains to some extent their desire to bring the informal parts of the (national) economies under government control and resist proposals such as a basic income [21].

In a more socio-psychological and philosophical vein:

- the *financial and social insecurity* which has accompanied the cultural changes in the 1970s and the emergence of neoliberalism in the 1990s may intensify the desire for (individual) wealth as a source of independence;
- with the rise of labour productivity and globalization in manufacturing, an increasing fraction of the population depends on activities of *income (re)distribution* via government and/or market services – which may strengthen the aspiration for growth in monetary flows cq. GDP as this is associated with one's own financial and employment situation;
- a *'bottomless barrel' of desires* may counteract any trend towards saturation in matter and energy fluxes, if the desires are directed towards private jets and spaceflights, personal robots and the like.

Whether this implies a continuing growth of GDP, as assumed in almost any official scenario, and whether this will be in a decoupling with energy and material flows is not clear [22]. There are forces at work, which tend to slow down the process of (economic) development. Saturation in the sense of 'having enough' or not being able in terms of skills or time to consume more, is one of those forces - as advertisement companies know in their attempts to annul it. Sometimes, as consumers become more aware and critical, there may be the realization that (part of the) *consumer desires* are (increasingly) activated by media, comparison, status and competition and therefore by their very nature never (fully) will be satisfied (cf. Hirsch 1977,

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[20] Attempts to preserve and/or create employment can be realized in various ways and by various groups, as the scenario approach highlights. In Europe, for instance, finance and high-tech jobs would prevail in an A1 future, reinforced by the logic of large government and business bureaucracies. In an A2 future, military and security services and surveying and monitoring systems would be a source of employment, as if happening right now. In a B1 world (inter)national organizations would create employment in their desire for diplomacy and negotiation.

[21] The I-trends comprise individualization, informalisation, informatization, internationalization, and intensification (www.scp.nl). An estimated one third of the GDP-growth in the Netherlands between 1990 and 2000 is related to an increasing fraction of women entering the formal labour market.

[22] Almost every official GDP-growth projection in OECD-countries assumes – desires, plans for – between 2 and 3 %/yr GDP-growth, as if in a competitive bidding process. This is possible because high income in GDP/capita is judged as an achievement and as a measure of well-being (see Van den Bergh, 2005 for a refutation). In low-income regions such as China and India, official projections extrapolate the trends in the last decade and assume GDP-growth rates between 7 and 11 %/yr.

Layard, 2005). Other developments, which may constrain and slow down or even halt the growth process:
- system aspects: although one would like to have the good or service, the system to deliver it is deficient, expensive or absent; this may be associated with the 'law of increasing complexity' (Tainter 2000);
- time use aspects: high consumption levels require a rather well-organized household management which not anyone is willing or capable for;
- spatial/environmental/ecological constraints in the form of traffic congestion (for increasing persons/km^2), declining air quality or high costs/efforts for experiencing nature; social and psychological constraints in the form of stress due to efficiency/market processes (advertisements, fraud, job insecurity), demand for high productivity etc.

2.5.1 Manufacturing and dematerialization

Is it possible to get a more systemic insight into the process of economic growth? Numerous books and papers have been written about it, theories and hypotheses abound. Here, I will only discuss briefly an approach, which may shed some more light on the matter-money relationship. At its core is the upper diagram in Figure 2.14, adapted and extended from (Ayres, 2003). It indicates two basic loops driving manufacturing as part of economic growth:
- population growth, with an associated demand for goods; and
- increase in knowledge (RD&D: incremental and breakthrough innovation) which causes a continuous increase in labour productivity.

As a result, the unit cost c tend to go down and, with fluctuations, the price too. This induces an increase in demand, at times spurred by advertisements by the producers who prefer growing markets over a competitive struggle for market share. Rising demand will lead to expansion investments, which tend to bring costs further down with economies of scale and mass production. Land use for manufacturing and offices will increase. The cycle presumes sufficient savings to provide capital at a sufficiently high reward. In the process, the natural resource base will be degraded, but the subsequent inefficiency and cost increase has been largely offset by RD&D.

The rising labour productivity has three important consequences, shown in the middle graph of Figure 2.14. The first one is rising demand as wages go up. Secondly, a lower demand for labour - except for high-skilled labour in the RD&D - and hence rising unemployment. Thirdly, an increase ion capital per unit of good and its usual complement, energy, as these are substituted for labour (cf. paragraph 4.1). In a wider context, as shown in the lower graph of Figure 2.14, the population becomes involved in more indirect and longer-term ways:
- as a political force to promote economic growth in order to maintain a desired level of (formal) employment; this can lead to a ‘race to the bottom’ with regard to perceived barriers to growth such as environmental regulations;
- as ‘small capitalists’ in order to assure a high return on their savings; this may actually reduce employment as capital can be drawn to other high-growth high-profit regions in the world and/or accelerate the call for economic rationalization in the form of rising labour-productivity.

What does this mean for the matter-money issue?

One way to look at dematerialization is in the framework of Figure 2.15 *(*cf. Appendix B*)*. There is a strong decoupling if for a positive change in economic activities – measured usually as GDP – there is a negative change in the environmental pressure – expressed as some combination of factors EP. For the reverse, there is recoupling. One can define other forms of de/recoupling. Economists often use the concept of growth elasticity to discuss these issues. One result from the numerous analyses for EP being energy and/or material flows is that the outcome is dependent on which system (country, sector) and which time-period is considered (see e.g. De Vries *et al.,* 2001b).

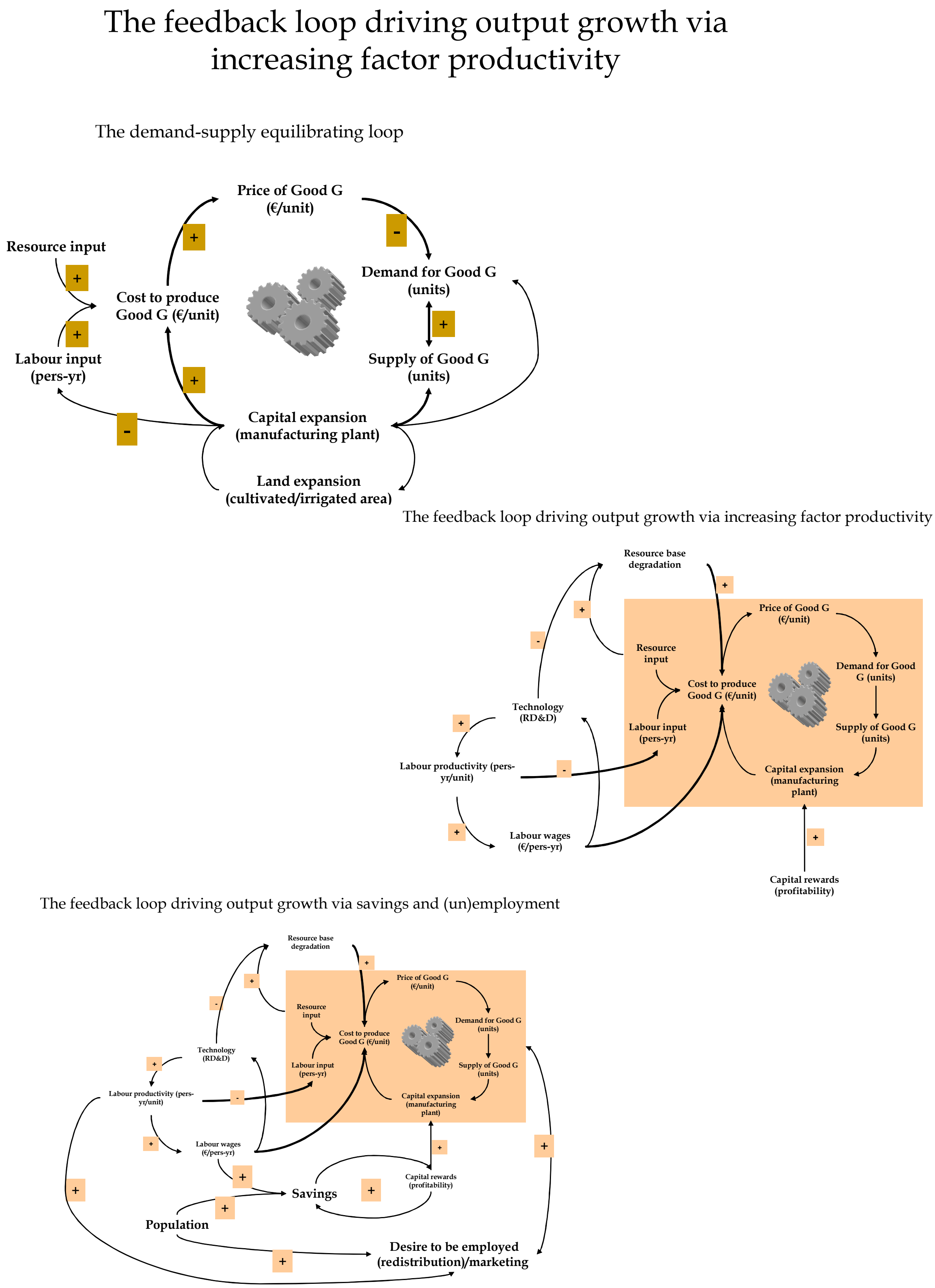

Figure 2.14. Elements in the dynamics of economic growth

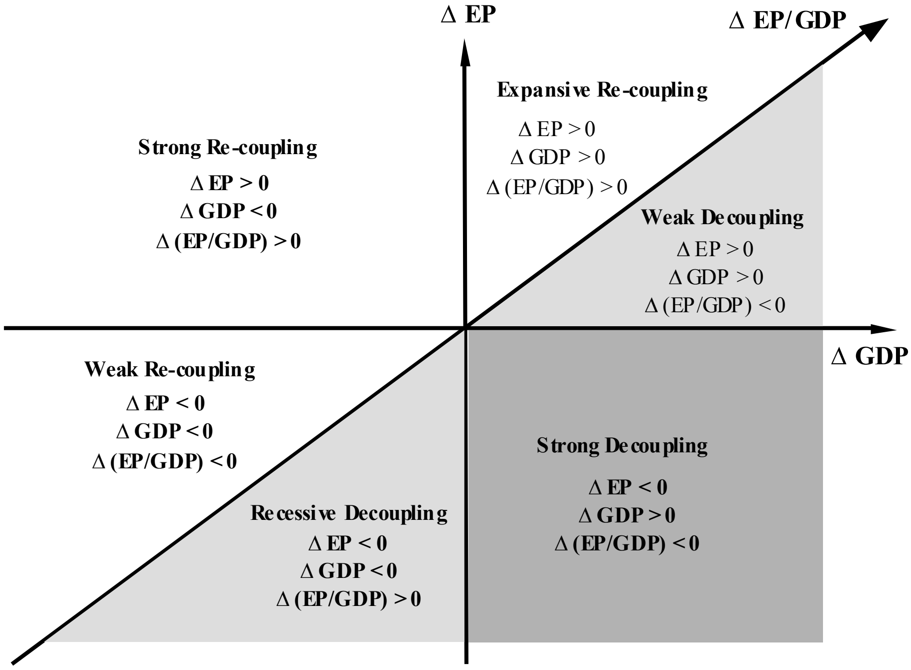

Figure 2.15. Dematerialization: decoupling of the indicator of economic activities: GDP, and some indicator of Environmental Pressure (EP) (Vehmas et al., 2003)

In the present context of forces of economic growth, I like to hypothesize a framework for further analysis sketched in Figure 2.16. Let us assume that the goods producing process shown in Figure 2.14 implies a gradual increase, then a maximum and gradual decline in the *economic productivity* defined as Value Added (VA) per unit of good, in €/ton (upper left graph). The initial rise is when a new product has still an unmet demand and profits can – and sometimes should in view of large RD&D expenditures – be large. As competitors enter the arena, labour productivity will increase and profits will be under pressure – hence the decline in VA per unit, although the decline can be slowed down by economies of scale and scope, oligopolistic prices settings and protectionist measures and subsidies. The way forward in an open, competitive economy is to innovate and develop a new product with superior quality and/or new functions.

Such a next stage (upper right graph) would entail an increase in VA per unit, partly in manufacturing but partly also outside manufacturing *per se*: research and consulting services, legal and financial services, transport etc. In this way, the economic productivity in the above sense can be maintained at a high level with an expanding spectrum of products and production activities. Unfortunately, such a shift cannot easily be derived from the available statistical data, which makes an empirical validation of the hypothesis quite a challenge (see Weiss and Patel, this report). There is abundant empirical evidence that the energy-intensity defined as the energy use required to produce the flow of goods, in GJ/ton, tends to decline – to some lower thermodynamic bound (middle graph). Combining these two trends, it can be argued that dematerialization in the sense of declining energy-intensity (in GJ/€: the reverse of the economic productivity) will only occur if the sector manages to sustain a high VA flow. If this is no longer possible, due to lack of innovations, demand saturation or whatever, the energy-intensity thus measured may actually start to rise (lower graph). In the process, there will probably be displacement of basic activities to other low-cost regions (e.g. steel to South America, chips to China). This may be another cause of declining energy-intensity, offsetting the possible failure of realizing sufficiently high VA flows. In my view, **it should be a challenge for statistical offices and energy analists to collect data and make analyses in order to test empirically this kind of hypotheses.**

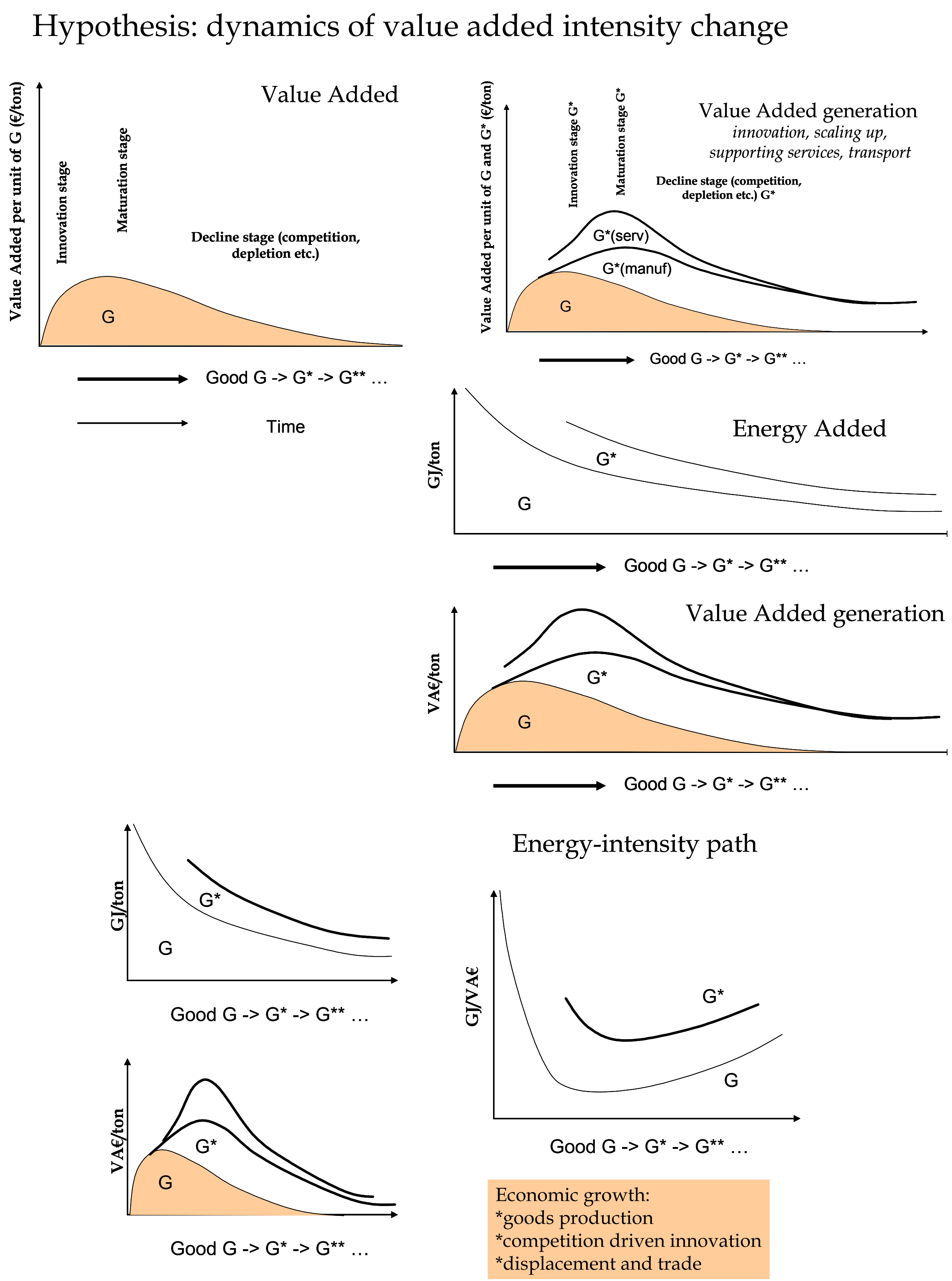

Figure 2.16. The possible dynamics of value added as a function of goods and services output

2.5.2 Services and dematerialization

An important and controversial part of the Matter and Money issue is, as mentioned before, the role of the service sector. It has been observed that productivity growth in the services sectors tends to be lower than in the manufacturing sectors [23]. For this, various reasons have been suggested (cf. paragraph 2). Evidently, the manufacturing sector has become more complex, as part of an ever more dense and extensive web of interacting institutions and organizations. The linkages are increasingly organized at the global scale, in networks of scientists, engineers, financial and production managers, traders and others. Part of the service sector has thus become a precondition to keep the manufacturing system running - engineering and outsourcing services, consulting services, financial and labour market services. This has also been invoked as a factor in dematerialization trends (paragraph 4.3).

The use of input-output (I-O) data and analyses are one of the most appropriate tools to analyse the relationship between physical and momenteary flows. The discipline of energy analysis, founded in the 1970s, draws to a large extent on this methodology. Most analyses are static (see e.g. Hoekstra, 2003). They are used to calculate the direct as well as indirect energy and material flows associated with monetary final demand expenditures. I-O tables can be used to explore the linkages between the manufacturing sector and (parts of) the service sector.

	AGRI	FoodProc	ManufInd	TranspServ	CommServ
AGRI	0,20	0,20	0,00	0,00	0,00
FoodProc	0,11	0,14	0,00	0,00	0,00
ManufInd	0,13	0,04	0,24	0,10	0,03
TranspServ	0,04	0,00	0,01	0,20	0,05
CommServ	0,09	0,09	0,10	0,19	0,47
Other	0,26	0,10	0,12	0,19	0,27
Import	0,17	0,44	0,52	0,31	0,17

The table shows for The Netherlands in 2000 the fractions of total sectoral intermediate deliveries for the aggregated categories agriculture, food processing, manufacturing industries, transport services and commercial services. It is seen that the manufacturing industry has 10% and the transport service sector 19% of its intermediate deliveries as commercial services. These interactions suggest caution in using only the resource inputs for manufacturing as a sign of dematerialization (cf. paragraph 4.3). The commercial services, which may be rather resource-intensive (transport), have to be included in the analysis - in fact, inasfar as they experience also a significant increase in labour productivity, they are an essential part in the growth of the industry-services complex.

I-O analysis has in some cases also been used in scenario construction. A dynamic analysis has been made in the 1990s by Duchin and Lange (1994) in order to explore the economic feasibility of the road sketched in the Brundtland/WCED report. Some suggestions for the use of I-O tables in the context of long-term dynamic (energy) scenarios are:

- *Using information on future consumption expenditures.* Assuming some trend in future private and government expenditures, one can make forward projections of resource use on the assumption that the total associated resource flows are on average not changing very much (see e.g. Vringer 2005). In this way it is possible to evaluate the possible (energy use) consequences of divergent consumer expenditure patterns - such as the growth of expenditures on private airplane use and garden, kitchen and comfort equipment (A1) versus the growth in expenditures on social services, health and childcare and the like (cf. De Vries *et al.* 2000).
- *Separating energy-intensive industries*. An option to improve the forward projection of industrial energy intensity is to separate the most energy-intensive products - iron&steel, aluminium, cement, fertilizer, paper - from the time-series of energy use and value-added.

[23] This phenomenon, referred to as the cost disease (Baumol, 1967), causes a relative decline in the price of manufactured goods cq. an overestimation of the price, and hence an underestimation of the energy-intensity, of service sector output.

The residue then covers all the remaining, diverse set of industrial activities, for which one can apply trend extrapolation or a macro-economic projection of industrial production. An example of this procedure is shown below for China, based on some recent data and projections for China (Figure 2.17; TUC, 2006). The energy-intensity in GJ/$VA is very high for the iron- and steel-industry (upper curve), much larger than for the whole of the economy. Excluding the iron- and steel-sector from the VA and the GJ data shows a slightly lower value for the energy-intensity of the whole economy-without-iron-and-steel. The outcome indicates that as of now the average energy-intensity of Chinese industrial production is still quite high. If dematerialization occurs, the separating out of energy-intensive sectors like iron-and-steel should give a larger separation with the rest of the manufacturing and services sectors, unless these sectors manage to maintain high economic productivity (cf. paragraph 4.3). This can help to locate in more detail whether declining energy-intensity stems from within-sector improvements or from intersectoral shifts.

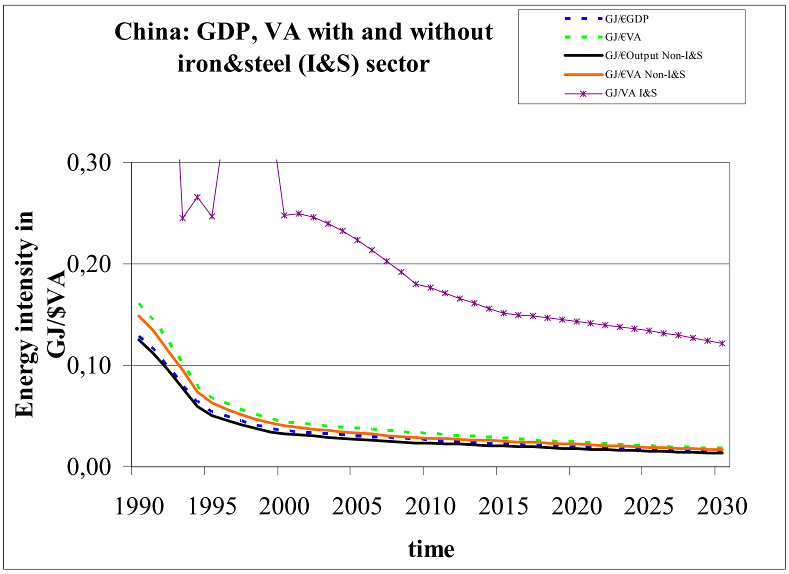

Figure 2.17. Enertgy-intensity trends in China in 1990-2000 and a possible course in 2000-2030; the energy-intensity (GJ/$VA) for the iron-and-steel industry is much higher than the average; excluding it from the average shows a (slight) decline in the average

Future consumption and the use of energy. Which will be the nature of future consumption is hard if at all to predict. Nevertheless, there are some trends which belong to a world in which innovations are largely driven by commercial interests of global firms in tandem with regional and national governments in their search for power and stability. Clearly, ICT-related expenditures will keep growing worldwide. Nowadays, an important and growing part of electricity use in Dutch households stems from equipment in the children's rooms such as tv, dvd and pc. A possible extension is the gradual introduction of distance-controlled equipment and household robots - developments which may simply be a down-scaling of commercial equipment (as is happening with laserprinters, do-it-yourself tools etc.). Another important avenue for increasing expenditures is health and, in its periphery, hygiene, body-training and psychofarmaca. A third area for expansion is education, recreation and travel, in physical and cyberspace and in the form of enter- and infotainment. In all these areas, ICT will play an important role - possibly accelerating the 'movement of electrons instead of bodymass' but possibly only raising the demand for goods and services from the real-world experience economy. It is still quite ambiguous how these changes in consumption of goods and services may directly (e.g. via changing time use patterns see e.g. Jalas 2002) or indirectly change energy and material flows.

2.6 Economic output and well-being

GDP as indicator. As has been set forth in the previous paragraph, an essential part of the economic process is adding value. The most widely used measure for economic activity and growth, the Gross Domestic Product (GDP), reflects this value adding process. However, there is increasing opposition against the use of GDP and GDP/cap as a meaningful and desirable indicator of performance and welfare (see e.g. Daly and Cobb 1989, Daly 1996, Van den Bergh 2005). One of the major drawbacks is that is measures any value added in the monetary economy, even if the associated activity is in fact an undesirable side-effect such as in the case of traffic accidents or air and water pollution or if it coincides with depleting and/or degrading a resource stock. Another drawback is that it does not incorporate aspects which in most people's perception are important ingredients of their quality of life. Among these are the existence of and access to the beauty of nature, the presence of silence and darkness, fresh air and clean water - in economic jargon: the available natural capital. Also the available social capital is in this category: is there a sense of security and belonging, for instance. The odd aspect of GDP/cap as a measure of welfare is that as soon as natural and social capital begins to diminish and/or degrade, actions are taken to restore or maintain them - which means usually that a value-added money flow is generated and hence GDP/cap tends to grow. Examples are the entrance fee for nature parks and tourism as a reaction to overcrowding and stress.

In the present context, the most interesting aspect is, in my view, how the maintenance of (the quality of) certain source and sink stocks interacts with the desire for more monetary income cq. material wealth. Enlarging and maintaining source size and quality requires investment of time, knowledge and labour. In fact, all value added is realized by improving the use-value of basic 'value-less' resources R in a transformation T[R]→ [C]+[W] with C consumption i.e. value added which is disappearing in the course of the period considered and W wealth i.e. value added operational for a longer period. The distinction between C and W is rather arbitrarily based on the usage time and confined to the monetarized transactions distinguished in the sectoral classes of the I-O tables. At the end of the consumption process, the goods are discarded into the environment - influencing sink size and quality.

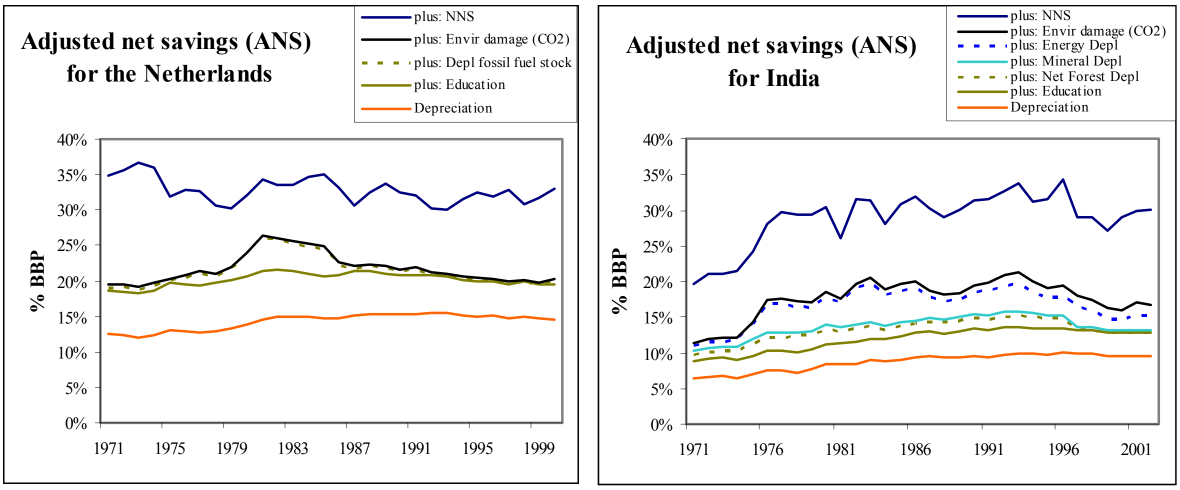

Figure 2.18. Some proposed adjustments of GDP time-series, for The Netherlands and India

The World Bank's Genuine Savings Rate (GSR) is an explicit attempt to include source-sink changes in the economic growth equation (Hamilton and Clemens, 1999). It. includes the 'depreciation' of natural capital stocks - not only of mineral and energy resources but also of ecological stocks such as forests and (some) substances filling up environmental sinks (such as CO_2). Figure 2.18 gives an indication of results for The Netherlands and India (World Bank 2004). As it turns out, an important part of net savings i.e. the difference between gross savings and depreciation, is in the form of investments in human capital (education) but also the estimated capital loss due to stock depletion (forest, minerals, fossil fuels) and CO_2-accumulation in the atmosphere is non-negligable. The measurement of human capital is of course a difficult question (see box). Recent attempts to broaden the capital notion into the social domain, with the introduction of social capital, has been confronted with even more methodological question marks (see box). Nevertheless, it functions just like the notion of human capital to make us aware that sustaining a society is about more than monetary investments in manufacturing and consumer goods - even more than investing in buildings and infrastructure.

Another attempt to replace GDP with a new index is the Index of Sustainable Economic Welfare (ISEW; Cobb and Daly 1989). It introduces corrections on the GDP/cap by subtracting expenditures which are made to compensate economic 'ills' (or externalities) such as traffic accidents, environmental and resource deterioration, unemployment and income inequality, defense and others. It has been found that welfare started to decline in the OECD-countries in the 1980s when measured with this index. An example of such a reconstruction of the GDP/cap is shown in Figure 2.19 for The Netherlands. Of course, such corrections have also consequences for the indicator used most often in the money-matter debate: the material- or energy-intensity. In constructing an 'appropriate' measure of energy-intensity for comparative and time-series use, one should first add the use of non-marketed ('non-commercial') fuels which may be large in low-income regions but also in some high-income countries. Then, the GDP has to be corrected for the activities not part of the formal economy, in particular when it appears to change over time ('shadow economy'). This can be done, at least partly, for intercountry comparisons with the ppp (purchasing power parity) correction (cf. paragraph 2.2).

Social capital. Van der Gaag (2005) distinguishes collective level and individual level social capital: is social capital a collective good, a collectively produced and owned quality, or is it an additional pool of resources embeeded in the social networks of individuals. The second option is chosen: *“Social capital is the collection of resources owned by the member’s of an individual’s personal network; which may become available to the individual as a result of the history of these relationships.”* (pp. 20). As such it fits in the capability approach of quality of life (Sen, 1999). It also corresponds with Bourdieu’s distinction of cultural, social and symbolic capital besides economic capital and the positioning of individuals in terms of their total capital and their – mutually exchangeable – economic and cultural capital (Bonnewitz, 2002).
Van der Gaag concludes that a one-dimensional measurement of social capital is neither possible nor desirable. Instead, and based on several measures and measurement protocols, he distinguishes the ‘Big Five’ independent characteristics of social capital:

- High prestige social capital, with measures such as highest accessed prestige;
- Low prestige social capital (with measures such as access to low prestige occupations);
- Network extensity, with measures such as work exchange relationships and their extent and diversity;
- Resources, with measures such as personal skills and political and financial skills social capital; and
- Network diversity (with measures such as diversity in age, education and gender).

The various social capital measures put more or less emphasis on one of these and reflect therefore different goal specificity and returns. For instance, high prestige social capital is about the resource and power benefits associated with accessing powerful network members and low prestige social capital is found to be especially useful in emergency situations.

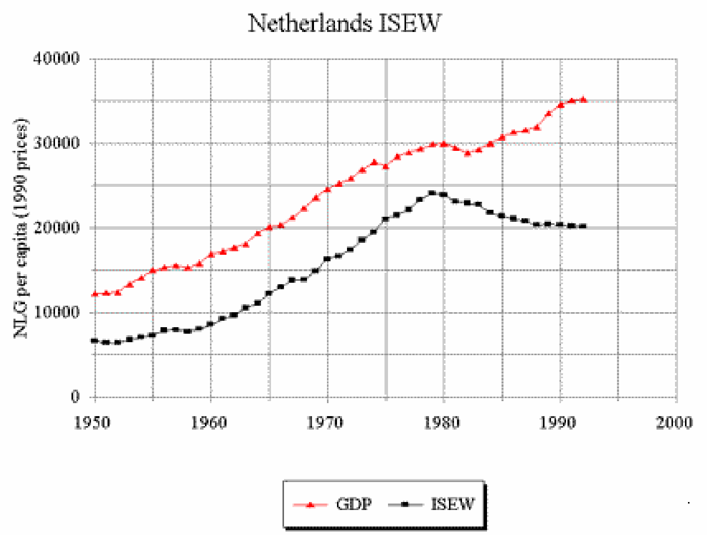

Figure 2.19. The GDP/cap in 1990 prices and the ISEW for The Netherlands (Max-Neef, 1995)

Income and happiness. It may be argued that income generation with no net depreciation of all the relevant capital stocks is the equivalent of sustainable development. However, a quite different but equally important aspect is whether the income makes people happy. In economic theory, the utility function has been introduced to denote that an individual person tends to derive less utility from every next item. If you are hungry, the first potato may satisfy you very much more than the tenth. This everyday observation has been enlarged into the space of economic abstractions to indicate that societal utility should be maximized by finding the largest value of the sum of the discounted utility of all its individual members. This approach is still at the basis of almost all macro-economic models used to explore desirable climate change policies.

The ludicrous inadequacy of such an approach has been discussed more intensely over the last decades, because sincere economists like Hirsch (1977) and Layard (2005) have started to question its validity. The utility function approach may have some validity at low income levels where for instance food and water shortages occur, but even there non-income-related aspects of life play a crucial role. A strong argument against the neoclassical economic formalism is its individuality: happiness of people depends to a considerable extent on their interaction with others via comparison and imitation (cf. Hirsch' positional goods). Indeed, the numerous surveys in the USA and the UK indicate that seven factors dominate the feeling of happiness of the inhabitants of these market economies: family relations, one's financial situation, employment, the social environment and health (in this order) plus personal freedom and a philosophy of life - most of them intricately social [24]. Hence, comparison is crucial in people's feeling of well-being, leading to what has been called 'reference drift'. To reduce such a finding to a single function U=U(C) with U the individual utility and C the per capita consumption (income/GDP) is simply unacceptable for anyone interested beyond the ideology of the consumer society. It is interesting to see what comes out of recent attempts to introduce interdependencies in the neoclassical formulation (see e.g. Brock and Durlauf 2001) [25]. Another inadequacy of the utitity function approach is its static character. It turns out that peoples' happiness is eroded by habit formation or 'preference drift', besides the aforementioned and related comparison or 'preference drift'. This phenomenon is strongly connected to the dynamic

24 One may add to the list, depending on where and when, environmental quality (with its relationship to health). Many other aspects may actually be subsumed under the seven factors listed, such as feeling safe, experiencing trust, having a cultural identity etc. (see e.g. The power of Identity by Castells 1997 and the Duurzaamheidsverkenning RIVM 2004).

25 Much interesting research is going on in this field, using agent-based modelling, game theory and other approaches.

high-tech society of the last decades - who can still make a child happy with a computer or a walkman of the 1990s?

Hence, one observes that GDP-growth is the most widely stated and supported ambition of most governments while at the same time it hardly adds to the feeling of happiness of the citizens. One tends to agree with Layard's (2005) suggestion that we should tax the rich disproportionately heavily because for every Euro they add to their income they create more unhappiness in others than happiness for themselves. Of course, such an advice - running counter to the present-day neoliberal trend - is correct within a utilitarian context but naïve in the world of vested interests and power and possibly also in view of the human longing for achievement, competition and adventure.

This brings me to the last point: can we make a link with socio- and psychological research into value orientations and the associated empirical data from marketing and management studies? If one can characterize several consumer goods/service clusters and several value clusters (cf. NIPO/TNS) and explore the incentives and constraints, which operate for each combination, the insights in how well-being relates to 'matter and money' may benefit. A first attempt in relation to environmental and sustainability issues has been made in the Sustainability Outlook of RIVM (2004).

Time and economic production: investing in human capital. Quality of life has many aspects, as for instance Max-Neef (1991) has indicated. One aspect is the use and experience of time. Too much 'time' is associated with laziness, boredom - and the 'unemployed'. Too little 'time' evokes feelings of stress, nervous breakdown and the call for 'Entschleunigung'. The German Bundesamt has constructed a time I-O table (ZIOT) for 1990. The total time available to the 63 million people was 554 10^9 hours in 1990. Using estimated of hours per DM, it was found that about 46 10^9 h were spent on the workplace and 15 10^9 for education. The depreciation on 'human capital' (education) was found to be twice as high as that on economc capital, in hours. Such I-O tables may help to quantify some aspects of human (and social) capital, not unlike attempts to quantify aspects of natural capital via ecosystem evaluation. It is an interesting idea to look at time as one of the important constraints, both for the affluent and the poor.

2.7 Conclusions

The main objective of this essay is to enrich the ways in which we think about our future, the future of the human race and of the earth. Models can help but tghey have to be improved to deal better with real-world complexity. They can be used in telling richer and more varied stories. In this way, also our perspective on what sustainable development pathways can and should be will be broadened, for instance vis-à-vis the matter-and-money issue. I have indicated a few roads which seem to me particularly promising for research. First, a better understanding of the functioning of subsistence economies and the conditions for development, using both earth science and social science theories and tools. Next, the analysis of what drives economic growth and which forces influence the (de)coupling of monetary growth from materials flows has to be strengthened. The role of services, including the ICT-sector, deserves more attention, as part of this analysis. Finally, the link between economic growth - and in particular GDP-growth - and the experience of well-being has to be investigated and debated much more thoroughly if we are serious about the quest for sustainable development. In the process we may discover that the road to happiness and fulfillment is really between heaven and earth, that large space where there is more to be found than one can think of.

3 Sector Study: Industry

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3.1 Introduction

Decoupling of physical and monetary growth in the industrial sector is widely considered as an important strategy towards sustainable development. This is because many industrial processes cause substantial environmental impacts, mainly as a consequence of their relatively high energy intensities. If high economic growth can be realized at comparatively low physical throughputs, this hence improves the chances of a more sustainable production (compare Chapter 2, Figure 2.15). In this chapter we therefore address the question of whether and to which extent decoupling is occurring in the most important bulk material industries. The outcome of this analysis is decisive for future projections on the development of raw material input, product output, energy use and emissions of the industrial sector. In energy models and in models for projecting developments of greenhouse gas (GHG) emissions (e.g. such as those published by the Intergovernmental Panel on Climate Change (IPCC)) the assumed relationship between physical and economic growth in the industry is crucial for future scenario building.

In the following chapters, we firstly present an overview of the importance of the industrial sector relative to the total economy in economic terms and in terms of energy use, emissions and physical throughput (Chapter 3.2). We then formulate hypotheses (Chapter 3.3) about the relationship between monetary and physical growth in the industrial sector, which we test as part of our discussion of empirical results. Due to the very limited availability of studies in this area we have conducted own empirical analyses for the purpose of this study, which are presented as part of Chapter 3.4. Finally, in Chapter 3.5, we draw conclusions.

3.2 The Industry Sector in Perspective

In the European OECD (Organization of Economic Cooperation and Development) countries, industry is responsible for around 34% of the total final energy consumption (Figure 3.1). Within industry, the largest users of energy are the chemical/petrochemical sector (5%) and the iron and steel industry (4%). In non-OECD countries the respective share of the industrial sector can be even higher due to the lower energy use of transportation and households (especially space heating).

As indicated by Table 3-1 the specific non-renewable energy requirements and consequently also the associated GHG (greenhouse gas) emissions differ substantially among the various bulk materials (for energy by more than a factor of 30 between cement and primary aluminium). The spread for price and value added is even larger (e.g. roughly a factor of 100 between cement and flat glass or aluminium).

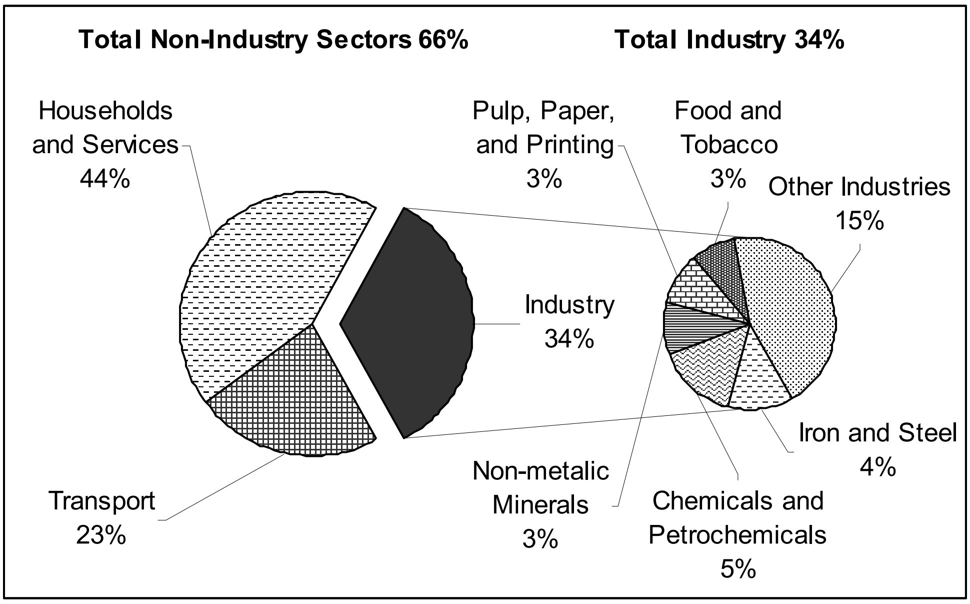


Figure 3.1. Share of the industry on the total final energy consumption in European OECD countries 2001 (IEA, 2004)

Table 3.1. Specific non-renewable energy use, GHG emissions, price, and value added for bulk materials in Germany

	Energy Consumption in GJ/t [1)]	GHG Emissions in kg CO_2 eq./kg [1)]	Price in EUR/t [2)]	Value Added in EUR/t [3)]	Share Value Added/Price in %
Cement	5	1.0	85	23	27
Steel - Primary - Secondary	 23 8	 1.9 0.6	515 [4)]	139 [4)]	27
Paper and Paperboard	15	1.0	727 [5)]	197 [5)]	27
Plastics	88	2.9	1,775 [6)]	469 [6)]	26
Glass - Container Glas - Flat Glass	 8 12	 0.6 1.1	 528 [7)] 8,627 [8)]	 216 [7)] 2,820 [8)]	 41 33
Aluminium - Primary - Secondary	 182 26	 16.1 1.9	9,239 [9)]	1,987 [9)]	22

1) Source: Öko-Institut, 2005, Heckert, 2000, Worrell et al., 1994; data refer to the system cradle to factory gate
2) data refer to physical production and gross value of production for Germany in the year 2003
3) specific value added based on physical production and nominal value added data as given by (Destatis, 2003a,b), (WVS, 2005), (KF, 2004) for various industrial sectors
4) including all steel products as listed under the PRODCOM code 27.10
5) including all paper and paper boards as listed under the PRODCOM code 21.12
6) including polymers as listed under the PRODCOM code 24.16
7) including container glass as listed under the PRODCOM code 26.13
8) including flat glass as listed under the PRODCOM code 26.11
9) including primary and secondary aluminium and first processing thereof

Compared to the bulk materials shown in Table 3.1 the value added of semi-finished and especially finished products is decisively larger (e.g., a car weighing 1 tonne may cost EUR 15,000). As a consequence, the environmental impact per value added is much larger for primary resource industries than for manufacturing, which in turn, has a higher environmental impact per value added than the service sector. This is shown in Table 3.2 at the example of GHG emissions and acidification caused by selected sectors in the United Kingdom (UK).

Table 3.2. Environmental impacts of selected economic sectors in the UK, data normalized by the value added of the respective sector (Clift and Wright, 2000)

Sector	Specific GHG emissions in t CO_2 equ./10^6 EUR	Specific acidification potential in t SO_2 equ./10^6 EUR
Energy Production	8,483	120
Resource Extraction	1,878	8
Manufacturing	839	6
Transport	750	8
Distribution	110	-
Education and Health	110	-
Finance	14	-

The ratio of physical flows to economic values is particularly high for agriculture, basic industries and the energy and utilities sector (Figure 3.2). The opposite is the case for the consumer sector. The service sector generates a very high value added while making use of relatively limited direct supplies of consumer goods, buildings and some capital goods (e.g., medicinal instruments). Within industry, we find large sector specific differences: for example, the value added per physical activity is considerably higher for producers of semi-finished and finished goods compared to basic/bulk materials producers (Figure 3.2).

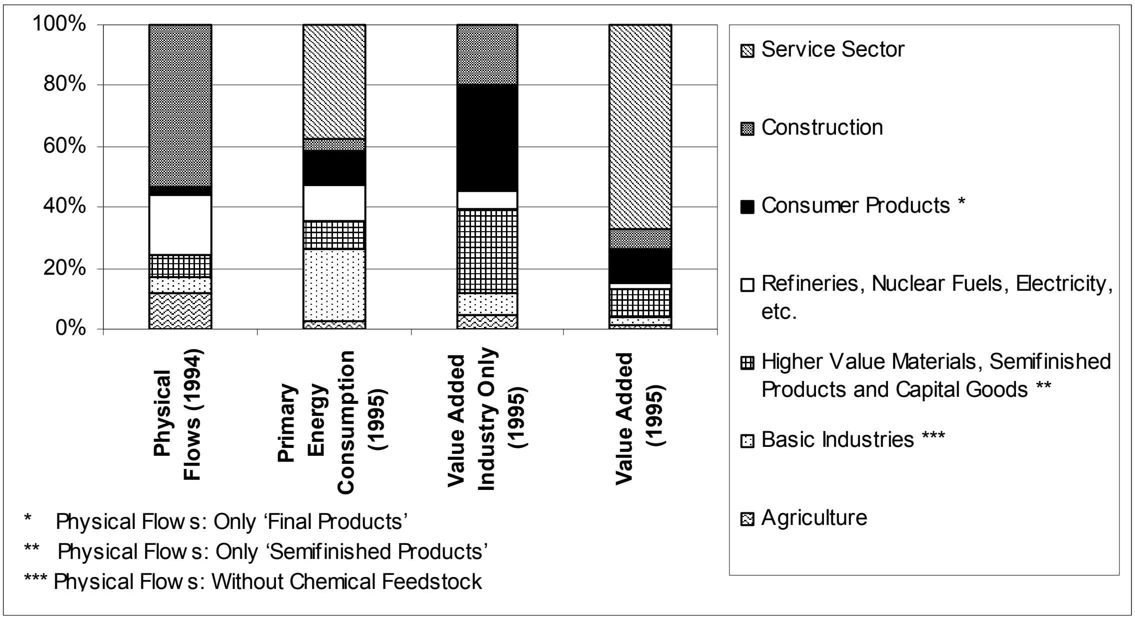


Figure 3.2. Relationship between physical and monetary values at the sectoral level (data refer to Germany and originate from Adriaanse et al. (1997) and AGE (1995) for physical flows and GGDC (2005) for monetary flows)

Figure 3.2 is indicative because the physical flows are not directly comparable: While, in some manufacturing industries sophisticated materials may be used, the major part of the physical flow in agriculture is biomass (fertilizers, herbicides, and pesticides account only for comparatively minor quantities). In the case of construction, excavated material has been excluded. The consumer goods, buildings and investment goods used by the service sector (and by other sectors) are not reported separately in order to avoid double counting. The primary energy use of the service sector includes commercial passenger and freight transport but excludes private, non-commercial passenger travel (e.g., travel activities in private cars). The relationships shown in Figure 3.2, are confirmed by Figure 3.3:

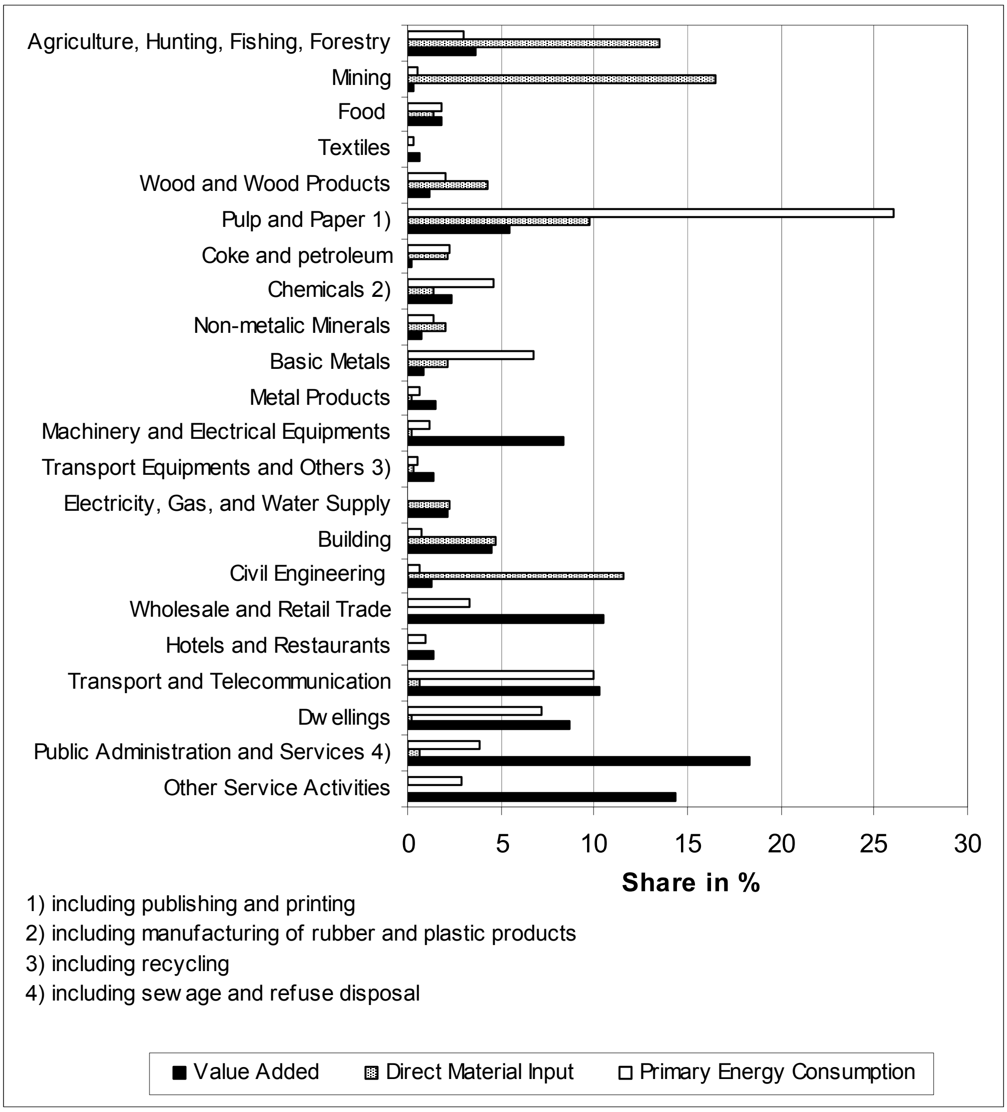


Figure 3.3. Sectoral shares of value added, direct material input, and primary energy consumption in Finland, 1999 (Mäenpää, 2005)[26]

The vast majority of value added in Finland's economy is generated in the service sectors. In contrast to that, the manufacturing industries have only a small share on the value added but use the largest part of the direct material inputs.

As Figure 3.3 further shows, the activities in the service sector require a large share of the total primary energy resources consumed in Finland. Despite the fact that the direct materials input in services is negligible, the service economy relies on indirect material deliveries, either in the form of energy or via buildings and infrastructure. This is not shown in Figure 3.3. While the size of the physical flows is not equivalent to the environmental pressure exerted, physical activity can be nevertheless seen as a first proxy for the level of resource use and environmental impacts resulting from production in the industry.

Studying the dynamics of physical flows in the industrial sector, both

[26] Note that the sum of direct material input and primary energy consumption over all sectors does not yield 100%. This is because roughly 26% of the direct material inputs and 19% of the primary energy is consumed by final demand, i.e. households, government, capital formation, and exports (Mäenpää, 2005).

- intersectoral structural changes (i.e., changes in the shares of the various sectors of the industry) and
- intrasectoral structural changes (i.e., changes in the shares of the various sub-sectors within one sector) can positively or negatively influence the level of resource use and environmental impacts.

Apart from these factors, also the level of activity (activity effect) and the specific amount of material and energy needed at the level of individual processes (i.e., the intensity effect) influence the relation between physical and monetary activity in the various industrial sectors (Figure 3.4).

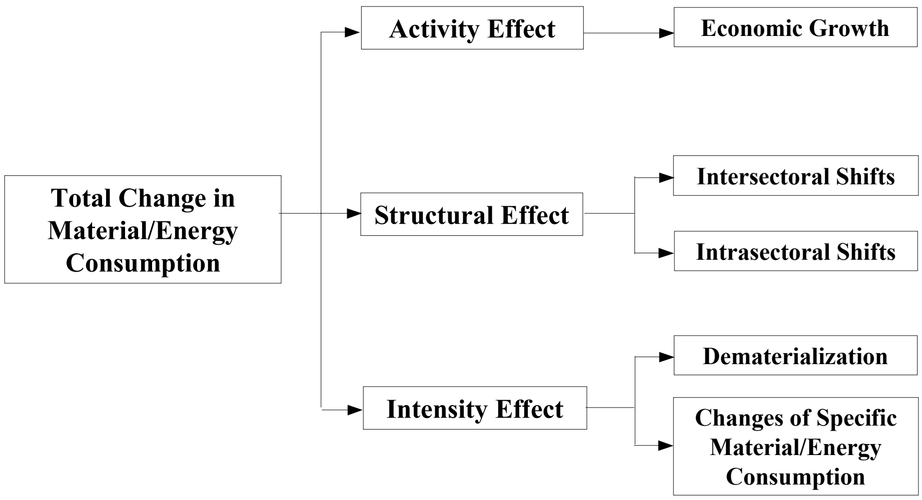


Figure 3.4. Factors determining the relation between physical and monetary activity in the industry (Farla, 2000)

Another implication of the widely differing ratio of physical flows and environmental impacts on the one hand and value added across the sectors on the other is represented in Figure 3.5 at the example of a final consumer product. The environmental burden is particularly high for raw material production (left side of Figure 3.5) while manufacture of complex parts and components and their assembly (right side of Figure 3.5) contribute only little to the overall environmental impact.

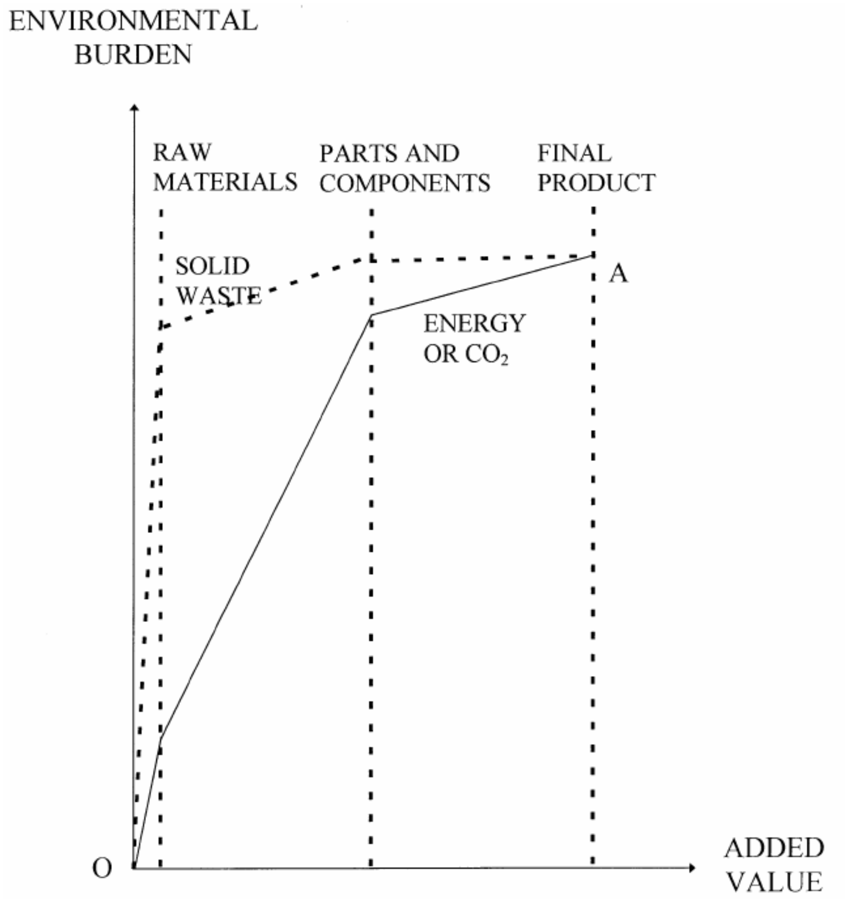
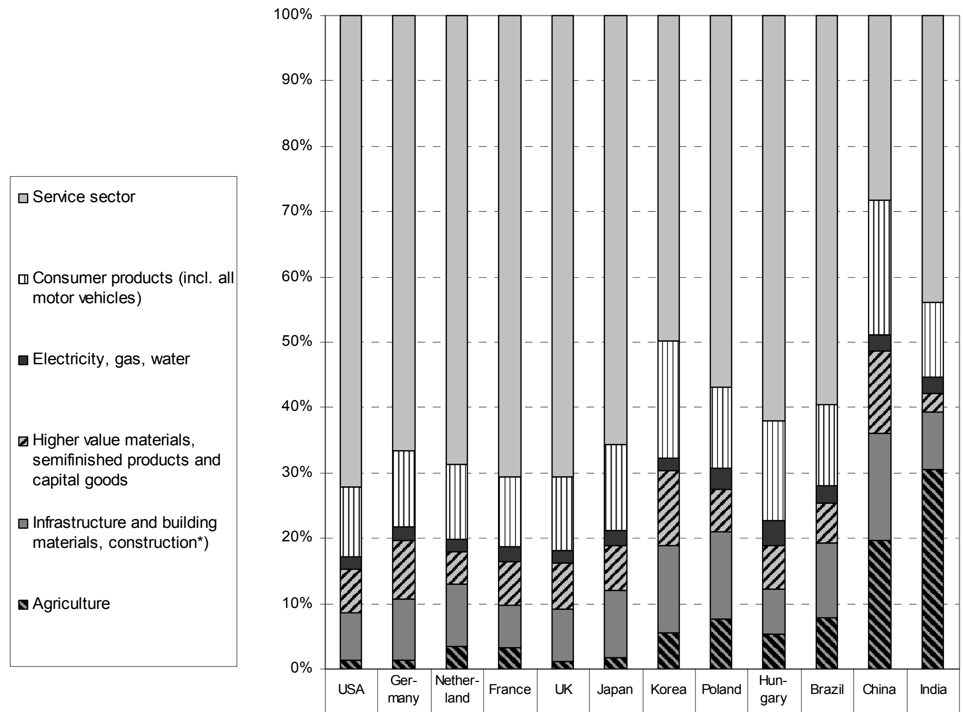


Figure 3.5. Energy use and solid waste generation along the supply chain for mobile telephones (Clift and Wright, 2000)[27]

Given these findings, environmental impacts of a country's economy can vary greatly depending on its structure, stage of development, and degree of specialization. As Figure 3.6 shows, there are substantial differences in the contribution of individual sectors to the total GDP across countries. For example, the contribution of industry targeted at infrastructure (as a proxy we chose the total of i) Mining/quarrying, ii) Iron/steel, iii) Non-metallic minerals, and iv) Construction) ranges between 7% and 10% in high-income countries, while it is at least 50% higher in booming developing countries (e.g. China, Brazil). The example of India (9%) on the other hand shows that such high shares are not representative for all developing countries and that it probably depends on their stage in the industrialization process.

In high-income countries, the very diverse category of 'Higher value materials, semi-finished products and capital goods' is in the same order of magnitude as the sector targeted at infrastructure while it can be considerably lower in less developed countries as the example of Brazil and India shows. Not unexpectedly, the countries differ largely in their importance of the agricultural sector (1% to 31%). The service is the most important sector in all economies, including also the developing countries. As the comparison of the values for the USA and China (Figure 3.6) shows there can be a difference of more than a factor of two in its importance.

27 Figure 3-5 excludes transportation, which, however, causes significant impacts for some industrial products. Please note that for reasons of commercial confidentiality, numerical values are not given, but the graph does show the relative contributions of the three life cycle stages.



	USA	Ger-many	Nether-land	France	UK	Japan	Korea	Poland	Hun-gary	Brazil	China	India
Service sector	72%	67%	69%	71%	71%	66%	50%	57%	62%	60%	28%	44%
Consumer products (incl. all motor vehicles)	11%	12%	11%	11%	11%	13%	18%	12%	15%	12%	21%	11%
Electricity, gas, w ater	2%	2%	2%	2%	2%	2%	2%	3%	4%	3%	3%	2%
Higher value materials, semifinished products and capital goods	7%	9%	5%	7%	7%	7%	12%	6%	7%	6%	13%	3%
Infrastructure and building materials, construction*)	7%	9%	9%	7%	8%	10%	13%	13%	7%	12%	16%	9%
Agriculture	1%	1%	4%	3%	1%	2%	6%	8%	5%	8%	20%	31%

Figure 3.6. Composition of value added in industrial and developing countries in the mid/end 1990s (OECD, 2005)

In view of these large differences in the formal economy it is plausible to assume that important changes can occur in the structure of the economy and, more specifically, in the structure of the industrial sector over time in one single country. We will study this aspect in more detail in Chapter 3.4, after having formulated research hypotheses in the following chapter.

3.3 Research Hypotheses

Conventional growth theories assume that economic growth is driven by exogenous changes of interchangeable production factors, i.e. stocks of capital and labour. Hence, industrial energy and resource consumption and changes thereof are regarded as result rather than cause of economic growth. In contrast to standard economic growth theories, Ayres et al. (2003) argue that resource and energy consumption within the economy is as much the driver for economic growth as it is a consequence thereof. They therefore see economic growth as feedback mechanism being accelerated by declining production costs followed by decreasing consumer prices, which ultimately enhance final demand. Rising levels of consumption trigger investment in production capacities, research, and technological development. Economies of scale cause decreasing production costs, as well as increasing production efficiency (Ayres et al., 2003). Ultimately, these phenomena push production costs down and enhance (in combination with increasing market competition) the growth cycle (Figure 3.7).

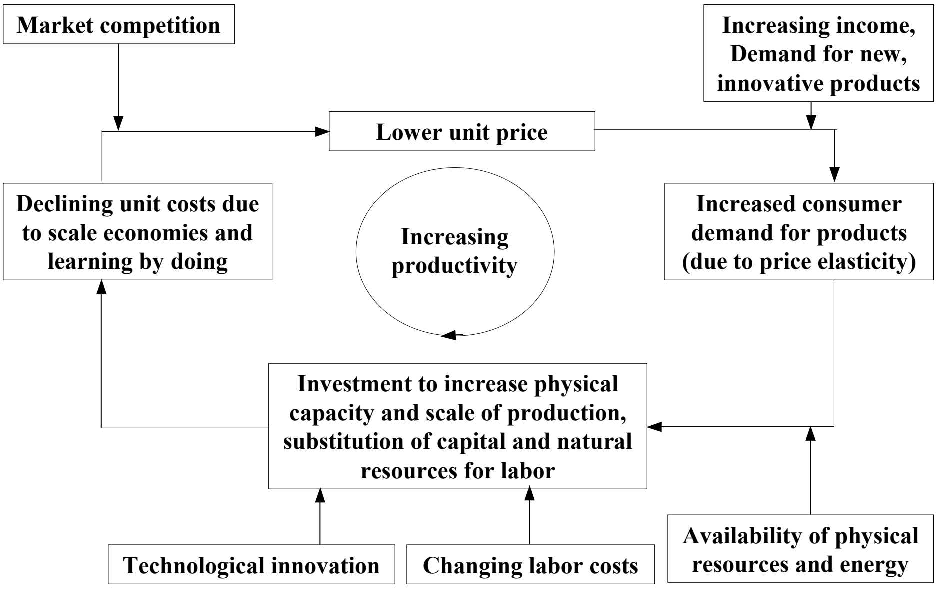


Figure 3.7. Cycle of economic growth (adapted from Ayres et al., 2003)

Economic growth is thus equally induced by changes in labour costs, technological innovations, and availability of natural resources and energy as well as by market competition and consumer demand for innovative products. For this reason, the innovation potential of a sector may play a crucial role for its physical and monetary growth. In the past, many sectors have undergone major changes as the result of the advent of new products and technologies (e.g. cars replacing horse driven chariots and coal-based energy subsequently being replaced by oil and natural gas). Also in industry, some bulk materials experience higher growth rates than others. As shown in Figure 3.8, steel and cement are examples of materials experiencing decreasing shares in the overall material mix (due to either faster growth of other materials or gradual material substitution), while paper, plastics and aluminium continue to gain market shares (glass takes an interim position according to Figure 3.8).

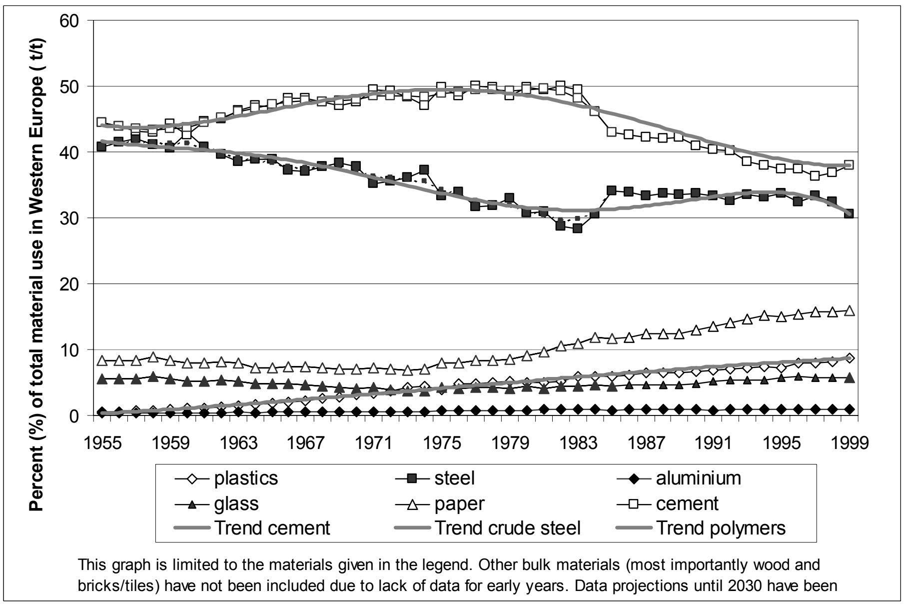


Figure 3.8. Bell-shaped curves representing the shares of bulk materials used in the EU (Crank et al., 2005)

Combining this theoretical background information with empirical data shown in Chapter 3.2, we now formulate research hypotheses, which serve as general guidance for the empirical analyses of the industrial sector (Chapter 3.4). We aim at finding empirical indication and evidence for the following research hypotheses:

Hypothesis 1: The value added per unit of physical output of bulk products (e.g. simple steel products, bulk chemicals such as commodity plastics) is expected to decrease over time as a consequence of productivity growth (e.g. increasing physical output per employee) and decreasing profits (relative to physical output) as a consequence of stronger competition[28]. This implies that an increase of absolute value added generated from the production of bulk products has to be realized by increased physical production.

Hypothesis 2: Following research Hypothesis 1 we would expect to find re-coupling between physical production and the value added generated by bulk products manufacturing.

Hypothesis 3: By increasing their share of innovative, high-value products, industry sectors partly compensate or even over-compensate the value added decline for bulk products[29].

Hypothesis 4: Less knowledge and know-how intensive bulk products are increasingly being produced in low-income countries while the high-income countries currently have comparative advantages for manufacturing of knowledge intensive, and high quality varieties of bulk materials. Therefore, the value added generated per physical unit of industrial production (including bulk materials) should be higher in high-income countries than in low-income countries.

Hypothesis 5: Associated to the law of comparative advantage, one would expect industrial production in high-income countries to be less material and labour intensive but more capital intensive relative to the production in low-income countries.

Hypothesis 5: Due to demand for infrastructure development, low-income countries should have a relatively high domestic demand for low and medium quality bulk materials compared to high-income countries.

In the following section we will assess these research hypotheses based on empirical analyses of several bulk industrial sectors in various countries and at different levels of detail.

3.4 Empirical Results

The relations between physical and monetary activity can be studied from various perspectives and at different levels of aggregation. We present in this chapter empirical results based on both, literature studies and own data analyses. We set out with analyzing in Chapter 3.4.1 the value added of various industrial sectors and its contribution to the total GDP in several OECD countries. After giving a short introduction on the concept of intensity of use curves in Chapter 3.4.2, we analyze physical flows at the most aggregated level, i.e. DMI (Direct Material Input) and TMR (Total Material Requirements). Afterwards, we study the dynamics of intensity of use and absolute per capita consumption of bulk materials as a function of economic development, i.e. growth of per capita GDP. In the following chapter (Chapter 3.4.3) we analyze the relation between physical output and value added for selected industries in four different regions. Based on a literature survey, we have a closer look at drivers and determinants of value added and physical production in the first part of Chapter 3.4.4. In the second part of the same chapter, we analyze developments and trends of the iron and steel industry and the chemical industry, mainly in the USA and Germany.

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28 This hypothesis does not only apply to bulk products included in our analysis but also to innovative' products such as computers, mobile phones, DVD recorders, and others.

29 It is important to note that value added increase is probably not the major key driver/motivation for industrial production, but rather company profits. However, both are closely linked to each other, as value added is the total of company profits, wages and depreciation.

3.4.1 Cross-sectoral Value Added Analysis

Assessing the relationship between physical and monetary growth of the economy requires detailed insight into the structure of individual economic sectors and their contribution to the total gross domestic product (GDP). The Groningen Growth and Development Centre (GGDC 2005) publishes a database, which presents a time series (1979-2002) of value added data for 57 economic sectors and 19 OECD countries.[30] Based on these data, we calculated the relative contribution of the value added of each economic sector to the total GDP in each of the 19 countries. In a second step, we calculated the arithmetic mean of the sector shares for all countries.[31]

In the 19 OECD countries, the 10 largest economic sectors contribute, on average, roughly 53% to the total GDP, while the remaining 47 sectors have only a total share of 47%. Among the 10 sectors with the highest contribution to the GDP, only two (agriculture and construction) produce physical goods and commodities while the remaining 8 sectors provide services. According to Table 3.3 the resulting total value added of the sectors producing physical outputs (i.e., agriculture/forestry/fishing, the conversion sector, industry and construction) account for around 31% in 2002, while the majority of the countries' total value added (69%) was generated in the service sector. The total value added of the sectors producing physical outputs decreased from 42% in 1979 to the mentioned 31% in 2002. The share of value added generated by the manufacturing sectors decreased between 1979 and 2002 by around 5.0%, with most of the decrease occurring in the non-bulk materials industry (-3.6%).

Table 3.3. Contribution to the overall GDP by the various economic sectors in 19 OECD countries (GGDC, 2005)

Sector	Year		
	1979	1990	2002
Agriculture, forestry and fishing	6.5%	4.4%	2.5%
Conversion sector*)	3.0%	2.9%	2.6%
Total industry, of which:	25.0%	22.3%	19.9%
*- Bulk materials**)*	*9.6%*	*8.4%*	*8.1%*
- Non-bulk materials	*15.4%*	*13.9%*	*11.8%*
Construction	7.5%	6.8%	6.1%
Service sector	58.0%	63.7%	68.9%
Total	100.0%	100.0%	100.0%

*) mineral oil refining, coke and nuclear fuel, electricity, gas and water supply
**) including mining and quarrying

Table 3.3 shows the development in 19 OECD countries for somewhat more than 20 years. The comparison of the data in Table 3.3 with sectoral shares of value added in some developing countries (e.g. the share of the service sector in China according to Figure 3.6 in Chapter 3.2) shows that developing countries may undergo further drastic structural changes during their future economic development. Details of the development of individual sectors producing physical output in the 19 OECD countries can be found in Figure 3.9.

30 EU-15, USA, Canada, Japan, Korea
31 This approach implies that the mean of the sector shares has been calculated with the same weight for each sector/country, regardless the size of the individual sector/country. A weighted approach would have required the conversion of the national currencies into one single currency unit. We did not follow this approach because exchange rates for each year and each country were not readily available to us.

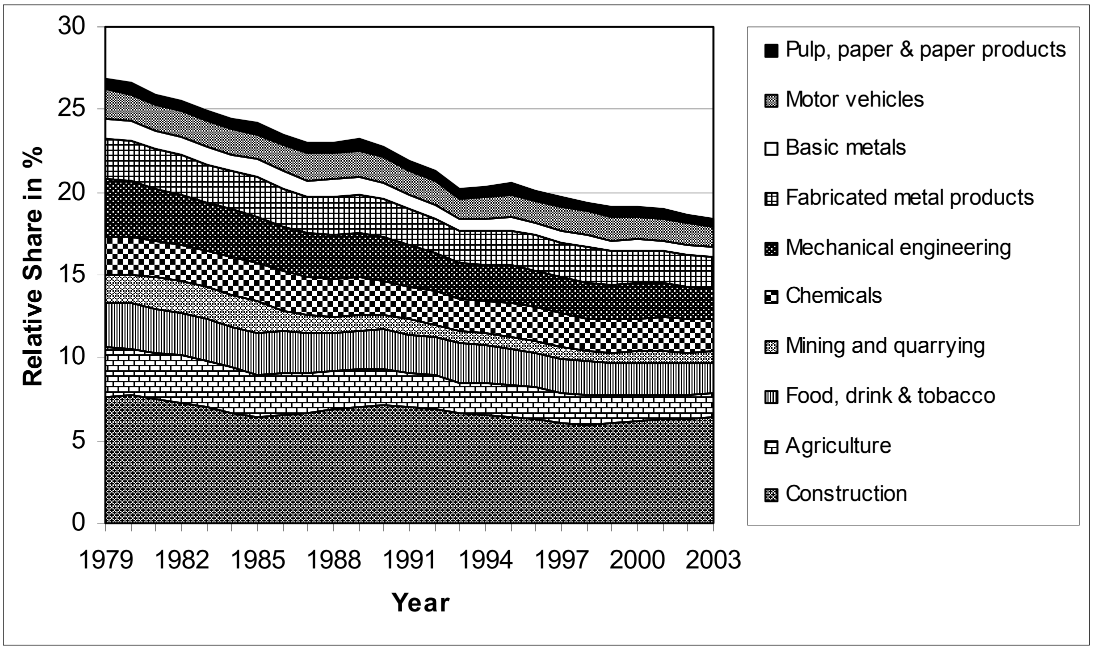


Figure 3.9. Relative shares of value added generated by the 10 largest sectors in the 19 OECD countries producing physical goods and commodities

The value added shares of the 10 largest producers of physical commodities decreased from roughly 27% in 1979 to 18% in 2002. This development is largely caused by declining value added shares on the total GDP for agriculture (-3.5% points), basic metals manufacturing (-0.8% points), and food, drink, and tobacco (-0.7%). The overall declining trend of value added shares of commodity producers is thus associated with an increase in the value added shares of the service sector. The declining overall trend according to Figure 3.9 makes it very likely that this development will continue in the next years.

Drawing conclusions regarding the dematerialization of the economy as a whole is (based on these findings alone) not straightforward. For example, identifying an increasing importance of the service sector for Sweden, Kander (2005) argues, that the shift towards the service economy (i.e., the decreasing shares of value added generated by industry and the increasing shares of value added generated by the service sector) is not necessarily associated with dematerialization. Kander (2005) points out, that 'this is because the shift to a service economy is an illusion in terms of real production, but is instead generated by the fall in the prices of manufacturing goods relative to services, which is in turn caused by a more rapid productivity growth [e.g. rapid increase in physical production/employee] in manufacturing than in services. […] Consequently, the idea that the transition to the service economy will lead to dematerialization of production and environmental relief is based on a misconception of what such a transition really means'.

The general economic development, which is characterized by decreasing importance (in monetary terms) of agriculture and manufacturing industries and increasing significance of the service sector might therefore lead to a weak decoupling (compare Figure 2.15) between physical and monetary growth as value added in the service sector raises faster than in the other sectors of the economy. This does, however, not necessarily translate into absolute decoupling as also agriculture and the manufacturing industries continue growing in physical and monetary terms, but only at a slower rate than the service sector. We will therefore analyze the relationship between physical activity and economic growth in more detail the following chapters.

3.4.2 Intensity of Use and Per Capita Materials

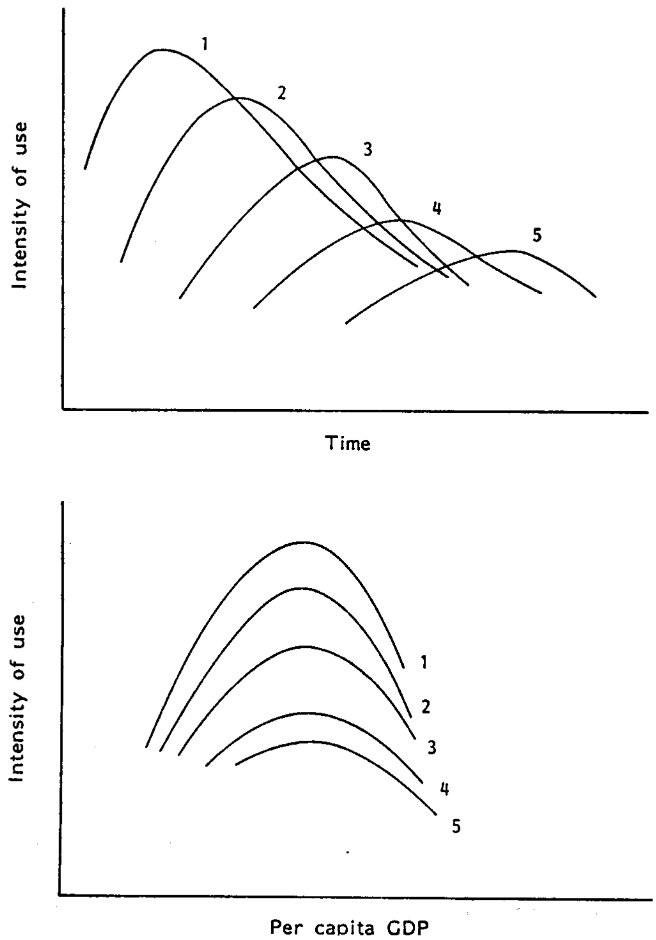
Theoretical Background

The relationship between physical and economic growth can be studied by a variety of methods (see Chapter 2). Possibly the most prominent - albeit rather phenomenological – approaches are the application of *Intensity of Use Curves* and *Per Capita Consumption Curves*. The intensity of use (IU) is defined as the consumption of materials or commodities divided by the Gross Domestic Product (GDP). The IU is usually plotted as a function of time or as a function of the GDP per capita (see Box 3-1; for further explanations see Chapter 2 of the report).

Intensity of use

= Materials Demand / GDP

(1000 tonnes/billion EUR GDP)



Box 3-1. Two ways of applying the Intensity of use concept for studying dematerialization

Malenbaum (1978) gives three explanatory factors for the inverted U-shape of an ‘idealized’ IU curve, which is expected to occur in the course of economic development:

- The demand for materials differs when an economy goes through various stages of development: At low income levels the demand for materials is also low due to simple housing and minimal machinery use in the agricultural sector. The process of industrialization first leads to increased material demand for infrastructure and the capital stock. With increasing industrial production, the relative importance of consumer goods rises. Finally, the service sectors becomes more important, which is accompanied by a comparatively low material intensity.
- Due to technological progress the efficiency with which raw materials are discovered, extracted, processed, distributed and used increases over time, thereby lowering materials demand.
- With the advent of new materials and cheaper production processes for advanced materials, material substitution occurs, leading to a gradual replacement of traditional materials.

Malenbaum (1978) pointed out that the inverted U-curve may have its maximum at lower values for countries which enter industrialization at a late stage. He argued that the (relative) rise and decline (as represented by the inverted U-curve) may occur in shorter time periods as a consequence of technological developments. Larson (1991) and Bernardini and Galli (1993) also discussed these repeating patterns and pointed out that developing countries might not require the same levels of intensity of materials use to reach a comparable standard of living. In the graphs shown in Box 3-1, this is represented by decreasing values for the maximum intensity of use with progressing time (represented by the numbers 1 to 5).

Next to intensity of use, per capita materials consumption can be analyzed in order to assess the degree of dematerialization of an economy. While declining intensity of use indicates weak or *relative* decoupling of an economy it is a necessary but not sufficient criteria for *strong* or *absolute* decoupling. The latter requires that per capita materials use declines in the course of economic development.

3.4.2.1 Direct Material Input and Total Material Requirements

DMI (Direct Material Input) and TMR (Total Material Requirements) are two aggregated indicators widely used for describing physical flows (in terms of volume or mass) associated with economic activity. DMI is defined as the sum of domestic materials extraction and imports. TMR comprises the DMI and the hidden flows, i.e. the unused materials extraction associated with imports[32].

Studying TMR data for Germany, Japan, The Netherlands, and the USA over a time period of 1975 to 1994 at a time series of 20 years, Adriaanse et al. (1997) found a gradual rise in per capita consumption of natural resources, i.e. a trend towards absolute dematerialization of the economy could not been identified. Looking at TMR as a function of GDP development, Adriaanse et al. (1997) identify a general trend towards declining material intensities. However, TMR data show trends towards levelling off in the last decade studied, indicating that the use of resources might be growing parallel to overall economic development.

Bringezu et al. (2004) analyzed per capita DMI and TMR as a function of per capita GDP for 26 and 11 countries respectively. Based on the data presented in Figure 3.10, an overall tendency towards higher per capita DMI with higher domestic income levels can be observed. At the level of individual countries, with the exception of the Czech Republic, Bringezu et al. (2004) found no significant strong decoupling of per capita DMI and per capita GDP. However, they identified a trend towards relative decoupling with a tendency towards stabilizing DMI/GDP ratios at different levels of DMI/per capita GDP for many high-income countries (Figure 3.10).

Countries vary, however, considerably regarding their specific TMR/GDP ratios. As Bringezu et al. (2004) point out, this finding indicates that a high level of resource consumption is neither necessarily as prerequisite for high levels of per capita GDP nor for economic growth in general. Based on an econometric analysis for individual countries, Bringezu et al. (2004) found (similarly to DMI) weak decoupling between per capita TMR and GDP.

Next to the study of Bringezu et al. (2004), also van der Voet et al. (2004) analyzed the dynamics of DMI. For the Netherlands, they found a trend towards increasing absolute DMI until 1992 with a trend towards levelling of in the years afterwards. Given the development of per capita GDP for the Netherlands in the same period (1980-2001), a trend towards declining DMI intensities and thus weak decoupling can be identified.

[32] DMI and TMR are aggregated material flow indicators, which exclude water but cover all other resource or material streams associated with human activity. The indicators provide a quantitative physical description of all natural resources directly or indirectly used in the economy, however they neither differentiate between individual materials or resources used nor do they account for the specific environmental impacts associated with the extraction and use of resources and materials.

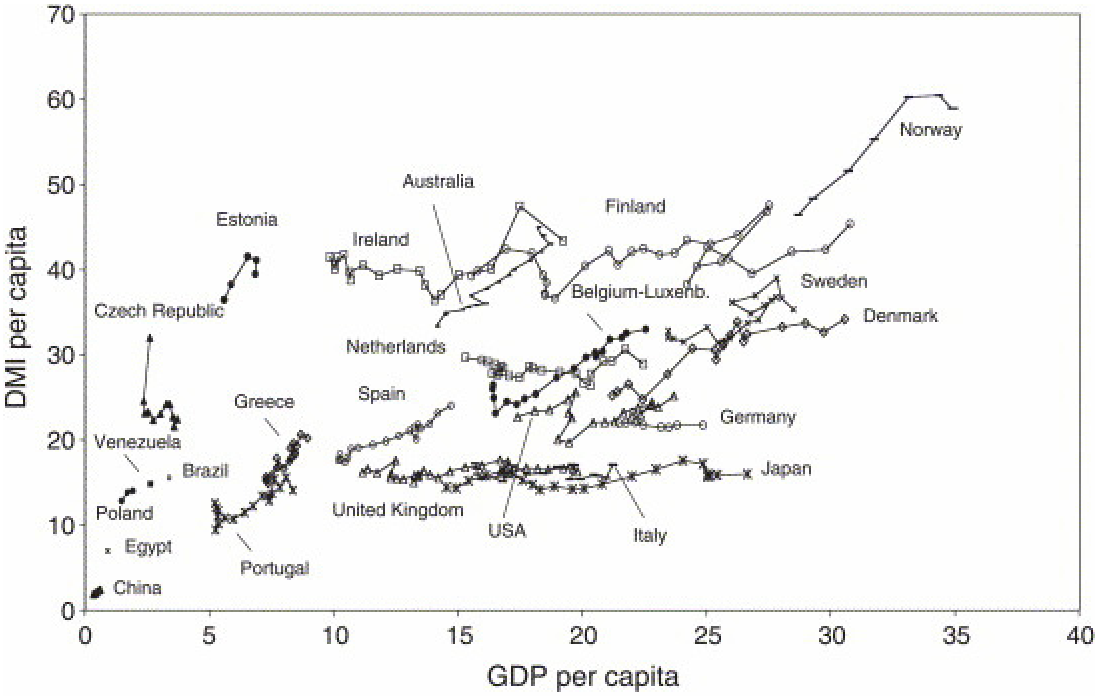


Figure 3.10. Development of per capita DMI and per capita GDP (Bringezu et al., 2004)[33]

Compared to the DMI analysis, similar trends were also found for the dynamics of TMR (Figure 3.11). As the cross-country comparison shows, with increasing per capita GDP levels, also per capita TMR raises.

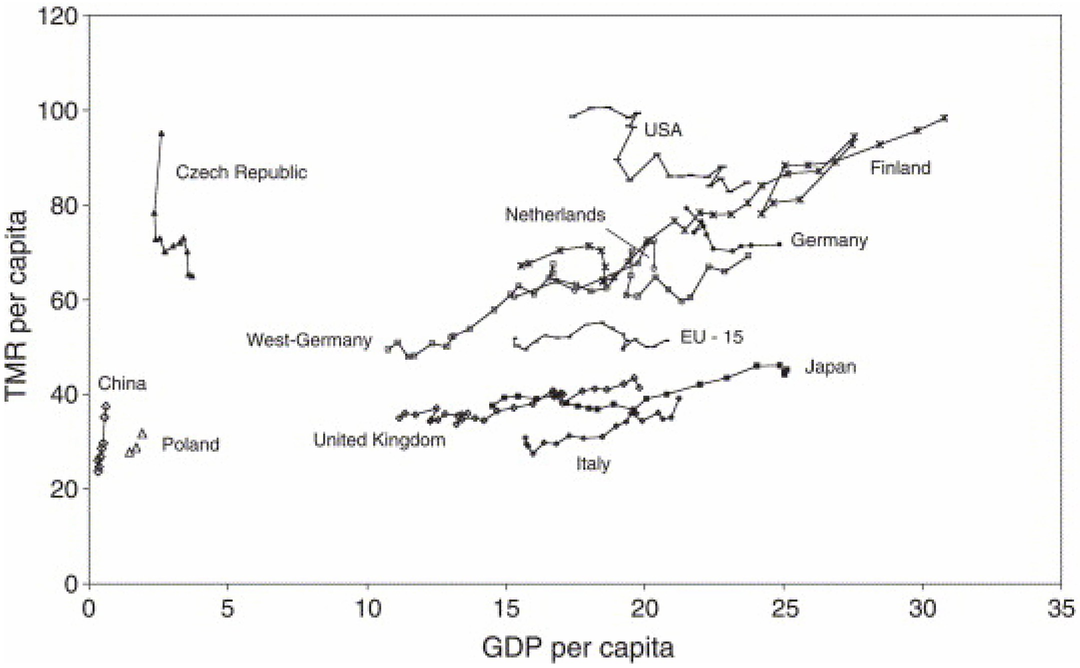


Figure 3.11. Development of per capita TMR and per capita GDP (Bringezu et al., 2004)[8]

33 GDP data given in constant 1990 US $, DMI and TMR given in tonnes.

Based on these findings, van der Voet et al. (2004) developed a hybrid method combining aspects of material flow accounting (MFA) with life cycle assessment (LCA) in order to prioritise materials regarding their environmental impacts. They found specific environmental impacts (on a per kilogram basis) to be highest for precious metals. However, the contribution of these metals to overall environmental pollution is small because volumes are extremely low. Van der Voet et al. (2004) identified materials with a relatively high specific environmental impact per kilogram and large volume flows such as the bulk materials iron and steel, aluminium, concrete and cement, and plastics but also biomass from agriculture as the most dominant sources of environmental pollution in the Netherlands.

The studies of Adriaanse et al. (1997), Bringezu et al. (2004), and van der Voet et al. (2004) show that TMR and DMI are indicators, which can be used for quantifying economy wide material consumption. Their explanatory value is, however, limited by the fact that these indicators (i) do not allow an understanding of the efficiencies developments regarding the use of individual materials, (ii) do not allow assessing development and potentials for material substitution, and (iii) do only very indirectly allow to link physical activity with environmental degradation. In this context, the analysis of van der Voet et al. (2004) shows how DMI and TMR studies can be meaningful extended in order to quantify environmental impacts associated with both the various physical flows and ultimately also with economic growth. Combining LCA data with DMI and TMR inventories might therefore be a promising approach to overcome the main shortcomings associated with these aggregated indicators of economy-wide material flows. Another way would be to analyze intensity of use and per capita flows on the level of individual materials, which have been identified by previous analyses (see van der Voet et al., 2004) as most relevant regarding the overall environmental impact. This type of analysis will be presented in the following chapter.

3.4.2.2 Intensity of Use and Per Capita Consumption of Individual Materials

In the following we focus on the intensity of bulk materials use. This analysis is of special importance because a considerable amount of environmental pressure results from the production of basic materials (compare Adriaanse et al. (1997), van der Voet et al. (2004). Figure 3.12 shows an example of an intensity of use curve for crude steel. The general trend for crude steel is that the intensity of use reaches a maximum at medium per capita GDP levels and then tends to declines with further economic growth. In 1991, Larson (1991) presented such intensity of use curves for a whole set of bulk materials for the USA (see Appendix A, Figure A.1 and Figure A.2).

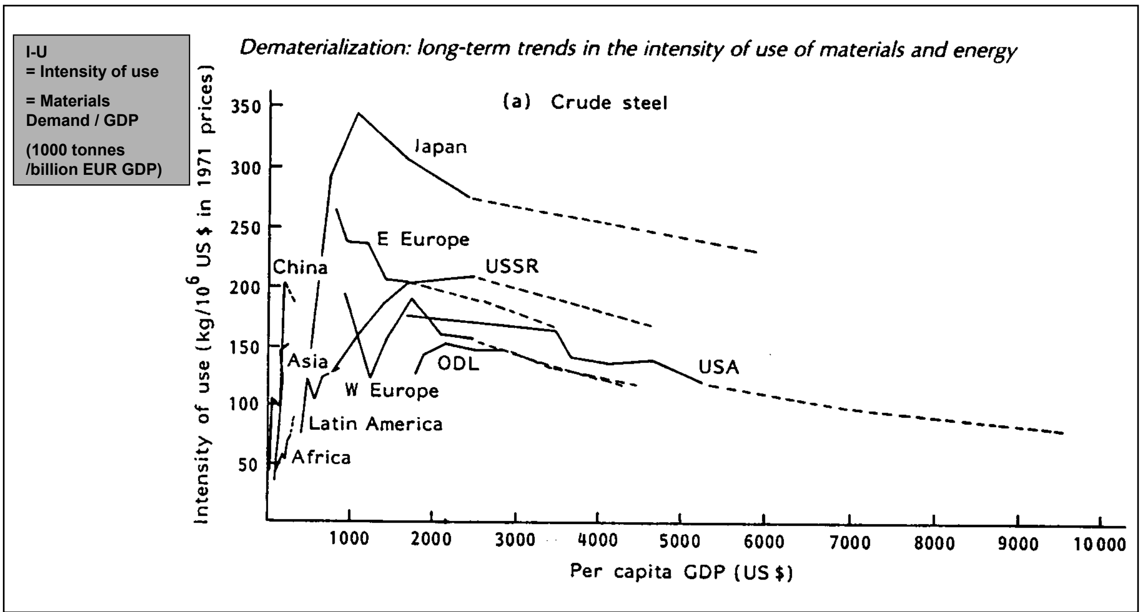


Figure 3.12. Intensity of use of crude steel as a function of per capita GDP (Malenbaum, 1978)

While Figure 3.12 shows an example of a material with declining intensity of use, Figure 3.13 shows the intensity of use curve for a material, which has not yet reached the maximum intensity of use. Aluminium, paper and polymers are the most important representatives of such materials, for which intensity of use is expected to further increase in the future.

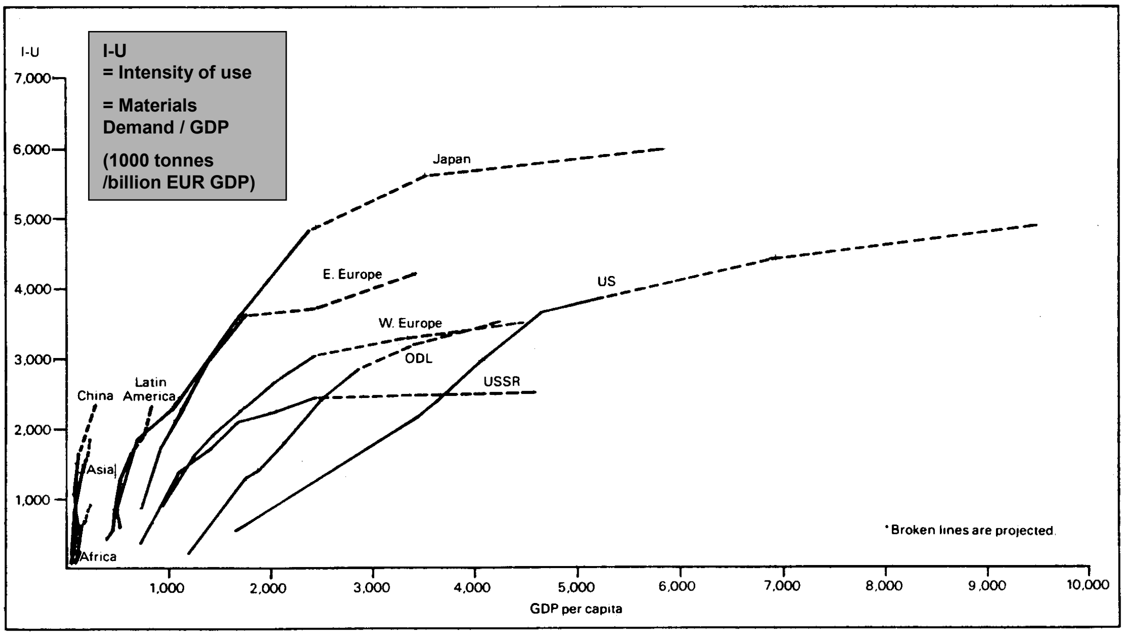


Figure 3.13. Intensity of use for aluminium as a function of per capita income (Malenbaum, 1978)

In the course of the EU funded VLEEM project (Chateau et al., 2005) we prepared comparable curves for steel and other bulk materials[34] . As shown in Figure 3.14 to Figure 3.21 the decrease of the maximum intensity of use with progressing economic development is not easily detectable for all materials.

While data for steel, cement, bricks, wood and ammonia indicate that the intensity of use is indeed declining with increasing per capita GDP, the opposite trend is observed for polymers, paper and aluminium. The intensity of steel use, for example, strongly depends on other influencing factors than levels of per capita GDP alone. For example, a particularly large apparent consumption of steel can result (i) from large exports of steel-based products (e.g. in Japan due to the strong automotive sector) or (ii) large net imports of semi-finished and finished products e.g. to the USA due to the lack of competitiveness of the U.S. steel industry, and (iii) other factors.

Especially for materials such as paper and aluminium the intensity of use appears to increase with economic growth due to the expansion of innovative sectors such as the information technology (IT) or the aerospace industry.

[34] The results of the VLEEM study refer in general to the time period of 1971-2000. Exceptions are however the data used for the former USSR and for several developing regions, where (depending in the specific bulk material studied) much shorter time series were analyzed.

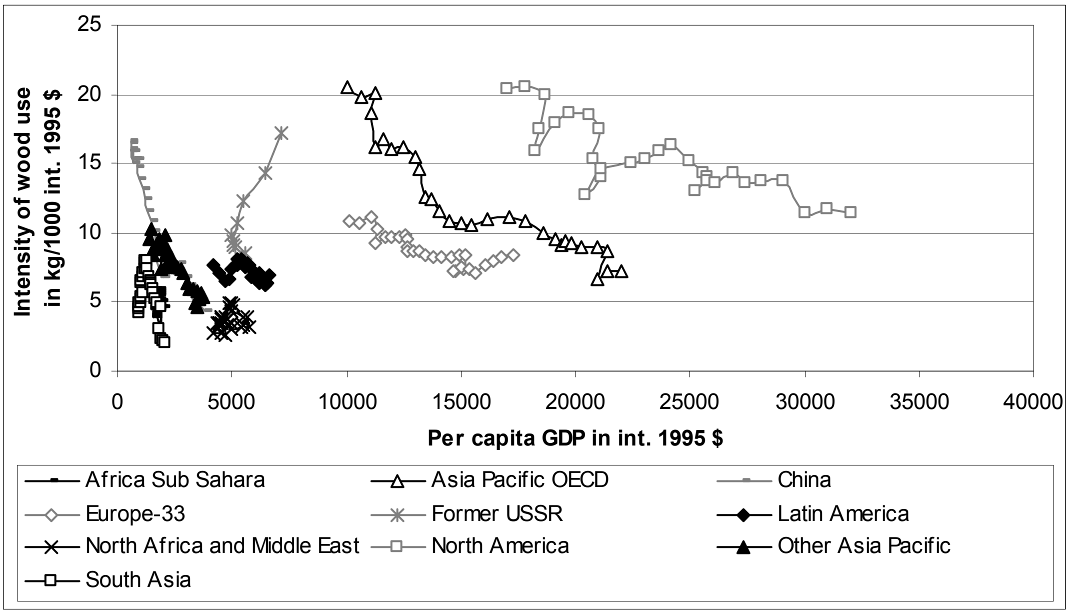


Figure 3.14. Wood - Intensity of use curve

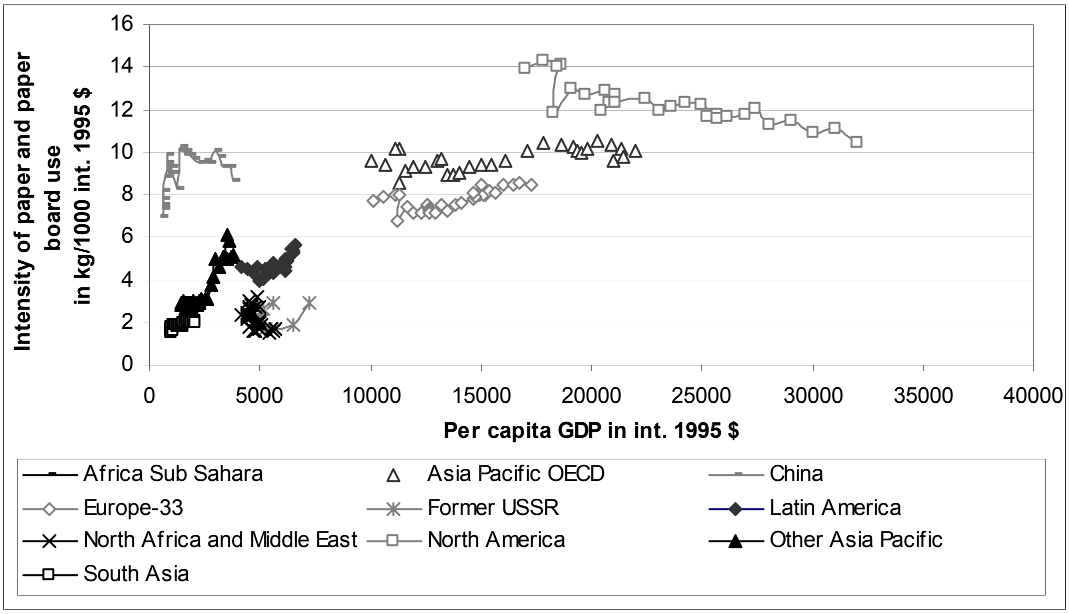


Figure 3.15. Paper and paper board - Intensity of use curve

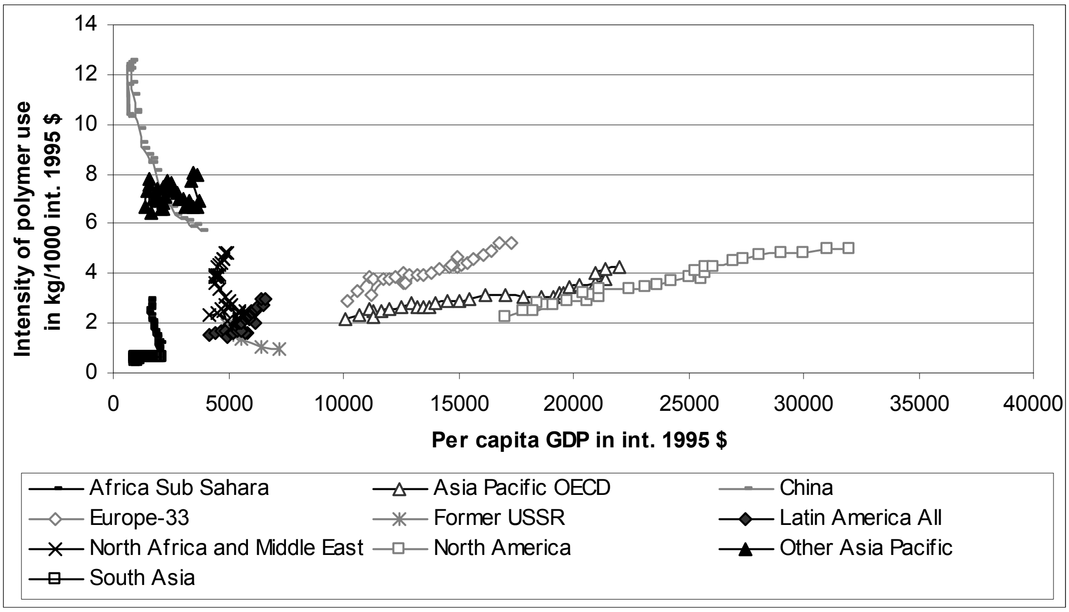


Figure 3.16. Polymers - Intensity of use curve

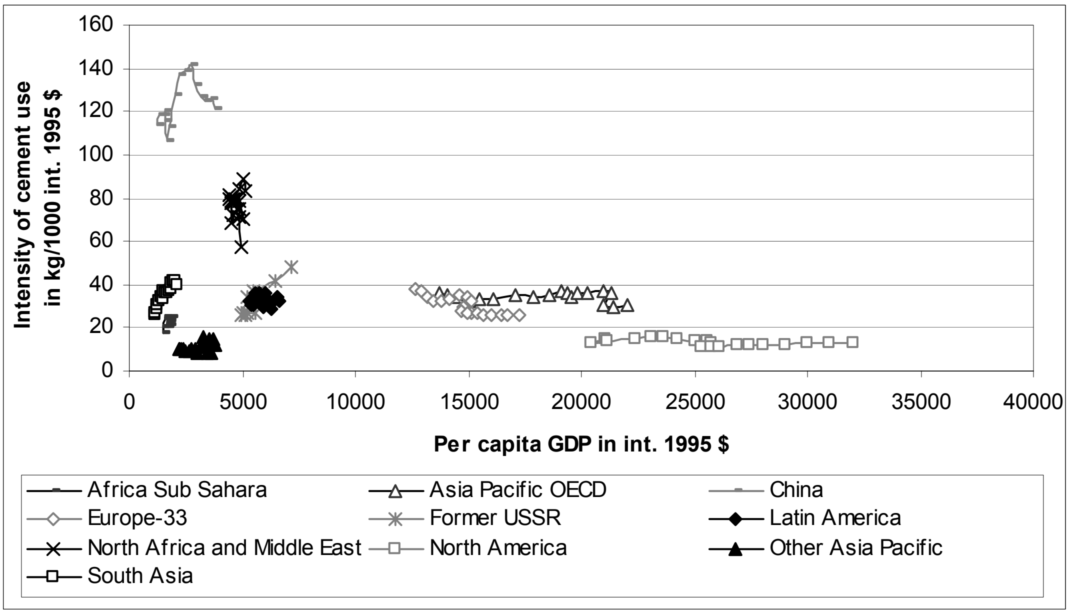


Figure 3.17. Cement - Intensity of use curve

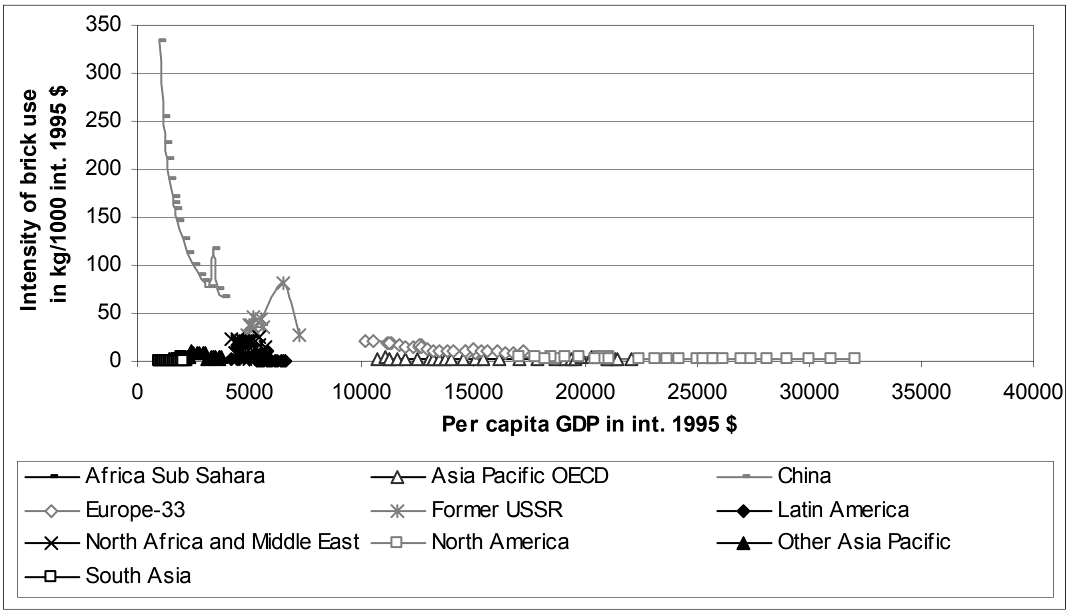


Figure 3.18. Bricks - Intensity of use curve

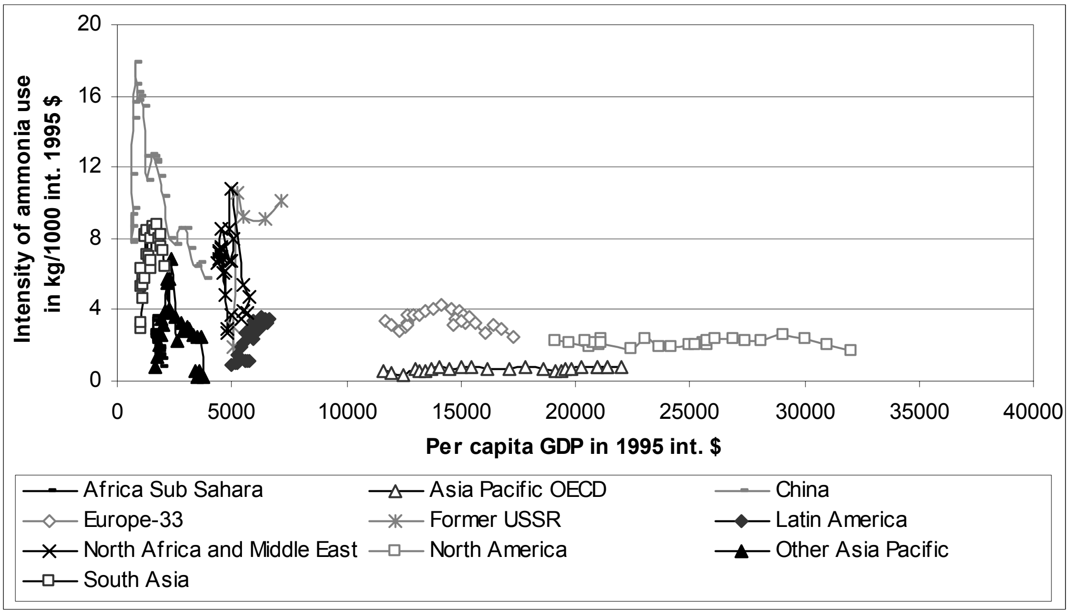


Figure 3.19. Ammonia - Intensity of use curve

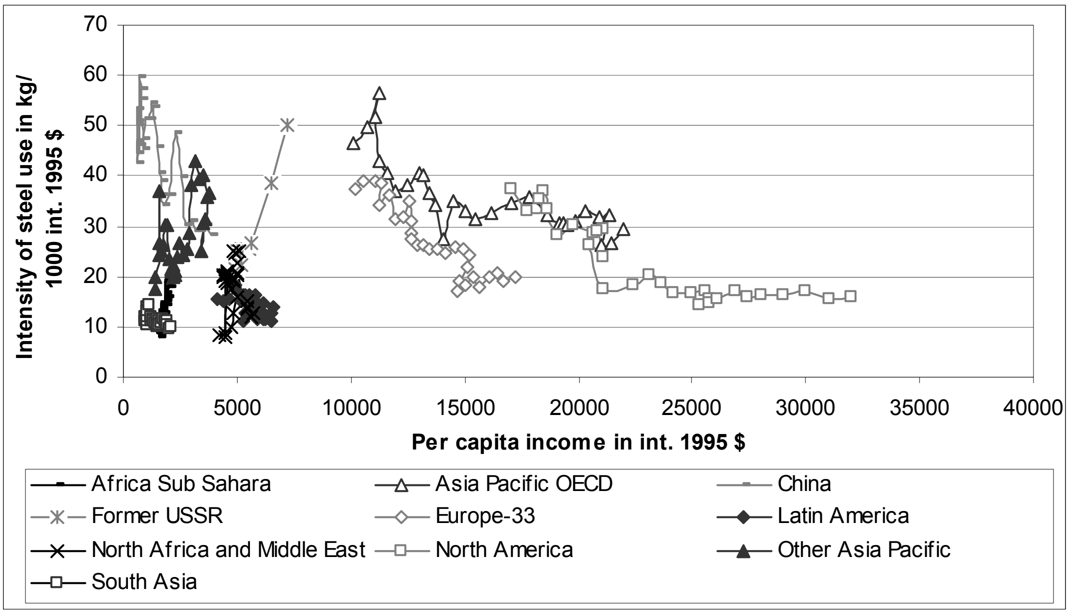


Figure 3.20. Steel - Intensity of use curve

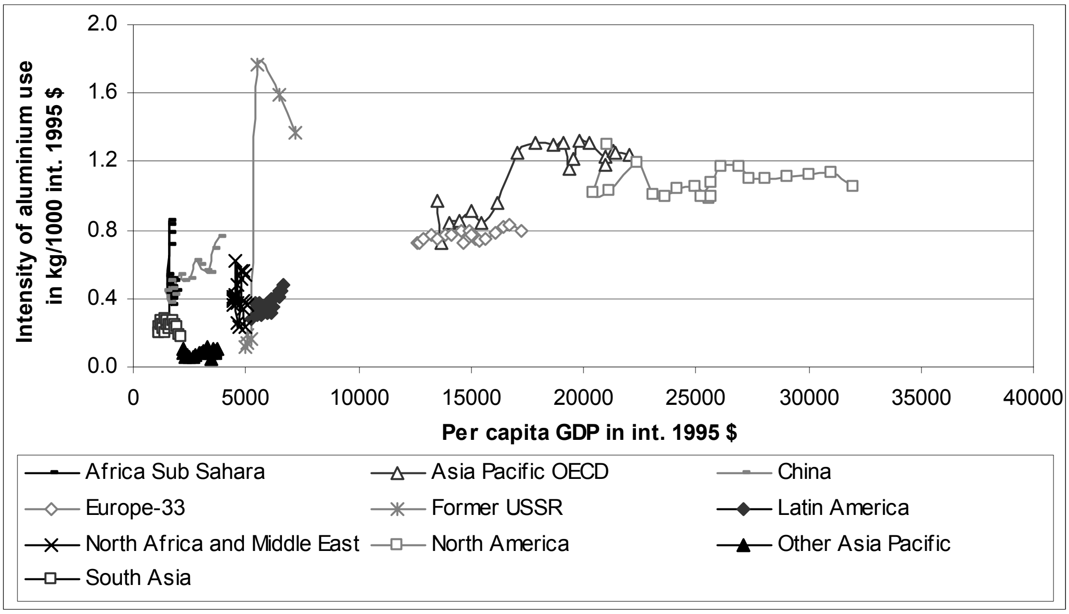


Figure 3.21. Aluminium - Intensity of use curve

Instead of plotting the intensity of use as a function of per capita GDP it is also possible to plot absolute or per capita material consumption or material production on the y-axis. Larson (1991) developed such graphs for per capita material consumption for the USA and Chateau et al. (2005) did so for 10 world regions as an input for scenario projections in the course of the VLEEM project. The Figures 3.22 – 3.29 show the results of our own analyses.

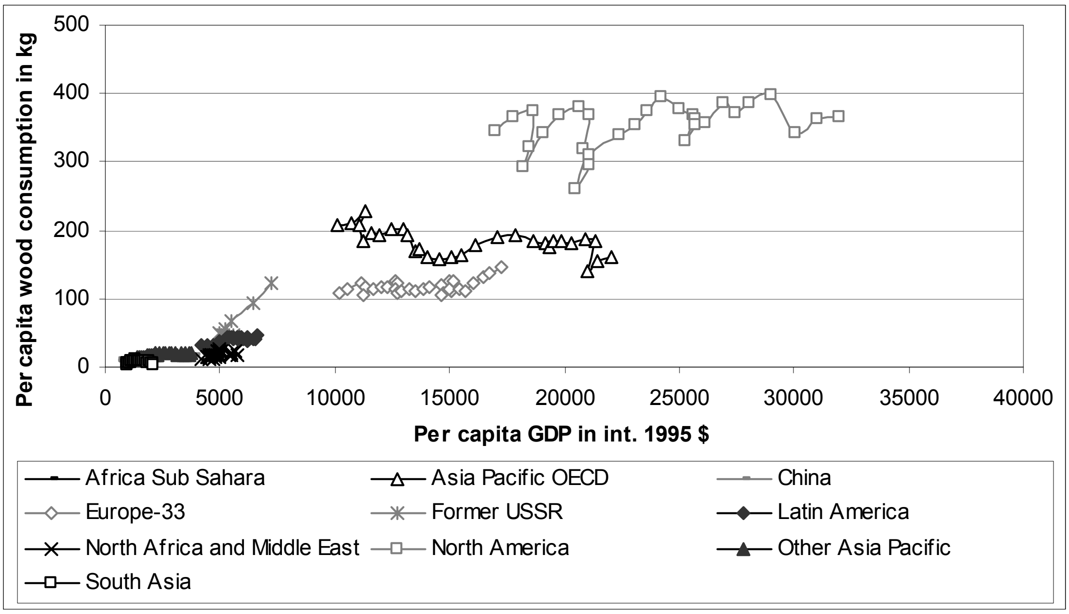


Figure 3.22. Wood - Per capita consumption

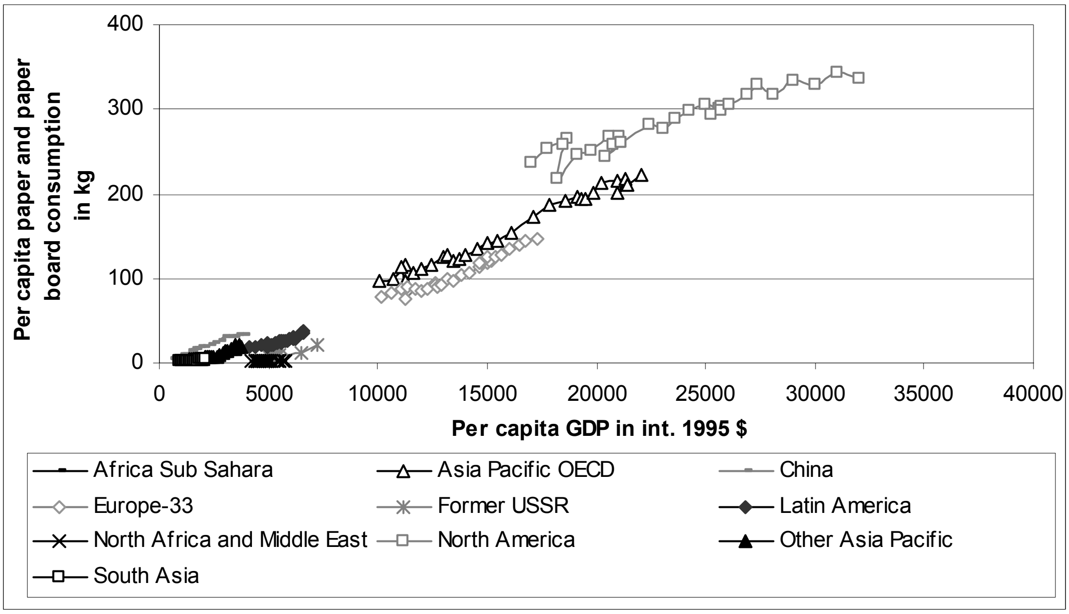


Figure 3.23. Paper and paper board - Per capita consumption

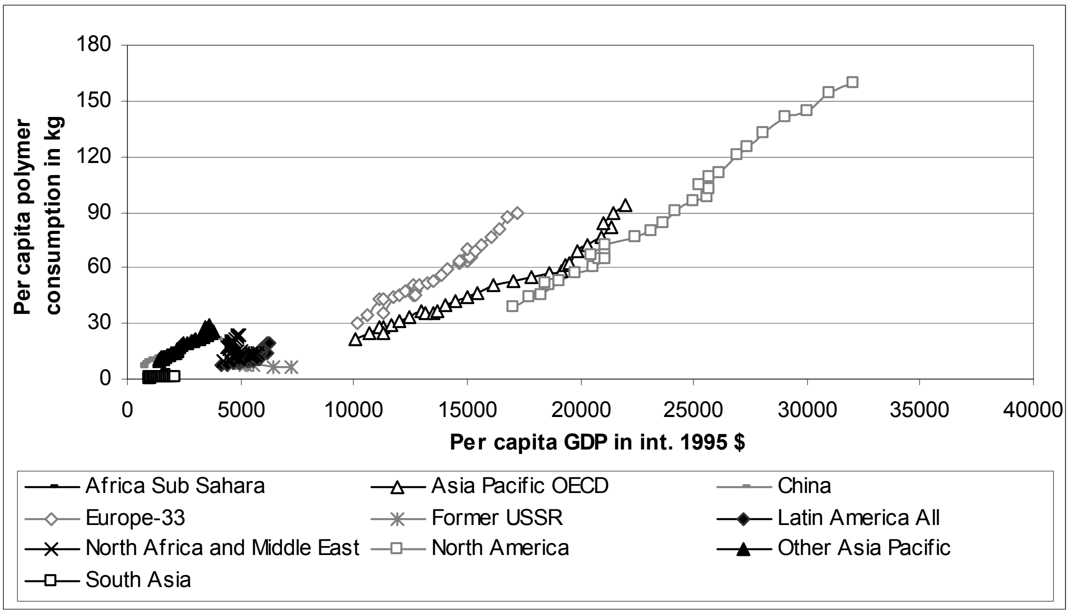


Figure 3.24. Polymers - Per capita consumption

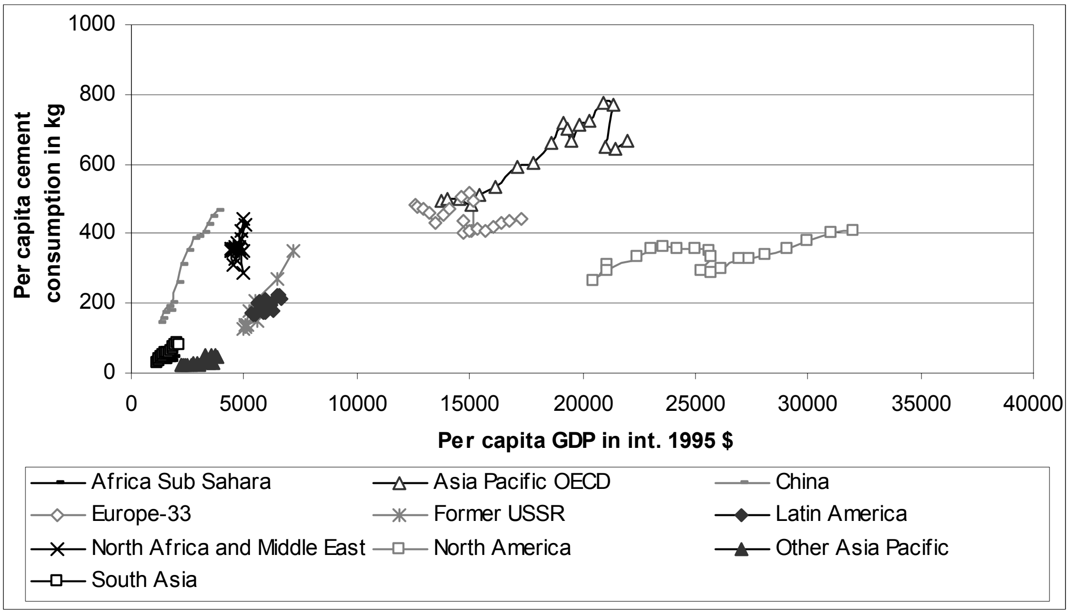


Figure 3.25. Cement - Per capita consumption

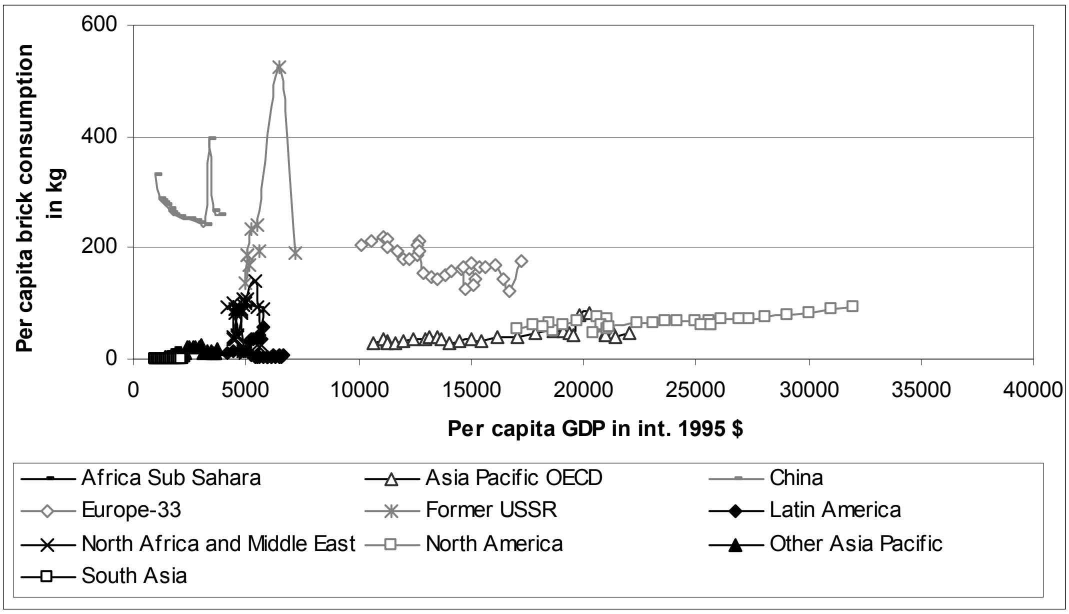


Figure 3.26. Bricks - Per capita consumption

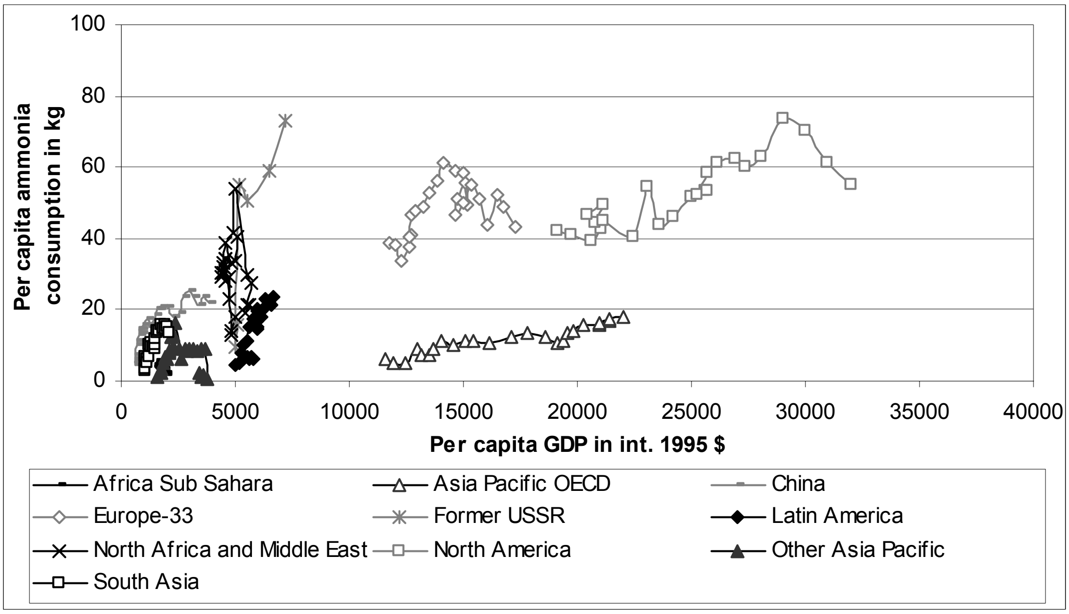


Figure 3.27. Ammonia - Per capita consumption

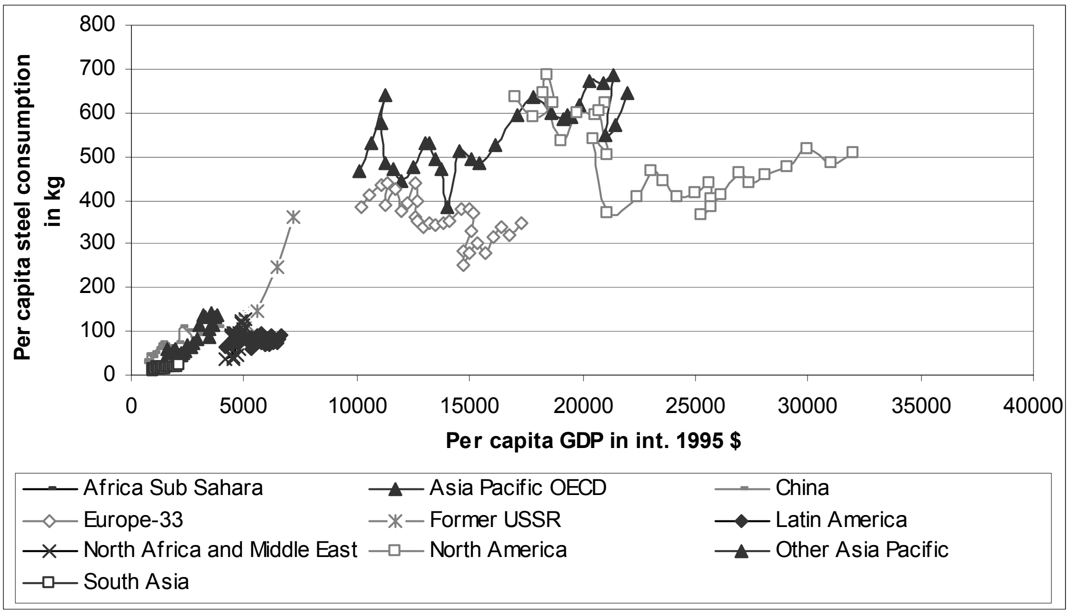


Figure 3.28. Steel - Per capita consumption

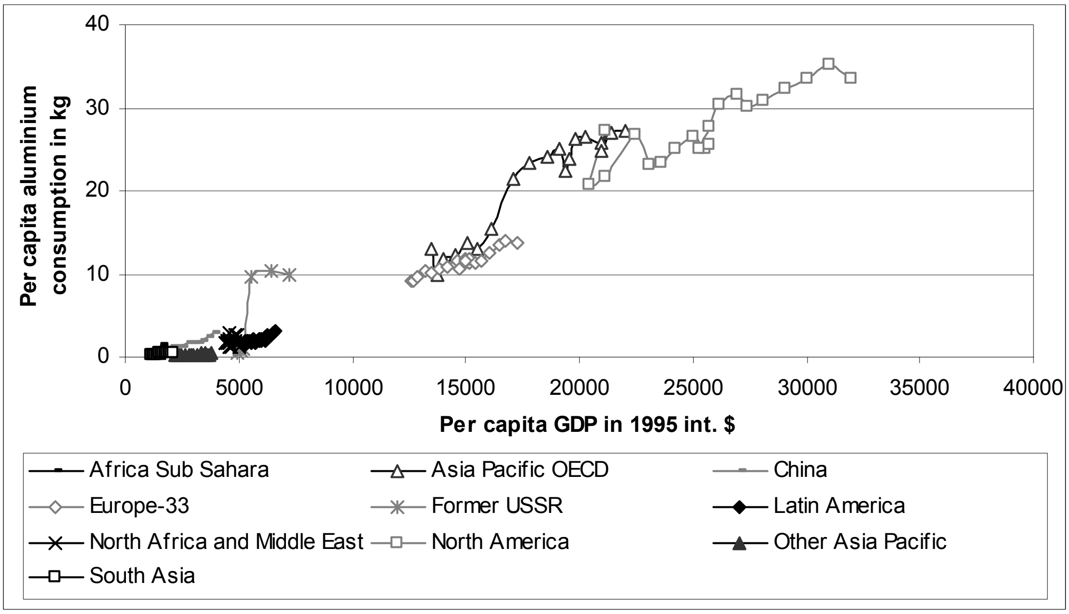


Figure 3.29. Aluminium - Per capita consumption

In contrast to the intensity of use data, the per capita physical consumption data for all materials covered covered in this analysis indicate increasing materials use with rising per capita GDP levels. This trend is particularly strong for polymers, paper, and aluminium and less pronounced for materials such as wood or bricks. Regarding the apparent per capita consumption of steel, the data indicate an increase at low and medium GDP levels (Chateau et al. 2005). However, especially the data for North America suggest some kind of saturation at per capita steel consumption of 400-500 kg for GDP levels beyond 25000 international 1995 $ per capita (Appendix A, Figure A.3 to Figure A.10). Wienert (1996) partially support this finding by an in-depth analysis of the iron and steel industry (with emphasis on structural changes in Germany). Based on data for 67 countries, Wienert (1996) found saturation levels for steel consumption of around 400 kg at per capita GDP levels of 4,000 - 30,000 US $. He concludes that the per capita steel consumption of a country depends largely on the stage of development (expressed by the level of GDP) and the structure of the GDP. Both, the share of industry and the intra-industrial share of the steel consuming sectors like automotive and machinery producers as well as the construction sector are of special importance for the intensity of domestic steel consumption.

Consumption data for 10 *bulk* materials were used by de Bruyn et al. (2003) to assess developments towards dematerialization in the period of 1990 to 2001 for The Netherlands. The authors found the apparent physical consumption of steel, copper, paper, sand, and chlorine to increase in the period studied, while the consumption of naphtha, aluminium, wood, cement, and soy beans showed large fluctuations or remained nearly constant in the period studied. De Bruyn et al. (2003) conclude that the material consumption of the Dutch economy increased in the period studied partially to a larger extent than GDP.

While previous authors choose (physical) material *consumption*, Jänicke et al. (1992) and Groenenberg et al. (2005) plot physical *production* on the y-axis (as a function of per capita GDP on the x-axis). Compared to per capita consumption, the spread of per capita production is generally larger, thus reflecting specialization in the industrial sector of the various countries. The most important results from Jänicke et al. (1992) are summarized in Table 3.4.

Table 3.4. General trends of per capita bulk materials production and consumption for 32 industrialized countries in the period of 1970-1990 (Jänicke et al., 2004)

Product	Parameter (y-axis)	General trend
Paper and Paperboard	per capita production	increasing production at all income levels
Cement	per capita production	increasing production until per capita GDP levels of 5000-8000 US $, generally decreasing production at higher GDP levels
Chlorine	per capita production	increasing production at all income levels
Pesticide	per capita production	increasing production at all income levels
Fertilizer	per capita production	increasing production until per capita GDP levels of 9000 US $, generally stabilizing production at higher GDP levels
	per capita consumption	increasing consumption until per capita GDP levels of 8000 US $, stabilizing consumption at higher GDP levels
Crude Steel	per capita production	increasing production until per capita GDP levels of 6000-10000 US $, decreasing or stabilizing production at higher GDP levels
	per capita consumption	increasing consumption until per capita GDP levels of 5000-9000 US $, stabilizing or slightly decreasing consumption at higher GDP levels
Aluminium	per capita production	increasing production at all income levels
	per capita consumption	strong increase of consumption at all income levels

As the data from Jänicke et al. (1992) show, in the course of economic development of the 32 industrialized countries included in the analysis there is a trend towards strong decoupling for steel and cement production and towards weak decoupling for fertilizer production. A heterogeneous trend can be observed for chlorine and pesticides while re-coupling is found for the production of paper and aluminium. The plots prepared by Groenenberg et al. (1995) for steel and aluminium support these findings (see Appendix A, Figure A.3 and Figure A.4).

In conclusion, intensity of use analyses and per capita analyses allow identifying, as a function of per capita income, the materials that grow rapidly and those that grow slower than GDP. The trajectory of intensity of use must be interpreted carefully because the substitution between resources can be misinterpreted as recoupling or decoupling. For example, in the case of aluminum substituting for steel, the ratio of steel use (in tonnes) over GDP may decrease over time, which could be wrongly interpreted as dematerialization. Moreover, the analysis of the ration of material use over GDP does not allow a better understanding of the relationship between the physical output produced and the monetary value generated in the industry. This analysis will be done for selected industrial sectors in the next chapter.

3.4.3 Comparative analysis of value added and physical production

Studying the relationships between value added and physical output of selected manufacturing industries allows (i) to obtain an overview of developments regarding dematerialization and re-materialization within individual sectors and (ii) to possibly identify underlying drivers for observed changes such as shifts in production factors (e.g. capital, labour, and materials). To evaluate the development of value added and physical production, we follow the terminology as outlined in Chapter 2, Figure 2.15). Both, weak decoupling and re-coupling coincide with increasing absolute physical production. Although strong decoupling implies declining or at least constant physical production, this does not indicate that the level of production is sustainable as the limits of sustainable resource use might well be exceeded.

At the end of the previous Section (3.4.2) we discussed the possible misinterpretation of the substitution between resources as being recoupling or decoupling. Contrary to the ratio of aluminium use (in tonnes) over GDP (see Section 3.4.2), this is by far less relevant or even irrelevant for the ratio of material use (e.g., steel in tonnes) over value added, as a function of time: If, for example, a boom of aluminum production and use entails price erosion for steel, the ratio of value added per tonne decreases for steel, indicating a re-coupling for this material (so, if the value added of the steel sector is supposed to be the same as in the preceding year this will only be possible by increasing the physical output and vice versa). The risk of misinterpreting the substitution between resources is hence smaller than in the case discussed in Section 3.4.2. The risk can be further reduced by simultaneously covering *all* key engineering materials, as we do in this report. While some of the materials are “winners” and others are “losers”, the aggregated analysis for the total of all these materials (see Figure 3-38 and Figure 3-43) provides good insight into the overall trends.

3.4.3.1 Results from Relevant Scientific Publications

First insight can be obtained by simply dividing the value added of a given sector by its physical output. We did not find any study, which systematically performs this type of time series analysis for both several economic sectors and different countries.

Ramirez and Blok (forthcoming) investigate, among other aspects, this issue for the food chain in the EU-13. The increase in value added of the agricultural sector and especially of the food-processing sector is by far larger than the increase of the respective physical flows (agricultural land and physical output of the food system) (Figure 3.30). The specific value added, expressed in EUROs per calorie output of the total food processing sector increased by 3.9% per year in the period 1960-2002 while the specific value added of the agricultural sector (by analogy expressed EUROs per calorie output of the agricultural system increased by 1.5% per year. Especially the food-processing sector is hence a very good example for successful decoupling between value added and physical output.

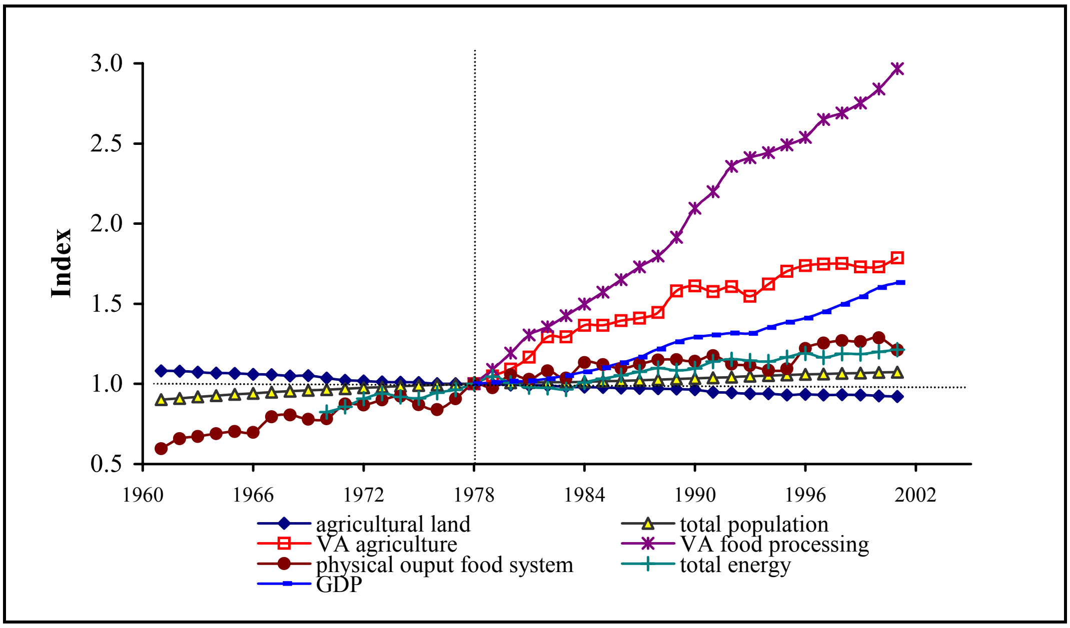


Figure 3.30. Development of physical and monetary indicators in the food supply chain of Western Europe (13 EU Member States) (Ramirez and Blok, forthcoming)

Hoekstra (2003) analyzed the development of value added to physical output for ten industrial sectors in the Netherlands for the years 1990 and 1997 (Table 3.5).

Table 3.5. Physical output and value added of selected products in the Netherlands for the period of 1990-1997 (Hoekstra, 2003)[35]

Products	Physical Quantities in Mt			Value Added in mill. 1997 EUR			Trend
	1990	1997	%	1990	1997	%	
Primary plastics	3.48	5.11	*47%*	736	1403	*91%*	weak decoupling
Plastics products	1.09	1.42	*30%*	1220	1472	*21%*	expansive re-coupling
Primary iron and steel	4.94	6.33	*28%*	1226	1329	*8%*	expansive re-coupling
Iron and steel products	2.80	3.92	*40%*	1965	2259	*15%*	expansive re-coupling
Machines	0.96	1.18	*22%*	3262	3619	*11%*	expansive re-coupling
Office equipments & computers	0.07	0.15	*124%*	78	244	*212%*	weak decoupling
Electrical appliances	0.26	0.51	*92%*	934	899	*-4%*	strong re-coupling
Electronics	0.19	0.51	*169%*	419	514	*23%*	expansive re-coupling
Cars and engines	0.56	0.63	*14%*	950	1367	*44%*	weak decoupling
Transportation equipment	0.41	0.29	*-29%*	399	425	*7%*	strong decoupling

The period of 1990-1997 was characterized in the Netherlands by re-coupling for the majority of products. Six out of ten production activities generate in 1997 lower value added per unit physical production than in 1990. Among these are primary iron and steel, iron and steel products, and plastics products, which can be regarded as bulk products with respect to the physical quantities produced (Hoekstra 2003). According to this analysis re-coupling between physical output and value added was an important trend in the development of the Dutch industry in the 1990s.

[35] Physical output is measured here in Mt of manufactured material or semi-finished and finished product.

3.4.3.2 Data Analysis Based on Available Physical and Monetary data

Since no further scientific studies assessing the relation between physical and monetary growth on the level of individual industrial sectors were available to us, we decided to conduct own analyses. To this end, we chose manufacturing sectors, for which data were readily available. Our analysis comprises industrial sectors producing bulk materials, i.e. the wood industry, the paper industry, the non-metals minerals industry, the chemical industry, the iron and steel industry, and the non-ferrous metals industry. All these industrial sectors are characterized by relatively high material flows associated with the value added generated.

We conducted our analysis based on monetary data from the Groningen Growth and Development Centre (GGDC 2005) and the United Nations Industrial Development Organization (UNIDO, 2006). For physical data, we made use of time series collected by Utrecht University for the VLEEM project based on various sources such as UN (2000) and several producer associations. For each individual sector, we identified one or two key products and analyzed the relation between physical output of this key product and the value added of the whole sector based on a time series for the period of 1979-2000 (Appendix B, Table B-2). Due to limited data availability the research was restricted to the regions of North America, Europe[36], South Asia[37] and China. The results of this analysis are presented in Figure 3.31 to Figure 3.37.

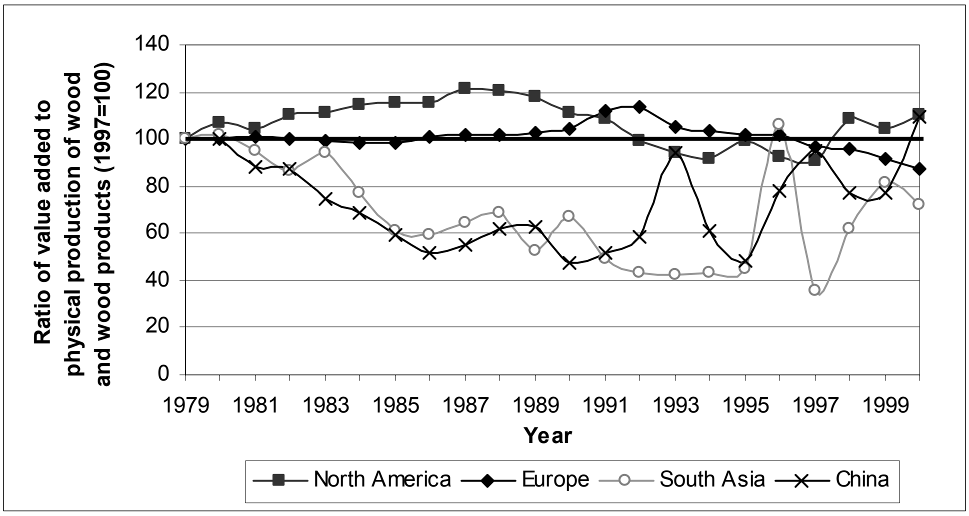


Figure 3.31. Value added and physical production in the wood and wood products industry

[36] The region of North America includes Canada and the USA. Due to data availability, the analysis for Europe is based on value added data for the EU-15 and on physical production data for the EU-33. This inconsistency is, however, acceptable because the majority of physical production originates from the EU-15 countries (e.g., 70-80% of crude steel production in the EU-33 originates from the EU-15).

[37] For this region, only a complete time series of value added data for India was available. We therefore compare in our analysis physical production of South Asia with the value added data for India. The findings of this analysis nevertheless provide a good indication for the developments in the analysed industrial sectors because India is by far the biggest economy in this region.

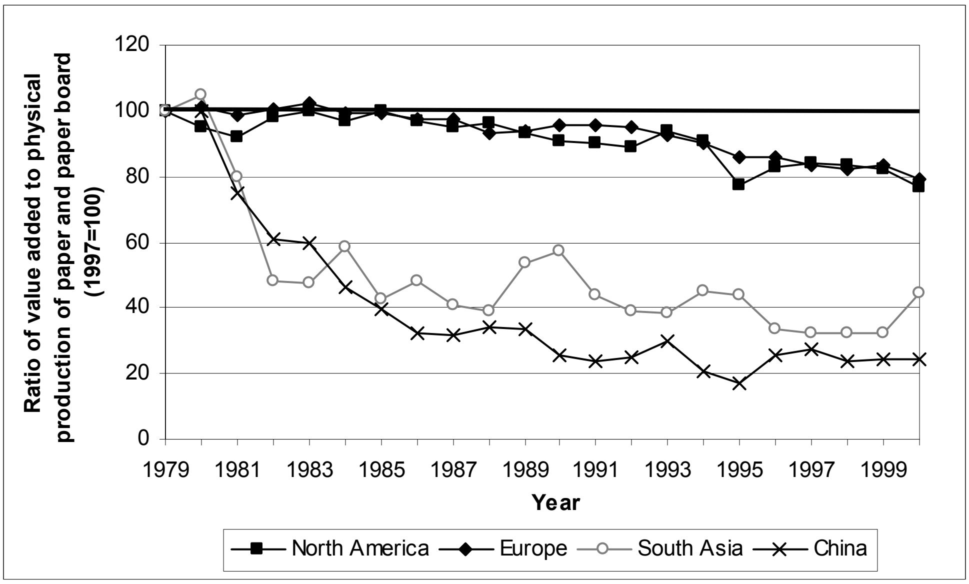


Figure 3.32. Value added and physical production in the pulp, paper, and paper products industry

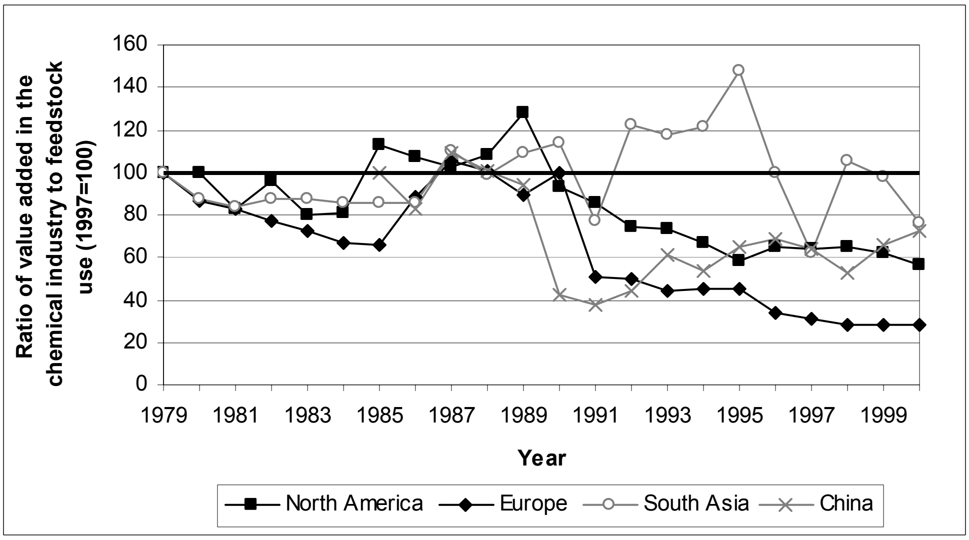


Figure 3.33. Value added of the bulk chemical industry compared to physical feedstock use

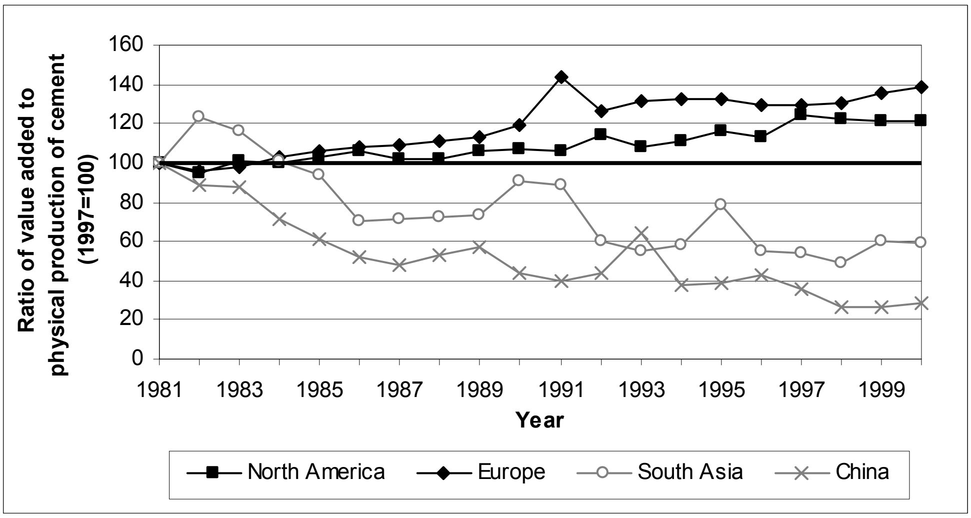


Figure 3.34. Value added and physical production of cement in the non-metallic minerals Industry

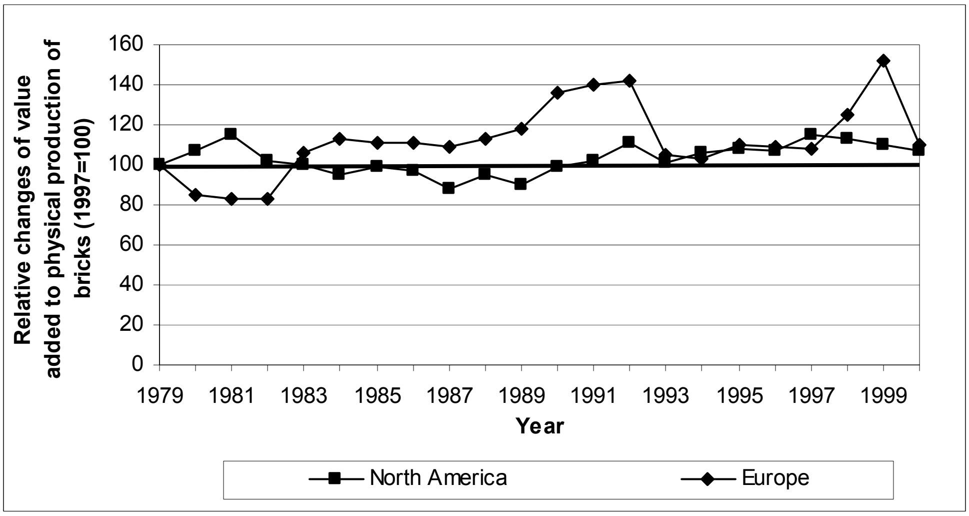


Figure 3.35. Value added and physical production of bricks in the non-metallic minerals Industry

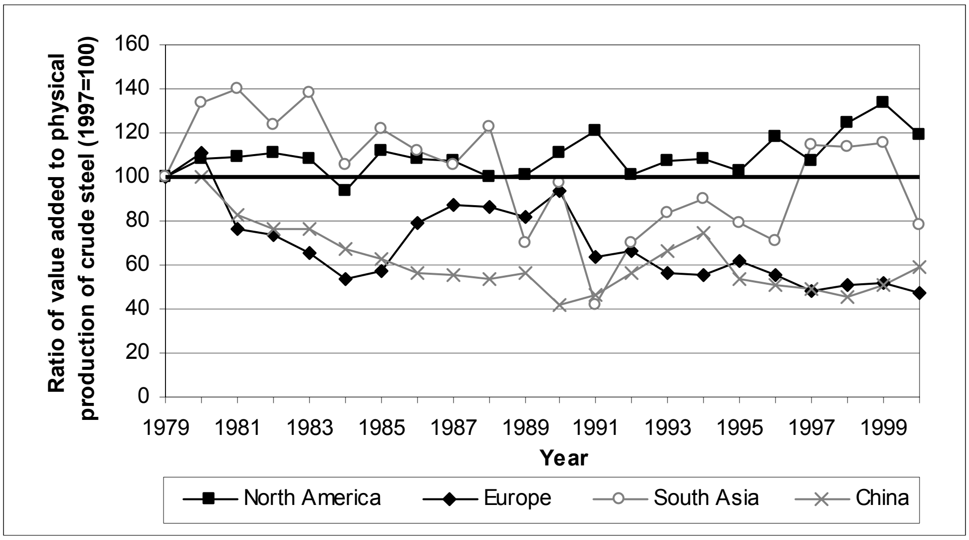


Figure 3.36. Value added of the iron and steel industry compared to physical production of crude steel

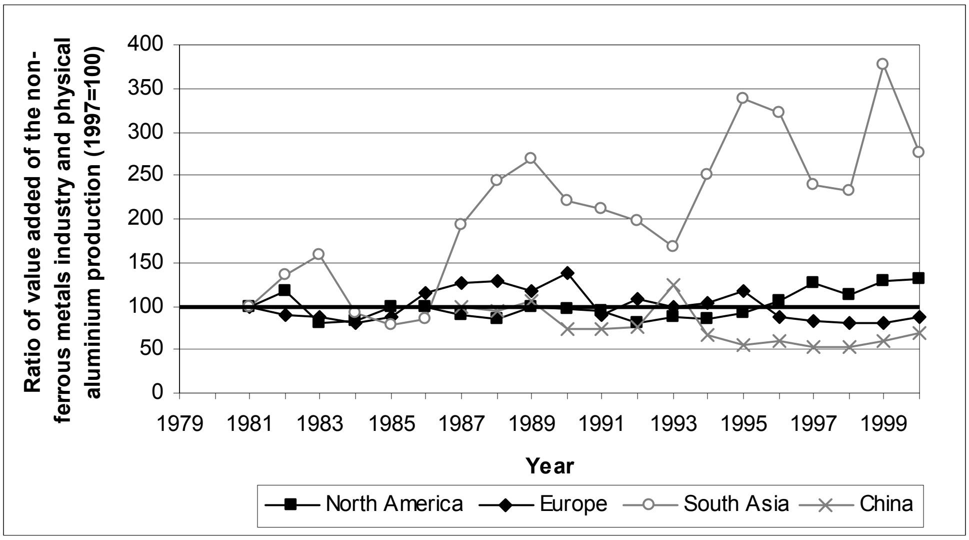


Figure 3.37. Value added of the non-ferrous metals industry compared to physical production of aluminium

For the production of wood, we cannot identify a trend towards either increasing or decreasing value added to physical output (VA/PO) ratios in the different regions (Figure 3.31). While the data for North America and Europe show only minor variations, especially VA/PO ratios for South Asia and China fluctuate considerably in the various years. Based on the data analyzed, a trend towards either decoupling or re-coupling in the wood producing industry can therefore not be observed.

The VA/PO ratios for paper and paper board production show a decreasing trend for all regions in the period studied (Figure 3.32). While the decline is moderate in North America and Europe (around 20% compared to the base year), China (76%) and South Asia (45%) experienced a remarkable drop of value added per physical output. The results reveal therefore an overall trend towards re-coupling of physical output and value added, i.e. indicating increasing material intensity of the paper industry in the four regions studied.

The VA/PO ratios for feedstock use in the bulk chemicals industry show decreasing trends for North America and Europe only in the years after 1989 (Figure 3.33). Especially for South Asia, data show large fluctuations. Based on our analysis for the whole period of 1979-2000, we cannot identify a clear trend towards either decoupling or re-coupling in the bulk chemical industry of the four regions[38].

For cement production, we observe a trend towards increasing VA/PO ratios for North America and Europe while there is a decreasing trend for South Asia and China (Figure 3.34). In particular, the data for China show a large decrease of value added per physical output as in the year 2000 physical production generated only 28% of the value added it produced in the base year of 1979.

Regarding the production of bricks in the non-metal minerals industry, only data for Europe and North America were available to us for the period of 1979-2000 (Figure 3.35). Especially the data for brick production in Europe show large fluctuations. For both regions, no trend towards increasing or decreasing VA/PO ratios can be identified based on the analyzed data.

Also in the iron and steel industry, no general trend towards either declining or increasing VA/PO ratios can be observed (Figure 3.36). While Europe shows a considerable decrease of VA/PO ratios (-52% in the year 2000 compared to the base year 1979), this decline is largely caused by a drop of VA/PO ratios in the years of the oil crisis between 1979 and 1983. In the time period afterwards, the data fluctuations between individual years are much higher than a possible trend towards decoupling or re-coupling. Also for other regions, the analyzed data show large fluctuations, which does ultimately not allow us to draw solid conclusions regarding decoupling or re-coupling in the iron and steel industry.

For the non-ferrous metals industry a strong increase of VA/PO ratio associated with large data fluctuations can be observed for South Asia (Figure 3.37)[39]. For all other regions, no tendency for a development could be identified as data fluctuations exceed a possible trend towards either decoupling or re-coupling.

Table 3.6 gives an overview of the qualitative developments regarding value added to physical output ratios in the analyzed industries. It is important to note that we did not perform a rigid statistical testing of the data series presented in Figure 3.31 to Figure 3.37. However, such a statistical analysis would be necessary in order to underpin the results as presented in Table 3.6.

We conclude from our empirical data analysis, that for the majority of industrial sectors analyzed (i.e. wood production, chemical industry, production of bricks, iron and steel, and partly also aluminium production in the non-ferrous metals industry) we are not able to identify a trend towards either decoupling or re-coupling between value added and physical output. Our study nevertheless reveals a **trend towards re-coupling in the paper and paperboard producing industry of all regions and for cement production in South Asia and China**. We furthermore identified a trend towards **decoupling (i) for cement production in North America and Europe and (ii) for aluminium production in China**.

[38] We compare here physical feedstock consumption with the value added generated in the chemical industry as included under the ISIC rev 2 code 351, i.e. including the manufacture of basic chemicals, fertilizers, synthetic resins, fibres, and plastic materials. High value final chemical products such as pharmaceuticals, varnished, lacquers, and cosmetics are excluded from this analysis.

[39] It is important to note, that we compare here the value added of the total non-ferrous metals industry with the physical output of aluminium. The development of VA/PO ratios as shown in Figure 3-37 are hence only a very indirect measure for dematerialization in the non-ferrous metals industry because aluminium production accounts in average only for around 40-50% of the total metals production of this industrial sector.

Table 3.6. Overview of the development of physical output and value added in selected industries in the period of 1979-2000 (numbers in brackets refer to the change of VA/PO ratio in the final year compared to the base year of the analysis)

	Trend
ISIC rev 2 Code 331: VA wood and products of wood and cork vs. physical wood production	
North America (1981)	no trend identified
Europe (1981)	no trend identified
South Asia (1981)	no trend identified
China (1981)	no trend identified
ISIC rev 2 Code 341:VA paper, and paper products vs. physical paper and paper board production	
North America (1981)	expansive re-coupling (-23%)
Europe (1981)	expansive re-coupling (-21%)
South Asia (1981)	expansive re-coupling (-55%)
China (1981)	expansive re-coupling (-76%)
ISIC rev 2 Code 351: VA industrial chemicals vs. physical feedstock use	
North America (1981)	no trend identified
Europe (1981)	no trend identified
South Asia (1981)	no trend identified
China (1985)	no trend identified
ISIC rev 2 Code 36: VA non-metal mineral products vs. physical cement production	
North America (1981)	weak decoupling (+21%)
Europe (1981)	strong decoupling (+38%)
South Asia (1981)	expansive re-coupling (-41%)
China (1981)	expansive re-coupling (-72%)
ISIC rev 2 Code 36: VA non-metal mineral products vs. physical brick production	
North America (1981)	no trend identified
Europe (1981)	no trend identified
ISIC rev 2 Code 371: VA iron and steel industry vs. physical crude steel production	
North America (1981)	no trend identified
Europe (1981)	no trend identified
South Asia (1981)	no trend identified
China (1981)	no trend identified
ISIC rev 2 Code 372: VA non-ferrous metals vs. physical aluminum production	
North America (1981)	no trend identified
Europe (1981)	no trend identified
South Asia (1981)	weak decoupling (+177%)
China (1987)	no trend identified
Totals	
North America (1981)	no trend identified
Europe (1981)	no trend identified
South Asia (1981)	expansive re-coupling (-36%)
China (1981)	expansive re-coupling (-64%)

The total developments of VA/PO ratios for the 6 industrial sectors combined (cumulated) are depicted in Figure 3.38 and at the bottom of Table 3.6. Although cumulative VA/PO ratios in North America are 13% higher in 2000 compared to 1981 and 6% lower in Europe for the same time period, we cannot identify a clear trend towards either decoupling or re-coupling in both regions. However, trends towards expansive re-coupling can be observed for South Asia and China (-36% and -64% respectively for the comparison of VA/PO ratios in 1981 and 2000)[40,41].

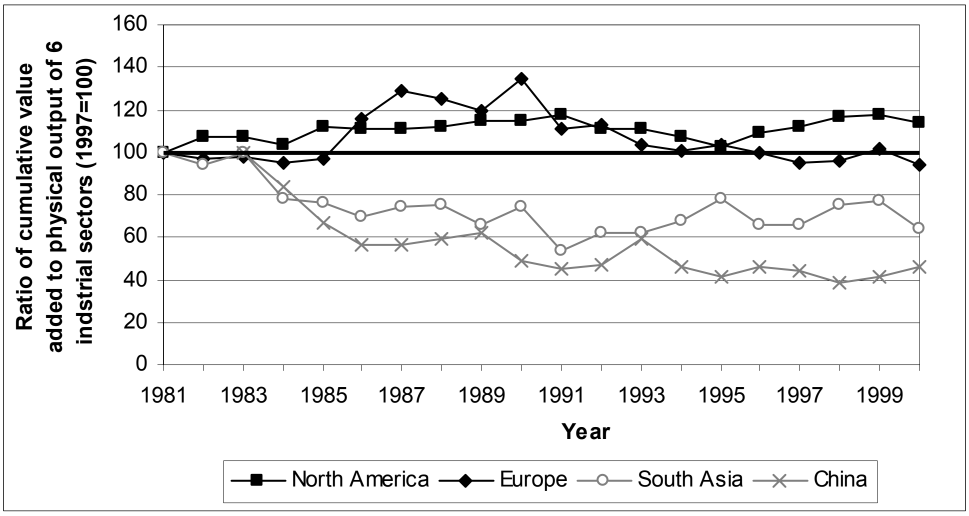


Figure 3.38. Development of the cumulative value added to physical output ratios

In Figure 3.39 and Figure 3.40 we give value added and physical output in absolute units for each of the four regions. As the data show, the considerable decrease of total VA/PO share for China in the period of 1983-1986 (see Figure 3.38) is mainly caused by the large expansion of cement production, which is not associated with a comparable increase of value added in the non-metal mineral industry of China.

Furthermore, the findings show that the chemical industry is in all regions the biggest generator of value added (among the industry sectors studied, see Figure 3.39) while cement production constitutes in general the largest physical output (Figure 3.40).

40 The totals in Figure 3-38 for North America and Europe include also brick production, while this is not the case for South Asia and China. Brick production is included for North America and Europe because we aim at getting a more complete overview of the developments of the bulk materials industries in each region. The system boundaries for total physical production and total value added in the industries of the four regions are therefore not entirely consistent with each other.

41 In order to determine the cumulated ratio of value added to physical production across the industrial sectors we did not apply any sort of weighing. We simply add the value added of all industrial sectors and divide by the total physical output expressed in units of mass (Mt).

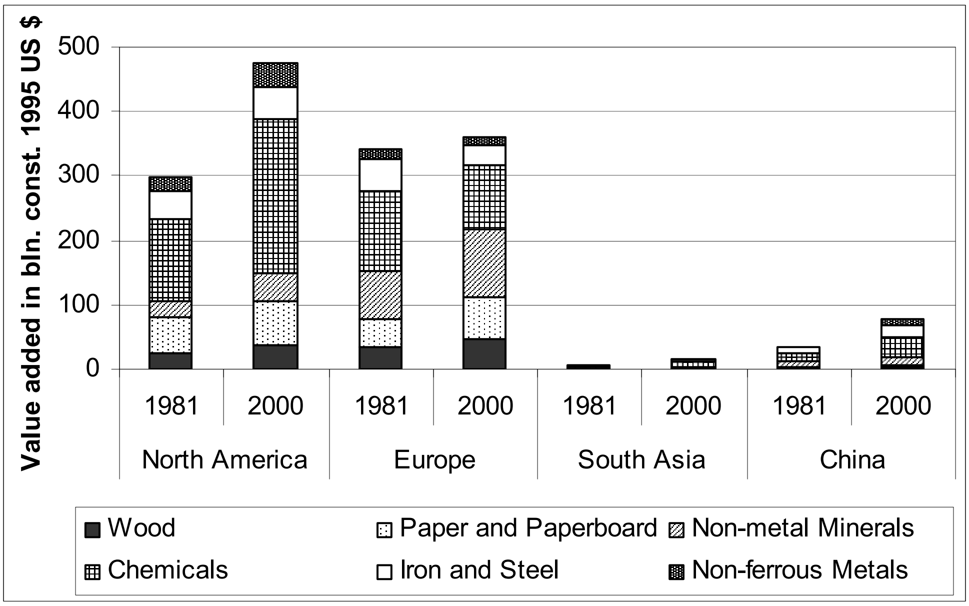


Figure 3.39. Value added generated in the selected industrial sectors of four regions

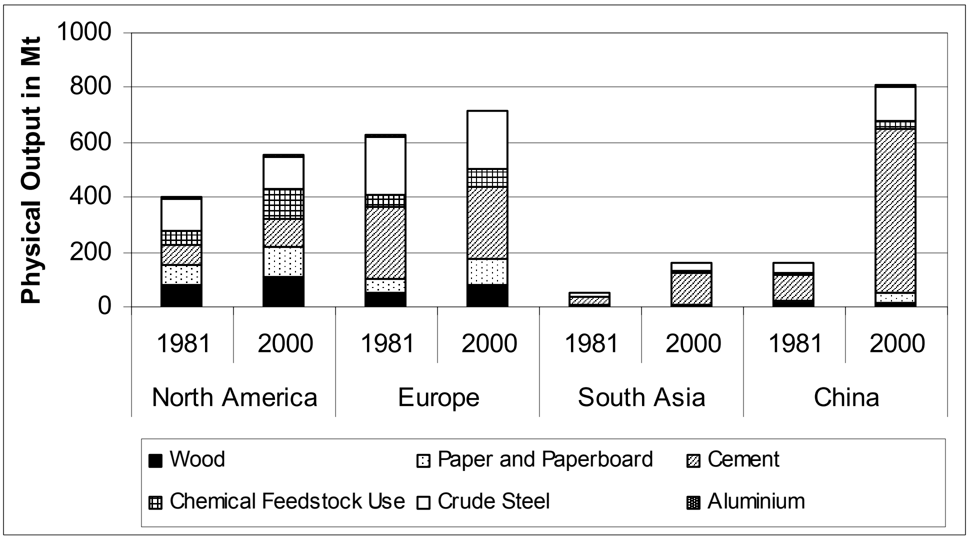


Figure 3.40. Physical output generated in the selected industrial sectors of four regions

The VA/PO ratios are highest for the non-ferrous metal industry[42] and for the chemical sector. Compared to this, the non-metallic minerals industries as well as both the wood industry and the iron and steel industries are rather material intensive sectors (Figure 3.41).

[42] Please note the value added refers to the total non-ferrous metal industry, while the physical output takes only aluminium production into account. Aluminium is however the most dominant non-ferrous metal produced, accounting for roughly 40% of total non-ferrous metals production in Europe. Therefore, as a rule of thumb, value added to physical output ratios in the non-ferrous metals industry are by a *Factor 2* lower than indicated in Figure 3-41.

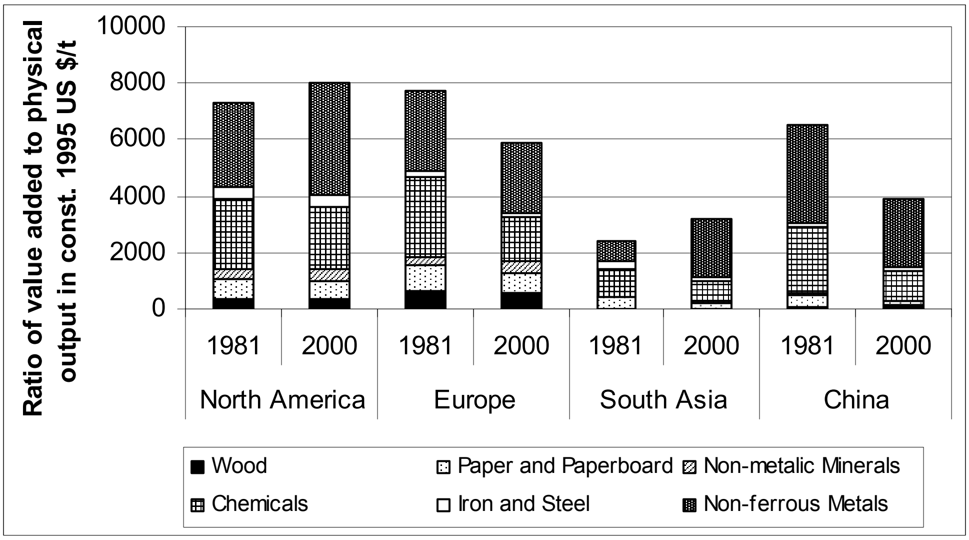


Figure 3.41. Ratio of value added to physical output for selected industries

To have a closer look at the environmental relevance of materials included in our analysis, we multiplied the physical output as shown in Figure 3.40 with the specific primary energy requirements for the production of each of the materials (Table 3.7), i.e. we calculated physical production indicators (PPI) (see also Farla 2000).

Table 3.7. Specific primary energy consumption for the production of selected materials (Farla, 2000, FAO, 2006)

Product	Value based on:	SEC in MJ/kg	Base year
Wood [43]	basic wood processing	1.6	-
Paper and Paperboard	arithmetic mean of the production of printing paper, packing paper, corrugated cardboard, other board, sanitary paper	11	1983
Cement	Production of cement	2	1986
Chemical Feedstock Use	arithmetic mean of the production of ethylene, propylene, benzene and butadiene	63	1986
Crude Steel	crude steel production from pig iron	13	1986
Aluminium	production of primary aluminium	180	1986

Energy intensive aluminium production and feedstock use in the chemical industry have a considerably higher physical production indicator than total physical output (compare Figure 3.40 and Figure 3.42). In contrast, especially wood production is less energy intensive. Therefore the PPI of wood products is much smaller than the total physical output.

[43] Unlike most other industries, there are considerable variations between different wood-processing plants regarding the energy consumption in the production of lumber, plywood or particleboard. The specific energy consumption for wood production is a rough estimate based on data presented by FAO (2006). We assume here wood density of 0.8 t/m^3.

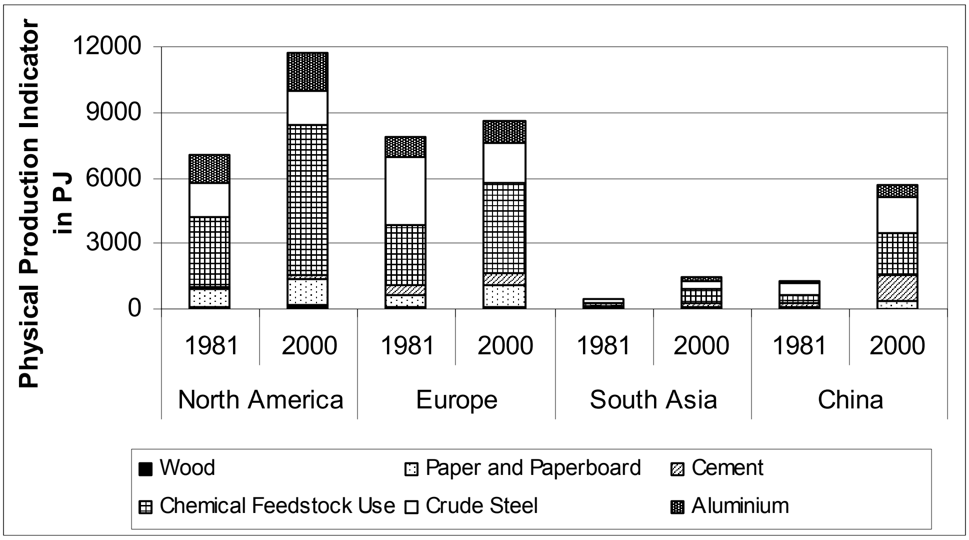


Figure 3.42. Physical production indicator (PPI) for bulk materials production

Comparing the absolute ratios of value added to physical production for all six industrial sectors, we find considerably lower value added per physical output in South Asia and China compared to Europe and North America (Figure 3.43 and Figure 3.44)[44]. This finding might suggest on the one hand that indeed less knowledge and know-how intensive products are being produced by low-income countries, while high-income countries striving for market niches producing knowledge intensive and high quality products.

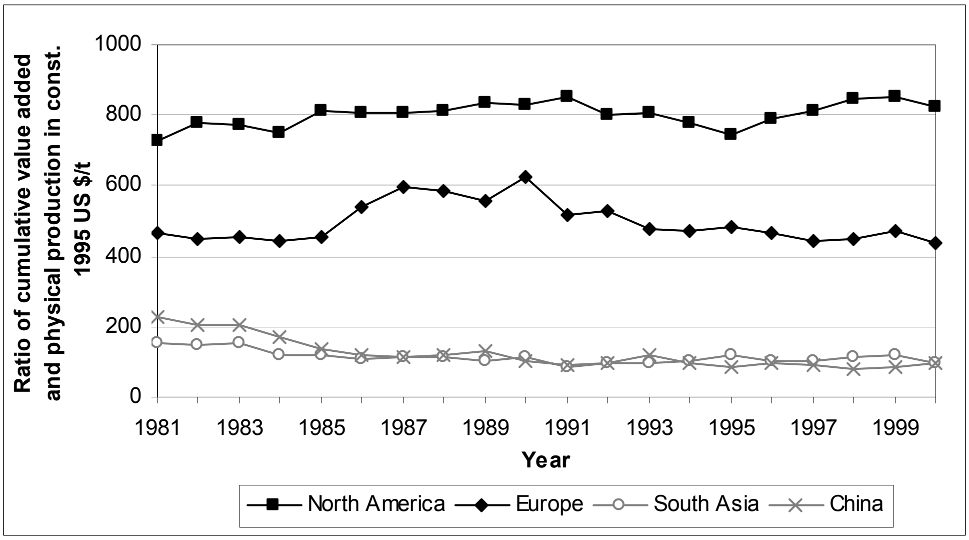


Figure 3.43. Development of the ratios of total value added and physical output in the analyzed industrial sectors (this graph is the non-indexed version of Figure 3.38)

[44] We include here the production of wood, paper and paperboard, cement, crude steel, and aluminium as well as feedstock use in the chemical industry.

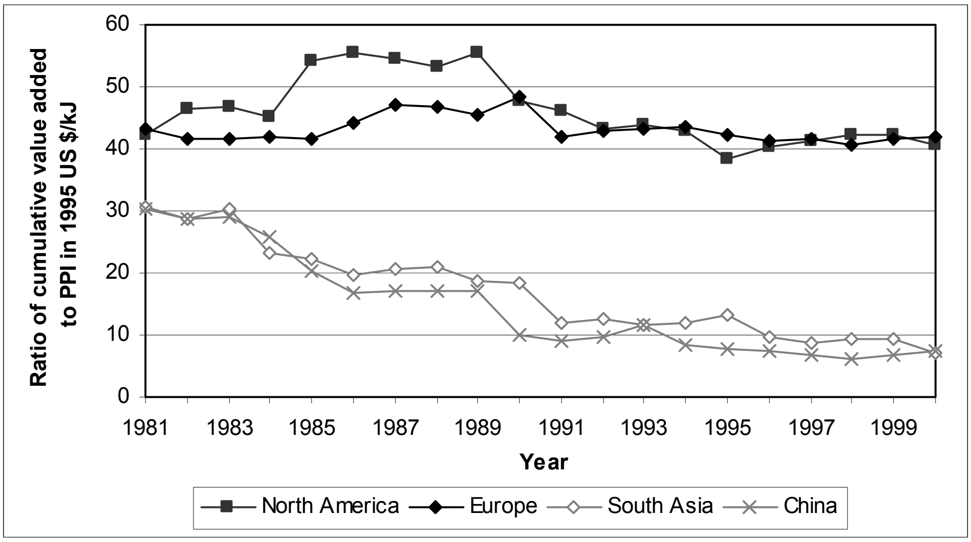


Figure 3.44. Development of the ratios of total value added to physical production indicator (PPI), i.e. energy productivity, in the analyzed industry sectors[45]

On the other hand this result may also be caused by undervalued currencies in developing countries like China. A further explanation could be differences regarding labour cost across the regions[46] but on the other hand, these are generally small for bulk materials compared to total production costs (Wienert 1996, Destatis 2003b) and therefore most likely play a subordinate role.

While energy productivity is in the same range for South Asia and China, the results in Figure 3.43 and Figure 3.44 indicate that compared to the physical output generated, the industrial production in Europe is less energy intensive than in North America. This result does, however, not reflect regional differences regarding the specific energy consumption of individual industrial processes but rather different shares of industrial sectors on the PPI of the industry (industry structure), i.e. due to lower energy prices, energy intensive industries (e.g. aluminium production, see Figure 3.42) are more dominant in the bulk materials industry of North America than in the one of Europe.

Analyzing the specific ratios of value added to PPI for the various regions we see relatively high values, if the specific energy consumption (SEC) of a production process is low (e.g. in the wood industry) or if product-specific value added is comparatively high (as it is the case for aluminium production in the non-ferrous metals industry). Rather small fractions of value added to primary energy consumption are found for developing regions mainly as a consequence of considerably lower VA/PO ratios compared to the high-income regions of North America and Europe (Figure 3.45).

45 It is important to note that the cumulative primary energy use does not reflect regional differences regarding product-specific energy consumption (SEC) as we multiply physical production with a uniform SEC factor for all regions (see Table 4-7).

46 Please note that we did not correct value added data for purchasing power parities (PPP) in this analysis.

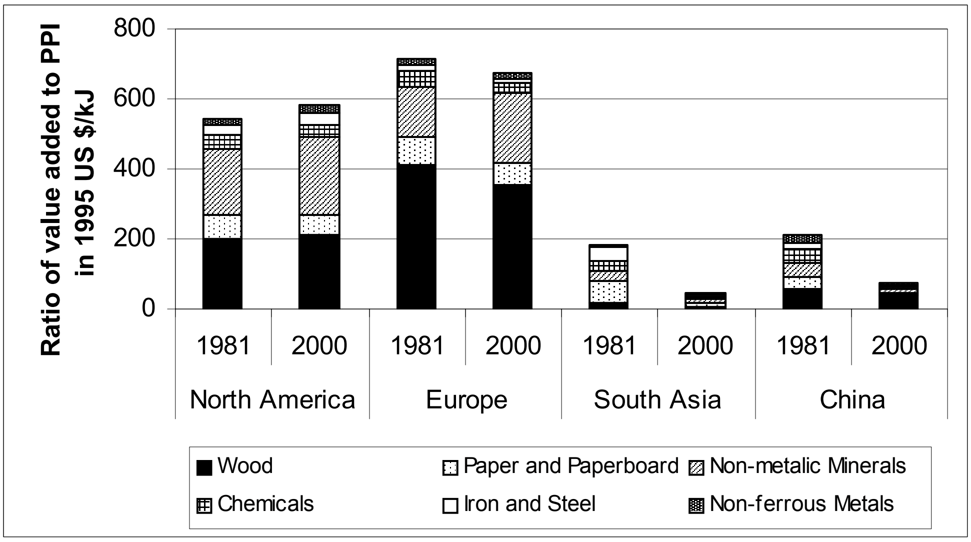


Figure 3.45. Sector specific energy productivity (ratio of value added and PPI) by sector and region

Having a closer look at the developments in the chemical sector, we plot for North America and Europe (i) the ratio of value added for the total chemical industry and (ii) the ratio of value added for industrial bulk chemicals versus physical feedstock use (Figure 3.46).

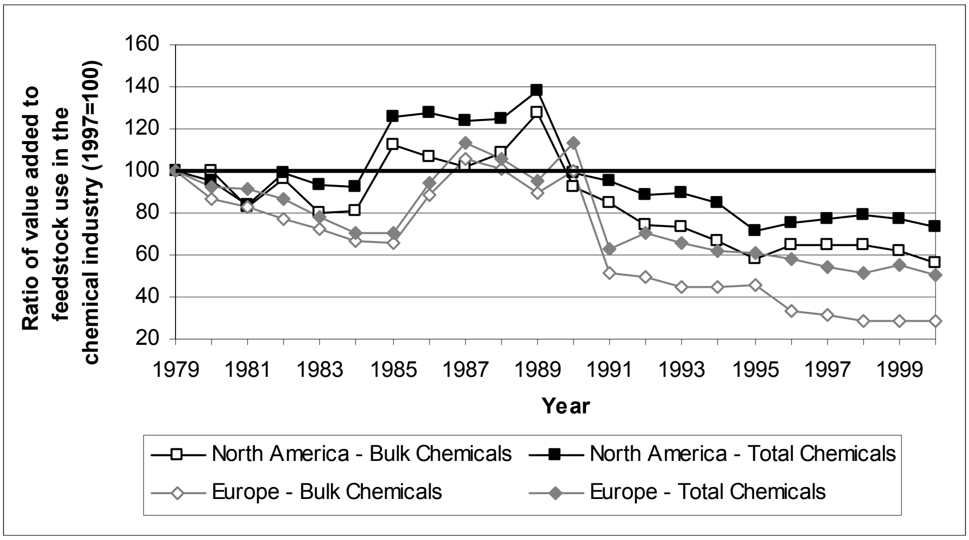


Figure 3.46. Ratio of value added to physical feedstock use (i) for the total chemical industry (ISIC rev 2 Code 35) and (ii) for the producers of bulk chemicals (ISIC rev 2 Code 351)

The results show that the decline of value added per unit of feedstock use of the total chemical industry (including the production of high-value, knowledge intensive products such as e.g. pharmaceuticals) is smaller than for bulk chemicals (e.g. basic industrial chemicals, fertilizer) alone. Figure 3.46 therefore shows that industry sectors can compensate for value added decline in bulk products manufacturing by increasing their share of innovative, high-value products. We herewith confirm our **Hypothesis No. 3** (see Section 3.3). This result is also supported by the earlier presented findings of Ramirez and Blok (forthcoming), who observed the value added increase in the agricultural sector and especially in the food processing sector to be higher than the increase of the respective physical flows. The very substantial increase in value added in the food sector is a consequence of product innovation, leading, for example, to special diet products and convenience food (instant microwave meals and frozen food).

The findings of our data analysis in this chapter are subject to uncertainties, which mainly arise from (i) incoherent system boundaries of physical production data and value added data and (ii) from the quality of the used value added data itself. A detailed list of data sources used and value added conversions applied for this data analysis, is given in Table C-1 in Appendix C. The main features regarding uncertainties in our analysis are as follows:

- In the case of Europe, we compare the physical production in the EU-33[47] with value added data for the EU-15. We chose this approach due to constraints on the availability of production and value added data. As a consequence, the absolute ratios of value added to physical production as calculated for our analysis are too small for Europe. This inconsistency is justifiable because roughly 80% of the industrial production in Europe originates from the EU-15. Nevertheless, we consider the trends of the VA/PO ratios found in our analysis for Europe give indication rather than proof for trends in the industrial sectors analyzed.
- Due to constraints regarding data availability, we used value added data of India as proxy for the value added generated in the respective industries of South Asia. This approach results in absolute VA/PO ratios which are slightly too low. The approach is nevertheless justified because India is by far the largest economy in that region (share of roughly 80% in 2001 on the total GDP in this region). For the same reason it is justified that we used data for the feedstock consumption in India as proxy for feedstock use in South Asia.
- In order to deflate value added data given in current US $ for South Asia and China (UNIDO, 2006), we used industry specific deflators of the USA. This approach was necessary because regional specific deflators were not available to us. The chosen methodology can be justified, if we assume that equal goods sell for equal prices worldwide. This ideal situation does, however, barely apply in reality as domestic markets are partially protected and exchange, i.e. trade of products is associated with costs, which finally preserves slightly different price levels for similar goods throughout the various world regions.
- Due to lack of more detailed information we applied the deflators given from GGDC (2005) for the chemical industry (ISIC rev 2 Code 35) and for the basic metals industry (ISIC rev 2 Code 37) uniformly to deflate value added data in the respective sub-sectors, i.e. the manufacturing of industrial chemicals (ISIC rev 2 code 351), the production of other chemicals (ISIC rev 2 code 352), the iron and steel industry (ISIC rev 2 code 371), and the non-ferrous metal industry (ISIC rev 2 code 372).

Apart from these methodological inconsistencies, the reliability of value added data as published by UNIDO (2006) and used for the analysis of India and South Asia are sometimes questionable (in view of the very large and sometimes implausible fluctuations). This is a further reason why we regard the result of our data analysis as indication (rather than proof) for the developments in the selected industrial sectors.

Factors further influencing the value added development apart from product innovation are:

- Business cycles at the national and international level
- Trade barriers such as transportation costs and import and export tariffs
- Income changes
- Revaluation and devaluation of

The product categories used in this analysis are too broad for analyzing the effect of product innovation based on the VA/PO ratio alone. The chosen categories also include a substantial amount of sub-products, which could not be classified or analyzed in detail.

Another aspect is related to the choice of products representing the output of certain industrial sectors. While crude steel production gives a good indication of physical production in the iron and steel industry, this is only partly the case for e.g. the aluminium production in the non-ferrous metals industry or cement and bricks production in the non-metallic minerals industry. This is because value added in these industries is only partly generated by the production of the chosen key products, i.e. these sectors also manufacture other materials (e.g. tin or copper in

[47] An exception is the chemical industry, where we used feedstock use data for the EU-15.

the non-ferrous metals industry). Our findings should therefore serve as starting point for more detailed data analysis in the future.

We can conclude that our analysis of selected industrial sectors in four different regions gives no indication for a general trend towards decoupling between value added and physical output in industry. For the majority of industrial sectors (i.e. wood production, chemical industry, production of bricks, iron and steel, and partly also aluminuim production in the non-ferrous metals industry) we are not able to identify a trend towards either decoupling or re-coupling between value added and physical output. However, the results of our study indicate that there is a trend towards re-coupling in the paper and paperboard producing industry and for cement production in the non-metallic minerals industry of South Asia and China. We furthermore identified a trend towards decoupling (i) between cement production and value added of the non-metallic minerals industries of North America and Europe and (ii) for aluminium production in the non-ferrous metals industry of China.

The data give therefore no general support for our research **Hypotheses 1** according to which the value added per unit of physical output of bulk products declines over time.

Also **Hypothesis 2** could only be verified for the paper and paperboard producing industry, where we found a general trend towards re-coupling between physical value added and physical production.

The data give some support to our research **Hypothesis 3** by finding evidence that the decline of VA/PO is smaller in the total chemical industry of North America and Europe than for the production of bulk industrial chemicals alone. This finding might indicate, that industry sectors can successfully compensate value added decline by investing into the production of innovative, knowledge intensive, high-value products.

Finally, our results give some support for research **Hypothesis 4** by showing differences in the absolute ratios of VA/PO between high-income regions in the North and low-income regions of South Asia and China. These differences can, however, not entirely be attributed to differences in the knowledge intensity and innovativeness of manufactured products. Although labour costs have generally only a minor share on the total value added compared to capital cost in the bulk materials industry, the interregional differences of absolute VA/PO ratios might partly reflect income inequalities between high-income and low-income countries. Furthermore also exchange rate disparities can be a factor influencing interregional VA/PO ratios.

So far the research **Hypothesis 5** has not been addressed. This will be done in the later Chapter 3.4.4.2.

For scenario projections on future energy consumption and greenhouse gas emissions, our overall findings ultimately mean that each percentage growth of value added in the bulk industries studied can roughly be approximated to lead to at least a comparable growth in physical output (compare Figure 3.38). Even though these results are subject to the uncertainties explained above, we consider this finding nevertheless as an important starting point for more detailed empirical analyses in the future.

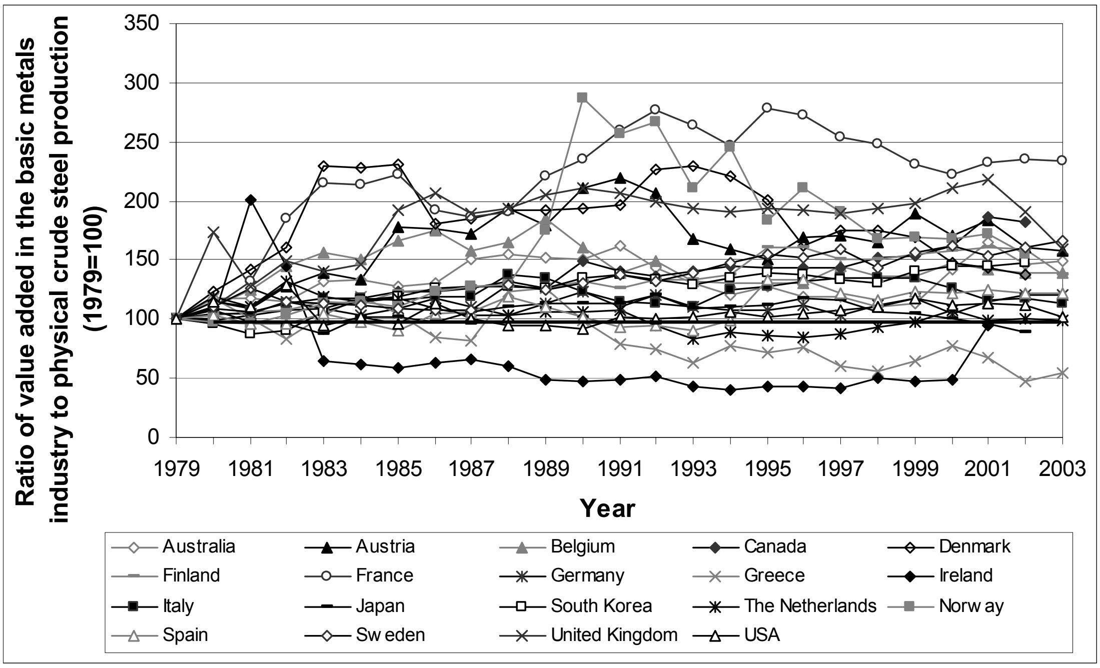
3.4.4 In-depth Analyses

3.4.4.1 Results from Decomposition Analyses

Studying dematerialization in detail requires understanding of the driving forces behind changes in physical output and value added. To this end, Hoekstra (2003) performed a structural decomposition analysis for selected products in the Netherlands for two discrete years, i.e. 1990 and 1997 (using physical production and value added data as presented in Table 3.5). The physical output of products included in Table 3.5 is not only effected by the level of final demand, but also by the overall level of foreign trade, the mix of traded goods, and only to a minor extent by changes in final demand mix, capital investment and input-output coefficients. The value added growth associated with physical output in the respective industrial sectors is mainly caused by increasing levels of final demand, while both, negative import substitution and negative value added coefficients exert considerable downward pressure on the total value added of physical products and are ultimately decisive for the found effect of expansive re-coupling (Hoekstra, 2003).[48]

Studying changes of materials use, Rose et al. (1996) performed a structural decomposition analysis on the factors determining the consumption of plastics, rubber, glass, iron and steel, and non-ferrous metals in the USA for the period of 1972-1982. They observed a reduction of materials use for iron and steel (-30%), non-ferrous metals (-7%) and glass (-6%). In contrast, the use of plastics and rubber increased by 16% and 25% in the same period respectively. For the period of 1972-1982, the U.S. economy seemed to experience a shift from the use of iron, steel, and glass towards the consumption of plastics, rubber, and non-ferrous metals. The largest drivers for increased materials use are the level of final demand and structural changes. The most important factors exerting downward pressure on materials use are structural changes in materials and intermediate substitution (Rose et al., 1996, Hoekstra, 2003).

The results of the decomposition analysis differ between Hoekstra (2003) and Rose et al. (1996). While the findings of Rose et al. (1996) suggest structural change and final demand mix to be factors contributing to lower environmental impacts, the study of Hoekstra (2003) indicates that these factors are drivers for increased physical throughput. One should therefore be cautious in generalizing both, the empirical results on the developments of value added and physical production on the one hand and the factors driving this development on the other[49]. As the results of our empirical data analysis for crude steel production in the basic metals industry indicate, the ratios of value added to physical production vary considerably throughout countries (Figure 3.47). Both the Netherlands and the USA experienced a constant ratio of value added to physical production in the period studied while the opposite is true for many other countries.



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[48] The value added coefficient is a measure for earnings per physical output. In average of all industries analyzed for the Netherlands, these earnings are decreasing by 60% in the period studied. This trend is therefore responsible for a considerable downward pressure on the total value added generated by the production of physical commodities (Hoekstra, 2003).

[49] Note that the analysis done by Rose et al. (1996) covers a period with strong structural change in the US industry. This should be kept in mind when comparing the results from their analysis with the findings of Hoekstra (2003).

Figure 3.47. Relative developments of the fractions of value added in the basic metals industry and physical output of crude steel in various countries[50]

As the results show, the development of value added and physical production do not show a uniform trend but rather deviate widely between different countries. Therefore, empirical results found for individual countries do not automatically apply to other countries.

3.4.4.2 In-depth Analysis of the Iron and Steel Sector

So far, we analyzed dematerialization and the relation between value added and physical production at the level of various industrial sectors. In this Section, we will have a closer look at the developments within one specific industrial sector in order to obtain a better understanding of intra-sectoral changes. Like barely any other industrial sector, the iron and steel industry experienced a process of intensive adaptations and structural changes during the last decades[51]. Despite higher growth rates for the physical production of other materials such as plastics and aluminium, world steel production continued to increase during the last 40 years. This can be explained by (i) the rising demand for products made of steel and (ii) the limited substitution of steel products by other materials. This is because the expansion of new materials (e.g. plastics and aluminium) is mainly driven by demand from new and innovative industrial sectors such as the aeronautics industry (Wienert, 1996).

Physical Deliveries of the Iron and Steel Sector

In Chapter 3.4.3.2 we analyzed ratios of value added to physical production for the iron and steel industry. In this part of the analysis, we are interested in shifts and changes regarding the product mix of this industrial sector. Due to restrictions with respect to data availability, we limit our analysis to the USA and Germany.

Possible indication for shifts towards the production of high-quality knowledge intensive steel products in high-income countries (addressing **Hypothesis 4** and **Hypothesis 5**) can be obtained by analyzing the developments of physical shipments from the iron and steel industry to the various manufacturing sectors. This is rather easily possible because certain sectors such as construction typically consume primarily simple, rather low-priced steel grades, while other sectors (e.g. machinery and automotive) require high-value steels. The steel markets are in general characterized by highly variable demand on the one side, which meets rather inelastic and only over long time periods adaptable steel supply on the other side (mainly due to the large investments involved). In addition, both relative high transportation costs for steel products[52] and governmental interventions to protect domestic steel producers, cause steel markets to remain partially regionalized (Wienert, 1996).

Figure 3.48 and Figure 3.49 show the developments of shipments of steel products for the USA and Germany.

[50] Please note that we plot here the value added of the total basic metals industry versus physical production of crude steel. The results are therefore only indicative for the actual development of VA/PO ratios in the iron and steel industry as the value added data used here also include value added generated in the non-ferrous metals industry.

[51] One of the most striking features of this development is the declining importance of the iron and steel industry relative to other manufacturing sectors. For example, the share of the iron and steel industry on the total turnover of the manufacturing sector declined from around 8% in 1960 to 2% in the mid 1990ies in Germany (Wienert, 1996).

[52] For steel products, transportation costs amount to around 10% of the product value for over-sea shipping. The costs of inland railroad transportation for distances between 800 km and 1000 km are in the same order of magnitude (Wienert 1996). This trade barrier gives local steel producers some freedom regarding the pricing of steel products because they have to some extent cost advantages for over international competitors.

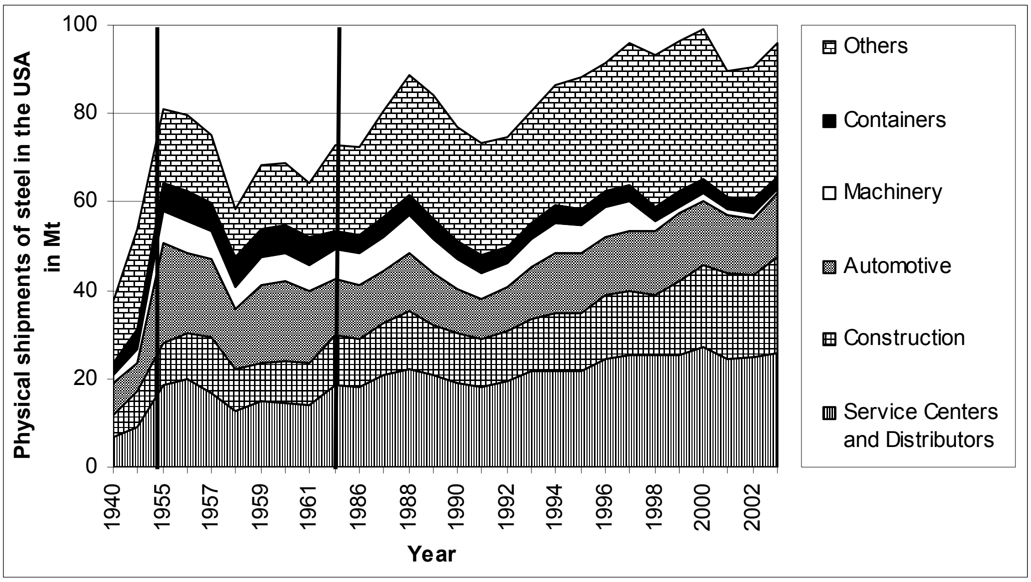
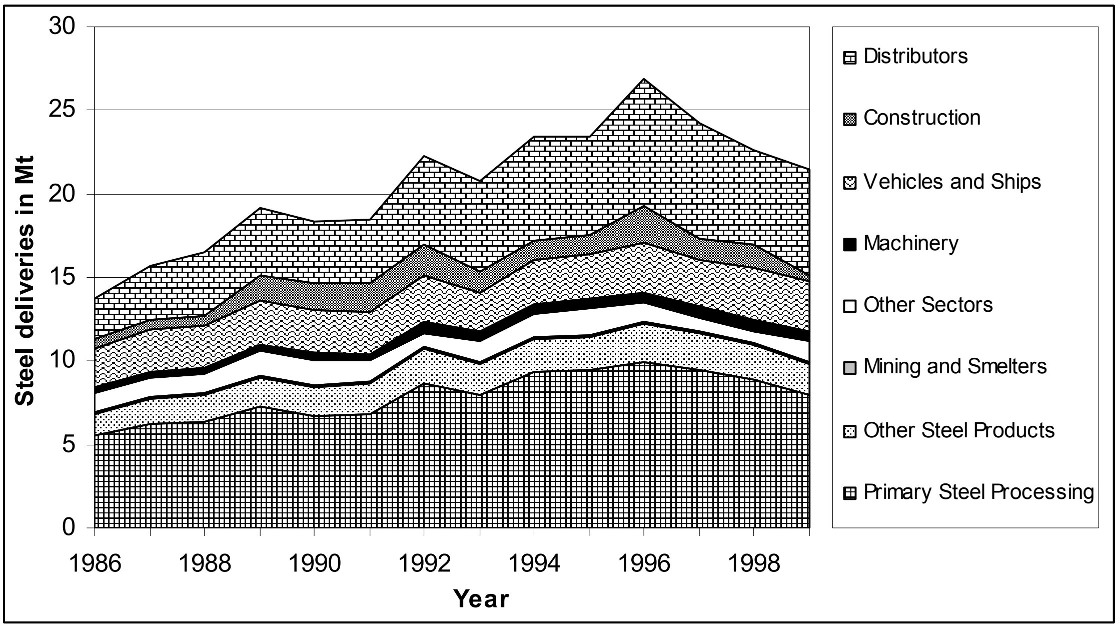


Figure 3.48. Shipment of steel from U.S. producers to the various consumers in the USA (USGS, 2005)[53]

The total physical deliveries of the U.S. steel industry increased in the period studied (Figure 3.48). However, none of the sectors consuming steel products show a considerable decline or increase in the relative amount of steel received. One exception from this trend could be the machinery sector, where the share of deliveries drops sharply in the year 1998. This development might however be a consequence of inconsistent system boundaries for this sector.

Analyzing the German iron and steel industry, we identify increasing physical deliveries until 1996 and decreasing overall steel shipments in the period afterwards (Figure 3.49). Also for the steel shipments in Germany, no major inter-sectoral shifts can be identified.



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[53] The data do not represent a consistent time series but stand for the discrete periods 1940-1941, 1955-1961, and 1985-2003. Furthermore, the system boundaries for sector classification remain uncertain and might not always be consistent throughout the years studied.

Figure 3.49. Shipments of steel from German producers to the various domestic and international consumers (WVS, 2005)

Dahlström and Ekins (2004) analyzed shipments of iron and steel to the manufacturing industry in the UK (Figure 3.50) and the sectoral shares on the delivery of finished iron and steel products (Figure 3.51).

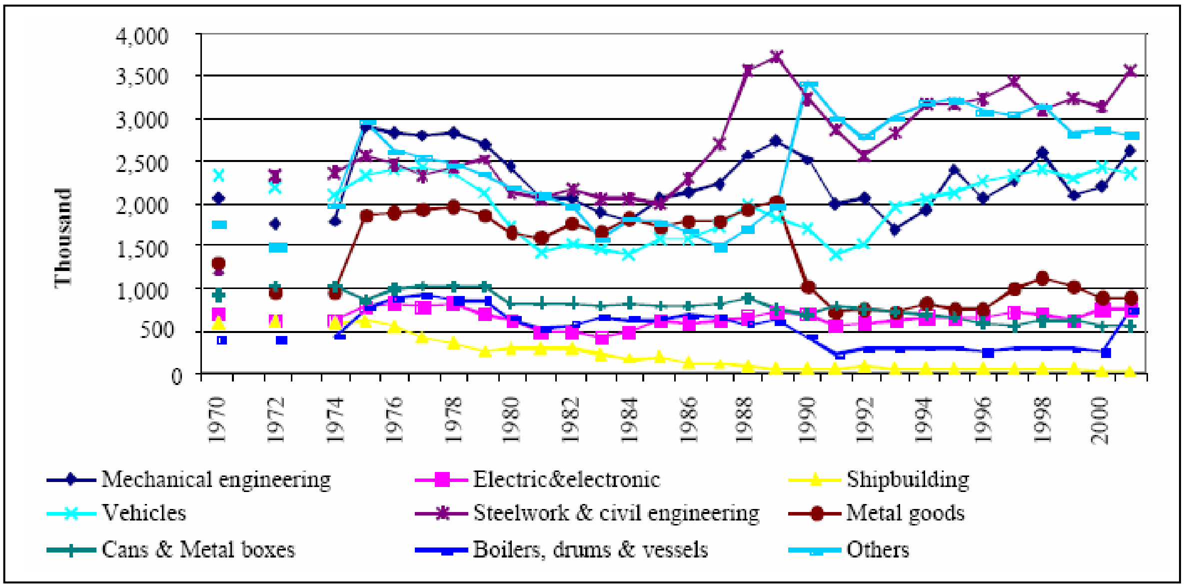

Figure 3.50. Delivery of iron and steel products to the UK manufacturing and fabrication (Dahlström and Ekins, 2004)

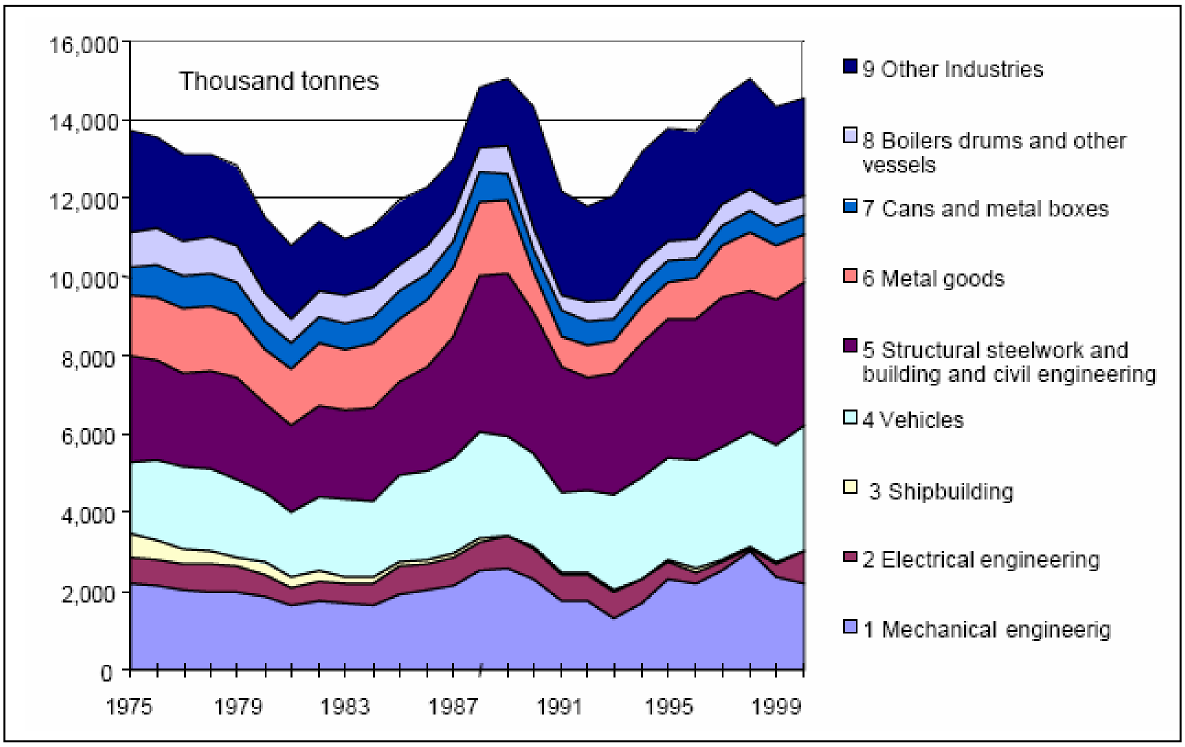

Figure 3.51. Deliveries of finished steel products in the United Kingdom (Dahlström and Ekins, 2005)

The data for the UK show slightly increasing shares of deliveries to the vehicle and construction sector, while shares delivered to the shipbuilding industry decline. It is important to note that the data from Dahlström and Ekins (2005) refer to the deliveries received by the UK manufacturing industries from iron and steel producers. The data therefore cover also imported steel. This is a major difference compared to the data presented for the USA and for Germany, which show the deliveries only of *domestic* steel producers to the various manufacturing sectors.

Based on the available data analyzed for the USA, Germany, and the UK, we are not able to draw conclusions regarding major shifts of physical production from low-quality to high-quality steel products.

Monetary Deliveries of the Iron and Steel Sector

While the previous chapter studied the structure of physical steel deliveries, we now analyze supply/demand structure in monetary terms based on available information from Input-Output tables.

Figure 3.52 shows that for all countries analyzed, the majority of steel products is delivered to industries manufacturing fabricated metal products and machinery. Large differences between individual countries can be found for deliveries going into the construction sector. This finding is partly explained by the stage of development (e.g. building of infrastructure in China) and partly by the strong business cycles, affecting especially the construction sector.

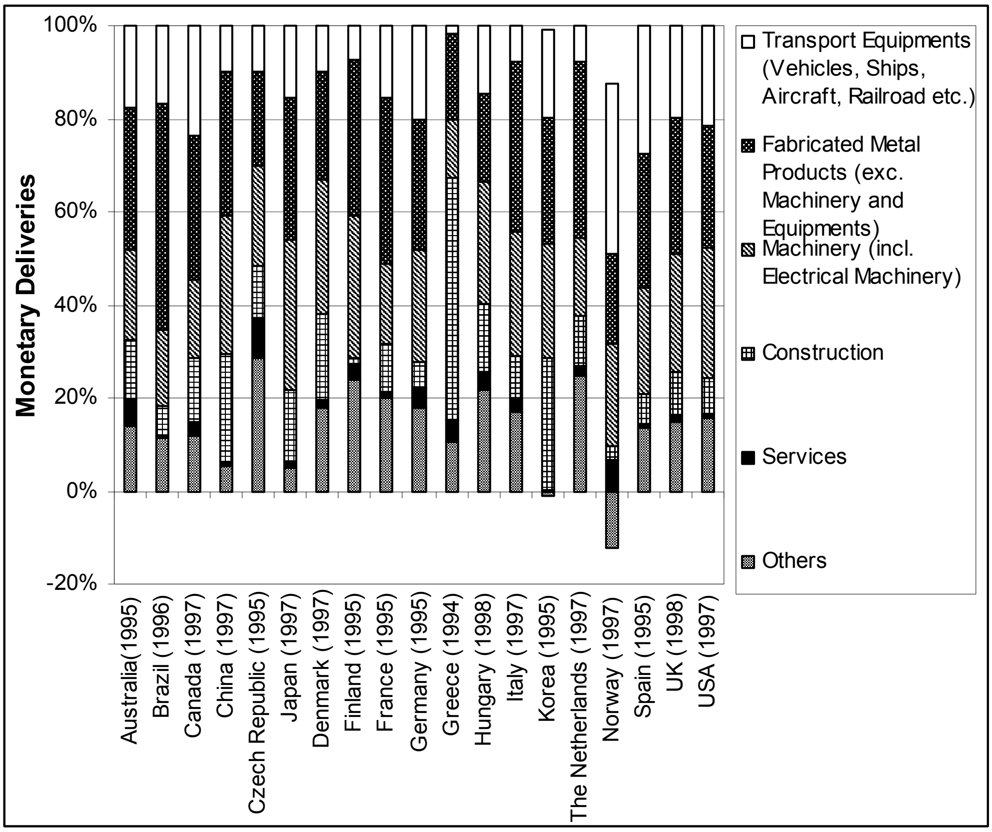

Figure 3.52. Monetary deliveries of the iron and steel sector in selected countries (OECD, 2005)[54]

Depending on the industrial structure of individual countries, large shares of the steel deliveries are also received by the automotive and transport equipment industry.

In order to study the dynamics of steel deliveries over time, we extracted monetary Input-Output data for Germany in the time period of 1978-2000 (Figure 3.53). The analysis is complicated by

[54] Negative values in Figure 3-52 result from changes in inventories and negative gross capital formation, which is included under the category ‘Others’.

a statistical break, i.e. inconsistent sector classification for the periods of 1978-1990 and 1991-2000. The considerable drop of deliveries to the ‚Basic Iron and Steel Products' manufacturers associated with an increase of deliveries to the final demand sector ‚Investment (Equipment and Buildings)' between 1990 and 1991 is caused by this fact.

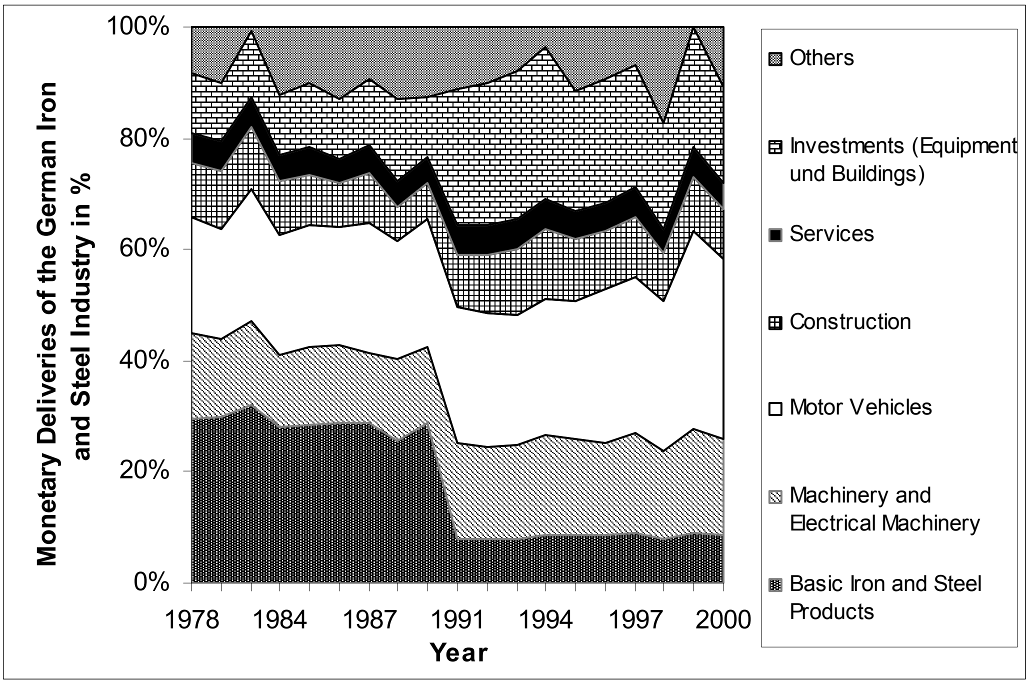

Figure 3.53. Monetary deliveries of the Iron and Steel Industry in Germany (Destatis, 1978-2000)

Figure 3.53 shows a trend towards (i) increasing shares of deliveries to the producers of motor vehicles (e.g. automotive and truck production) and (ii) slightly decreasing shares of deliveries to the investments sector (if changes in system boundaries are accounted for). For all other sectors, the shares either show large fluctuations (see deliveries to 'Others') or remain almost constant in the period of 1978 to 2000.

From the analyses presented in this chapter we obtained insight into the structure of deliveries (expressed in monetary units) from the iron and steel industry to other industrial sectors and to final consumer categories. However, our data analysis does not allow drawing solid conclusions regarding shifts in the output of the iron and steel industry in high-income countries towards high quality and knowledge intensive products (due to statistical breaks, large fluctuations and product categories composed of very diverse products). The increase of deliveries to the motor vehicles industry in Germany accompanied with a slight decrease of deliveries to the investment sector gives some indication that this type of development might indeed happen because in buildings (which are included under the category investments) mainly low-grade steel products for concrete reinforcement is used.

Furthermore, we tried finding some evidence for the fact that in developing countries relative large quantities of low-grade steels are produced. This is, amongst other reasons, probably caused by huge demand of low-grade steels for infrastructure developments. As the international comparison in Figure 3.54 shows, the shares of the construction sector on the total deliveries of the steel industry are indeed comparatively high for Korea (29%) and China (23%). However, shares in Greece are even higher (52%) and the fraction of steel deliveries received by the construction sector in Brazil is much lower (6%). We therefore conclude that the structure of the manufacturing sector in a specific country might have a larger effect on the relative demand of steel products than the general income level (reflecting the stage of development). It is therefore not possible for us to assess research Hypothesis 4 based on the data analyzed in this chapter. This conclusion is also based on the findings shown in Figure 3.54 where we found severe differences between the physical deliveries and the monetary deliveries of the iron and steel sector in the USA.

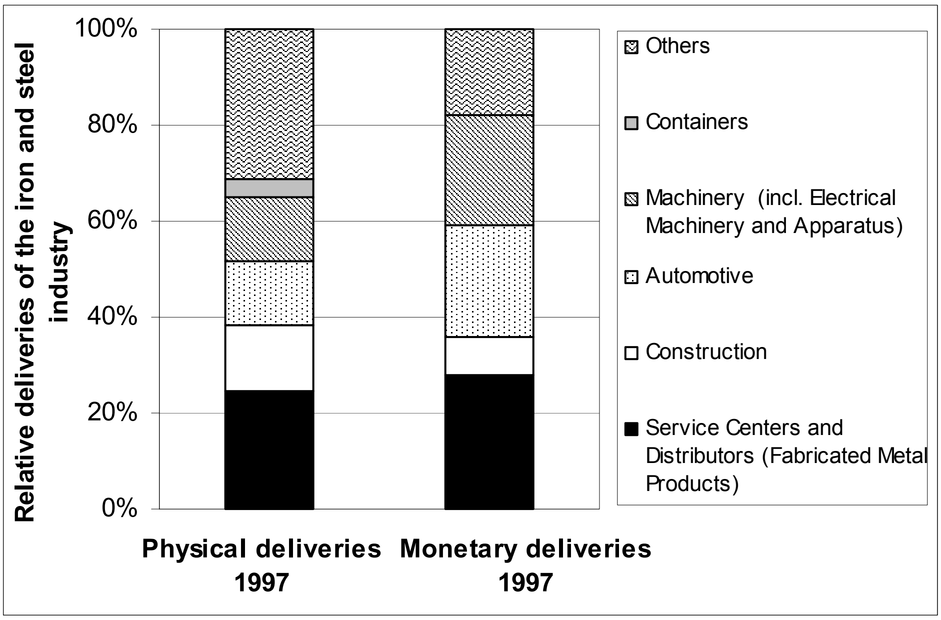

Figure 3.54. Comparison of monetary and physical deliveries of the US iron and steel industry (USGS, 2005, OECD, 2005)

While the machinery sector receives only 7% of the physical deliveries of the iron and steel industry in the USA, it obtains 28% of the monetary deliveries. Conversely, the construction sector receives 15% of the total physical steel products but only 8% of the deliveries in monetary terms. The discrepancy in the data for physical and monetary deliveries is mainly caused by price differences of steel products delivered to the individual intermediate and final demand sectors. The data shown in Figure 3.54 give therefore good indication that indeed low-value steel products are preferably consumed in the construction sector while higher value speciality steels are used for machinery and vehicle manufacturing. It is, however, important to note that system boundaries for physical and monetary deliveries are not always consistent. The results presented here give therefore only rough indication for differences between physical and monetary deliveries of the iron and steel industry in the USA.

A trend towards increased demand for high-value added steel products at the expense of low-value added products (e.g. construction steels) could, in principle, allow decoupling of physical and monetary development in the iron and steel sector. The time series discussed above for Germany (Figure 3.53) does not show clear trends towards such a structural change in steel demand.[55]

Developments in the Iron and Steel Industry of Germany

In this part of the chapter, we will have a closer look specifically at developments in the German iron and steel industry in order to understand and empirically underpin drivers for change in this industrial sector. In the German iron and steel industry, we observe a trend towards increasing material intensity, i.e. lower ratios of value added to physical output (Figure 3.55 and Figure 3.56).

[55] We assume here, that high value steel products generate a higher product-specific value added than low-value steel products.

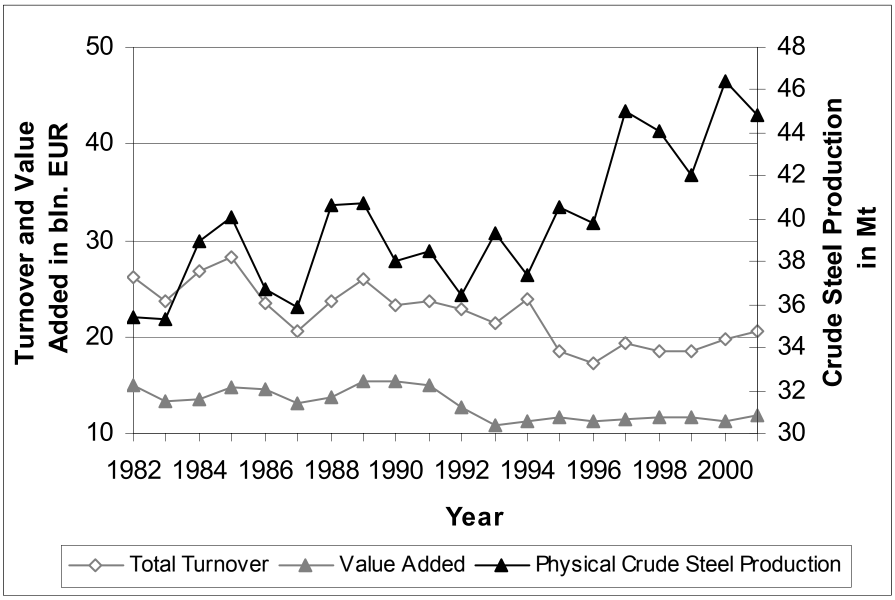

Figure 3.55. Turnover, value added and physical production of crude steel in the iron and steel

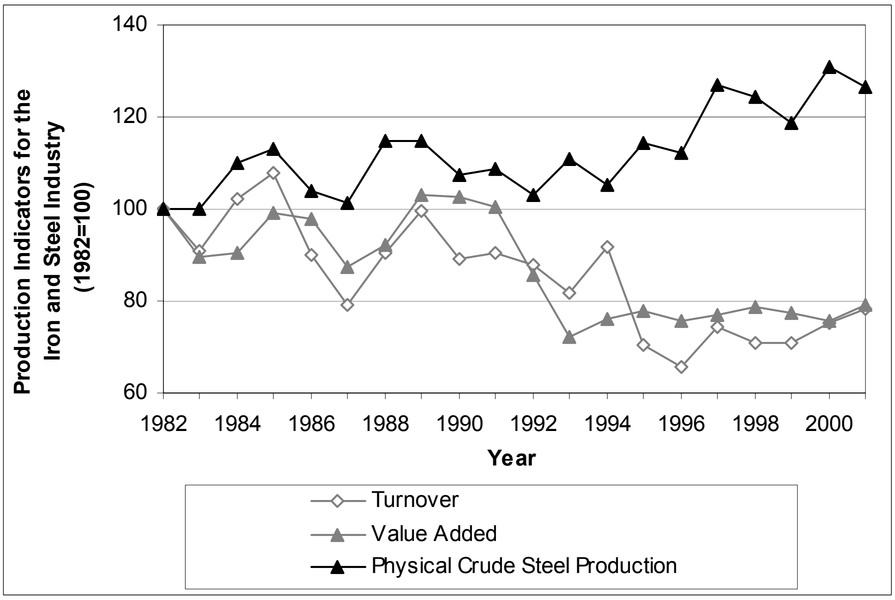

Figure 3.56. Development of turnover, value added and physical production of crude steel in the iron and steel industry of Germany in the period of 1982-2001

In the period of 1982 to 2001, both total turnover (-23%) and value added (-20%) declined in absolute terms, while physical production increased by around 27%.[56] These findings give a clear indication for absolute re-coupling between physical output (i.e. crude steel production) and value added.

The value added decline gives support for the proposed growth cycle (Figure 3.7) according to which industrial development is driven by a subsequent spiral of technological change and substitution of production factors leading ultimately to declining producer costs and decreasing

56 Both absolute and relative values for total turnover and value added in the German iron and steel industry were deflated with deflators as given by GGDC (2005) for the total German basic metals industry.

unit prices. Given the product portfolio of the iron and steel industry and the maturity of production technologies the potential for technological product innovation is relatively limited. Therefore both declining unit prices and declining value added are predominantly compensated by increasing physical output rather than product innovation[57].

Given the trend towards declining turnover in the German iron and steel industry (Figure 3.55 and Figure 3.56) we will now have a closer look at the development of steel prices for individual products. Analyzing a longer time period (1949-2003), we can distinguish five different phases in the development of steel prices in Germany (Figure 3.57).

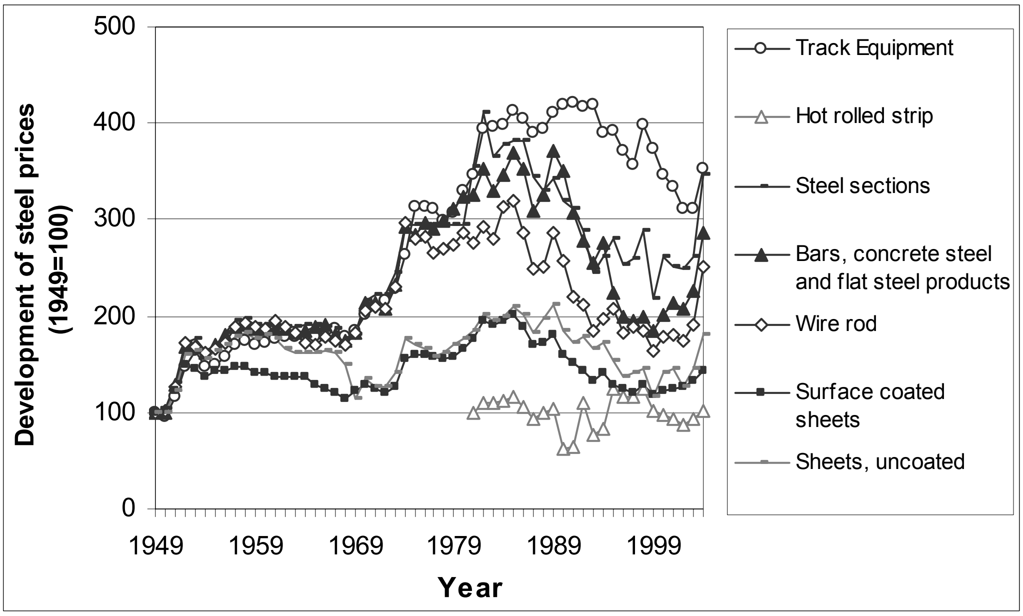

Figure 3.57. Price development of selected steel products in Germany (Destatis, 1949-2004)

The first phase is characterized by a sharp increase of price levels of steel products (period of 1949-1955) due to increasing steel demand for rebuilding the German infrastructure after World War II. In the second phase until 1970, steel prices remained almost constant and price levels even dropped for flat steel products like surface coated sheets. In the period of 1970-1983 steel prices increased considerably, while they dropped for many products to price levels of the early 1970ies in the period of 1983-2000. The fifth period after 2000 is generally characterized by increasing levels of steel prices due to growing steel demand induced by economic growth mainly in Asia, i.e. China and India[58].

Based on their price development, the various steel products can be divided into three main groups. Group one consists of uncoated and coated steel sheets with rather moderate price fluctuations in the total period studied. The second product group consist of wires, bars, concrete steel, and steel sections, which show relatively large price fluctuations. Apart from this, there is track equipment (railway tracks), which follows the price development of the *group two* products but shows comparatively smaller price decline in the period after 1990.

57 The opposite might be the case for knowledge and technology intensive sectors (e.g. electronics industry) where technological development enables the sector to compensate for the declining of both value added and unit prices by product innovation rather than increasing physical output. As a rule of thumb, we might argue that the more knowledge intensive and technology intensive the products of an individual manufacturing sector are the greater might be the potential of this particular sector to compensate declining unit prices and decreasing value added by product innovation and not primarily by increasing physical output.

58 The steel prices as shown in Figure 3-57 and Figure 3-58 are nominal, non-deflated prices.

Looking at the relative price developments at a shorter time period (Figure 3.58), we find similar price trends (i.e. declining prices until 2001/2002 and increasing price levels in the years afterwards) for the majority of products. However, while electrical steel sheets and simple hot rolled strip underwent considerable price decline in the mid 1990s, strip steel and steel pipes experience increasing price levels in the period studied. Based on the data analyzed we cannot distinguish different price trends for high value steel products such as surface coated sheets and low value concrete steels.

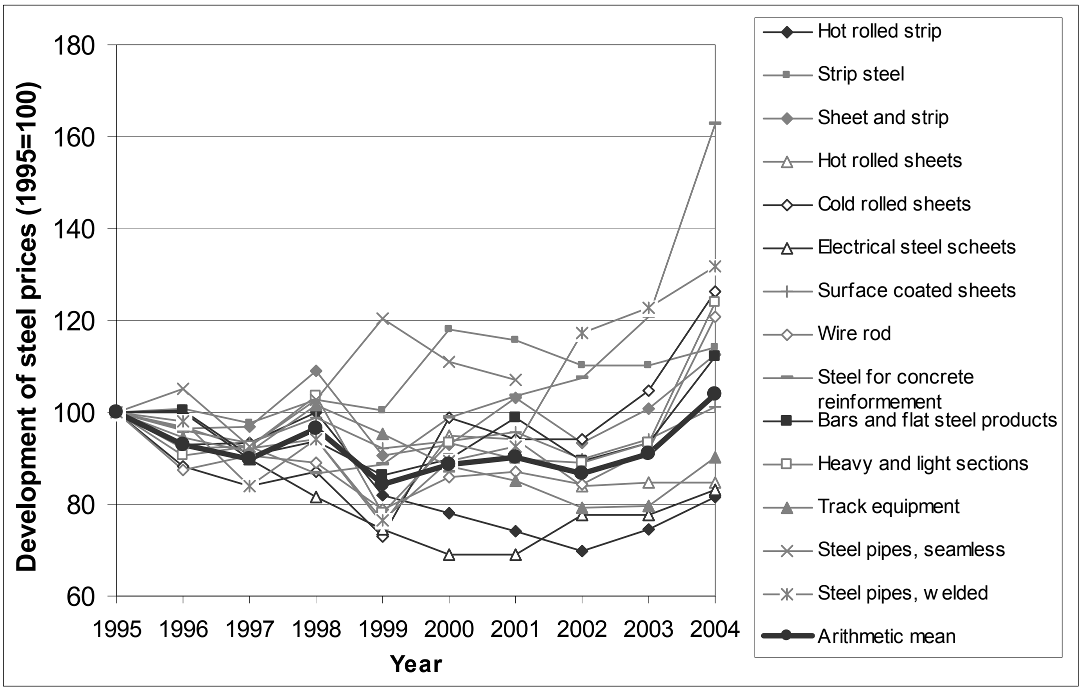

Figure 3.58 Development of steel prices in Germany (Destatis, 1949-2004)

Based on this analysis, we tried to identify trends for the production of high-value and low-value steel products in Germany. To this end, we grouped 14 steel products based on their specific price into an upper quartile, a medium 50% quantile and a lower quartile. We then compared the total value and the total physical output of steel product falling into these three categories for the years 1995 and 2004 (Figure 3.59)[59].

[59] Using this approach, we filter out general trends in the price level of steel products and do only consider relative changes within the group of the 14 steel products analyzed.

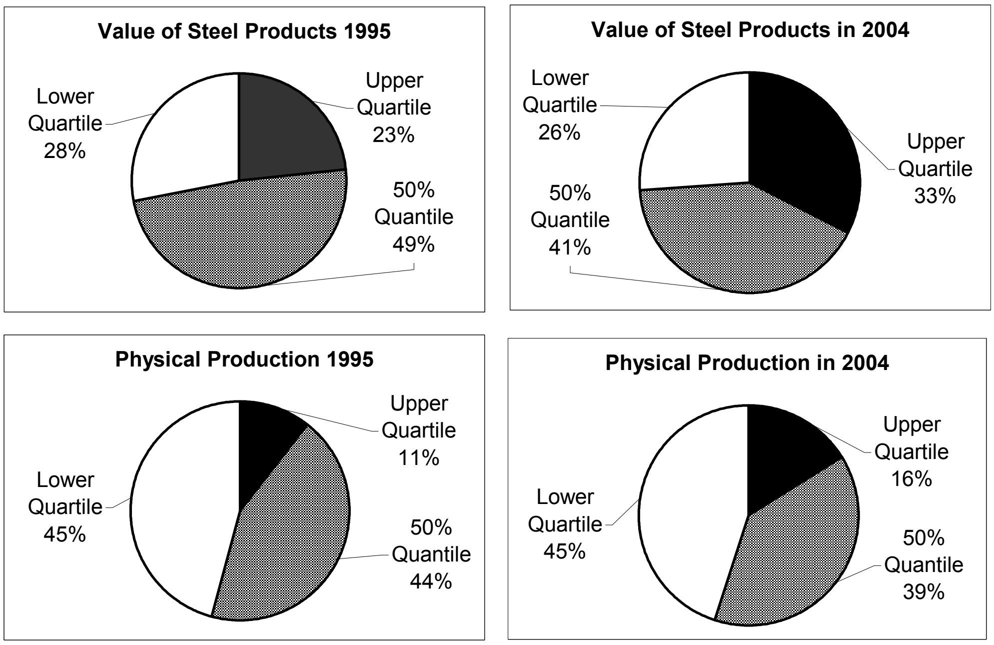

Figure 3.59. Shares of high value and low value steel products manufactured in Germany

Compared to 1995, the share of high value steel products (upper quartile) on the total value of all steel products included in this analysis increased from 23% to 33% in the year 2004. The value share of low-price products remained almost constant, while the value share of medium-priced products decreased and the value share of high-priced products increased. Also the total *physical* output of high-price products increased from 1995 to 2004 from 11% to 16%. This development is associated with a declining physical share of medium-price steel products (from 44% in 1995 to 39% in 2004).

These results indicate a trend towards the manufacturing of high value steel products in the last 10 years. The development is however not associated with declining shares of low-value steel products but rather realized at the expenses of medium-value steels. The analysis done for Germany comprises steel products accounting for around 50-60% of the total turnover generated in the German iron and steel industry (Figure 3.60).

Hence, our analysis excludes parts of the German steel production. We would therefore conclude that our findings in Figure 3.60 give indications regarding the dynamics of steel production in Germany but are neither complete nor conclusive.

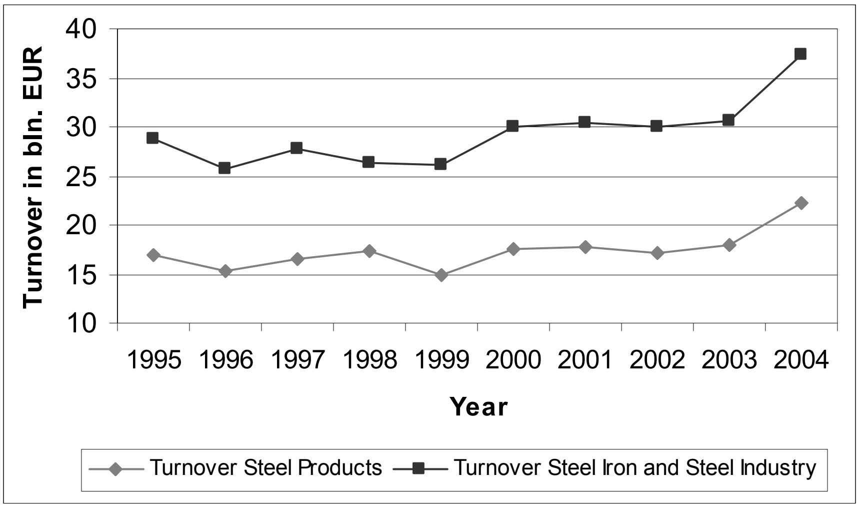

Figure 3.60. Share of steel products covered by our analysis on the total turnover of the German iron and steel industry

3.4.4.3 In-depth Analysis of the Chemical Industry

Given the limited data availability, we restrict our analysis to the Chemical Industry of Western Europe and Germany. In this section we perform a similar analysis as presented for the iron and steel industry in the previous part of the report (see Chapter 3.4.4.2).

Analyzing the chemical industry in Germany (Figure 3.61), we find a trend of increasing total turnover in the period of 1978-2000. In the course of this development, we cannot identify major shifts regarding the shares of individual sectors. As it is the case for the iron and steel sector, the data analyzed give no support for our research **Hypothesis 4**, i.e. we find no indication for a shift of production from low-value bulk chemicals (e.g. basic chemicals in Figure 3.61) towards high-value products (e.g. pharmaceuticals in Figure 3.61).

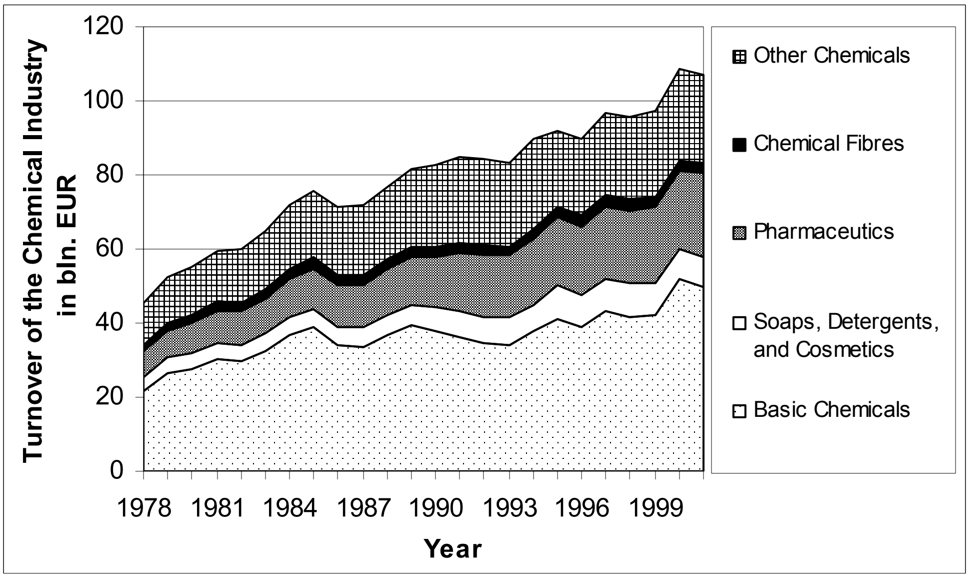

Figure 3.61. Turnover in the chemical industry of Germany in the period of 1978-2001 (VCI 1990-2005)

A more detailed analysis for one specific sub-sector of the Western European chemical industry, i.e. plastics manufacturing is shown in (Figure 3.62).

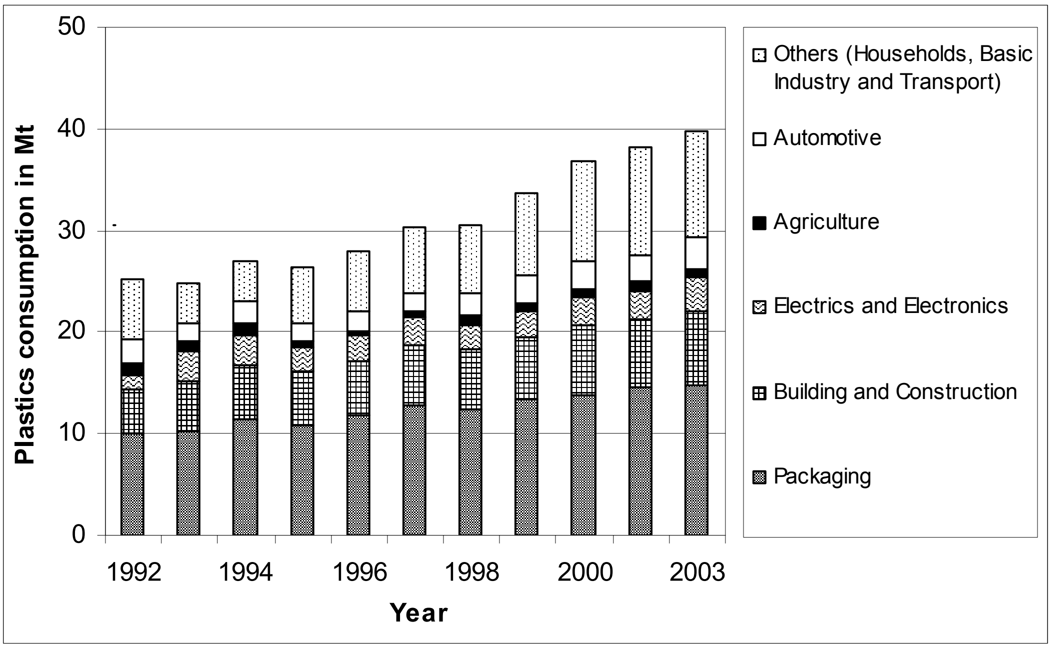

Figure 3.62. Consumption of plastics in Western Europe (EU-15) in the period of 1992-2003 (APME, 1990-2003)

The overall plastics consumption increased in Western Europe by 58% in the period studied. In contrast, we found a trend towards declining plastics consumption in the agricultural sector (-25%). Plastics consumption showed only small increase in the automotive industry (+26%) while we found strong increase in the electrics/electronics sector (+124%). In absolute terms, however, these changes are minor compared to the increase of plastics consumption in the category 'Other' (+4.5 Mt in the period of 1990-2003).[60]

Based on the findings presented in Figure 3.62, we are however not able to identify shifts regarding the production of low-value and high-value plastics. This would require a more detailed analysis on the level of individual plastics delivered to the various economic sectors.

Based on available data for Germany, we tried to obtain an overview of the relationship between the turnover generated in the German chemical industry and the actual physical production (Table 3.8).

60 It is important to note that the trend identified in this analysis highly depend on the base year chosen. Selecting other base years for assessing the dynamics of sector specific plastics consumption in Europe might as well yield different results.

Table 3.8. Development of turnover and physical production in the German chemical industry in the period of 1990-2001

Year	Turnover Chemical Industry in bln. EUR	Chemicals Production in Mt	Average Price in EUR/t
1990	38	39	979
1991	36	38	955
1992	35	38	908
1993	34	39	871
1994	38	43	880
1995	41	44	935
1996	39	46	838
1997	43	48	906
1998	42	50	830
1999	42	52	809
2000	52	55	933
2001	50	54	923

Table 3.8 shows slightly decreasing price levels for chemicals[61]. However, data fluctuations are considerable, making it impossible to identify a clear trend regarding the development of prices as indicator for relative value added (ratio of value added to physical production) in the chemical industry.

To summarize, the data analysis for the chemical industry in Germany is insufficient to make a clear statement regarding our initial research hypothesis. For this, analyses of longer time-series also for additional countries would be necessary.

3.5 Conclusions – Analyses Industrial Sector

Combining empirical data analyses and information from literature leads us to several conclusions regarding the relationship between physical and economic growth of industry. As data for 19 OECD countries show, the industrial sector accounts only for roughly 20% of the total GDP in high-income countries. This share is expected to decrease even further in the course of development towards service-dominated economies.

However, this finding does not mean that the absolute value added of the industry declines. Rather the opposite is true, as the value added of the industrial sector continues to increase but at slower rates than the total economy (around 5.5% nominal growth per year of industry versus 7.3% nominal growth of the total economy in the period 1979-2002). This development is also reflected by the consumption of various bulk materials: While we find a general trend towards declining intensity of use with increasing per capita GDP, we identify at the same time increasing absolute per capita materials consumption. These results indicate that the shift towards the service economy leads on the one hand to weak decoupling between physical and monetary growth but does on the other hand not mean absolute decoupling, i.e. the absolute decline of materials consumption.

Our analysis further revealed that the ratio of physical flow to economic value is particularly high for sectors producing basic bulk materials (the ratio is up to 20 times higher than for the industry on average). For this reason we conducted detailed analyses on the relationship between the physical output and value added for several industrial sectors producing bulk materials. We found a trend towards re-coupling between physical output and value added for paper and paper-board production and cement production in South Asia and China. We furthermore identified a trend towards decoupling (i) between cement production and value added of the non-metallic minerals industries of North America and Europe and (ii) for aluminium production

[61] Prices base on nominal turnover data for the chemical industry. The specific price decline of chemicals would even be higher, if inflation is into account.

in the non-ferrous metals industry of China. For all other bulk material industries analyzed (i.e. wood production, feedstock use in the chemical industry, production of bricks, iron and steel, and aluminium production in the non-ferrous metals industry of North America, Europe, and South Asia) we cannot identify trends towards either decoupling or re-coupling between monetary and physical activity.

Despite the fact that we identified a trend towards declining value added associated with increasing physical production in the German iron and steel industry, the results give in general no support for our research **Hypotheses 1** and **2** according to which specific value added of bulk materials is generally declining, causing a trend towards re-coupling in the bulk materials industries.

The analysis conducted at the sub-sectoral level for the chemical industry of North America and Europe indicate however that the decline of value added per unit of physical production of high-quality, knowledge intensive niche products (e.g. pharmaceuticals in the chemical sector) is smaller than for bulk products alone. By increasing their share of innovative, high-value products, industry sectors can therefore compensate for considerable value added decline associated with bulk products manufacturing. Further empirical support for research **Hypothesis 3** is found by Ramirez and Blok (forthcoming), who observe a clear value added increase of the agricultural sector (around 70% between 1978 and 2002) and especially of the food processing sector (even 290% in the same period) that is by far larger than the increase of the respective physical flows (around 22% between 1978 and 2002, based on energy content). Especially the food-processing sector is hence a very good example for successful decoupling of physical and monetary growth by generating value added through product innovation, i.e. mainly nutritional and diet products as well as convenience food.

The results of our analysis indicate considerably lower value added per physical output in South Asia and China compared to Europe and North America in all industrial sectors analyzed. While this result might be partly caused by wage differences in the analyzed regions and possibly also by undervaluation of the currencies of emerging industrial countries, it also suggests that research **Hypothesis 4** might hold: according to this hypothesis less knowledge and know-how intensive products are being produced by low-income countries, while high-income countries strive for market niches producing knowledge intensive and high quality products. Plotting the development of shipments from the iron and steel industry to the various industrial sectors over time for the USA and Germany we find, however, no additional support for **Hypothesis 4** based on the empirical data available.

Analyzing the physical and monetary deliveries of the iron and steel sector, we found no support for research **Hypothesis 5**, according to which low-income countries have a relatively high domestic demand for low and medium quality bulk materials compared to high-income countries. Neither the cross-country comparison of monetary steel deliveries nor the time series analysis for Germany and the USA allows identifying shifts of steel production as a function of the developmental stage of a country. Our analyses indicate, however, a slight trend towards the production of high-value steel products in Germany over the last 10 years. It nevertheless remains questionable whether (i) the identified trend is statistically significant and (ii) representative for the development of steel production over longer time periods in Germany.

Analyzing production in the chemical industry of Germany we were not able to identify major shifts regarding the physical output of this industrial sector. Furthermore, our findings cannot confirm a trend towards either increasing or decreasing value added per physical output due to considerable data fluctuations.

Our findings are subject to uncertainties due to dubious quality of some of the production and value added data used. The trends identified for the industrial sector have not been subjected to sound quantitative testing. To that end, a more rigorous statistical hypothesis testing via regression analysis can be applied (i) to fit idealized curves to the empirical data and (ii) to test the significance of the identified statistical trend. Furthermore, the driving forces for developments in industry were predominantly discussed qualitatively in this assessment.

Decomposition analysis, as it was applied by Hoekstra (2003) can not only help deepening the understanding but also quantify the effect of major driving forces behind the observed dynamics in the industrial sector. In the course of this research project it was not possible to assess shifts in material demand and substitution effects in greater detail. Furthermore, direct and indirect environmental impacts resulting from production in the analyzed bulk materials industries are not studied.

The analyses of the development of value added to physical output give only indirect indication regarding future developments of energy consumption and greenhouse gas emissions. This is especially true because changing production technologies might lead in the future to more efficient energy and material use in the production process. Therefore, rising physical output of industrial production does not necessarily mean increasing overall energy and material use (see Farla, 2000, Neelis et al., 2004).

The overall results of this assessment project give, however, no indication for a general trend toward decoupling between physical and economic growth in industry. For scenario projections, this means that each percentage growth of value added in the bulk material sectors can roughly be approximated to lead to at least a comparable growth in physical output. Regarding bulk materials consumption, we expect for the future a continuing trend towards decreasing intensity of use, i.e. weak decoupling between materials use and economic growth. This development is, however, by no means associated with absolute dematerialization of the economy as levels of per capita consumption for most bulk materials continue to increase. This finding is simply a consequence of the development towards the service economy, which is characterized by slower economic growth of the industry compared to the service sectors. In spite of the remaining uncertainties, we consider our findings as important starting point for more detailed empirical analyses in the future.

To this end, data mining should be extended in order to perform a more thorough analysis regarding the development of physical output and value added (i) for other industrial sectors (e.g. producers of semifinished and finished products) and (ii) for regions and countries, which are not included in this analysis so far. To assess sector-immanent dynamics in greater detail, further disaggregation of value added data (down to the level of individual products) would be preferable. In a second step, the physical output of selected industries should be coupled with specific material and energy requirements in order to obtain more detailed insight in the relationship between production and associated overall physical activity. The identified trends have to be assessed with rigid quantitative statistical methods in order to derive useful information for scenario projections on future energy consumption and GHG emissions.

4 Sector Study: Transport

Hein de Wilde and Jos Sijm, ECN

4.1 Summary

This study provides an analysis of the interaction between the economic and physical growth in the transport sector, over the approximate time period of 1970-2000. The transport sector plays a crucial role in economic development and is responsible for about half of the world's oil consumption. Over the past decades, the transport of both passengers and freight has been growing faster than GDP over the past decades (expansive decoupling). Air transport exhibited the fastest growth over the past decades, but road transport is by far dominant.

The rising income has induced a shift towards faster passenger transport modes, resulting in increased energy use and CO_2 emissions. Likewise, freight transport demand has shown a trend to specialized high-speed logistic freight chains (just in time delivery), along with reduced load factors, as compared to traditional bulk oriented logistics. As a consequence, sectors with a large contribution to GDP (e.g. manufactured goods) may have a small transport demand if expressed in ton.km, but not if expressed in costs and energy. Although the energy efficiency of all transport modes has increased over the past decades, the transport volumes have been growing substantially faster. The energy use of the transport sector will continue to increase, since saturation in both passenger and freight transport is not yet occurring (Figure 4.40, Figure 4.41). The transport sector will likely become the major CO_2 emitting sector for the next decades. Since decoupling of travel demand from economic growth is unlikely, at least during the next decades, these effects will increase energy use.

Passenger transport
In the time period considered, passenger transport performance, and the associated consumption of energy, largely grew in parallel with the growing world economy. Growth in passenger transport has been the biggest contributor to increased oil demand in IEA countries. Between 1970 and 2000 the total final energy use for passenger transport increased from about 17 to 26 Exajoules per year. In the same period GDP increased by about 220%. This increase was driven by several factors. Income played a crucial role. As average income increased, the annual distance travelled in passenger transport rose by roughly the same proportion, especially in the private car sector. In developing countries people typically spend 3 to 5% of their income on transportation, i.e. mostly non-motorised and public transportation. At higher incomes this fraction tends to stabilise at 10 to 15%, with car ownership ranging from 0.4 cars per capita in Europe and Japan, up to about 0.6 cars/cap caput in the US (still growing). In addition, passenger transport is influenced by average travel distance, infrastructure and fuel prices. In the US, Canada and Australia, most energy is used per caput for car travel, since distances are large and fuel prices are low. Low fuel prices also resulted in less fuel-efficient car fleets. In contrast, countries with high fuel prices such as Italy and the Netherlands have developed relatively efficient car fleets, resulting in a lower share in the national fuel consumption.

With rising income there has been a shift to faster transport modes. People spend a rather constant part of their time on transport (~ 1-1.5 hours/day), relatively independent of income, social and geographical conditions. The growing demand for more mobility therefore resulted in a shift to faster modes of transport, enabling to travel larger distances in the same time. At low incomes people shifted from slow buses and trains to cars that operate at higher speeds and offer more flexibility. At higher incomes, as observed in the OECD countries, slower modes were increasingly replaced by higher speed modes, especially planes (and in some countries to high speed trains). As a consequence, aviation showed the largest increase. Nevertheless road passenger transport by car is still dominant in all countries.

Freight transport
The movement of goods and materials by air, water and road is essential for the global economy. As the world economy grows, the more it is likely to trade, and the more goods will be moved. Consequently, the growth of the world economy over the past decades fuelled the demand for transport services. The increase in freight transport was even larger than the increase in passenger transport. In the IEA countries the total final energy use for freight transport increased from about 6 to 11 Exajoules per year over the time window 1970-2000. Over the same tome span GDP increased by about 220%. This increase was driven by several factors. The rising demand for customized freight flows, with faster reaction and delivery times, induced a shift towards road transport, which is more energy intensive than rail and shipping. The dominant road freight sector accounted for more than 80% of the transport-related energy demand. Even during the two oil price shocks in the 1970s, the fuel use in the transport sector was not as much affected as in other sectors. Nevertheless, the decreasing cost of motor fuel per vehicle-km since the late 1970s did stimulate the trend towards more road transport.

Interaction with other sectors
The interaction of the transport sector with other sectors is visualised by several trends. Major factors include the rising demand for specialized and customized products in several sectors, implying faster reaction times and less massive transport flows. These factors have resulted in additional growth of transport, especially in the road and aviation sectors.

Future outlook
Decoupling of economic growth on the one hand and physical growth and energy consumption on the other hand, is rather complicated for the transport sector. The impact of energy conservation policies is counteracted by the growth of the transport sector. In addition, load factors for both passenger transport and freight are decreasing because of increasing societal individualism, and demand for customized and high-speed logistic chains. As a consequence transportation is becoming the major final energy consumer. Decoupling of travel demand from economic growth is highly unlikely. In addition, decoupling of CO_2 emissions from energy use is the most complicated in the transport sector. For this reasons the transport sector will likely be the major CO_2 emitting sector for the next decades.

As compared to other sectors, the transport sector may be regarded in an earlier stage of the ‘Kuznetz curve’, with respect to energy use and CO_2 emissions. Public acceptance and other social factors also hamper emission reductions, especially in the passenger transport sector. Due to the low price elasticity between fuel prices and transport, emission reductions for cars can only be achieved at very high fuel prices. The costs for CO_2 emission reductions in the transport sector are about 5 to 10 times higher than in other sectors. The complex situation in the transport sector calls for innovative policy measures.

4.2 Introduction

The transport sector is important worldwide, as it satisfies the basic need of going from one location to the other, a need shared by passengers, freight and information. As economies continue to grow, the demand for transportation services increases correspondingly. The movement of goods and materials by air, water and road remains crucial to the global economy. As the world economy grows, the more it is likely to trade, and the more goods will be moved (Kheshgi *et al.*, 2003). Transportation plays thus a critical role in economic development.

All economies do not share the same level of mobility. Economies that possess greater mobility are often those with better opportunities to develop than those suffering from scarce mobility. Reduced mobility impedes development while greater mobility is a catalyst for development. Mobility is thus a reliable indicator of development (Rodrigue, 2006).

4.2.1 Objectives and approach

This chapter aims to provide an overview and synthesis of the economic and physical growth in the transport sector. This includes an assessment of the relationship and synergy between transport activity and the economy, approximately for the time period of 1970-2000.
Our analysis is based on a compilation of data and a literature overview serving to identify key trends in the physical growth of passenger and freight transport and their split over the transport modes. Subsequently, the main drivers of the identified trends are evaluated. In addition the energy use, associated with transport, is considered. Figure 4.1 visualises the major goals of this study.

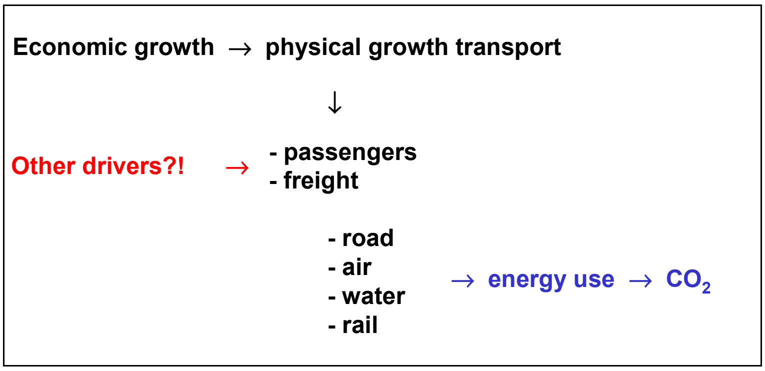

Figure 4.1. Schematic view of the objectives

4.2.2 Boundaries of this analysis

Historically people relied on animals to meet their transportation needs. Then came railways, which opened up entire nations and continents. With the arrival of the internal combustion engine, road networks grew as well, encouraging the development of roadbased mass transport. Road transport is the dominant mode. Representing 90% of all passenger journeys and 75% of all freight hauled, it has boomed in recent decades. In the last 25 years, the vehicle fleet has more than doubled in the OECD countries (80% of the world fleet). Today, there are nearly 600 million private automobiles over 200 million light trucks registered in the world (Plouchart, 2005).

For this reasons, the present study focuses on road transport, and to a lesser extent on the rapidly growing sector of air transport. Rail transport and shipping are only briefly discussed. For our analysis, we focus on the time period of 1970-2000.

4.3 Passenger transport

4.3.1 Key trends in passenger transport (Physical indicators)

Worldwide countries have experienced a sustained increase in passenger travel activity over the last decades (See Figure 4.2, Figure 4.5, and Figure 4.8). Yet, the picture varies widely from country to country. For example, Figure 4.2 shows that the increase inpassenger-km travelled per capita between 1970 and 2000 varied substantially, ranging from 35% increase in Sweden up to 150% increase in Italy. Italy shows similar trends in passenger increase as other countries, with relatively low levels of travel in 1970 and a very substantial increase since then. Yet in 2000, there was still a wide spread between countries in average travel per capita (IEA, 2004). The United States, Canada and Australia are well above the European countries, and even significantly separated from each other. The United States has the highest levels of travel per capita in the world, more than 25000 kilometres per person per year. This reflects high US car ownership and utilization rates (see Figure 4.2 and Paragraph 4.3.4.1).

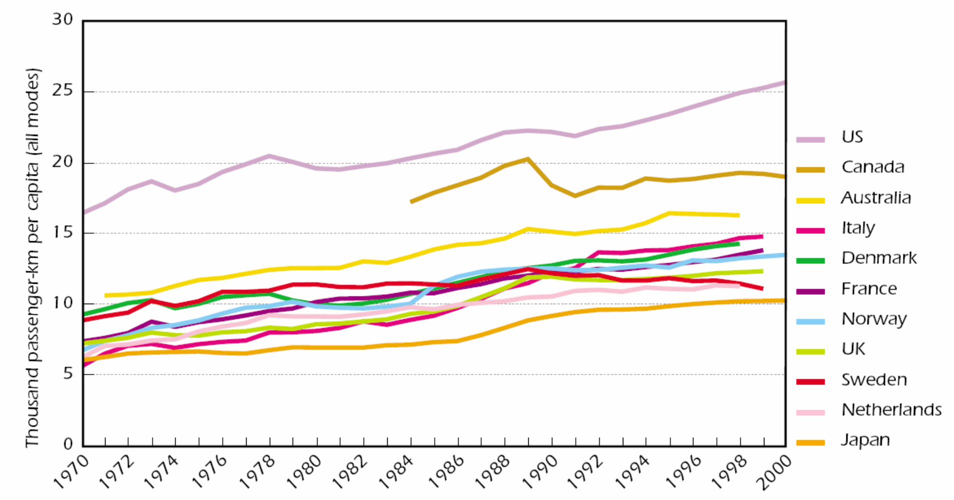

Figure 4.2. Passenger Travel per Capita, by all Modes in IEA countries (IEA, 2004)

4.3.2 Modal split and public transport

Road transport, dominated by private car use, is by far the most important mode, representing 90% of all passenger journeys. The dominant influence on passenger km of private cars is clearly demonstrated for Europe in Figure 4.3 The US and most other OECD countries show comparable trends (Figure 4.4) Even Japan, characterised by a good public transport system, showed a strong increase in passenger car km (Fig. 4.5.), although the relative share of public transport is still much higher than in most other countries (see also Paragraph 2.1.1.1).

70% of the European passenger transportation is accounted for by road vehicles. On a global level, the share is 53%. This share has been increasing over time (Gielen, 2004).

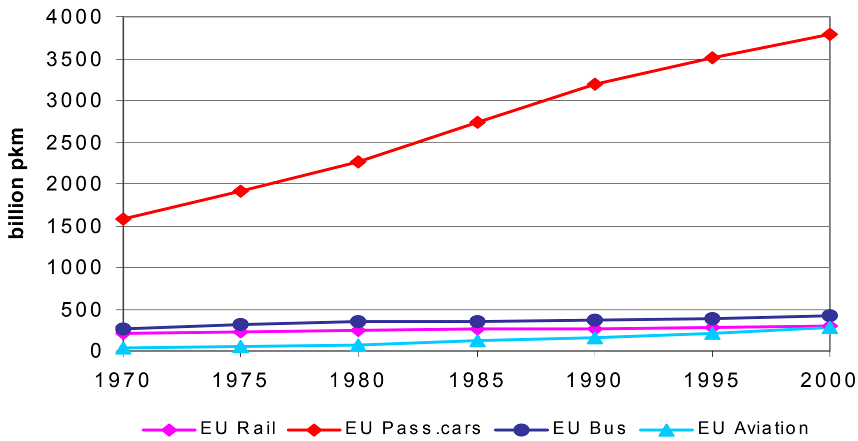

Figure 4.3. Passenger transport trends by mode in the EU (Caïd, 2004)

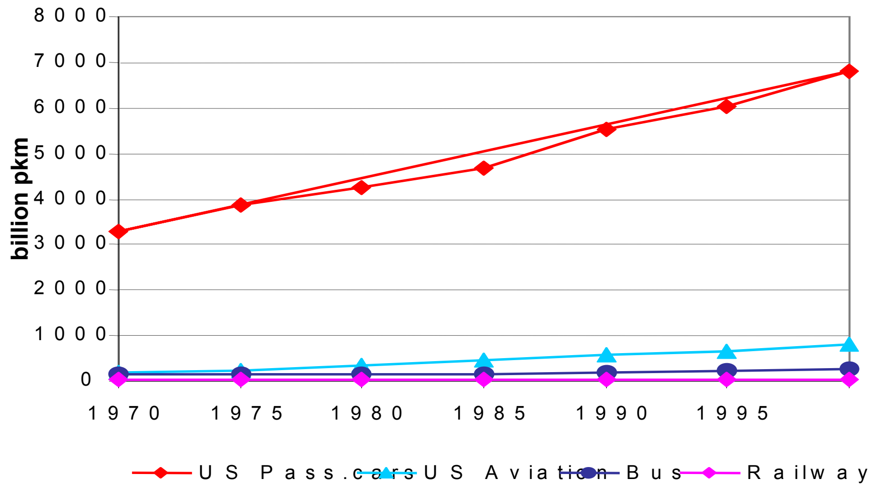

Figure 4.4. Passenger transport trends by mode in the US Source (Caïd, 2004)

Although still relatively small compared to road transport, air travel exhibited the fastest growth over the past decades (Figure 4.5), while the share of road and rail remained approximately constant. Changing the modal split towards rail transport and away from passenger cars was not achieved over the last decades. There are still no signs of this common transport policy goal being met in more recent years. Transport by road and rail are growing at the same rate as total passenger transport volume. In addition, the share of aviation on the total passenger km traveled is increasing, whereas the share of bus and coach is decreasing.

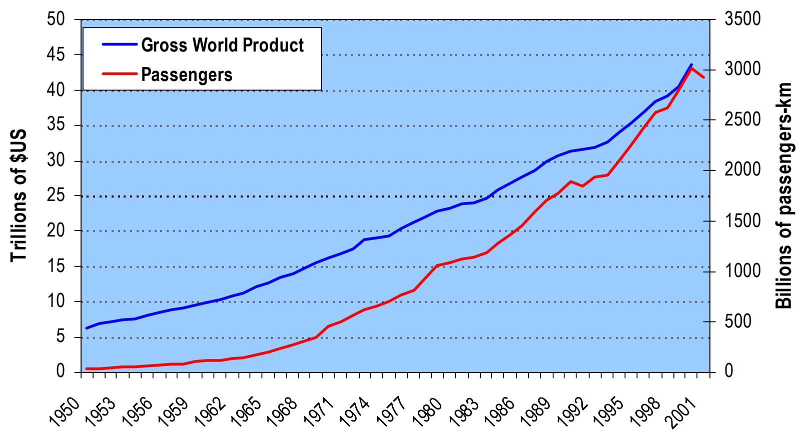

Figure 4.5. World Air Travel and Gross World Product, 1950-2001 (Worldwatch Institute)

Examples of high public transport levels

In regions with a relatively good public transport system the share of rail and bus can be much higher as illustrated by the following examples.

Japan

Relatively high levels of public transport use as compared to the EU and US, characterize Japan because of its relatively well-developed public transport infrastructure,

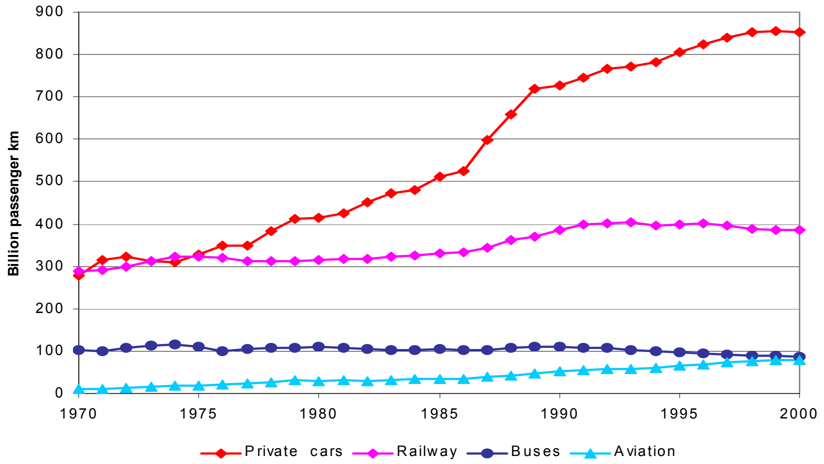

Figure 4.6. Passenger transport trends by mode in Japan (Caïd, 2004)

Curitiba, Brazil

Due to lack of funds to finance a proper metro system, the city of Curitiba in Brazil (about 1.5 million inhabitants) set out to construct a cheap metro-like bus system 30 years ago. In spite of having a level of car ownership similar to many EU countries, around 70% of commuters use the bus system every day. This represents a high share for a city of relatively modest size. The success was helped by 30 years of political support in the form of land use planning that located people and businesses in such a way as to allow easy use of public transport (OECD, 2002).

4.3.3 Relationship passenger transport with economic growth

Nearly all data available suggest that personal income and traffic volume grow in tandem (see Figure 4.7 and Figure 4.8). As average income increases, the annual distance travelled by car, bus, train or aircraft rises by roughly the same proportion. The average North American earned $ 9600 and travelled 12.000 km in 1960. By 1990 both per capita income and traffic had approximately doubled (Schäfer and Victor, 2000). In the EU, passenger transport volumes have grown in most Member States, largely following GDP. Relative decoupling, i.e. decreasing passenger transport along with increasing GDP, has been achieved in only some of the new EU Member States (EU-10). It is however likely that with time the development in the EU-10 will show the same trends as the older member states (EEA, 2006).

As a result of the strong increase in private car use and aviation, public transport generally shows a decoupling with increasing GDP over the past decades (Figure 4.9).
In developing countries the decoupling between increasing income and passenger transport is less tight, partly because of the shift from non-motorized to motorized transport. This is visible for some regions in Figure 4.9. Most explicitly some African regions do not fit in the trend.

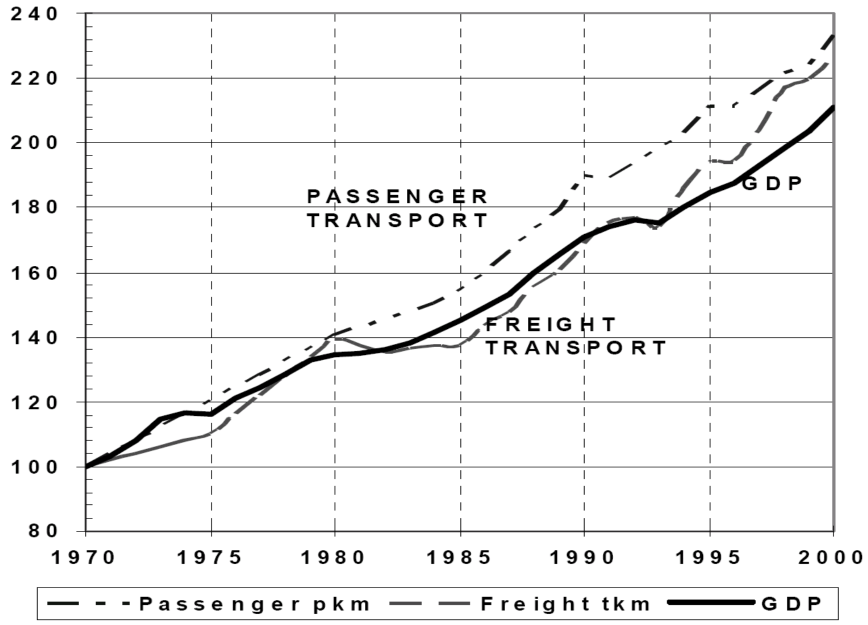

Figure 4.7. Trends of GDP and Transport Activity in the EU, 1970-2000

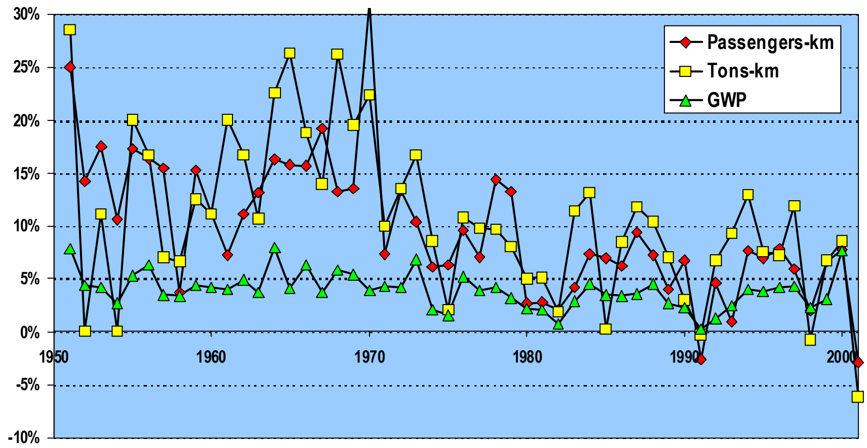

Figure 4.8. Air transportation growth (passenger and freight) and economic growth (GWP = Gross World Product), 1950-2001 (Rodrigue, 2006, based on data of the Air Transport Association and the Worldwatch Institute)

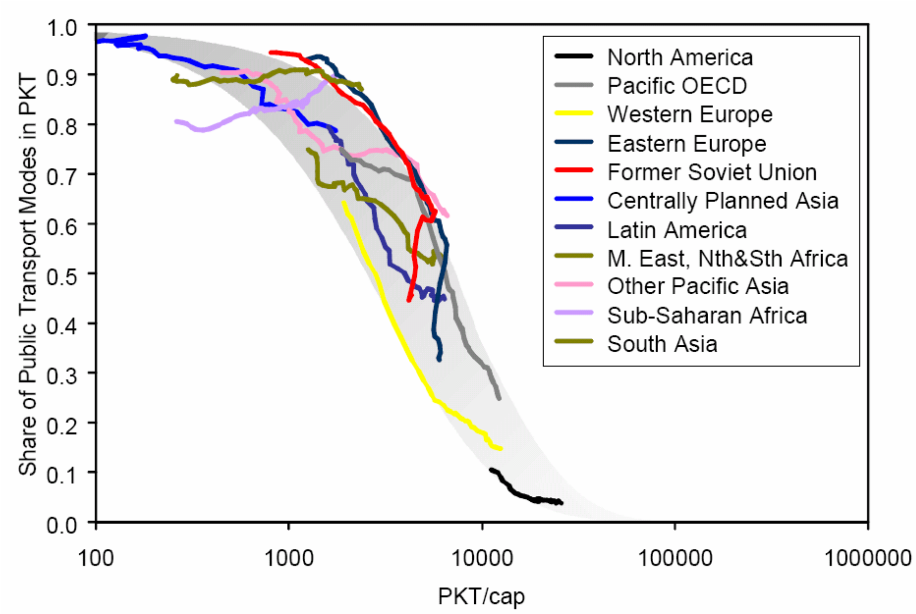

Figure 4.9 Global public transport trends as a function of income (Schäfer, 2005)

4.3.4 Underlying mechanisms driving passenger transport

Over the last few decades, growth in income, improvements in technology and infrastructure, and increasing time available for leisure trips have allowed people to travel more and longer distances. The choice of modes of travel depends largely on such factors. Numerous studies suggest that increasing levels of disposable income do have a strong effect on traffic growth, as car ownership increases up to a high level when saturation effects are observed (Caid, 2004). However, the amount of traffic is also influenced by prices, speed and quality of transport, and also by personal preferences and priorities. In addition, factors such as commuting distance and the distance between home and school play a role. The main drivers of passenger transport demand are listed below (IEA, 2004 and Plouchart, 2005) and subsequently explained in more detail in the next paragraphs.

- income levels (allowing to spend more on car ownership, travelling etc.)
- relative prices of transport (compared to other expenditures),
- speed (due to vehicle technology and infrastructure),
- separation of home and workplace,
- more leisure time spent on travel and tourism,
- journeys that allow access for individuals to consumption opportunities, such as shopping,
- tourism,
- journeys that bring people to work, education and training, in economic terms supplying labour,
- journeys that allow access for individuals to other individuals (e.g. visiting friends and relatives),
- family structure (e.g. the trend towards more single households).

4.3.4.1 Car ownership

Car ownership is the single biggest driver of travelling by private car (Fulton, 2004). Regarding passenger travel, various studies and models have indicated that income is by far the main factor driving vehicle ownership. Vehicle ownership, in term, is the main driver for passenger km travelled. This factor appears to be more important than fuel price, vehicle price, infrastructure, or population density (Caid, 2004). Car traffic, including traffic in cities, has been rapidly growing over the past decades, mainly driven by post-war urban development and growth in income combined with relatively cheaper cars (Walsh *et al.*, 2000). The world private car fleet has more than tripled in 30 years (Figure 4.10). In 2003, it numbered nearly 600 million vehicles, with 64%

in the US, Japan, and the EU combined. The scale of air transportation is relatively small, but it is a fast growing component of the global transport system.

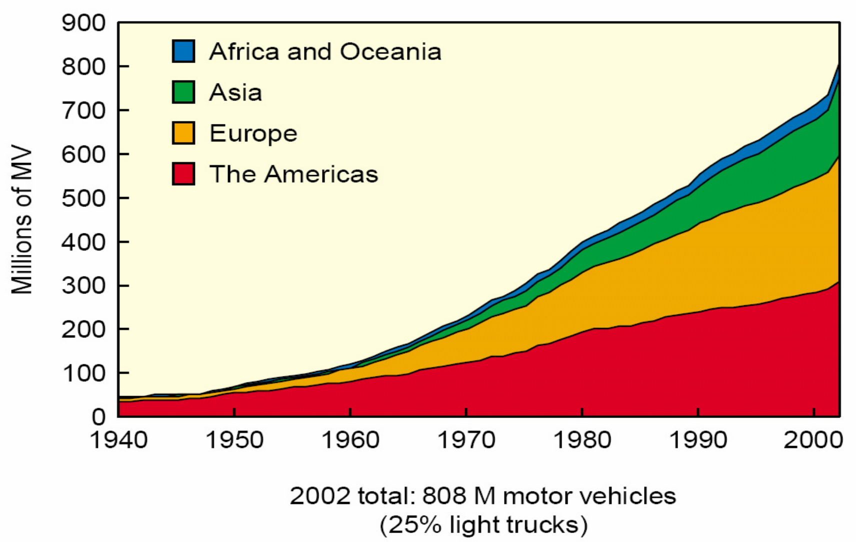

Figure 4.10. World fleet of motor vehicles (MV), 1940-2002 (CCFA, 2005, after Plouchart, 2005)

Since the 1950s, the number of automobiles has considerably increased, especially in developed countries. This process of motorization involved a significant reduction in the number of people per automobile, from 48.2 in 1950 to 11.1 in 2001. There are consequently more vehicles per capita, which is a good indicator of potential mobility. In 2002, the global automobile fleet was estimated to be around 531 million vehicles, with an annual car production of around 40 million cars. Along with number of vehicles, the distance traveled per vehicle is also rising. In the United States, each passenger vehicle travels around 12,000 miles (19,200 km) annually (2001 figures), up from about 9,000 miles (14,400 kms) in 1980 (Rodrigue, 2006).

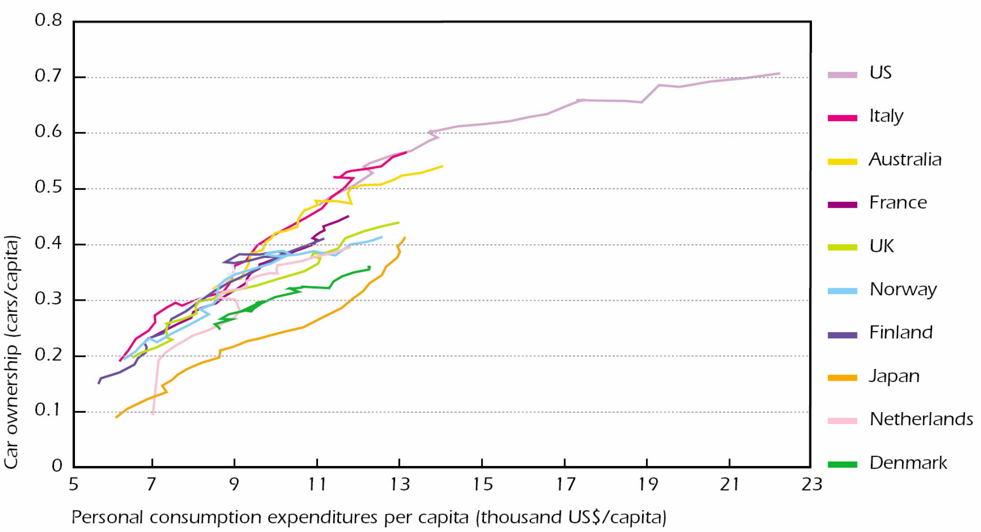

Figure 4.11. Car Ownership per capita and personal consumption expenditures, 1970-2000 (IEA, 2004)

Over time, the household transport budget in developed countries has remained fairly constant at about 13% of total household revenue (Plouchart, 2005). Induced by growth in GDP and by substantial improvements in infrastructure and technology, there has been an increase in motor vehicle ownership per capita during the last decades (Figure 4.11 and Figure 4.12). The United States reports the highest ownership rate: 775 private cars per 1000 inhabitants, 25% higher than in Japan or the EU-15. This is due to its low motor fuel taxation, large size and a road system that is well-developed, unlike other transport systems. This rate seems to be stabilizing in the U.S. around 750 vehicles per 1000 inhabitants and converging towards 500 vehicles per 1000 inhabitants in Japan and Europe (Plouchart, 2005). Among European IEA countries, Japan and Australia, there is significant variation in the relationship between car ownership and personal expenditures. Though the rate of change is similar among these countries, some have much higher car ownership levels relative to expenditure. Japan has historically had the lowest ratio (reflecting its high urbanization and strong mass transit systems), but ownership growth is strong there and it is rapidly approaching the levels of many European countries. Denmark's and Norway's relatively low ownership level reflects high vehicle taxes. The United Kingdom's relatively slow growth rate in recent years may be related to high fuel tax increases and other policy initiatives to control the growth of car travel. Italy's position may simply reflect a propensity towards relatively high car ownership at given income levels.

It is likely that other IEA countries may take many more years to reach the high ownership levels of the United States. Figure 4.11 and Figure 4.12 show that the 1970 car ownership rate of the United States was comparable tot the recent car ownership rate of most other IEA countries. It is clear though that the rate of growth in car ownership in the United States has slowed as the average expenditure increased above about $13 000 per person per year. Many studies have identified the strong relationship between income and car ownership. But these analyses also show that the relationship of vehicle ownership to income in each country tended to be non-linear indicating saturation effects at high levels of income (Caid, 2004). See Figure 4.12. The United States appear to be reaching a saturation point somewhere around 0.7 cars per capita.

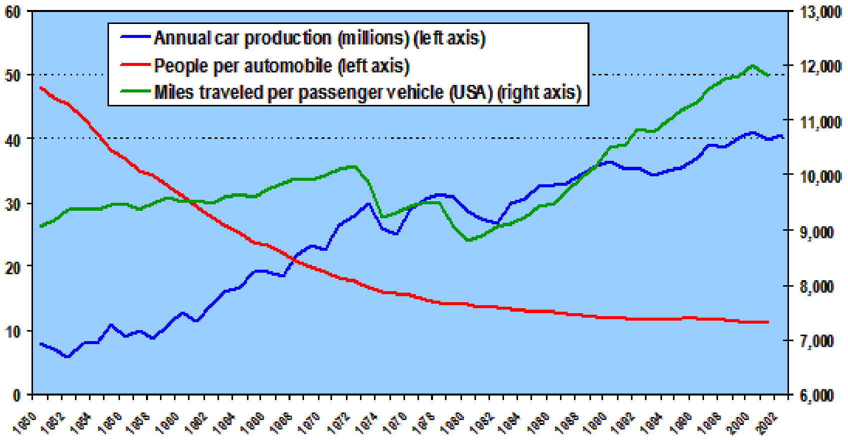

Figure 4.12. Vehicle use indicators, world, 1950-2002 (Rodrigue, 2006; based on data from the Worldwatch institute and the Bureau of Transport Statistics, BTS)

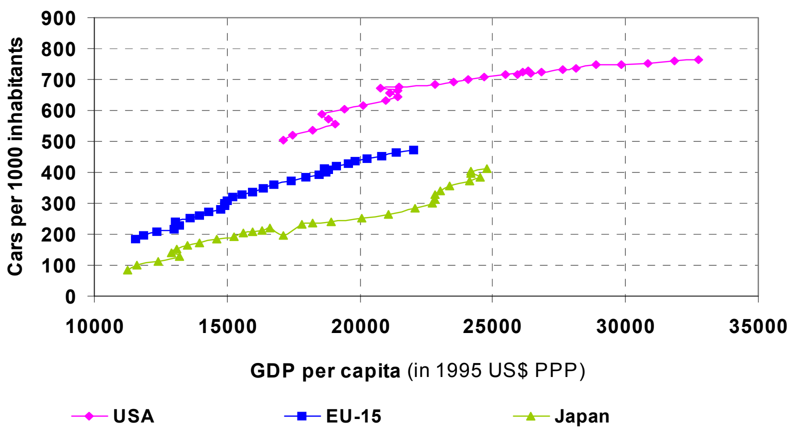

Figure 4.13. Motorization level and wealth in OECD regions 1970-2000 (Caïd, 2004)

4.3.4.2 Fuel prices

Real gasoline prices peaked in the early 1980s and have generally fallen since then. In most European countries much of this decline was offset by increasing fuel taxes. Still consumer prices (including taxes) were lower in the late 1990s than in the early 1980s in almost all IEA countries. Since average car fuel intensity has declined in most countries, although moderately, the real costs per kilometre of driving has generally fallen since 1973, and particularly since the early 1980s (IEA, 2004). These combined effects lowered the relative price of car driving more and more during the 1980s and 1990s.

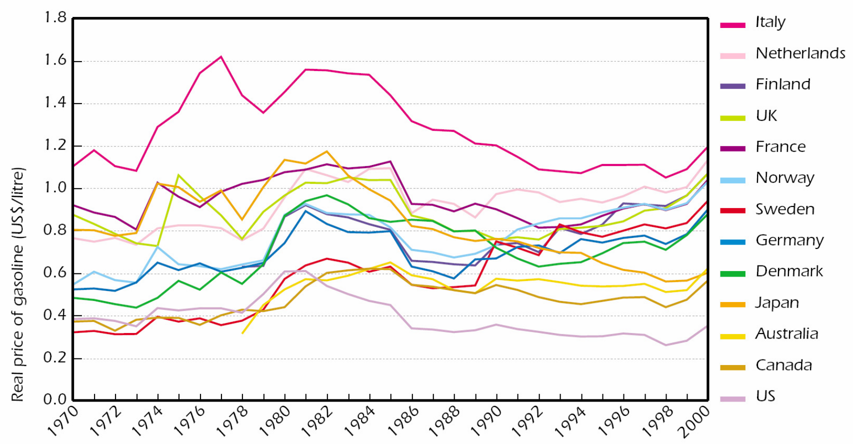

Figure 4.14. Trends in retail gasoline prices in real terms, including taxes (IEA, 2004)

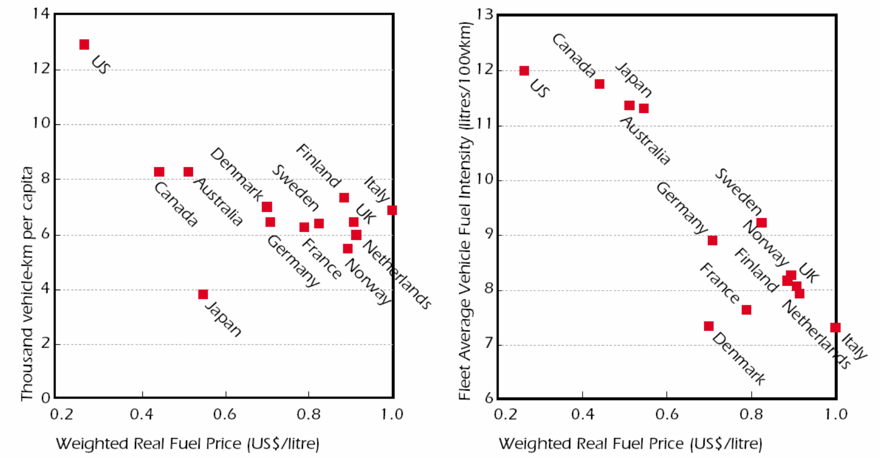

Figure 4.15. Passenger car travel per capita (left panel) and car fuel intensity right panel) versus average fuel price, 1998 (IEA, 2004)

The left panel of Figure 4.15 indicates a weak correlation between low fuel prices and high car travel rates (the United, States, Canada and Australia). Japan is out on the range because of its relatively well-developed public transport system. The right panel of Figure 4.15 shows a relatively clear correlation between higher fuel prices and lower car fuel intensity, also within the group of European countries. Although the short-term impact of high fuel prices on vehicle use is weak, on the long term high fuel prices appear to induce the development of a fuel efficient car fleet.

Figures from the US for example show that this fraction remained rather constant, even during the two oil price shocks of the 1970s. Travellers compensated for higher operating costs by buying less expensive and more fuel-efficient cars (Schäfer and Victor, 1997).

4.3.4.3 Travel time and budget

Travel time

Daily time for travelling is surprisingly independent from household revenues, geographical and social conditions. To a lesser extent budget spend on travel is also rather constant. The travel-time budget is typically between 1 and 1.5 hours per person in a wide variety of economic, social and geographical settings (see Figure 4.16), (Schäfer and Victor, 1997).

That humans around the world spend similar amounts of time and money (as a percentage of their overall budgets) on travel is increasingly recognized by research on passenger travel. On average people spend a roughly predictable fraction of their income on transportation. This fraction is typically 3 to 5% in developing countries were people rely mostly on non-motorised and public transportation. The fraction rises with car ownership stabilising at 10 to 15% at ownership levels of 0.2 car per capita (Figure 4.17). Nearly all members of the OECD countries have completed this transition.

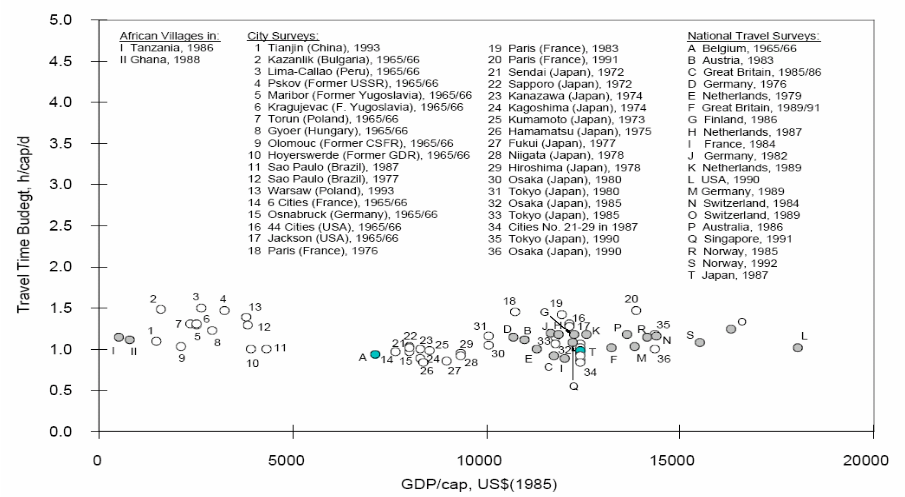

Figure 4.16. Travel-time budget (Schäfer and Victor, 1997)

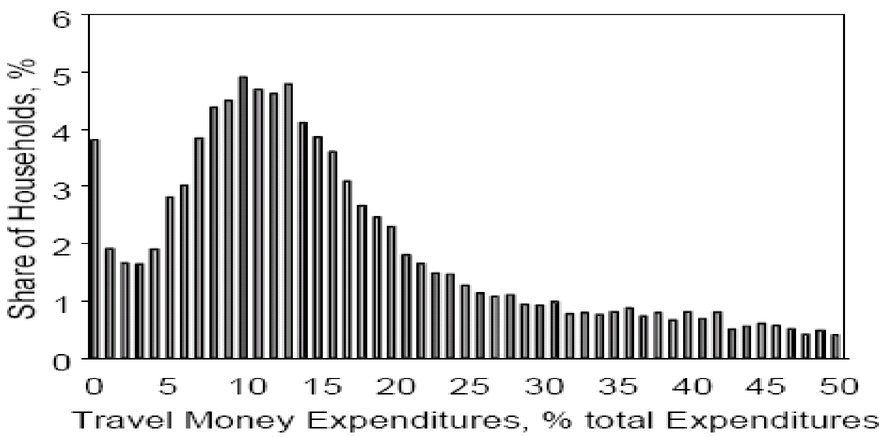

Figure 4.17. Travel money expenditures, expressed as% of total expenditures, base on data of approximately the same countries as listed in figure 4.16 (Schäfer and Victor, 2000)

Higher budget, higher speed, higher energy use

If people hold their time for travel constant (Schäfer and Victor, 1997), but demand more mobility as their income rises (Rodrigue, 2006), they will select faster modes of transport to travel larger distances in the same time.

At low-income levels, people shift from slow buses and trains to cars that operate at higher speeds and offer more flexibility. The share of traffic volume supplied by cars peaks at approximately $ 10,000 (1997) per capita. At higher incomes slower modes will be replaced by planes and high speed trains (Schäfer and Victor, 1997).

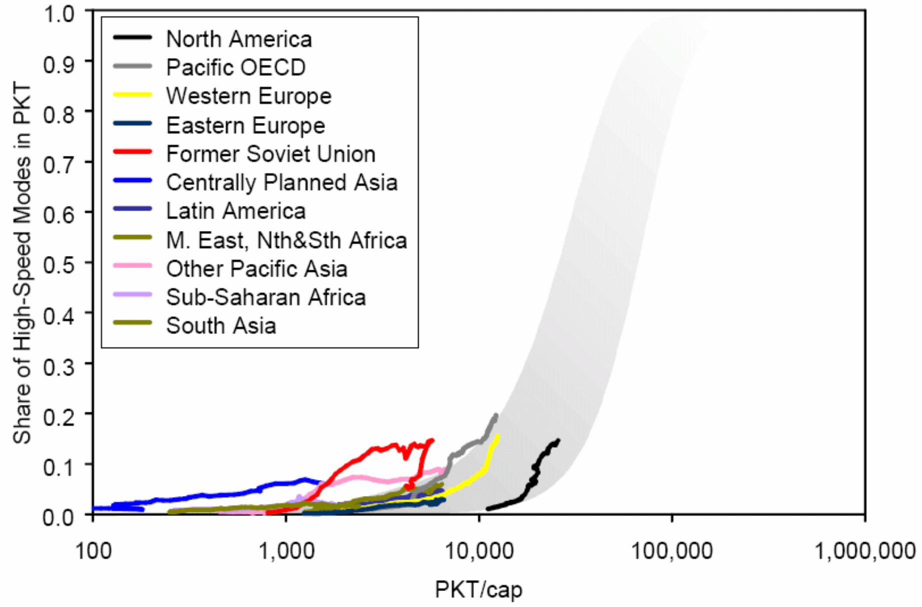

Figure 4.18. Higher incomes result in a shift to faster transport modes (Schäfer, 2005-c)

Schafer (2000) conducted a review of patterns across a wide array of countries, with quite varying incomes, including both motorized and non-motorized modes of travel in their analysis. The results suggest that as people gain access to faster modes of travel, they do not cut down on the amount of time they spend traveling - instead they travel farther. People will unlikely pay more than a certain percentage of their income on traveling. So in order to move to faster modes, they need higher incomes. Conversely, as incomes increase, people are likely to switch to faster modes (Schafer, 2000).

In general, energy use increases with increasing speed of travel mode (Figure 4.19).

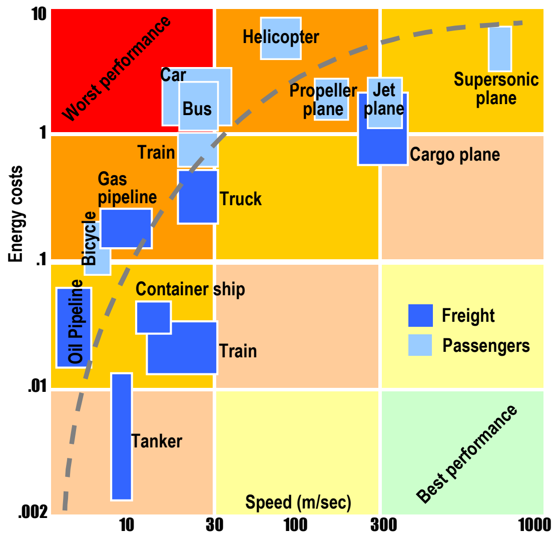

Figure 4.19. Energy efficiency by transportation mode expressed as energy costs vs. speed in m/s (Rodrigue, 2006)

4.3.4.4 Social factors

In several countries, including the Netherlands, private trips account for the largest parts of personnel km travelled (NOS, 2006). In the UK shopping, commuting and personal business are the three most significant reasons for travelling. Together, they accounted for 20%, 19% and 18% respectively of journeys per person per year (SACTRA, 1999). Surveys in Germany and the U.S confirm to a certain extent these results, although they are not entirely comparable as the methods used differ. In the UK, shopping, commuting and visiting friends make the majority of trips, while business travel in the US is the reason of majority of trips, but in Germany it is leisure which is the main reason for traveling (Caid, 2004).

4.3.4.5 Role of geography, demography and infrastructure

The analysis of the transport trends in the different regions (Europe, the U.S and Japan; see previous paragraphs) revealed the main economic driving factors that are behind these trends, which include the supply of infrastructure that boosted transport. In particular important was the expansion of the highway system through large investments during the past thirty years. This expansion of highways has facilitated movements, with increasing speed, improved access, market integration, longer distances travelled, while overall transport costs were decreasing. Worldwide the density of the transportation network varies considerably (Figure 4.20).

The improved and extended road system and the availability of attractive alternatives to individual motorized transport explains the difference between the US and Europe in car ownership and car use (Figure 4.11, Figure 4.13, Figure 4.15). Similarly, the US, EU and Japan trends in transportation are determined by differences in infrastructure, with Japan having a much higher public transport performance (Figure 4.21, Figure 4.22) than the US or Europe and thus a lower average level of motorization. Other constraints in terms of disposable income, available parking space and tax structures also influence the modal choice by individuals and businesses (Caid, 2004).

Urbanization has been one of the dominant contemporary processes as a growing share of the global population lives in cities. Considering this trend, urban transportation issues are of foremost importance to support the passengers and freight mobility requirements of large urban agglomerations (Rodrigue, 2006).

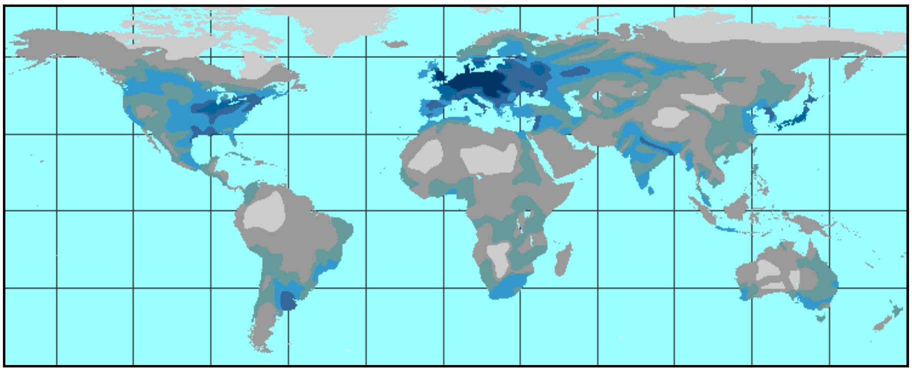

Figure 4.20. Transportation network density (in km per 100 km^2) in 2000 (Rodrigue, 2006)

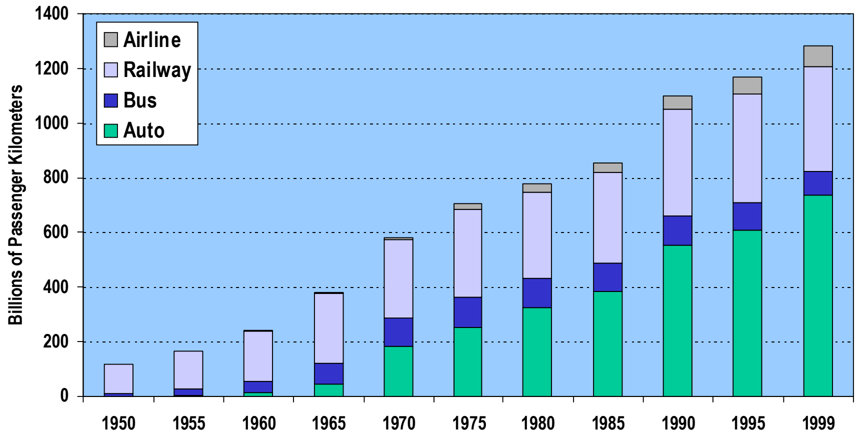

Figure 4.21. Passenger transport by mode, Japan, 1950-1999. (Rodrigue, 2006; based on data of the Japan Ministry of Transport)

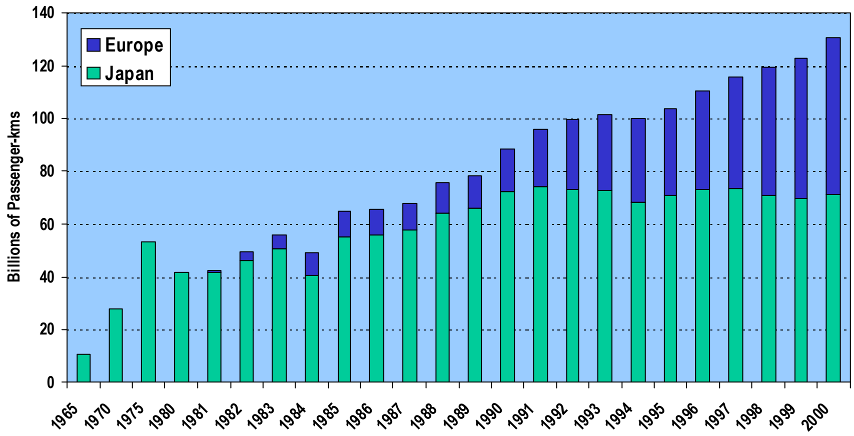

Figure 4.22. Development of hight speed train traffic, Europe and Japan, 1965-2000 (Rodrigue, 2006; based on data of the International Union of Railways, http://www.uic.asso.fr)

4.3.5 Socio-economic factors

Transport systems are closely related to socio-economic changes. The mobility of people and freight and levels of territorial accessibility are at the core of this relationship. Economic opportunities are likely to arise where transportation infrastructures are able to answer mobility needs and insure access to markets and resources. However, even if transportation has positive impacts on socio-economic systems, there are also negative consequences such as congestion, accidents and mobility gaps.

4.3.6 Passenger load factor/vehicle occupancy rates

Cars

A main driver behind the decreasing occupancy rates of passenger cars is the growth in car ownership (up from 305 to 380 cars per 1000 inhabitants during the 1990s, in the European union, more than 700 in the US, see paragraph 2.3.1). Furthermore, the average size of households has declined over the past 15 years (see chapter 5 on households). Changes in lifestyles and disperse spatial pattern (urban sprawl) have led to individual transport patterns that cannot be pooled easily. As a result, people travel more either with less people in the vehicle or alone.

Car occupancy factors decline in countries for which data are available. There are few data available on occupancy rates and load factors. Data for a few countries show average occupancy rates for passenger cars are lower than a decade ago. Growing car ownership, the decreasing average size of households, and disperse spatial patterns are the main causes for low occupancy rates (EEA, 2006).

Trains
but train occupancies are generally low. For most countries, less than 30% of the seats are on average occupied (OECD, 2002).
Occupancy rates in rail transport declined in most Member States, so the efficiency of use has not improved between 1980 and 1998. Occupancy rates in the Netherlands have increased markedly (by more than 30% between 1980 and 1998) (TERM, 2001).

Buses and coaches
No clear trends appear for public transport modes, Occupancy rates for buses and coaches in the EU vary widely between Member States. For example, in the United Kingdom an average bus carries around 9 persons while in France this figure is around 25. The differences between Member States can be explained by different organization of public transport (fares, frequency, accessibility, etc) (TERM, 2001).

Aircraft
Aircraft occupancy rates are much higher at around 60% (OECD, 2002).

4.3.6.1 Price elasticities

10% increase in fuel prices leads to a 1% decrease of car ownership and a 7% decrease of car fuel demand (Caïd, 2004).
From 1973 to 1998, energy service demand grew less than GDP in most IEA countries, partly because production of energy-intensive goods became a smaller share of GDP, and building area and travel activity did not grow as fast as GDP (IEA, 2004).

4.3.7 Energy use resulting from passenger travel

The transport sector is responsible for a large proportion of the global energy consumption (approximately, 20%). Transport was responsible for about 34% of total energy consumption in 1998 (EEA, 2006). Oil provides nearly all of this energy. Transportation comprises about half of the global petroleum use (Figure 4.23)

During the 20th century, transport sector demand in the OECD and many other countries boomed. This trend can be traced back to the industrial revolution, it significantly accelerated in the second half of the 20th century as trade was liberalized, economic blocs emerged and the comparative advantages of global labour and resources were used more efficiently (Rodrigue, 2006).

The main drivers for growth were road transport and, more recently, air transport. The OECD countries are the main drivers of petroleum product consumption in the transport sector. Collectively, they absorb 75% of the 1.75 Gtoe consumed by world transport, especially the United States, Europe and Japan accounting for 55%. Compared to petroleum products, the share of other energies is marginal, i.e. in total only about 1.9%. Electricity accounts for 1%, biomass for 0.5%, coal for 0.3% and natural gas for 0.2% (Plouchart, 2005).

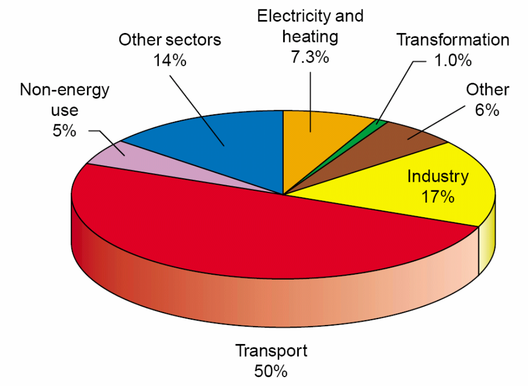

Figure 4.23. World petroleum product consumption in 2002: 3.5 Gtoe (IEA, 2004, after Plouchart, 2005)

Road transport accounts for 81% of transport-related energy demand (Figure 4.24) and is, apart from aviation, the most energy-intensive mode of transport (per tonne of product hauled and/or per passenger carried per kilometer (Figure 4.25) (Plouchart, 2005).

Energy use for passenger travel in a group of eleven IEA countries (IEA-11) has increased by 45% since 1973 (Figure 4.24). However, the growth has been uneven. Energy use dipped after the two oil price shocks in the 1970s, and during the two recessions in the early 1980s and 1990s. Yet the overall direction has been substantially up. The vast majority of the overall increase in energy use, about 80%, is from light-duty vehicles (LDVs), which include cars, minivans, sport utility vehicles and personal-use pickup trucks (referred to collectively as ‘cars’ in this publication). Rising air travel accounts for most of the rest of the increase. While energy use for buses, passenger rail and ships also increased, by 1998 these modes represented only 4% of passenger transport energy use. Cars accounted for 84%, a share only slightly lower than in 1973. Overall, the modal mix of energy use has changed little over the past decades (Figure 4.24).

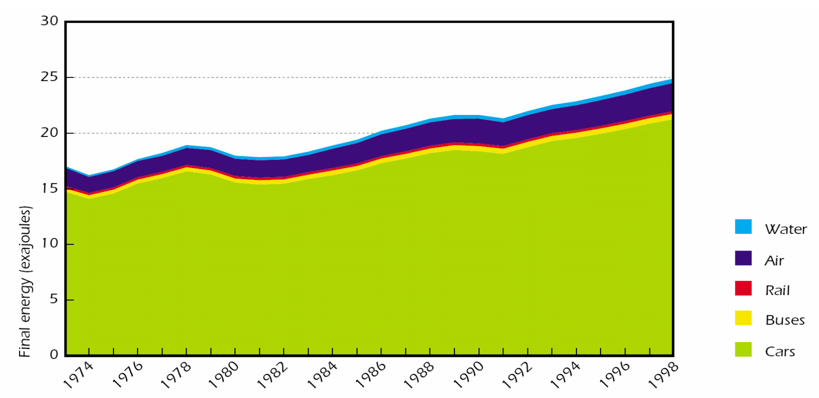

Figure 4.24. Energy use in passenger transport by mode (IEA-11, 2004)

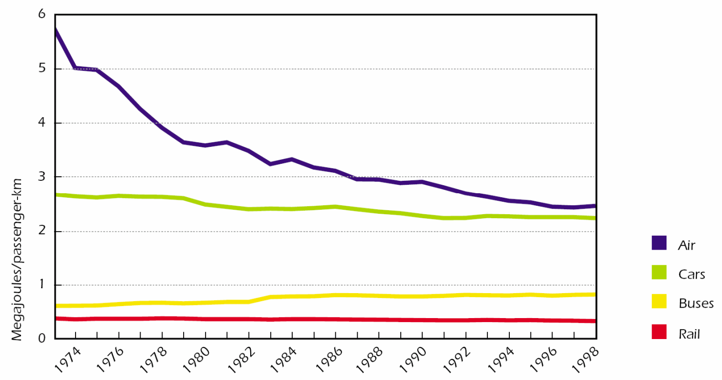

Figure 4.25. Energy per passenger-kilometre by mode, IEA-11 (IEA, 2004)

Energy intensities for all passenger transport modes have declined, but not nearly enough to offset the growth in travel activity and the shift to more energy-intensive modes (i.e., away from buses and trains to cars and planes). The rate of decline in average energy intensity for all travel modes slowed in the 1990s compared with the 1970s and 1980s. Air travel intensity declined the fastest, but not fast enough to offset the growth in air travel activity, with significant increases in air travel energy use as a result (IEA, 2004).

4.3.8 Main findings passenger transport

- Passenger transport, expressed in passenger km, shows a recoupling with GDP.
- Income is strongly coupled to car ownership, tending to saturate at high levels of in-come. In term, car ownership is strongly coupled to passenger car km driven.
- Aviation shows the strongest recoupling, followed by private car use.
- Public transport generally shows a decoupling with increasing GDP over the past decades, as a result of the strong increase in private car use and aviation.
- In developing countries the decoupling between increasing income and public passenger transport is less tight, partly because of the shift from non motorized to motorized transport.
- Passenger transport has been shifting toward faster and more energy-intensive modes
- There is a trend toward larger and more powerful light-duty vehicles

4.4 Freight transport

Societies have become increasingly dependent on their transport systems to support a wide variety of activities ranging, among others, from commuting, supplying energy needs, to distribute materials and products between factories. Developing transport systems has been a continuous challenge to satisfy mobility needs, to support economic development and to participate in the global economy (Rodrigue, 2006).

4.4.1 Key trends in freight transport (physical indicators)

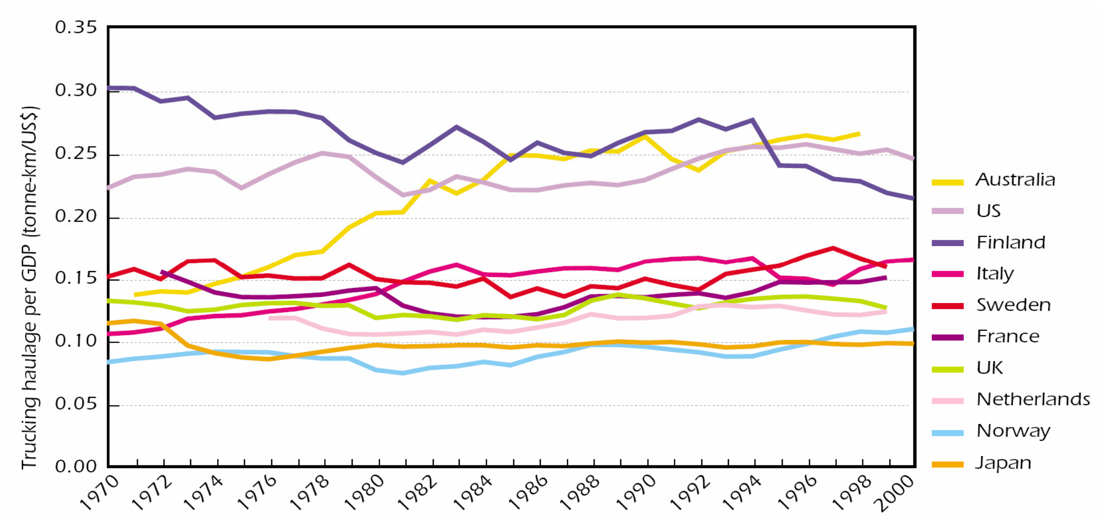

Figure 4.26. Truck freight tonne-kilometres per GDP (IEA, 2004)

The relative flatness of most of the lines in Figure 4.26 reflects a near unitary long-term elasticity between economic growth and trucking growth. The major exceptions are Australia, which has experienced far more rapid growth in trucking than in GDP, and Finland, which has experienced a decline (IEA, 2004)

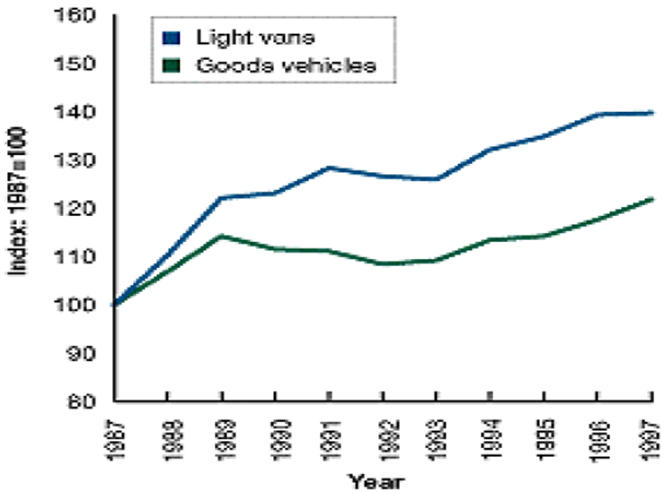

Figure 4.27. Trends in numbers of goods vehicles UK (Vickerman, 2002, 2003)

4.4.1.1 Modal split

Transport over land is in most countries dominated by trucking. The share of road transport has grown steadily over the past decade at the expense of rail and inland waterway in many regions, including the EU and Japan. This is mostly due to rapidly growing road transport volumes (EEA 2006). In total, intra-EU traffic road carries 80% of total tonnage but only 44% of total freight expressed in tonne-km (Figure 4.28), since an average haul by road is 110 km against 245 km by rail and 280 km by inland waterway (Gielen, 2004). With a 77% market share, road transport dominates freight transport over land in the EEA member countries.

For heavy (bulk) goods Europe and Japan show a preference for maritime and road transport solutions.

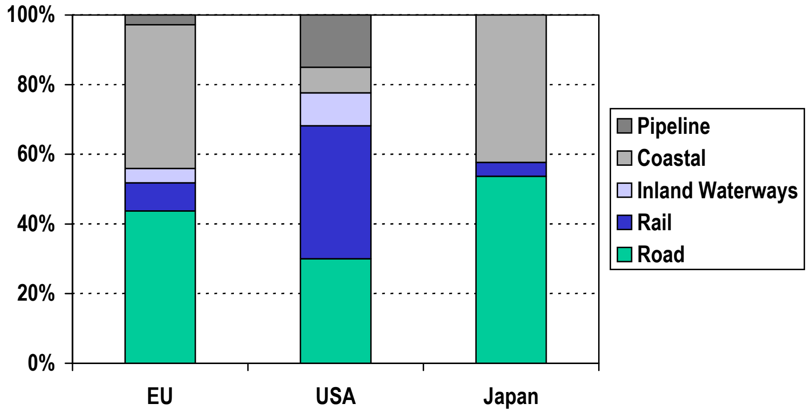

Figure 4.28. Modal split in the EU, United States and Japan, 2000 (in % of ton-km) (Rodrigue, 2006)

In the US road transport is not economically viable for long hauls. Therefore other transport modes, especially rail, have been (and will be) essential for domestic freight haulage (Figure 4.29). On the other hand, the road segment is still winning market share from the rail sector in Europe and Japan, where the geographic scale is smaller (Plouchart, 2005).

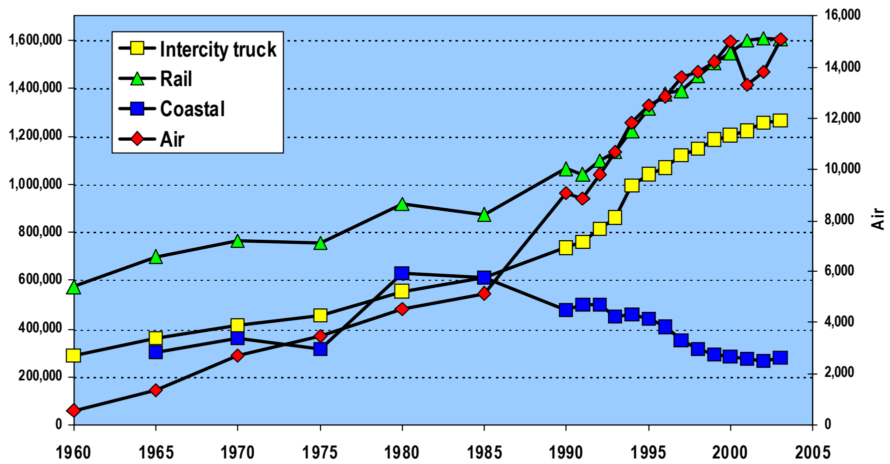

Figure 4.29. Ton-miles of transported freight, United States, 1960-2003 (millions) (Based on BTS data, as published by Rodrique, 2006)

4.4.2 Relationship freight transport with economic growth

Freight transport growth is a market-driven process. Growing incomes enable people to consume more and this in turn increases transport demand. Production chains are also subject to globalization. Distances between consumers and producers grow, facilitated by the removal of barriers to trade in the internal market and in the wider world. Low transport costs allow companies to benefit from differences in labor costs and skills in different regions. Components are produced all over the world and assembled at various locations. This happens because the differences in production costs are higher than the transport costs, making transport more profitable than local production (EEA, 2006).

Increasing GDD has boosted world trade, the main driver for freight transport. Globalization is accelerating because world trade (expressed in value) has expanded at higher rates (+170%) than GDP (+50%) in the last two decades (Figure 4.30). The increase in total distances traveled was larger than the increase in total tonnage hauled. Partly because of lighter goods being transported.

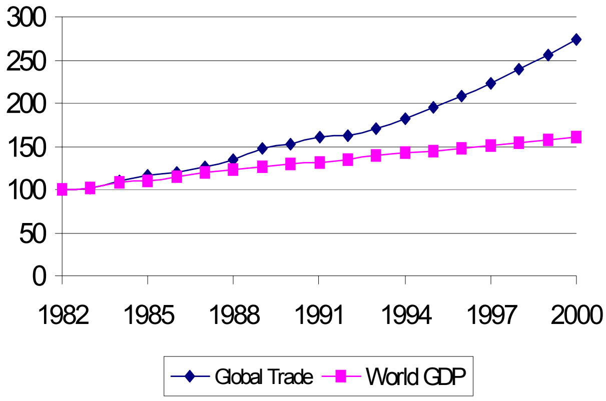

Figure 4.30. Growth in word trade and GDP (Caïd, 2004)

There are numerous and complex interrelations between the transport activity patterns, the access system, and spatial structure. A strongly simplified overview of the links between the economy and transport is visualized in Figure 4.31.

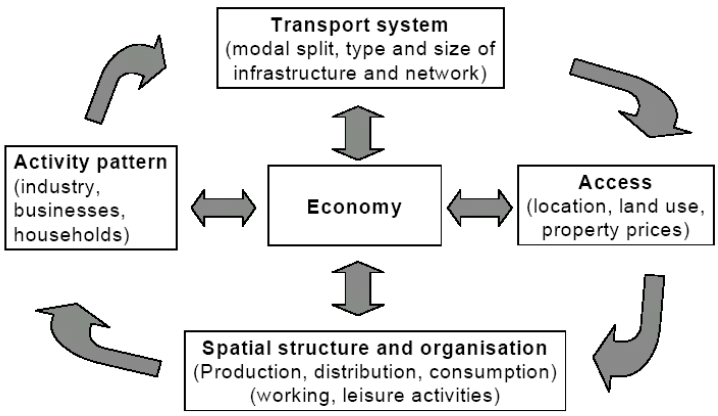

Figure 4.31. Links of transport and the economy (Ecoplan, 2003, as adapted by Caid, 2004)

In general, freight transport volumes have been growing with no clear signs of decoupling from GDP, i.e. we found a trend towards expansive re-coupling, (EEA 2006). Ever increasing amounts of goods have been transported over longer distances and more frequently (Figure 4.32, Figure 4.33). Until around the mid-1980s there was a fairly constant relationship in the EU between transport growth and GDP growth; for freight this was an elasticity of about unity. Hence freight forecasts could be made fairly accurately on the basis of economic growth forecasts. The transport intensity has even accelerated in the 1990's. From that time onwards this relationship has broken down and freight transport has grown much more rapidly than economic growth (Gielen 2004). (Figure 4.33). Freight transport volumes in IEA countries have grown 34% between 1990 and 2000, while GDP increased by 24% (expansive recoupling). The transport activity in the EU-15 showed almost the same behavior (Figure 4.33). Total freight haulage largely follows GDP in most countries (Plouchart, 2005). Weak decoupling of growth in freight volumes from economic growth has only been achieved in the new EU member states (EU-10), where the growth in GDP exceeds the high growth in transport volume (EEA, 2006).

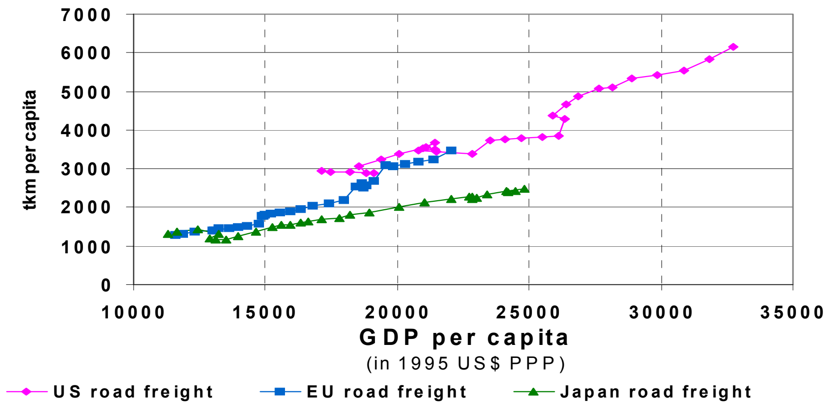

Figure 4.32. Road freight intensity and wealth 1970-2000 (Caïd, 2004)

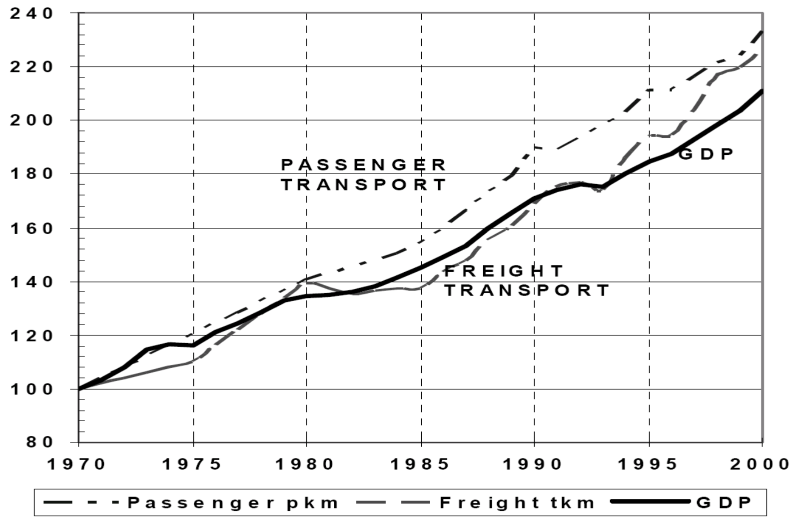

Figure 4.33. Trends of GDP and transport activity in the EU, 1970-2000; the vertical axis shows relative growth in GDP, normalized to 100 in 1970 (Caïd, 2004)

Value added data only exist for commercial sectors but not for private consumers. In order to apply the analysis of the relationship between physical flows and value added data to the transportation sector (in line with the analysis conducted for the industry sector, see Chapter 3.4.3.2) it is hence necessary that we limit ourselves to

- passenger transport without private vehicles, i.e. we limit ourselves to public passenger transport by rail, busses and air,
- freight transport by rail, trucks, air and ships.

Economic activity data originate from the WorldScan model and have been kindly provided by the Dutch Environment and Nature Plan Bureau (MNP) and the Dutch Central Planning Bureau (CPB) (MNP, 2006, CPB, 2006). However, this data was not available to us with the distinction between public passenger transport and freight. It was therefore necessary to study these two components as *total*, representing the entire commercial transportation activities. While value added data can easily be added up, this is less straightforward for physical activity data for transport because they are given as person-kilometre for public passenger transport and as tonne-kilometre for freight. In order to aggregate the two activity indicators we weighted person-kilometres with a factor 1/2 compared to freight. This weighting factor was chosen on the basis of specific energy use, which has been estimated at 0.95 MJ/pkm for public passenger transport (rail, bus and air) and 2.10 MJ/tkm for freight.

Using this approach we calculated physical activity data rising from approximately 1000 (tkm + 1/2 pkm) in 1980 to around 1600 (tkm + 1/2 pkm) in 2002. The division by value added data leads to values with a remarkably small range, namely from 7.9 to 8.3 (tkm + 1/2 pkm)/EURO[62]. Indexing the starting year to a value of 1.0, the values within a 20-year period can be expected to lie between 0.85 and 1.1.

While further work would be required to ensure the use of a good data source, the outcome seems acceptably accurate to present a back-of-envelope calculation later on in this report (Chapter 6.2).

4.4.3 Underlying mechanisms driving freight transport

Freight transport growth is driven by a complex structure of many factors. Some of the main factors driving freight transport are listed below, and will be discussed in more detail in the next paragraphs (IEA, 2004; Plouchart, 2005; Vickerman, 2002):

- production increases,
- increase in the average length of hauls,
- market liberalization, globalisation, outsourcing of manufacturing,
- market integration (EU, NAFTA, APEC),
- changes of consumer preferences,
- efficiency improvements (load factor, vehicle size),
- investment into transport infrastructure.

4.4.3.1 Shifting logistic demands

Over the last decades logistic chains have been expanded geographically. Component are produced all over the world and assembled at various locations. In addition the demand for 'just in time' delivery of goods has enormously increased. Over the past decades logistic chains have shifted flows from bulk delivery by manufacturers (push supply chain) to just in time customer demand delivery (pull supply chain). See Figure 4.34. In addition, trade companies have changed their distribution policy from decentralised stocks to a small number of large distribution centres using fleets of bigger lorries over longer distances.

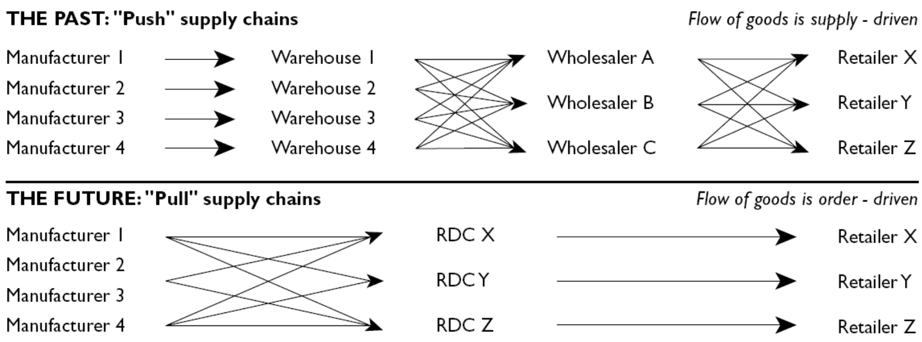

Figure 4.34. The effect of changes in supply chain control; shift from 'push' to 'pull' supply chains (Euro-CASE, 2001)

The rise of such supply chain management and just-in-time deliveries of freight loads, has resulted in declining utilisation of heavy goods vehicles. Smaller but more frequent loads are delivered exactly when needed. While offering benefits, the greater flexibility required by the transporters leaves less room to optimise load factors. While more efficient loading generally leads to economic savings, these are outweighed by costs involved in achieving the efficiency gains, such as costs of storage (EEA, 2006). Even the progress in logistics has not reversed the

62 The analysis bases on constant 1995 EURO.

overall trend of declining use of large vehicles and a trend towards transport of lighter goods at higher speeds at lower load factors (Figure 4.35).

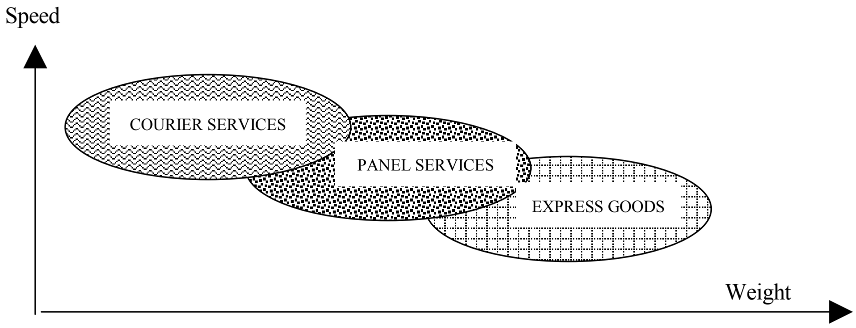

Figure 4.35. The non-defined borders in express goods transport (Albrecht et al., 1996)

The express goods transport sector is an active part of the transport industry that started to grow rapidly from the mid ‘80 onwards resulting in a very dense logistics network in Europe (Albrecht et al. 1996). This development has most likely substantially contributed to the already mentioned sharp increase in freight transport from about 1985 onwards.

4.4.3.2 Value, weight and transport speed

Several studies report that sectors with a larger contribution to GDP, in terms of value, have a relatively smaller transport demand (e.g. manufactured goods) and the sectors with a lower contribution to GDP have a large transport demands (e.g. agriculture) (Caid 2004). One indirect driver of decoupling could be dematerialisation of the economy since decreasing the material intensity of a product can help to decrease the demand of transport

Products from sectors with a large contribution to GDP may have a small transport performance expressed in ton km. This does, however, not necessary mean low transport intensity expressed in other parameters, especially in terms of speed of transport and associated energy use. An average road cargo is valued at 1674 Euro/t, compared to 924 Euro/t for rail freight and 87 €/t for inland waterway traffic (Gielen 2004). Especially the express delivery of valuable small goods and parcels may be characterized by very high energy use due to:
1. the use of fast and energy intensive transport modes (see also Figure 4.19);
2. the relatively low load factor of these type of special transports. The shift at increased freight value to faster and more energy intensive modes (Figure 4.35), is shown in Figure 4.36.

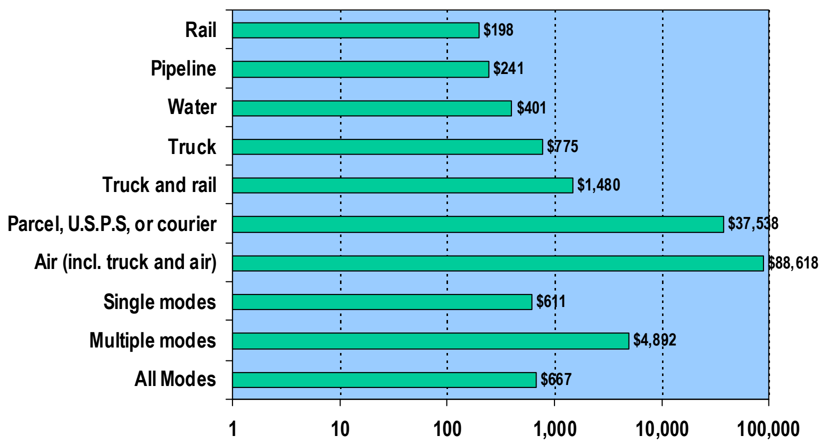

Figure 4.36. Value per ton of U.S. freight shipments by transportation Mode, 2002 (Based on BTS, data as given by Rodrigue, 2006)

Laksman and Anderson (2002) have ranked the composition of commodities in the US that make up the freight stream, have been ranked by value and ton- miles (Table 4.1). The top five commodities by value account for just fewer than 40% of the value and 6% of the ton-miles. The top five commodities by ton-miles account for a little over 40% of the ton-miles and 10% of the value. Thus expensive goods are light weighted and/or transported over short distances.

Table 4.1. Top five freight sectors by value and ton-miles in the US, 1993, 1997 (Laksman and Anderson, 2002)

Top 5 Sectors by Value				Top 5 Sectors by Ton-Miles			
1993		1997		1993		1997	
Sector	**Value/Ton**	**Sector**	**Value/Ton**	**Sector**	**Value/Ton**	**Sector**	**Value/Ton**
Electronic & Other Electrical Equipment, Office Equipment	$19,915	Electronic & Other Electrical Equipment, Office Equipment	$21,955	Coal	$21	Coal	$22
Motorized and Other Vehicles	$6,216	Motorized and Other Vehicles	$5,822	Cereal, Grains	$122	Cereal, Grains	$110
Miscellaneous Manufacturers	$9,727	Textiles, Leather, etc.	$11,591	Basic Chemicals	$539	Other Prepared Foods, Fats & Oils	$1,008
Machinery	$8,356	Machinery	$9,926	Gasoline & Aviation Fuel	$225	Coal & Petroleum Products, n.e.c.	$158
Textiles, Leather, Etc.	$8,266	Other Prepared Foods, Fats, & Oils	$1,008	Other Prepared Foods, Fats & Oils	$873	Basic Chemicals	$446
% of Total Value of Top 5 Sectors	37.6		38.3		10.4		10.6
% of Total Ton-Miles	6.1		6.5		42.8		42.7

Two contrasting sets of commodities emerge as the top five when they are ranked by the different measures of freight - value or ton-miles. The top value commodities derive from knowledge-intensive high value adding industries such as electronics and electrical equipment, motorized vehicles, machinery and textile and leather products. The top commodities in terms of ton- miles are low value raw materials such as fossil fuels, basic chemicals, grains, etc. Since the usual statistical picture of the progress of a freight system derives from the available data on ton- miles, one often misses the trends in the emerging high value adding sectors whose growing importance and freight requirements are changing the spatial reach, nature of operations, functions, and services of the freight services industry.

4.4.3.3 Categories of freight

Figure 4.37 shows a subdivision of freight transportation by category of goods. The share of the different freight categories, is given as their percentage of the total of all freight categories, expressed in tons and ton.km. The largest category, in terms of tons, is minerals and materials. In terms of ton-kilometres, manufactured articles constitute the main category. During the last decade there has been a slight shift towards manufactured articles, but this shift is of secondary importance compared to the strong growth of total freight transport (Gielen, 2004).

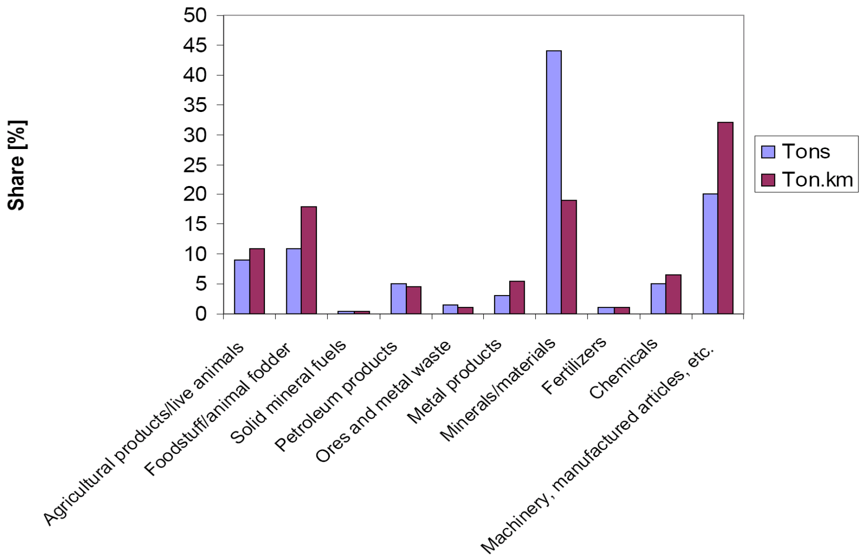

Figure 4.37. EU national freight transport, share of goods (standard goods classification for transport statistics (NST/R)) (Eurostat, 2003, as given in EEA, 2006)

4.4.3.4 Load factor

The limited data available also show a trend towards poorer use of heavy goods vehicle capacity. Apparently, the higher transport costs, resulting from lower utilisation, are exceeded by benefits such as reduced production costs. A reverse of these market trends could reduce environmental impact. The data in the EU 'Transport and Environment Reporting Mechanism' (TERM), show that in a few countries, for which reliable data are available, the utilisation of road transport vehicles is declining. But the average load factor has also declined for heavy goods vehicles, albeit at a lower rate. A decrease in the share of empty rides with heavy goods vehicles is largely compensated for by a decrease in the average load factor of loaded trips. As a result, more vehicle-kilometres are necessary for the same number of tonne-kilometres or passenger-kilometres. Improvement in the use of available capacity in transport vehicles could allow for the current amount of goods to be transported, at a lower environmental cost (EEA 2006).

Also in the United States, the average-weight truck shipment has declined, reflecting a trend towards moving lighter-weight products, which resulted in an increase in fuel use per tonne-kilometre shipped. These trends are in line with the value and weight related aspects of freight as discussed in paragraph 3.3.2. Load factors measure the use of total weight capacity. It is, however, often the volume or deck space of the truck that sets the limit on what can be carried. Therefore, decreasing load factors may also reflect a change in what is being transported by specific modes.

4.4.3.5 Transport intensity

Transport intensity of freight is usually measured as tonne-km (passenger transport intensity is measured in passenger-km). Hence changes can be influenced by both changes in the volume of trips being generated and the volume of the goods being carried and the length of each trip. For freight this is important because there has been a tendency towards a fall in the weight of goods being transported, due to structural changes in industry, In addition there has been a trend towards an increase in the value to weight ratio of freight, thus tending to reduce the weight of goods lifted (see previous paragraphs). This has been more than counteracted by increases in trade, increases in regional specialization and increases in the length and complexity of the logistics process, both transport and production logistics. Hence, for any given weight of goods moved, the length of haul has increased more rapidly.

The transport intensity debate has developed surrounding the issue of decoupling economic growth and transport growth. The concept of transport intensity is an attempt to capture a measure of the amount of transport needed per unit of output. Thus transport intensity expresses the relative rates of growth of, for example, tonne-km of freight and GDP (Vickerman, 2002).

Figure 4.38 shows that most of the new EU members (EU-10) have very transport-intensive economies compared with those of the EU-15. This is an indication of the high share of bulk industries compared to EU-15, where there is higher share of services rather than production and manufacture. Some differences can be explained by geographical factors, thus comparisons should primarily be made between comparable states (EEA 2006). For example, the geographically larger countries such as the United States and Australia have relatively high levels compared with smaller ones such as the Netherlands.

The transport intensity, measured as tonne-km per euro GDP, is much higher in the EU-10, compared to the old EU-15, but has declined by 13% since 1995 (Figure 4.38). This decoupling is linked to the transition to more service-oriented economies, as is the case in the EU-15. The differences between EU-15 and EU-10 countries show that high economic growth, or a more competitive economy, does not necessarily imply higher transport intensities. If the decline in transport intensity in the EU-10 continues to fall to the levels seen in the EU-15, decoupling in the EU-10 could continue at the current pace for decades. But in spite of decoupling, transport volumes have grown and continue to grow in the EU-10 (EEA 2006).

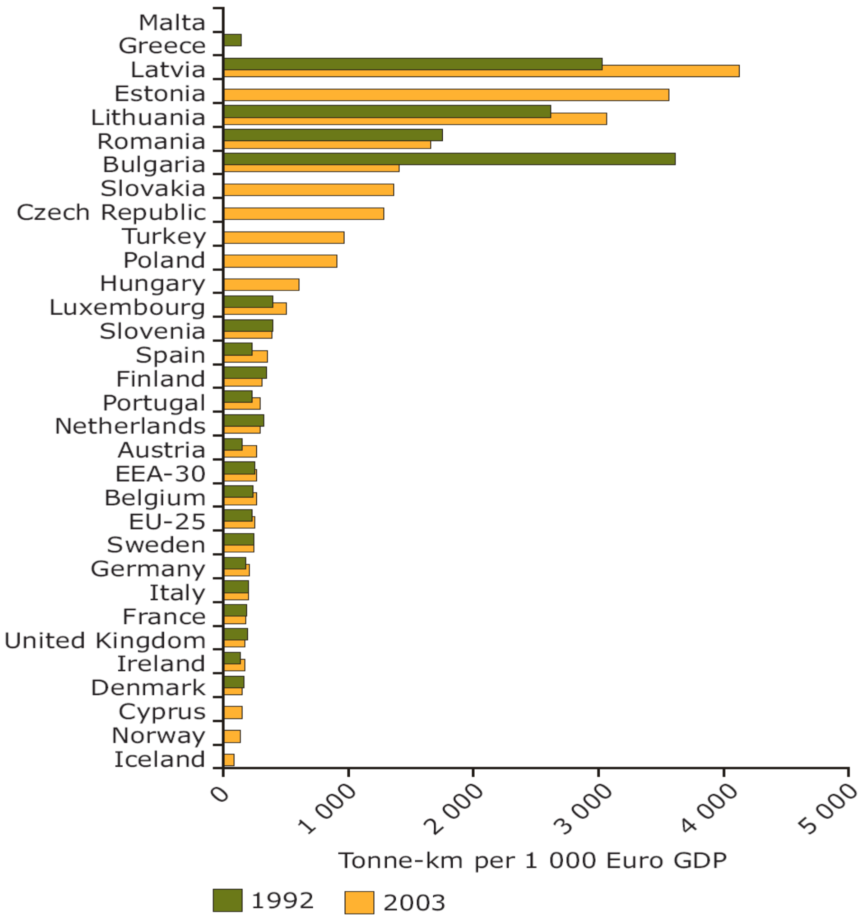

Figure 4.38. Freight transport intensities in the EU; transport intensity is a measure of the amount of transport in relation to the size of the economy (EEA, 2006)

4.4.3.6 Energy

Freight is the end use sector with the strongest relative growth in energy demand since 1973. Its share on total final oil demand for IEA-11[63] went up from 15% in 1973 to 26% in 1998 (Figure 4.39). The 80% increase in freight fuel demand over the period came as a result of tonne-km haulage growing in line with GDP in most countries and a shift towards trucking, which is more energy intensive than rail and shipping. This growth was accompanied by generally modest overall declines in fuel intensities.

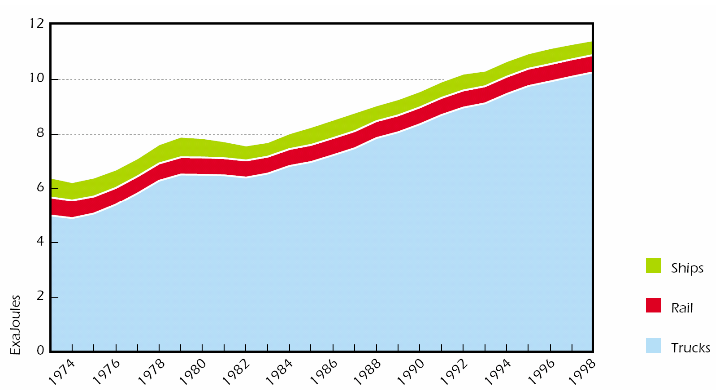

Figure 4.39. Energy use in freight transport by Mode, IEA-11 (IEA, 2004)

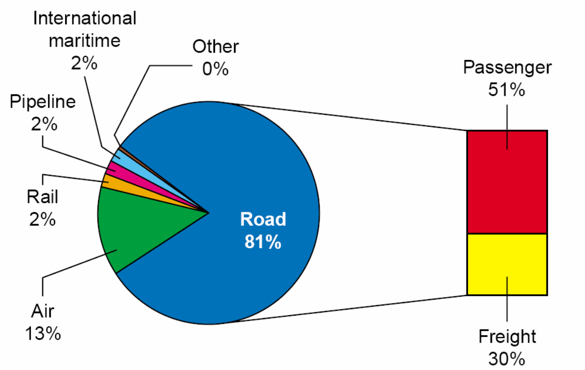

Figure 4.40. Energy consumption breakdown for the transport sector (IEA and IFP, estimates as given by Plouchart, 2005)

Road transport accounts for 81% of transport-related energy demand (Figure 4.39, Figure 4.40) and is, apart from aviation, the most energy-intensive mode of transport per tonne of product hauled. High road transport growth limits the impact of energy conservation policies in the area of environmental protection as well as it increases oil dependence. One key factor in this paradoxical trend is that transport modes consuming little or less energy such as rail and waterborne transport are not sufficiently competitive and/or lack the necessary infrastructure. These alternatives are becoming less and less adapted to current economic requirements, such as the industrial ‘just in time’ management and rising consumer demand for specialized, customized products. In addition, transport destinations become increasingly less centralized (Plouchart, 2005). Despite the efficiency improvement of al transport modes, the above described trends result in a higher energy use per capita for freight transport as well as for passenger transport. These aspects are summarized in Figure 4.41.

[63] Countries for which the IEA has complete times series with detailed data (1973 to 1998), including: Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom and the United States.

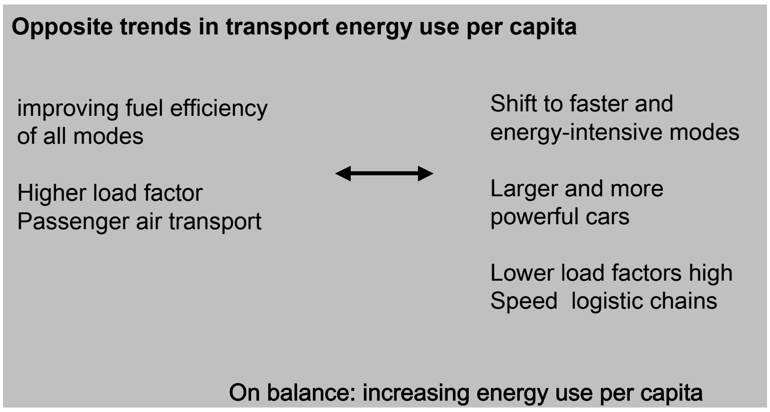

Figure 4.41. Opposite trends in transport energy use per capita

While consuming large quantities of energy, especially oil, vehicles also emits numerous pollutants such as carbon dioxide, nitrogen oxide and noise and transport infrastructures have damaged many ecological systems. Many of the environmental impacts of transport systems have been externalised, implying that the benefits of mobility are realized by a few while the costs are carried by the whole society (Rodrigue, 2006).

4.5 Conclusions and outlook in the future

Transport of both passengers and freight has been growing faster than GDP over the past decades (expansive decoupling). Air transport exhibited the fastest growth over the past decades, but road transport is by far dominant.

The rising income has induced a shift towards faster passenger transport modes, resulting in increased energy use and CO_2 emissions. Likewise, freight transport demand has shown a trend to specialized high-speed logistic freight chains (just in time delivery), along with reduced load factors, as compared to traditional bulk oriented logistics. As a consequence, sectors with a large contribution to GDP (e.g. manufactured goods) may have a small transport demand if expressed in ton.km, but not if expressed in costs and energy.

Although the energy efficiency of all transport modes has increased over the past decades, the transport volumes have been growing substantially faster. The energy use of the transport sector will continue to increase, since saturation in both passenger and freight transport is not yet occurring (Figure 4.40, Figure 4.41). The transport sector will likely become the major CO_2 emitting sector for the next decades. Since decoupling of travel demand from economic growth is unlikely, at least during the next decades, these effects will increase energy use.

As compared to other sectors, the transport sector may be regarded in an earlier stage of the 'Kuznetz curve', with respect to energy use and CO_2 emissions. Public acceptance and other social factors also hamper emission reductions, especially in the passenger transport sector. Due to the low price elasticity between fuel prices and transport, emission reductions for cars can only be achieved at very high fuel prices. The costs for CO_2 emission reductions in the transport sector are about 5 to 10 times higher than in other sectors. The complex situation in the transport sector calls for innovative policy measures. Technical measures aimed at efficiency improvement and/or low CO_2 fuel chains are likely the most effective.

Decoupling of harmful traffic emission, especially soot and nitrogen oxides, is easier and becoming increasingly effective, especially due to stricter emission standards for the different transport modes. Nevertheless, air quality in cities does not yet meet the limit values set by various regulatory frameworks all over the world, and still has a major negative impact on human health.

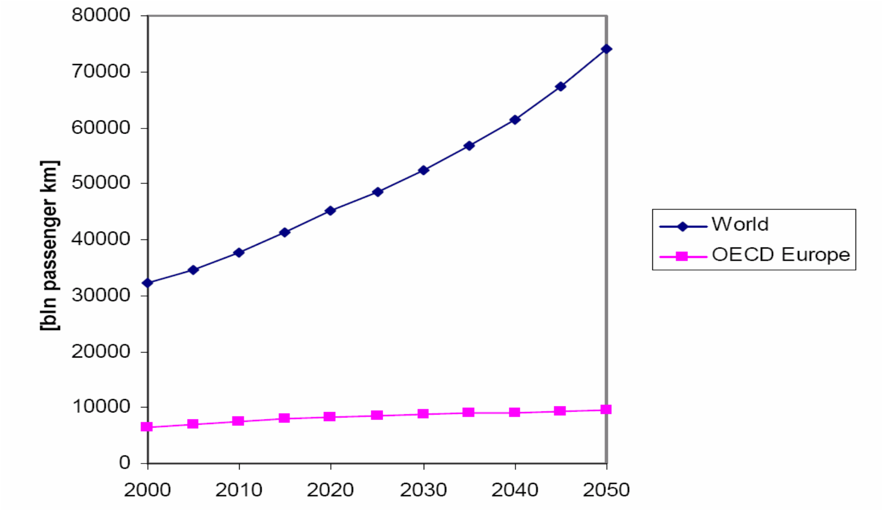

Figure 4.42. Demand for passenger transportation (IEA, 2004)

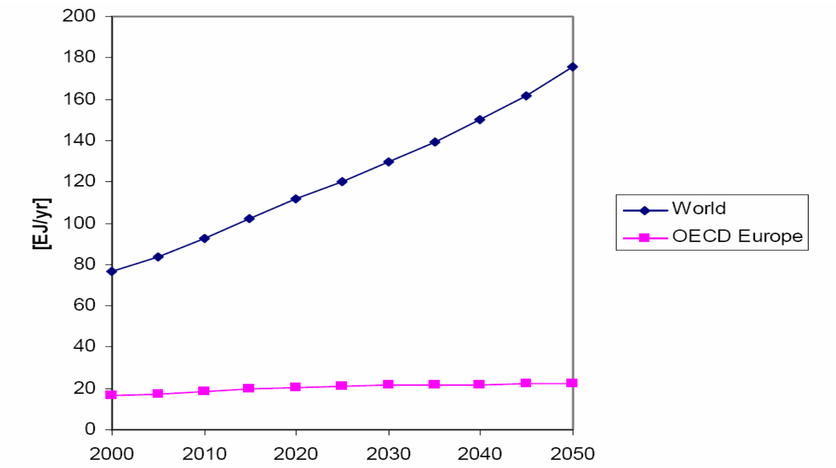

Figure 4.43. Demand for freight transportation (IEA, 2004)

5 Sector Study: Households and Services

Suzanne Joosen and Erika de Visser, Ecofys

5.1 Introduction

This chapter deals with economic and physical growth in two economic sectors: the residential sector (households) and the service sector. The contribution of these sectors to the overall economy differs from country to country according to their state of development. In industrialized countries we see that the service sector is relatively important in terms of value added compared to developing countries. The economic structure of developing countries is different because agricultural activities (still) make up an important part of the economy.

The economic activities that a country exploits give rise to a certain pattern of energy use. Before we go into further detail on the drivers behind energy use and the physical activities within the studied sectors we will have a more broadly look at the structure of developed and developing societies and their patterns of energy use. In developed countries, the most dominant economic sectors regarding energy use are industry and transportation, which respectively consume 29% and 34% of the final energy (Chow et al., 2003). The residential sector follows with a share of 19% in total energy consumption. The focus of this study is primarily on the OECD countries, which all are developed countries. The energy consumption in the residential and services sector in these OECD countries is considerable, respectively 20% and 10% of the countries' total energy consumption. In developing countries the residential sector (34%) and industrial sectors (35%) are most important in terms of energy consumption patterns. The service sector is less developed in these countries and its share in the total energy consumption is only 4% (Chow et al., 2003). In absolute figures service sectors of the 10% richest nations consume more than 250 times the energy as the service sectors of the 10% poorest nations (Kopp and Portney, 2003). This difference is equivalent to about 3.5 barrels of oil per capita per year (Chow et al., 2003).

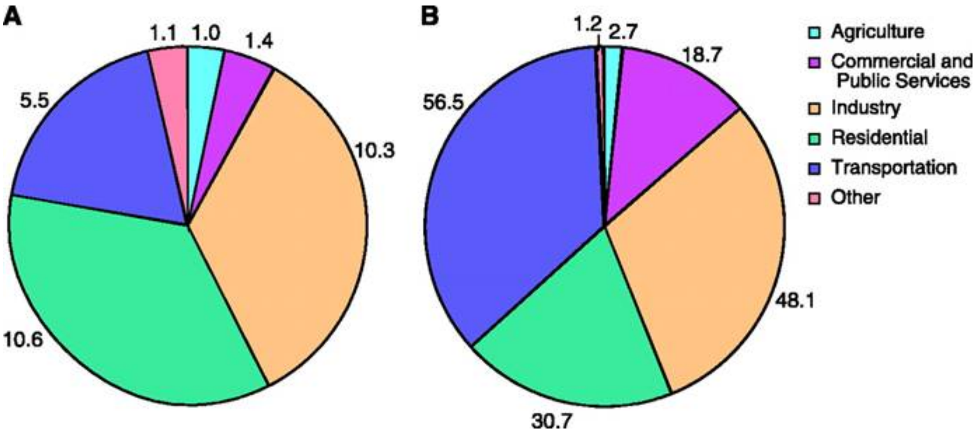

Figure 5.1 Per-capita energy consumption by sectoral end use in (A) the developing world and (B) the developed world (in gigajoules) (Chow et al., 2003)

When economies develop they tend to move towards more service-based societies. This transition goes together with an increasing energy use. Today's energy and climate scenarios often base their calculations on a growth in energy use that is proportional to the economic growth of a country. Figure 5.2 shows at several moments in time different projections of total primary energy use. The same figure also shows the actual primary energy use. These projections show that differences between actual energy use and projections that we make on basis of assumptions on technology development only can be huge. With this picture in mind the question comes up how we can improve scenarios of future energy use.

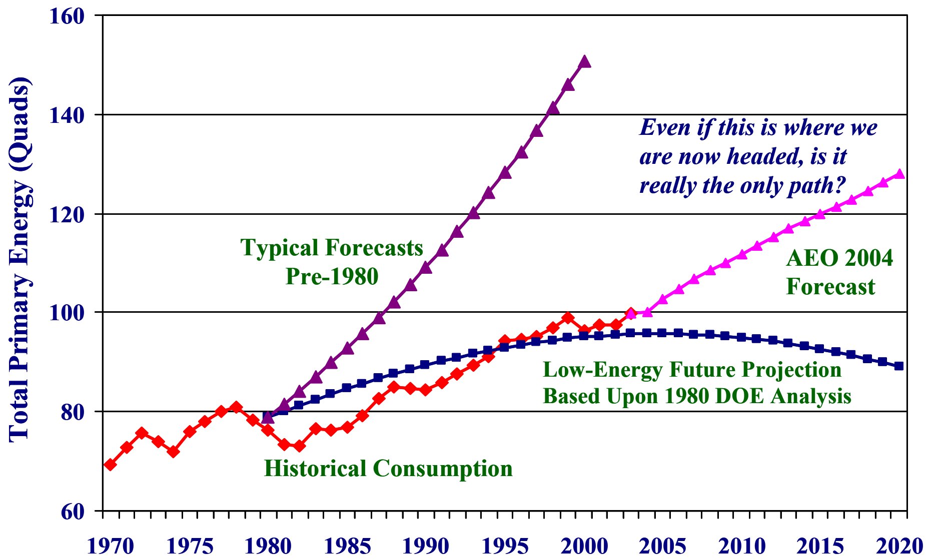

Figure 5.2. Comparison of U.S. Energy Projections: A Difference in Technology Assumptions (Sources: DOE (1980), EIA (2003), and EPA estimates)

The following research question will be addressed in this report:

How is growth in monetary terms related to growth in physical terms in the residential and services sector of OECD-countries and what are the underlying mechanisms of the observed trends?

Based on an assessment of literature, indicators of physical activities are derived for both sectors. These physical activities are assumed to be important in the way that they have significant impact on the sectoral energy use. The analysis of the development of these physical indicators in relation with increasing economic growth should provide answers on important questions like, to what extent do we see saturation processes occurring with continued economic growth, and do we see physical and economic growth keep in pace or do we see a decoupling trend? The decomposition method is used to address the effect of these indicators on the level of energy use. Next paragraph deals with a short theoretical background of the decomposition method.

Figure 5.3 shows a model of the driving forces and their physical activities of the energy requirement in the built environment. Blue marked are the indicators, which are studied in detail. We will restrict this study to an analysis of each physical indicator and do not attempt to aggregate these physical activities to a common driver for energy use. We try to answer following sub questions:

- How does the physical activity develop and what explanation can be given for the development pattern?
- Does development of physical activity show a saturation trend?
- Is there a re-coupling or decoupling trend between the physical activity and monetary growth?

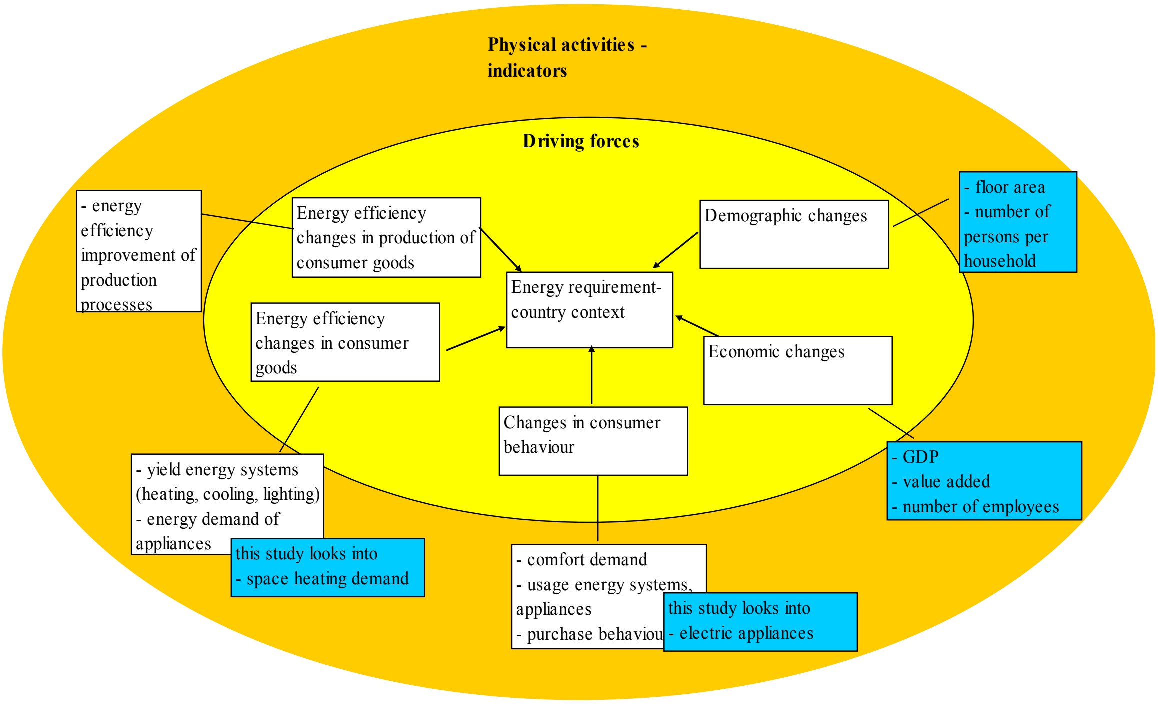

Figure 5.3. Overview driving forces of the energy requirement in the household and services sector (buildings) and their physical activities, based on (Vringer, 2005), blue marked are the indicators, which are studied in detail in the EPIST-project

5.2 Used methods

5.2.1 Time series on energy use

As a first step in determining the relationship between physical and monetary growth, time series for the energy use of both the household and service sector are constructed. These historic analyses, for the period 1970-2000, are the starting point of the sector studies and give us a better overview of what trends in households and services energy use actually occur.

5.2.2 Physical activities

Next to population and GDP other factors do influence the actual energy use. As already said it is expected that there are good reasons to include physical activities in energy modeling. Therefore, the analysis of physical activities gets most attention in the sector analysis. A deeper insight in weather economic wealth translates into physical growth helps to find answers to the overall research question.

When speaking about physical activities one should think about number of persons per household or the office space used per person. For a better understanding we graphically present the development trends of these physical activities:
- On the x-axis; economic growth in GDP per capita in 2000 US $ and
- On the y-axis; the physical activity per capita (e.g. m^2 per capita, capita per dwelling)

The data used in this study are mainly derived from the IEA Indicator Database (2004). This database contains those IEA-countries where consistent, long-term time series are available: Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States. To discuss aggregated trends and differentiate between developed and developing countries IEA Energy Balances of OECD Countries (2005) and IEA Balances of non-OECD Countries (2005).

5.2.3 Decomposition method

The actual level of energy use is not solely caused by an increasing or decreasing level of physical activities, but also the energy efficiency of activities and population or GDP growth plays a significant role. For example, an increase in per capita energy use does not mean that the end-use energy efficiency has not improved. To understand the evolution of the energy use in economic sectors or society as a whole, the decomposition approach is often used. It implies a disaggregated investigation of changes in per capita energy use and relating it to improved end-use energy efficiency and structural changes. Many decomposition studies on residential energy use are performed during the years by Schipper et al. (1992, 1993, 1995), Unander et al. (1997) and Unander and Schipper (2000). Although the service sector becomes more important for economies in OECD countries, decomposition studies on services energy use are scarce (Krackeler et al., 1998).

The decomposition approach used in this study to analyse the changes of demand structure is based on a decomposition of per capita residential and services energy. The energy use per capita in these sectors is disaggregated according to following equation:

$$E = A \cdot S_i \cdot I_i$$

Where,
E = residential energy use
A = activity (population or GDP)
S_i = structure component for each residential end use i
I_i = energy intensity of each end-use i

The first decomposition level introduces residential energy use as a product of GDP (activity), floor area per GDP (structure) and energy use per capita (energy intensity).

$$(1) \qquad Energy\,use = GDP \times \frac{m^2}{GDP} \times \frac{energy}{m^2}$$

Indices are used to present the changes in activity, structure and intensity components over time and compared to the energy use in a reference year. The decomposition of energy use is presented by means of indices that present the level of energy use related to the base year 1970. They can can be thought of as “all else being equal” indices, because they describe the evolution of energy use that would have occurred if all but one factor remain constant (Unander et al., 2004).

The second level decomposition shows two types of decomposition, one driven by GDP and one driven by population. The structure component (m^2 per GDP) is replaced by two different structure components, namely dwelling area per capita and m^2 per GDP. These components give a more detailed picture on housing trends. When GDP is replaced by population the structure components become living area per capita and average dwelling, see equation (3).

The equations corresponding to these decompositions are respectively:

$$(2) \qquad E = GDP \times \frac{m^2}{capita} \times \frac{capita}{GDP} \times \frac{energy}{m^2}$$

$$(3) \qquad E = population \times \frac{m^2}{dwelling} \times \frac{dwelling}{capita} \times \frac{energy}{m^2}$$

For the service sector we also make a decomposition analysis. Either the value added of the service sector or services floor space could be used to measure activity in commercial buildings. We rely on the value added of the service sector, which results in following equation:

$$(4) \qquad E = value\,added \times \frac{employee}{value\,added} \times \frac{m^2}{employee} \times \frac{energy}{m^2}$$

5.3 Households

5.3.1 Time series energy use and GDP

Before we start with a detailed analysis of the underlying drivers of trends in household energy use we take a look at the residential energy use itself. In absolute terms the final demand for residential energy has increased in most of the countries studied. The total final energy consumption in households of IEA member countries shows an increase of 1% per year in the period 1971-2003 (IEA, 2005). The growth rate for OECD countries is also 1%. For the OECD-total and IEA member countries the share of household energy consumption in total energy consumption continued to be about 20% of total energy consumption (IEA, 2005). In the same period the annual growth of Gross Domestic Product is on average 3% for the OECD (and for IEA-member countries). In figure 2 and 3 the development of energy, GDP and some other important indicators is given for both OECD and non-OECD countries. In OECD countries the growth of GDP outpaces the growth of total final energy use. In developing countries this effect is even larger, GDP growth has been almost 5% per year in the ten year period 1994-2004 and growth in energy use has been more moderate with almost 2% per year (Figure 5.5).

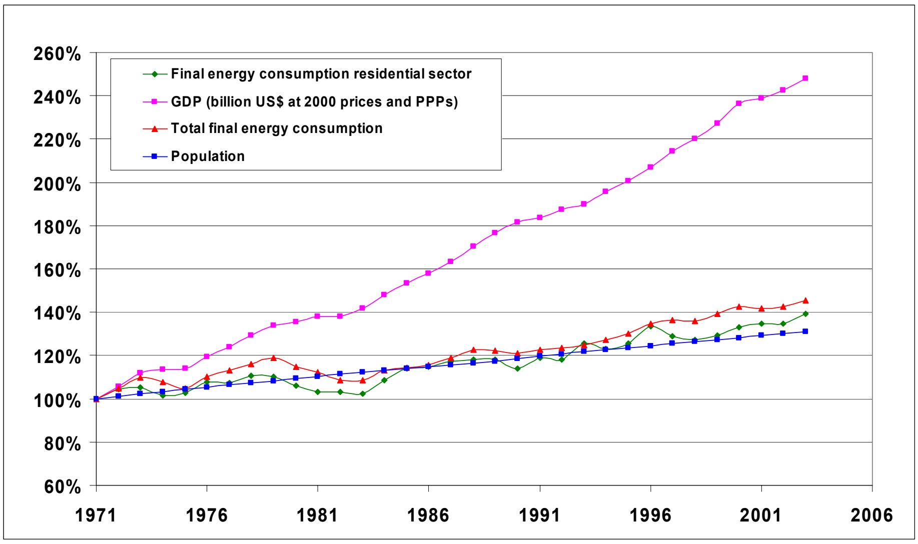

Figure 5.4. Developments in energy use, population and GDP in OECD-countries (IEA, 2005)

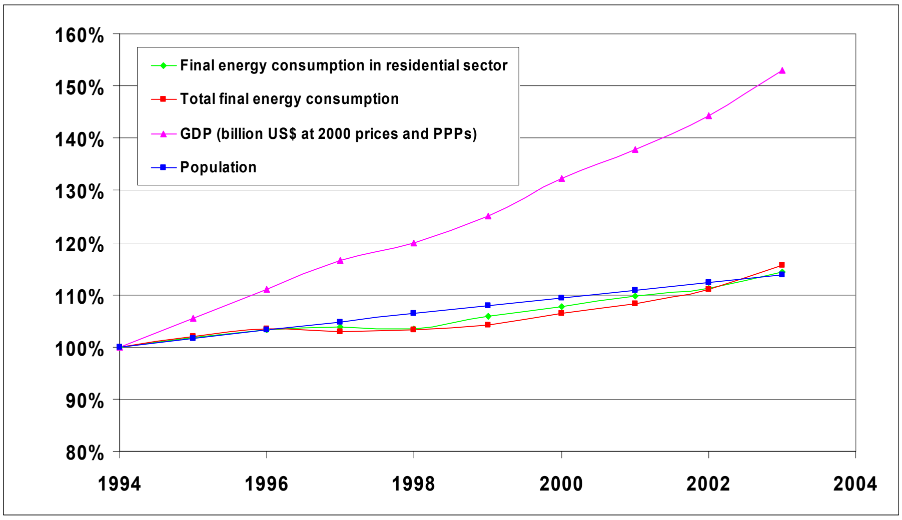

Figure 5.5. Developments in energy use, population and GDP in non-OECD countries (IEA, 2005)

The figures demonstrate that economic growth is not the most suitable indicator to forecast energy use, because there is already a slight decoupling trend visible of GDP (pink line) and total and household energy (green line). In OECD countries this trend is clearer than in non-OECD countries. In order to find out how GDP and energy use are related we take a closer look at the development of final energy use with economic growth as depicted in Figure 5.6.

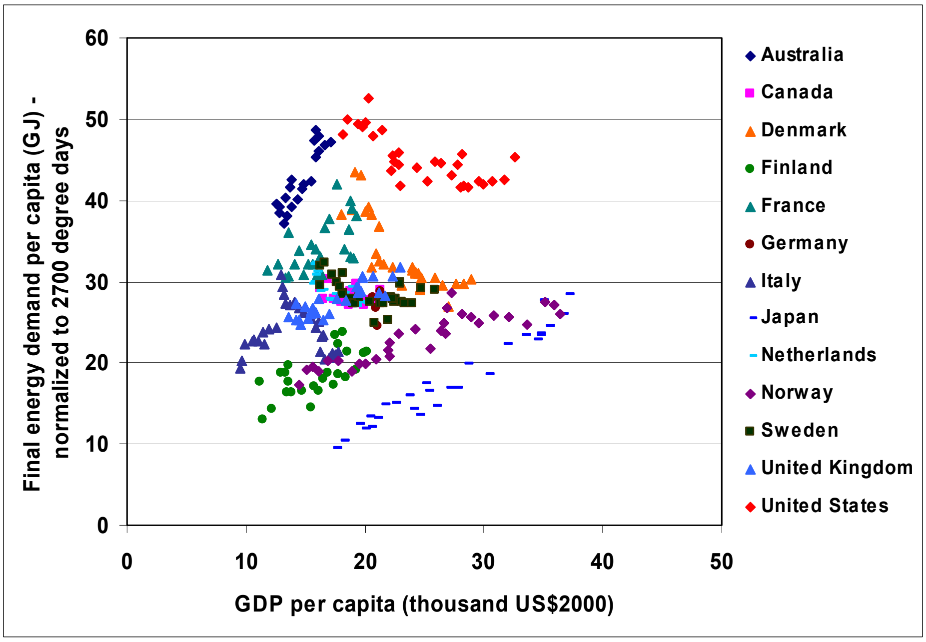

Figure 5.6. Final residential energy demand in OECD countries (OECD/IEA, 2004b)

Residential energy is used to fulfil several energy functions in households like space heating, lighting, cooking, water heating and appliances. All these energy functions have their effect on the final demand for energy. Countries that start at a relatively high level of energy use per capita tend to reduce their energy demand per capita with increasing wealth, like Denmark and the United States for example. On the other hand we see that countries with relatively low residential energy use per capita at a certain GDP level like Japan, Finland and Norway increase their energy use per capita. Although developed countries show very large differences in energy use per capita a common tendency towards less differentiated levels of residential energy use per capita. Our hypothesis that per capita energy use will reach saturation level at high stages of economic development and living standards is not strongly supported by the trend observed in Figure 5.6. Other factors like national policies and lifestyle probably influence the trend in Figure 5.6 as well. From literature we derive more support for our hypothesis. The link between economic growth and energy use is expected to become weak and energy demand is lagging behind economic growth (IEA/OECD, 2005). This statement deserves a more in-depth analysis of the underlying mechanisms of household energy use.

With the residential energy use as a starting point, we discuss the underlying drivers of these trends in residential energy use. In order to come to an answer on what actually is the relationship between growth in monetary terms and physical terms in this sector we take a closer look at the underlying mechanisms in the residential in next paragraph. As said before, the main focus is on physical activities.

5.3.2 Underlying mechanisms

Typically, future residential energy use is forecasted on basis of household income (and hence GDP). Explaining trends in energy use based only on household income might lead to wrong conclusions since several other factors are affecting the energy use in households. In literature several key factors are determined that affect the energy use in households (OECD/IEA, 2004a) (Schipper et al., 2001). Much work on indicators to analyse energy use is done by the International Energy Agency (OECD/IEA, 1997). Different types of indicators are developed. These indicators combine energy data with data that describe activities driving the energy consumption.
The type of indicator one should use depends on the specific research question. Because the main interest of this report is on physical activities we make use of indicators that measure activity levels. The indicators are partly derived from the IPCC Special Report on Emission Scenarios (2000) which describes a number of factors that contribute to household energy use: population size, rate of urbanization, type of dwelling and number of dwellings. The physical activities that we discuss in section 5.3.2.1 are:

- Dwelling area (m^2)
- Number of persons per dwelling (persons/dwelling)
- Average living area per capita (m^2/capita)
- Appliances per capita (saturation of appliances in %)

To assess the relationship between the commonly used scenario driver GDP/capita and physical growth patterns charts are made that depict this relationship. GDP is given in constant 2000 US dollars, taken from the IEA Energy Balances (2005). One of the questions that should be answered with the eye on better forecasts of physical growth and related energy use is if saturation of the physical activities occurs. It is not realistic to assume that physical activities continue to grow with the same pace, and therefore we want to know if some saturation levels are already reached. We also state whether there is a re-coupling or decoupling trend of the physical activity with GDP per capita.

5.3.2.1 Physical indigators

Physical indicator: dwelling area
As of 1970 the continued growth in dwelling area with increasing GDP per capita is striking. Even during periods of economic recession the dwelling areas often continued to grow (OECD/IEA, 2004). In the United States homes are largest and dwelling area increased with 0.5% per year in the period 1973-1998. Finnish homes were among the smallest in 1973, but dwelling area increased with the same annual growth rate like the United States (0.5%) during the same period. Current trend in dwelling area development shows that growth is slowing or even stabilising in several developed countries, like Canada, United Kingdom and Japan among others (Figure 5.7).

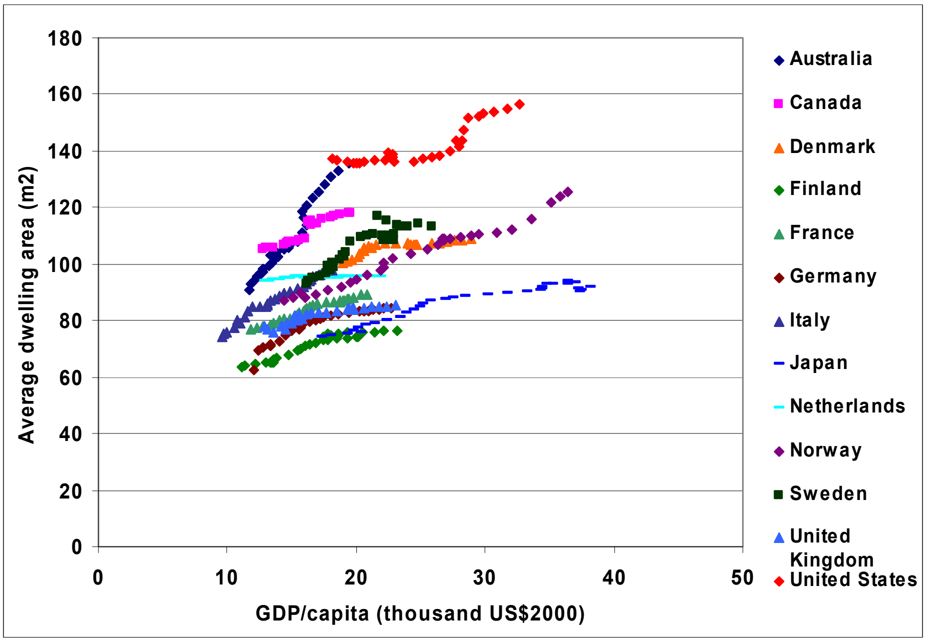

Figure 5.7. Trends in average dwelling area in OECD countries, 1970-2000 (OECD/IEA, 2004b)

Physical indicator: number of persons per dwelling

The change in number of persons per dwelling is a demographic trend. In each country analysed we see a lower household occupancy with increasing GDP per capita. Past decades the structure of families has undergone significant changes. In Europe for example there is a rising number of persons living alone and lone parent families (European Communities, 2004). This phenomenon of lone parent families is a growing trend in many developed, industrialized countries. From Figure 5.8 it is not so obvious that each country will achieve the same level of persons per household at GDP per capita levels.

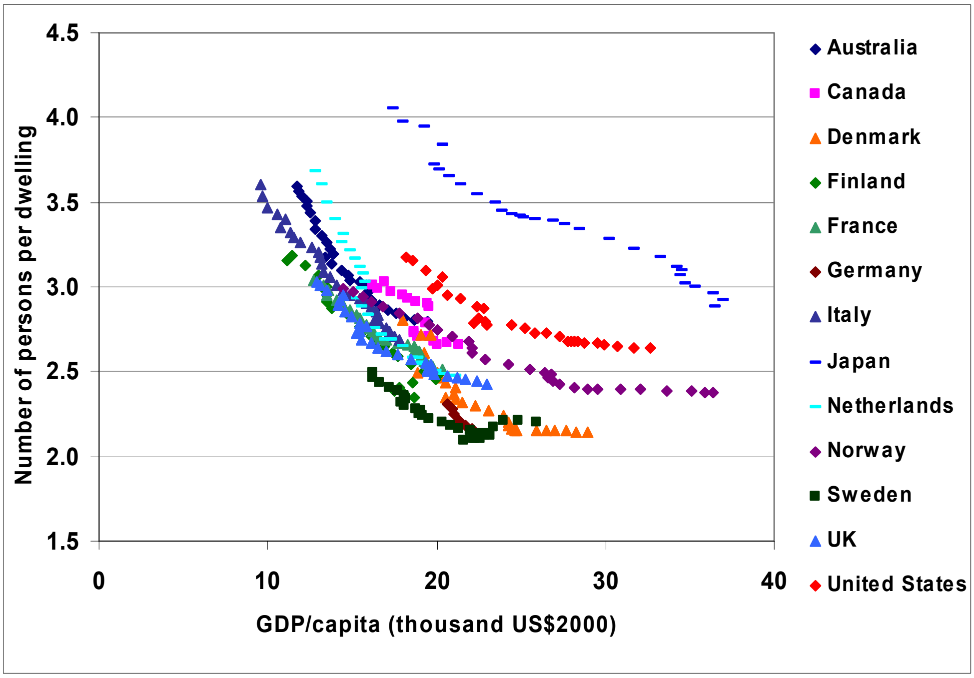

Figure 5.8. Trend in number of people per dwelling in OECD-countries, 1970-2000 (OECD/IEA, 2004b)

At GDP levels below approximately 20,000 US $ (deflated using the base year 2000) the decline in persons per dwelling is relatively high compared to the decrease at GDP levels higher than approximately 20,000 US$2000. Especially Japan experiences a rapid decrease of the number of people that form a family. Before 1970 there lived on average over 4 persons in one household, today it is less than 3 already. The number of persons per household seems to come down to between 2 and 2.5 persons per household according to the trends in Figure 5.8.

Physical indicator: living area per capita

The physical indicator living area per capita actually is a combination of the first two indicators discussed, namely dwelling area and number of persons per dwelling. Figure 5.9 shows the results on how the living area per person varies with increasing GDP per capita. In general, we see that people tend to have larger living spaces with increasing economic welfare. In all member states of the European Union the average number of rooms per capita has grown during the last two decades, and most in Ireland and the Netherlands (Eurostat, 2004). When the living standard of people increases people spend more money on housing. According to (OECD/IEA, 2004) the decreasing number of persons per dwelling had a larger effect on the average dwelling area per capita than the growth in dwelling area.

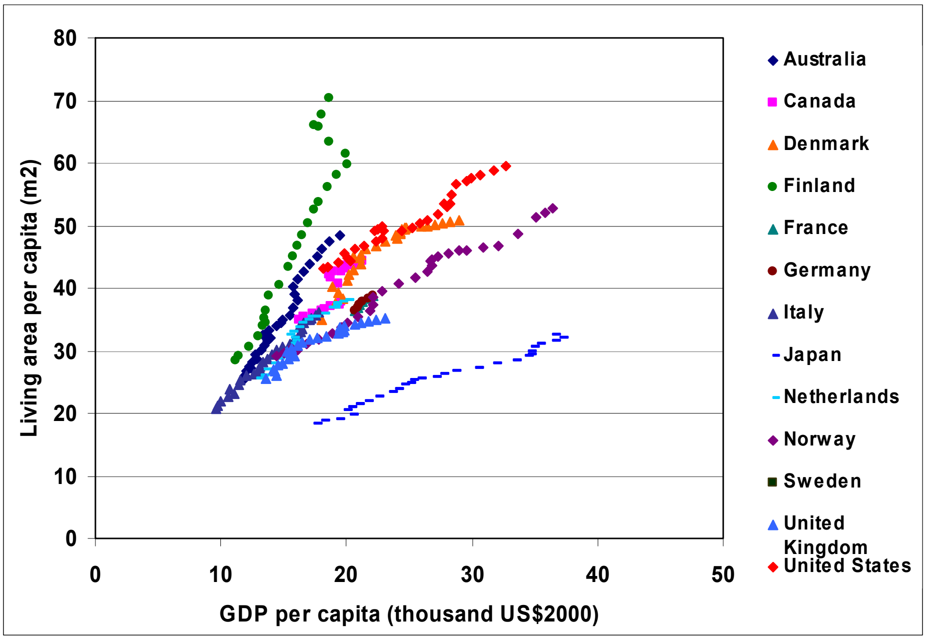

Figure 5.9. Trends in living area per person with GDP per capita in OECD countries, 1970-2000 (OECD/IEA, 2004b)

It is apparent that living space continues to grow with income for all countries according to Figure 5.9. All countries went through significant growth in floor area per capita between 1973 and 1998, often by more than 50% (OECD/IEA, 2004b). Between countries structural differences exist in the amount of dwelling area per capita, due to demographic and cultural factors (living standards for example). Today, people in the United States have almost twice as much space per person than Japanese people, almost 60m^2 and 30m^2 respectively (OECD/IEA, 2004a). Figure 5.10 shows this particular phenomenon that between countries large differences exist in the amount of living area per person. All countries have incomes higher than 5000 US$2002. The two cities Hong Kong and Singapore are characterized as ‘small space’ and have smallest living area per capita, because of high population density and limited available space. The USA falls in the category of ‘large space’ (over 40m^2 per person) and shows the largest floor space per person.

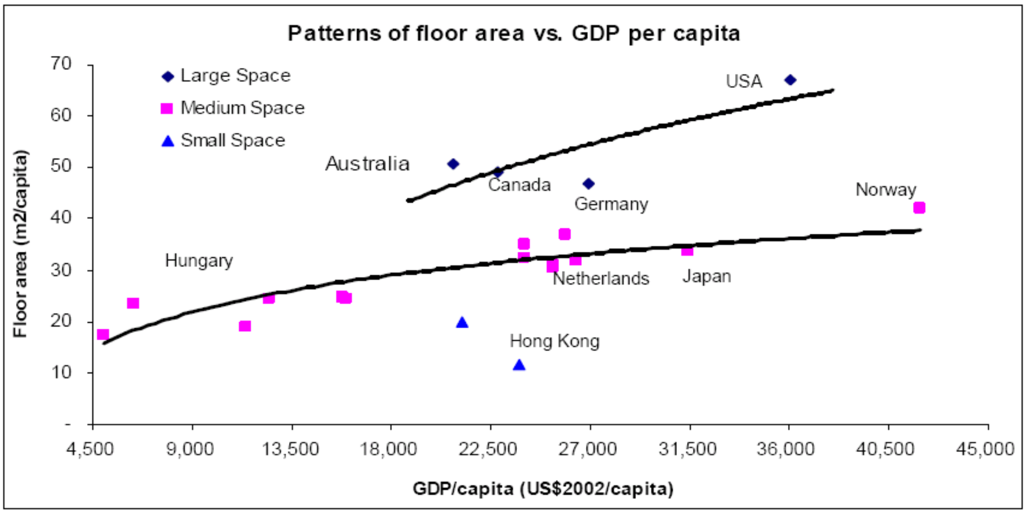

Figure 5.10. Patterns of floor areas for countries, whose GDP/capita are higher than 5000 US$2002, calibrated (Shen, 2006)

The black lines in Figure 5.10 give the impression of a trend towards a saturation level about 40 m^2 per capita for medium space floor area. This strong saturation trend is however not so clear for the countries in Figure 5.9 In some countries the amount of living area per capita is levelling off; the growth in living space is decreasing. A good example is Finland where the growth rate of floor space per capita declines each decade from 0.9% in 1970-1980 to 0.7% in 1980-1990 and 0.3% in 1990-2000 (OECD/IEA, 2004b). This indicates a decoupling trend of income and living area per capita.

Physical indicator: ownership of electric appliances
Our modern lifestyle seems to depend heavily on electric systems and devices. With increasing access to electricity households are expanding their use of electric equipment. General Electric began selling its first domestic appliances late 1880s, it were heat producing devices. Electric fans were patented in 1902, washing machines went on sale in 1907 and the first refrigerators were marketed in 1912 (Smil, 2003). The introduction of electric appliances primarily served the aim to free their users from manual labour. With the introduction of the TV in the ‘70s electric appliances also had an entertaining function to people. Since then the number of electric appliances in households significantly increased in OECD countries. Today, not the entertaining function of appliances is most important, but that many appliances are purchased for providing communication services in homes. Especially multimedia devices like cable TV, ADSL, internet etc. are coming up nowadays.

A general trend in developed countries is that the number and diversity of electric appliances is growing (IEA, 2003). Among these appliances TVs are most widespread in all countries. In 2003, the ownership of TVs was over one per household in all OECD countries; OECD Europe had on average 1.48 TVs per household and OECD North America having the highest ownership with 2.44 TVs per household (IEA, 2003). Ownership of refrigerators and washing machines is now practically universal around the world. A 1997 survey showed that 99,9% of the American households had at least one refrigerator and 92% of the households in single-family houses had a washing machine (EIA, 1999).

Large differences exist in ownership and use of other electric devices like air-conditioning systems for example. In the United States we see high penetration levels of air conditioning (central and room), whereas in the Netherlands this cooling function is of minor importance (Figure 5.12). Of course temperature difference plays a role, but life style probably affects the use of air-conditioning as well. The share of air conditioned houses in the United States, with either central or room air conditioning, doubled from 23% to 47% in the period of 1978 to 1997 (EIA, 2003). Central air conditioning used “all summer” rose from 33% in 1981 to 52% in 1997. Besides, we see a strong trend towards central air conditioning instead of room air-conditioning in the United States. Almost 80% of new homes are equipped with central air conditioning. The use of air conditioners in urban China shows a rapid growth during the past thirty years. Today, over 80% of the households have an air-conditioning system in operation compared to almost no air-conditioning use some thirty years ago[64]. Another interesting trend in urban China is the rise and fall of the video tape recorder. This appliance is pushed out of the market by the DVD player (Figure 5.11).

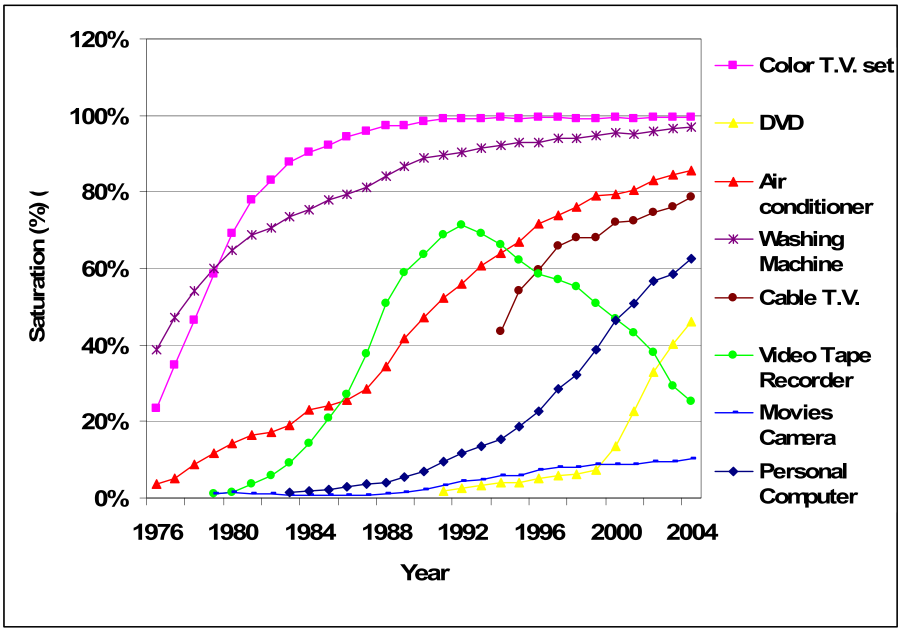

Figure 5.11. Ownership of electric appliances in urban China, 1974-2004 (China National Bureau of Statistics, 2005)

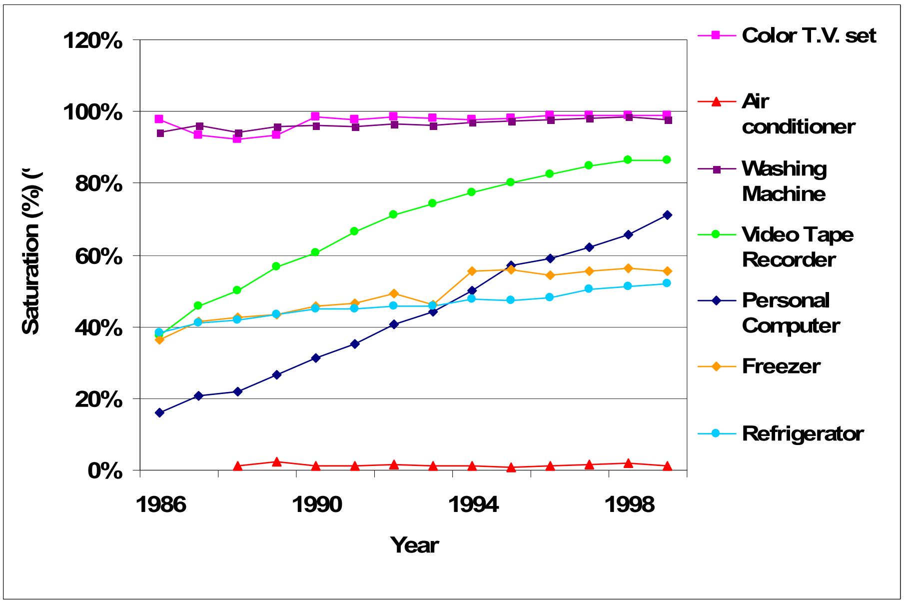

Figure 5.12. Ownership of electric appliances in the Netherlands, 1987-2000 (EnergieNed, 1987-2000)

In urban China some electric devices seem to reach a saturation stage like colour TVs and washing machines. All urban Chinese households own (at least) one colour TV in the year 2004. This figure however does not give information on the possibility of more than one TV per

[64] The Urban Household Survey of China covers all households in urban areas and country towns.

household and its trend over time. According to Smil (2003) the average number of colour TV sets was about 1.1 in 2000.

For most electrical appliances we see a trend of saturation after a period of significant growth. However, studying electric appliances on an individual basis does not make sense, because the feeling for how the aggregated activity of appliance use develops is lost. Farla (2005) developed physical indicators of activity for all economic sectors because they might give us a better understanding of energy intensity developments compared to economic indicators. The use of physical indicators of activity for the household sector is common, because this sector does not generate value added. The physical indicator for electricity consumption in households is based on the diffusion of 13 electric appliances with energy use in a reference year and an estimate for lighting electricity consumption per dwelling. In Farla (2005) this indicator is calculated for the year 1980, 1985, 1990 and 1995. The physical activity indicator increases from 100% in 1980 to 185% in the year 1995, an annual growth rate of about 4% (Farla, 2005). This means that the diffusion of electric appliances in households increased with 85% over a period of 15 years. At the same time the energy intensity of household appliances decreased by 2.7% per year (Farla, 2005). Own calculations showed that the physical production index of electric appliances increased further to 215% in the year 2000. Figure 5.13 shows the relationship of the indexed physical activity indicator with GDP per capita (in US2000$). A significant growth shows of and no trend of saturation is seen. Concluding, there is a re-coupling trend of the physical activity ownership of electric appliances and GDP in households.

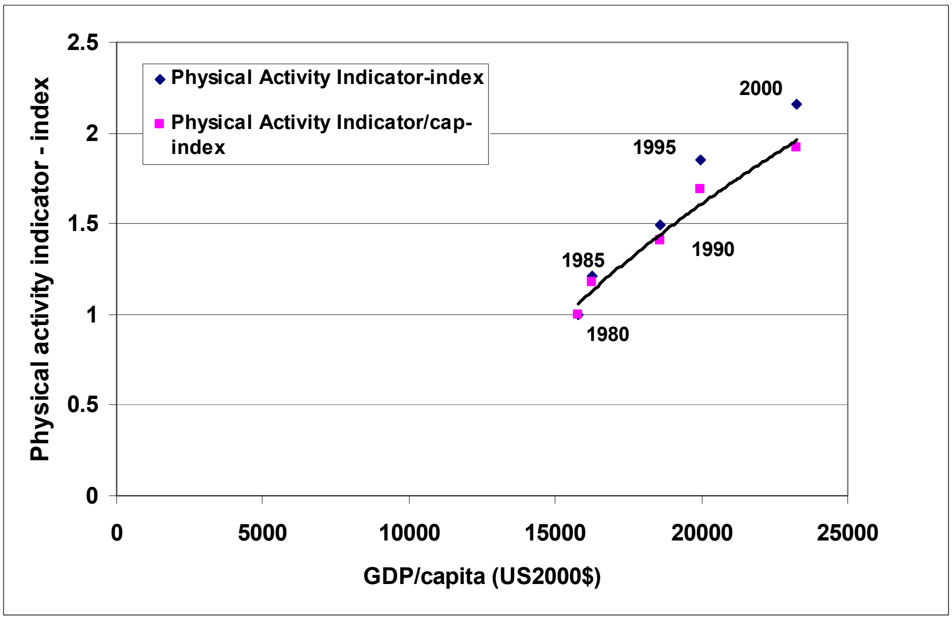

Figure 5.13. Physical activity indicator index for appliances in the Netherlands (Farla, 2000) and own calculations for the year 2000

5.3.2.2 Decompositon Analysis

We analysed several activity trends in the households sector in section 5.3.2.1. and proceed with a further analysis on the driving factors behind energy use. The question comes up to what extent the physical activities discussed are driving factors behind the energy use in this sector. Household energy use is not an outcome of just one variable (for example income or population), but several other factors like the ones we have discussed in the section before might also push the energy use up or down. Several decompositions of energy use are made here to get a better understanding of how these factors actually influence the energy use.

Decomposition of energy use driven by GDP

For the first decomposition the energy use is driven by Gross Domestic Product as is presented by equation (1). In Figure 5.14 the separate impact of each decomposition factor (GDP, m^2/GDP and GJ/m^2) is given for Australia. With 1974 serving as base year, one factor is allowed to vary, while the others remain constant at their 1974 values. Australia is a good example to observe what happens with the energy use in case it would be solely driven by GDP; the energy use would have increased with 550% over a period of (almost) 30 years.

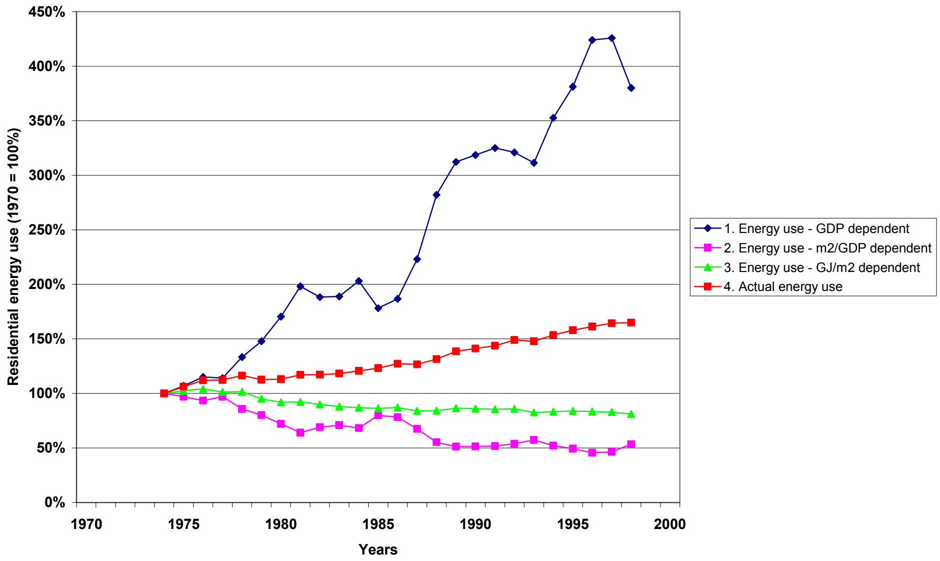

Figure 5.14. Results of decomposition of residential energy use in Australia, 1974-1999 (own calculations)

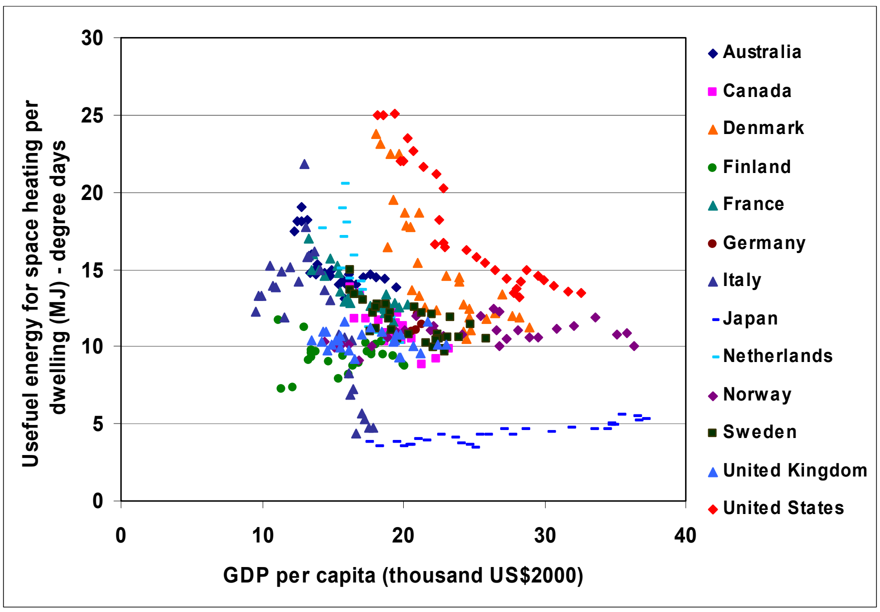

Figure 5.15. Trends in energy use for space heating, 1970-2000 (OECD/IEA, 2004b)

The structure component (m^2 per GDP) is not very useful here, since the living area per GDP does not indicate how important the indicator living area per capita is in predicting energy use. The energy intensity factor which measures the energy use per m^2, declines with economic growth. Further disaggregating into end uses of residential energy requires a breakdown into energy intensities per end use. For most countries the energy intensity of space heating changed most and therefore has the most significant impact on the level of energy use (Figure 5.15).

An opposite trend is observed for electricity use for electric home appliances (Figure 5.16) where we see the electricity use is growing at a fast pace. Decreasing energy use per squared meter is mainly caused by a lower energy use for space heating, although the demand for space heating has developed quite different among countries according to Figure 5.15. The amount of heat required per squared meter fell in most countries, but the rates of decline vary significantly.

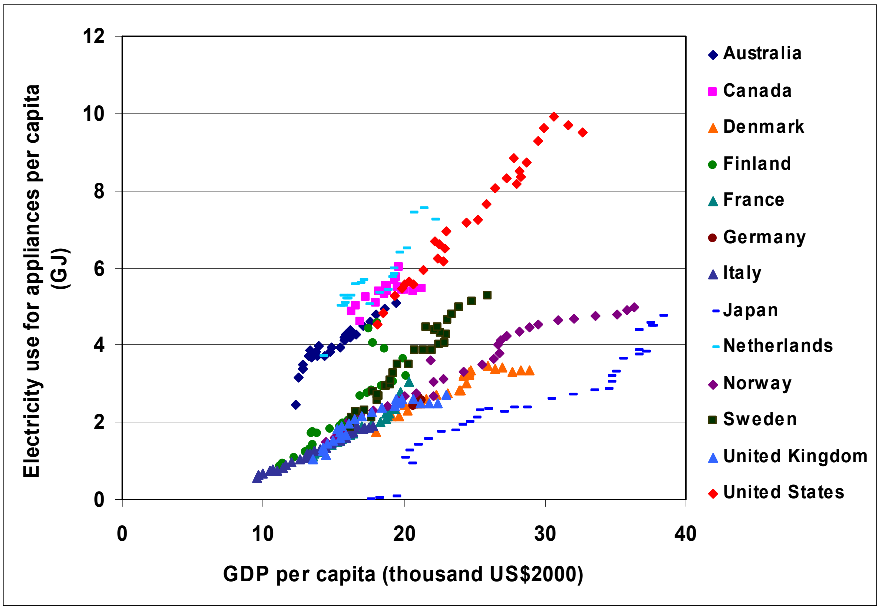

Figure 5.16. Trends in electricity use for home electric appliances, 1970-2000 (OECD/IEA, 2004b)

Figure 5.17 shows the outcomes of a more detailed decomposition represented by equation (2). in section 5.2.3. The structure component m^2/GDP is unravelled in two components; m^2/capita and the inverse of GDP per capita. In the physical activity analysis it has already been shown that the living area per capita tends to increase with increasing wealth (Figure 5.9). Here we see that the energy use of Australian households increases with 60% in the period 1974-1999 if it would have been dependent on the growth of living area per capita alone. Herewith the assumption that living area per capita is an important indicator for energy use is supported.

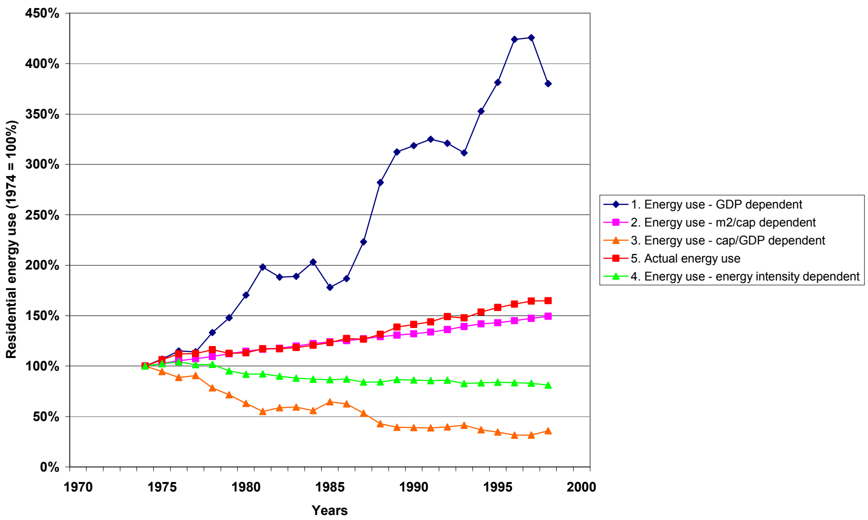

Figure 5.17. Results of decomposition of residential energy use in Australia, 1974-1999 (own calculations)

Decomposition of energy use driven by population

The decomposition of energy use driven by population gives us some other views on the change of energy use as a function of GDP. Instead of GDP we use population for our decomposition of residential energy use in Australia. We see a gradual growth of the structure components dwelling per capita and squared meters per dwelling. With increasing dwelling per capita the trend of smaller average family sizes is reflected. This trend is observed in most OECD countries. Explanation for this could be that family life is changing over the years with fewer children per couple, more divorces, and more one parent families. In the Netherlands the energy intensity showed an increasing trend up to 1980, thereafter the energy use per squared meter has been declining due to insulation and more efficient appliances.

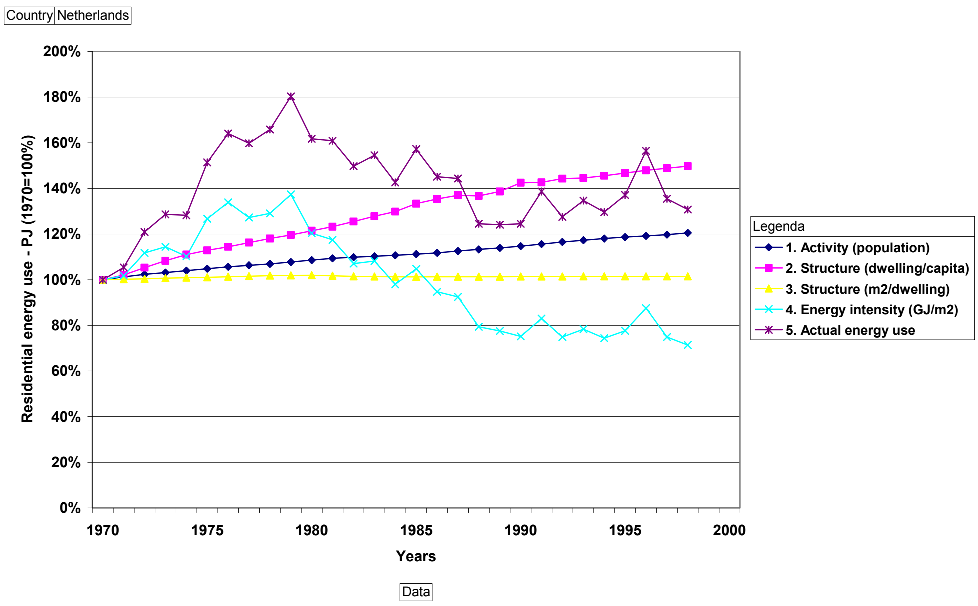

Figure 5.18. Decomposition of residential energy use in the Netherlands, 1970-2000 (own calculations)

5.3.2.3 Summary of main findings

With above analyses some drivers for energy use in households can be identified. The development of physical activities in the residential sector gives some important points of departure for addressing the relationship between physical and monetary growth.

The growth in dwelling area is levelling off after a long period of continuous growth. With potentially slowing or even declining populations a stabilisation of living area is an important parameter in future energy demand projections. Despite this decline in growth rate of dwelling area, the average living area per capita is still increasing. The underlying reason for this development is that the number of persons per dwelling is rapidly declining due to changing lifestyles and consumption patterns.

The average living area per capita is still increasing, although the growth rate is declining.
The number of persons per dwelling is rapidly declining. Families are becoming smaller and less traditional as fertility rates fall and more persons live alone. Although this trend is ongoing, the number of persons per household seems to reach stabilization at a level of 2 to 2.5 persons. Over time we see a decrease in number of persons per household with the size of houses almost unchanged.

The number of appliances per capita is increasing rapidly. Some appliances such as refrigerators and washing machines have (almost) reached saturation. For other home electric appliances the saturation level is not clear at the moment. The penetration of colour TVs for example seems not to stop at one per household, nor at two per household. Although some electric appliances reach saturation levels the electricity use for electric home appliances increases, since the number of electric appliances per household is still increasing.

The decomposition analysis shows that the activity components GDP and population both have a strong positive effect on energy use. The growth of population and GDP is outpacing the growth of energy use significantly. There exist strong evidence in literature that GDP and energy use and population and energy use will decouple with increasing GDP and prove to have not a very strong link. We therefore hypothesized that some other factors might be important in forecasting future energy use among which are physical activity indicators (living area per capita, appliances per capita). The physical indicator living area per capita, which is included in the decomposition, shows a positive effect on residential energy use. This indicator shows re-coupling with GDP.

5.3.3 New energy functions in households

The development of new possibilities based on electronic devices is still underway. Smart home technology is the integration of technologies and services with the purpose of automating them and obtaining increased safety and security, comfort, communication and technical management. Some examples are:

- Entrance button: with one push on a button, heating goes to programmed level, lighting switches on, television switches to favourable channel etc..
- Leaving button: with one push on a button, all lighting and electric appliances (except refrigerators and freezers, indoor climate controls) switch off.
- Central server through which all electronic multimedia devices in various rooms can communicate with each other.

These intelligent technologies can be implemented to save energy, for instance by accurate tuning of heating, cooling and lighting systems. However, based on historic trends, it can not be expected that smart home technologies will conserve energy on the short term, because of the introduction of new and more appliances in households.

A LOOK INTO THE FUTURE

Nowadays, it is already technical possible to realize buildings with a very low energy requirement. For instance, in so called ‘passive houses’ – buildings with a comfortable interior climate that can be maintained without active heating and cooling systems – the annual heating requirement is less than 15 kWh/m^2. The annual heat demand in a new house is on average two to four times higher (40 $kWh/m^2/yr$). Furthermore the primary energy consumption of living area of a European passive house may not exceed 120 kWh/m^2 per annum for heating, hot water and household electricity. This is considerably less than the energy consumption of an average European house (220 kWh/m^2 per annum). Additional energy requirements apart from space heating may be completely covered using renewable energy sources (e.g. solar, geothermal, wind and biomass). The final energy consumed by a passive house is therefore less than a quarter of the energy consumed by the average new construction that complies with applicable national energy regulations.

Although there are many initiatives for buildings with a self-supporting energy supply, the implementation rate has been low. It only covers a very small segment of the building stock (5000 passive houses are realised until now) (BouwIQ, 2006).

As already stated in the previous section 5.3.2.1, the energy consumption of electric appliances is far from saturation yet. Automation and especially energy management systems offer good opportunities for structural energy conservation. In addition, breakthrough technologies, such as LED for lighting, can be expected. However, it is not clear to what extent these opportunities will be seized.

According to Vringer (2005) it appears that the energy requirement for dwellings is the only domain that is expected to decrease in absolute terms in 2030. The required primary energy is expected to increase by 30% (European Coordination Scenario) and 60% (Global Competition Scenario) per capita from 1995 to 2030. These figures represent an annual growth of 0.8% and 1.3% per capita, respectively. The relative shares of the consumption domains of food, dwelling and clothing decrease, while the relative shares of the domains households, holidays, indoor leisure and outdoor leisure increase. This means that the indirect energy requirement becomes more important, with its share increasing from about one-half in 1995 to two-thirds in 2030 (see also section 5.5.2)

Text box *1: A look into the future*

5.4 Services

The increasing complexity of modern economies drives service sector activity and the resulting energy use. The need for services (health, education, financial, government) increases as populations increase. The degree to which these additional needs are met depends in large measure on economic resources, whether from domestic or foreign sources, and economic growth. Economic growth also determines the degree to which additional commercial sector activities are offered and utilized. Higher levels of economic activity and disposable income lead to increased demand for hotels and restaurants to meet business and leisure requirements; for office and retail space to house and service new and expanding businesses; and for cultural and leisure space such as theatres, galleries, and arenas (EIA, 2005).

5.4.1 Time series energy use

The service sector consists of businesses, institutions and organizations that provide services. The sector encompasses many different types of buildings and a wide range of activities and energy-related services. Most commercial energy use occurs in buildings or structures, supplying services such as space heating, water heating, lighting, cooking, and cooling.

Figure 5.19 shows the development of services energy use for the world and OECD-regions and EU-15. On a global scale, the energy use in the service sector increased with 76% over the period 1971-2003 (IEA, 2005). In the OECD-region the development of services energy use follows more or less the same pattern as services energy use on a global scale, although growth is more moderate, namely 68% (IEA, 2005). Developing countries or economies in transition experience the largest growth in energy use, their services energy use grows much faster compared to global or OECD growth rates. The sharp decline of services energy use in the year 1992 is caused by a changed methodology of the IEA Energy Balances database.

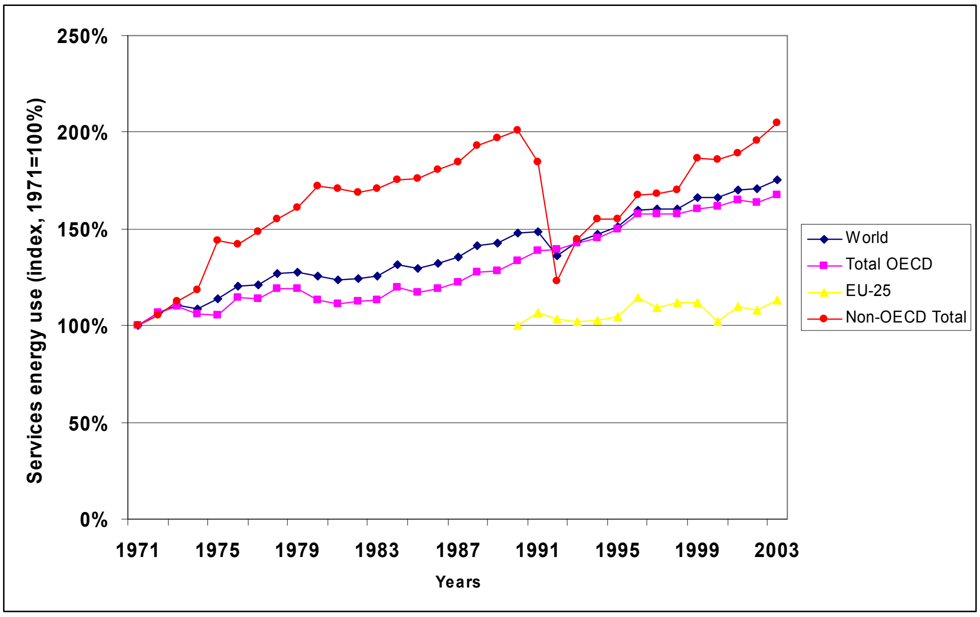

Figure 5.19. Development of service sector energy use over the period 1971-2003 (IEA, 2005)

The services energy use in the IEA member countries studied in this assessment shows a gradual increase. In 1970, large differences existed in the level of energy use between countries and this is still the case in the year 2000.

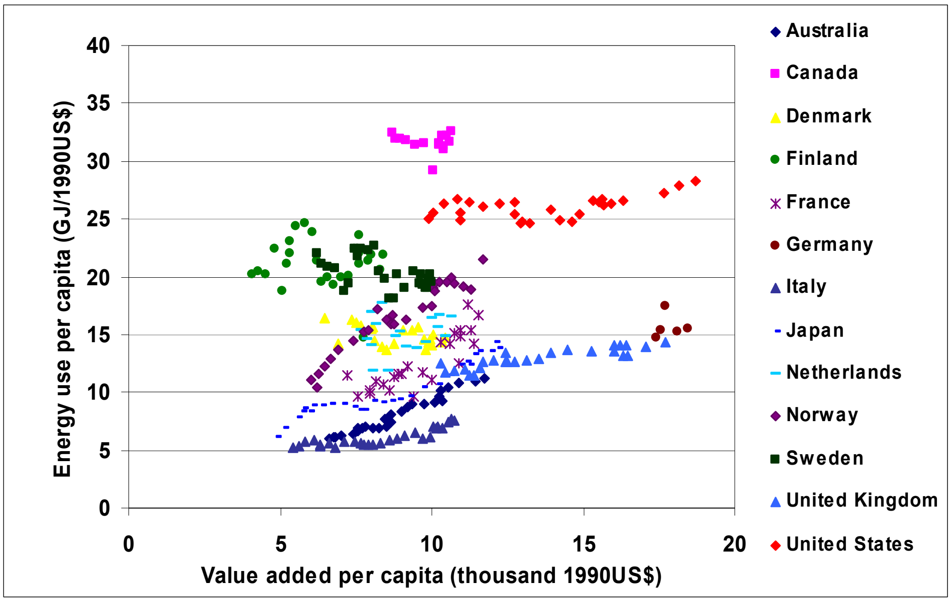

Figure 5.20. Service sector per capita energy use as a function of service sector value added per capita 1970-1999 (OECD/IEA, 2004b)

5.4.2 Underlying mechanisms

The increasing complexity of modern economies drives service sector activity and the resulting energy use. The need for services (health, education, financial, government) increases as the number of people that want these services increases. The degree to which these additional needs are met depends in large measure on economic resources - whether from domestic or foreign sources - and economic growth (International Energy Outlook, 2005).

Economic growth also determines the degree to which additional commercial sector activities are offered and utilized. Higher levels of economic activity and disposable income lead to increased demand for hotels and restaurants to meet business and leisure requirements; for office and retail space to house and service new and expanding businesses; and for cultural and leisure space such as theatres, galleries, and arenas.

Also for this sector we expect that other factors than population and economic growth are important in determining services energy use. The number of employees is often said to be the fundamental activity driver for the level of energy use in the service sector and all activities at sector level are influenced by trends in employee growth.

These other key activity drivers in the service sector are derived from existing literature. Next to the overall population level, the size of the services labour force and commercial floor space influence the actual energy use (Price et al., 1998). The demand for commercial services increases along with the number of people (population) that wants these services. In the service sector more demographic factors are important. Development of the following physical activities in the service sector is discussed in next section:

- number of employees working in the service sector
- commercial floor space per employee (m^2 per employee)
- use of office equipment (number of computers and photocopiers per employee)

5.4.2.1 Physical indicators

Physical indicator: number of employees working in the service sector
The database of the OECD/IEA (2004) that is used for this analysis differentiates between the following types of services within the service sector:
- transport, storage and communications,
- government services,
- finance, insurance, real estate and business services
- wholesale, retail, hotels and restaurants.

The structure of the service sector, which is defined by the contributions of each type of service, differs from country to country. In absolute terms the number of employees in each of the sub sectors and in the service sector as a whole rose in all countries. In relative terms the contribution of each sub sector to the total services workforce does not significantly change over time.

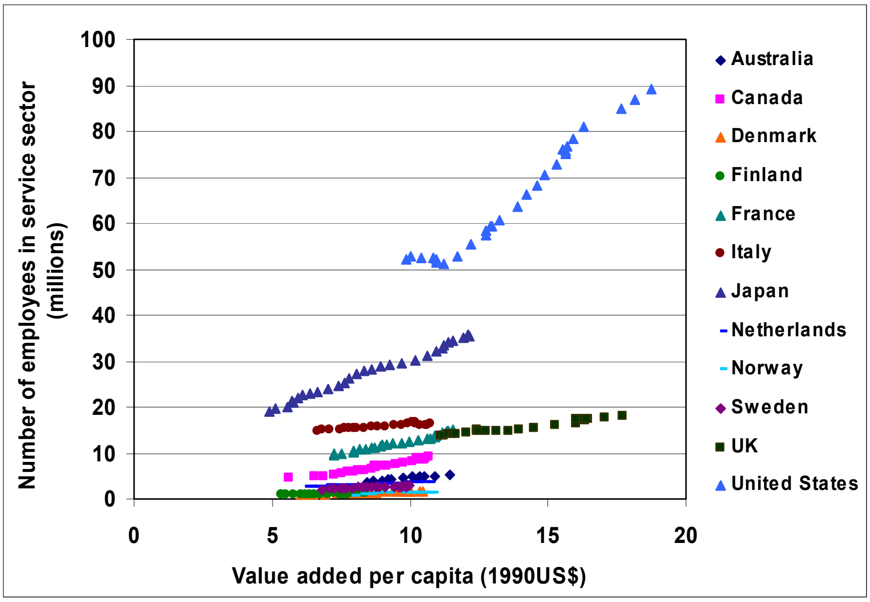

Figure 5.21. Number of employees in the service sector as a function of value added per capita (OECD/IEA, 2004b)

Physical indicator: floor area per employee
The size of buildings and the amount of floor space largely depends on the way buildings are constructed in a specific country. It is assumed that people need more office space when commercial services become more important in an economy. First we take a look at two time series (Figure 5.22 and Figure 5.23) that depict the development of floor area per employee and floor area per added value of the service sector.

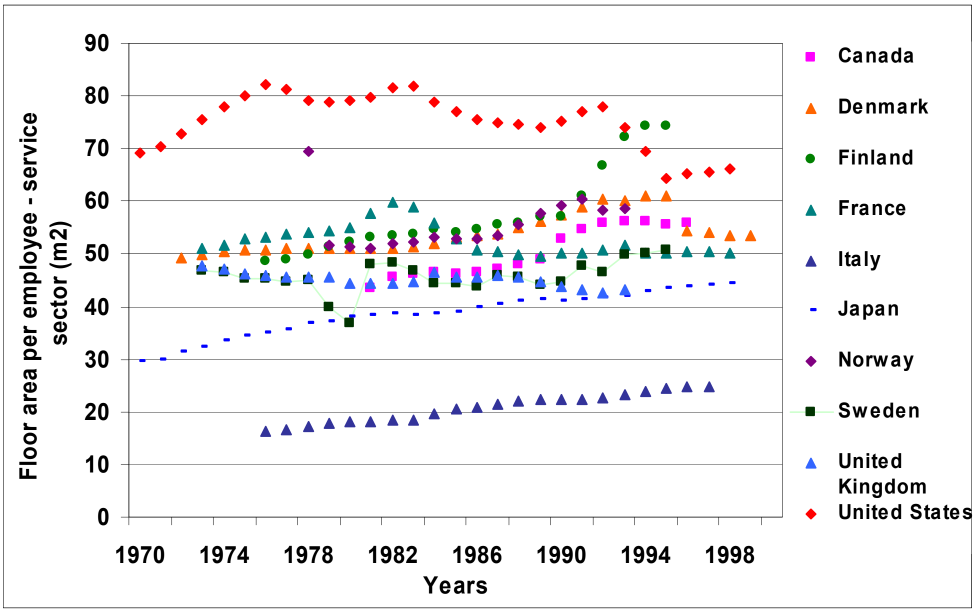

Figure 5.22. Floor area per employee in OECD-countries, 1970-2000 (OECD/IEA, 2004b)

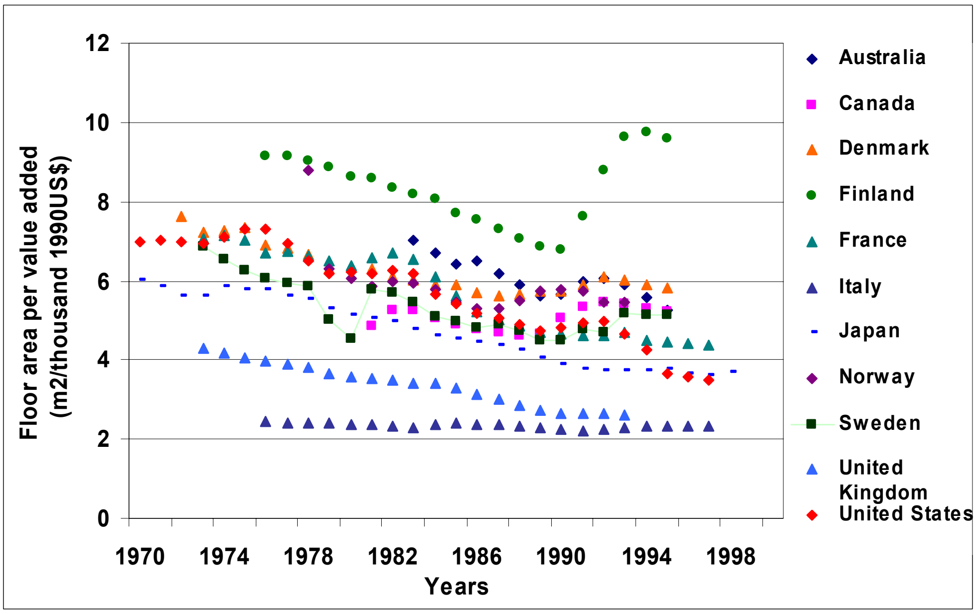

Figure 5.23. Time series of floor area per value added in OECD-countries, 1970-2000 (OECD/IEA, 2004b)

The amount of office space per employee (in m^2) is relatively stable over time, except for Italy and Japan, where the amount of office space per person is slightly increasing. From Figure 5.23 we see that absolute floor area per value added decreases over time. The development of office space per value added in all European countries together (for which we have enough data) shows a decline of 0.8% per year over the period 1973-1993. This aggregated figure represents office space development in Denmark, Finland, France, Italy, Norway, Sweden and the United Kingdom together. Although this is not a very commonly used indicator it shows that the output of the service sector more strongly increases than the does the squared meters of office space. Italy and the United Kingdom use least office space to generate a unit of service sector value added.

The time series on energy use per value added over time give more or less the same picture as floor area per value added over time. We see a decoupling trend of energy use and value added, the growth rate of energy use in the service sector is less than the growth rate of value added. In absolute figures the energy use per value added is declining at a stronger rate in countries that start at a high level of energy use per value added in 1970 (see Sweden and Finland). To compare, in relative figures the decline in energy per value added is about 1.5% for countries like Italy and United Kingdom and about 2.5% for countries like Sweden and Finland.

Although no clear trend can be observed from the different countries studied, it is helpful to use physical activity indicators like floor area in forecasting exercises as an important step towards improving scenario development.

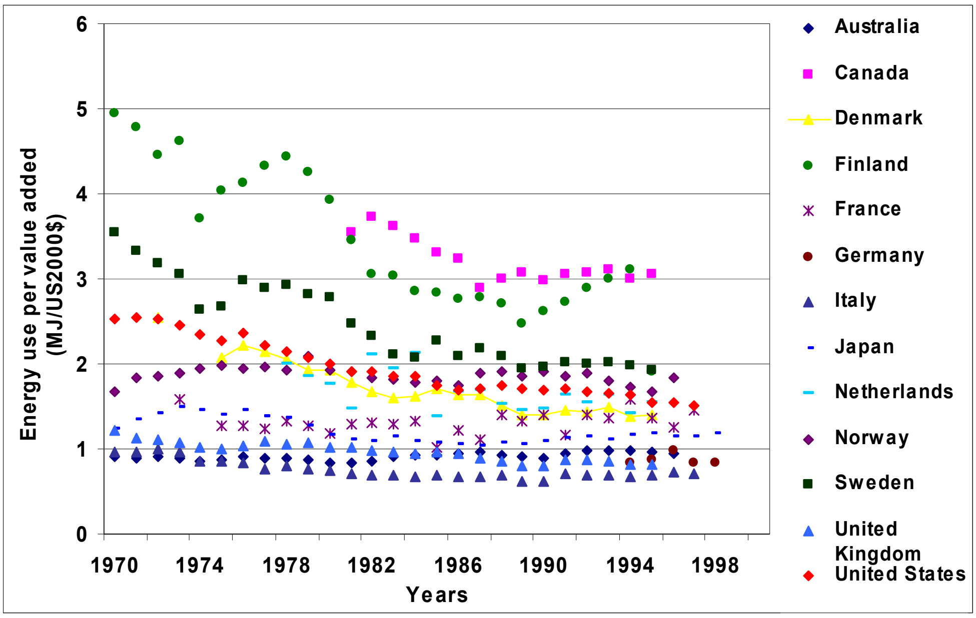

Figure 5.24. Time series of energy use per value added in IEA countries, 1970-2000 (OECD/IEA, 2004b)

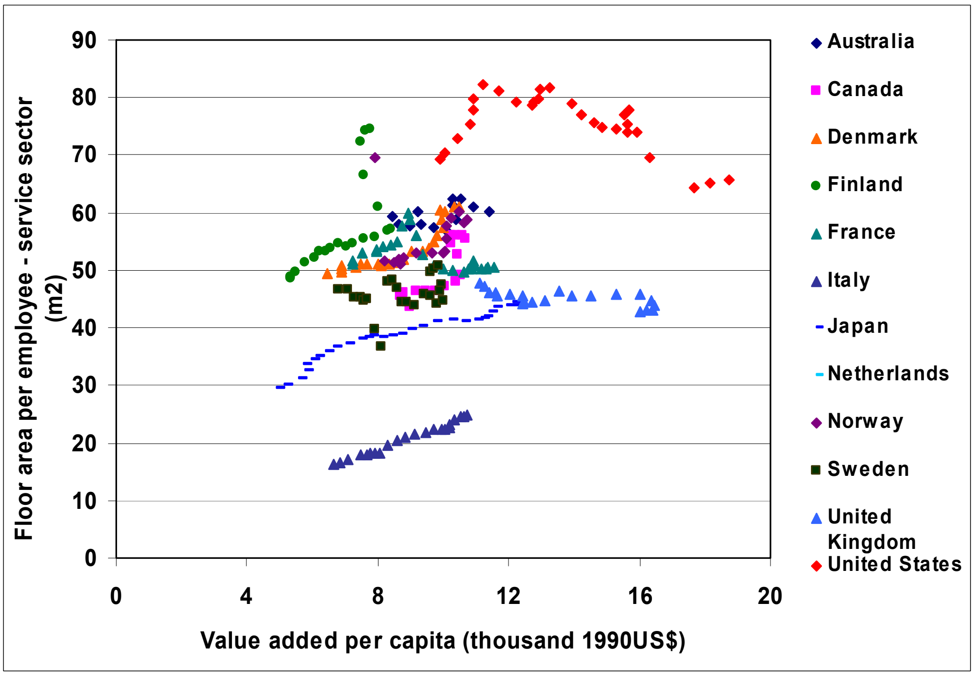

Figure 5.25. Floor area per capita as a function of value added per capita in the service sector, 1970-1999 (OECD/IEA, 2004b)

We combine Figure 5.22 and Figure 5.23 to Figure 5.25, which shows the amount of office space per capita versus increasing value added of the service sector. For some countries, like Italy and Japan we clearly see that the floor area per employee increases when economic output of the service sector increases too. For most other countries it is not possible to state how average floor area per employee develops, because no smooth time series result.

Physical indicator: office equipment
The use of office equipment has increased significantly in last ten to fifteen years. Although no information on numbers of all types of office equipment could be found, from the Commercial Buildings Energy Consumption Survey we derived data on the number of computers and photocopiers in US offices[65]. Since 1992, there has been a steady increase in the number of computers in commercial buildings (Figure 5.26). Both the ratio of computers per employee and computers per square feet increased (EIA, 1992-1999). Growth slowed down for most building types in the period 1995-1999. The annual growth rate was 7% for the period 1992-1995 and slowed down to 5.5% in the four years afterwards.

The number of computers in office buildings shows relatively small growth rates, but initially (in 1992) the number of computers was higher in office buildings than in other buildings (Figure 4.8). In 1992, there were 60 computers per 100 employees; this figure increased to 80 and 95 in 1995 and 1999 respectively (EIA, 1992-1999). Commercial offices and education buildings adopted this technology first.

In the report on computers and computer terminals in commercial buildings of 1995 it was speculated that one computer per person might be a natural saturation point for the computer market. For most commercial buildings this hypothesis still holds, except for education buildings. The use of computers in educational buildings increased to 1335 per 100 employees. This has to do with the large number of students using the computers in educational buildings while not regarded as employees of these buildings. The category 'others' also shows an extremely high growth (462%) of computers in the period 1995-1999. This development is mainly caused by data centres included in this category.

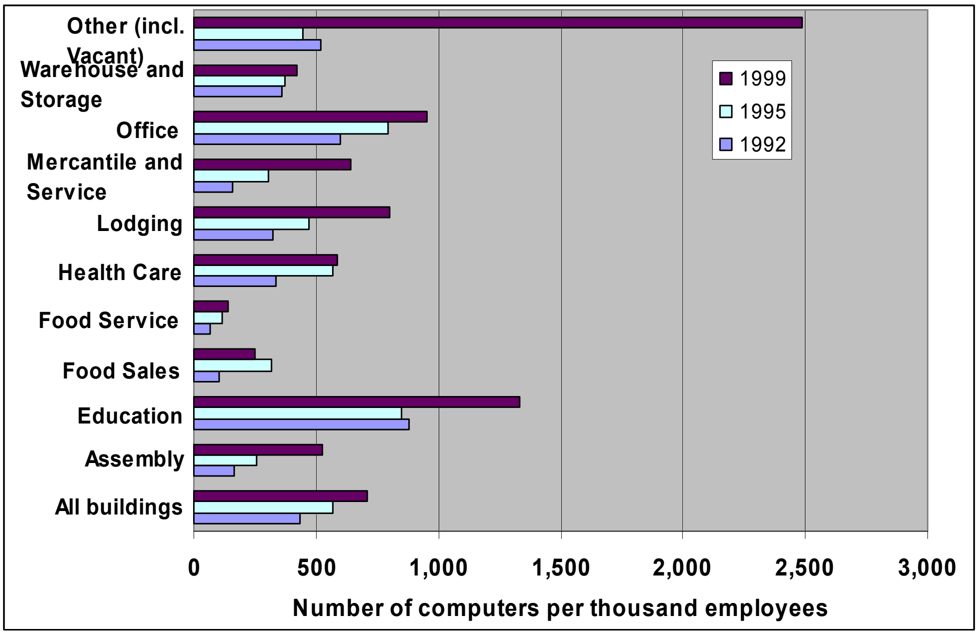

Figure 5.26. Number of computers per thousand employees in commercial buildings in USA (EIA, 1992/1995/1999)

[65] Once every four years these surveys are conducted, with the latest version publicly available of 1999.

Photocopiers show a different trend compared to computers, because the saturation level of photocopiers is lower. In 1999, about 40% of all commercial buildings had at least one photocopier. Of those buildings, 24 percent had only one copier, while 76% had two or more. On average there were 60 photocopiers per 1000 employees, or 1 photocopier per 17 employees (EIA, 1999). This type of appliances has a different use, while not every employee needs his own photocopier. The number of photocopiers per employee is highest in small companies, while at least one photocopier is needed per office.

Although we have limited information on the penetration of office equipment, based on the penetration of computers and photocopiers, we expect that the number of office appliances is still increasing. Saturation will occur depending on the type of equipment used. Computers will probably have a different saturation level compared to photocopiers for example.

5.4.3 Decomposition analysis

Like for the residential sector we also make a decomposition analysis for the service sector. The effect of several factors on the energy use is studied for each factor separately and is indexed according to the level of energy use in the year 1970. Next to the physical activities addressed in previous paragraph other components make of the level of energy use in the service sector. According to equation (4) we distinguish between activity effect, structure effect and energy intensity effect:
- Activity (service sector value added)
- Structure (employee per value added)
- Structure (floor area per employee)
- Energy intensity (MJ per floor area)

Although the indicators are quite aggregated it gives some understanding on how the separated components do affect energy use. Figure 5.27 and Figure 5.28 present the decomposition of services energy use for Australia and Finland to show that similar decompositions do not always lead to similar results. For Australia the actual energy use increases at more or less the same pace as the activity component (value added). In this case the value added of the service sector proves to be a good indicator for the energy use of this sector. In Finland, the service sector value added increases much more than the actual energy use in the period 1976-1994. The energy intensity (MJ/m^2) decreases, while the floor area per employee increases significantly.

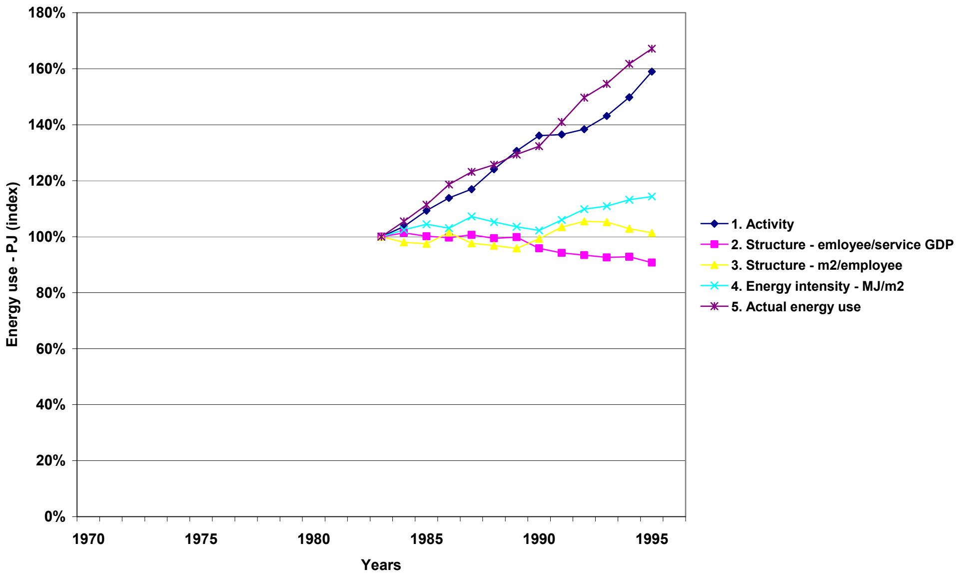

Figure 5.27. Decomposition of energy use in the Australian service sector, 1983-1995 (OECD/IEA, 2004b)

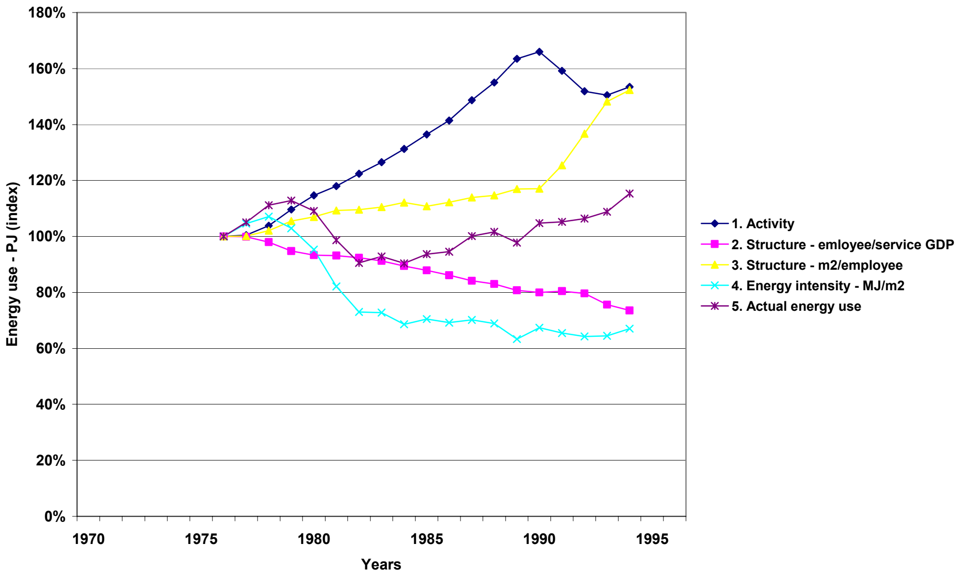

Figure 5.28. Decomposition of energy use in the Finnish service sector, 1983-1995 (OECD/IEA, 2004)

5.4.4 Summary of main findings

Analyzing several physical activities that occur in the service sector we identified the following trends:

- The number of employees in the service sector is still increasing. Analysis of the data gives no indication of saturation of the number of employees working in the service sector (as function of the total workforce).
- For most countries no clear trend can be distinguished regarding the development of floor area per employee in relation to the value added of the service sector. Only in Italy and Japan a relationship between floor area per employee and value added has been observed. The absolute floor space per value added is gradually decreasing. The observed trend suggests a decoupling trend between floor space and value added.
- Office equipment did not reach a saturation point yet. Equipment for communication purposes becomes evermore important resulting in increasing penetration of this type of equipment.

The decomposition analysis shows that large specific country differences exist in what factors have largest influences on the actual energy requirements. In general it shows that GDP is outpacing the energy requirements in this sector and that effect of structure components such as employee/value added and m^2/employee vary on a country-by-country basis.

5.5 Interaction with other sectors

5.5.1 Inventory of influences

The influences of other sectors on the household and services sector are in this project assessed by using already undertaken input-output analyses. Input-output analysis is a top-down economic technique that uses sectoral monetary transactions data to account for the complex interdependencies of industries in modern economies. Subsequently, it can be applied to environmental effects (water, energy, resources, and pollutants). The underlying question for energy requirements of a sector is: if a sector consumes/produces something, how much primary energy is needed to have this something consumed/produced, including all upstream activities. The result is generally expressed as the energy intensity (or cumulative intensity) of the output of this sector, i.e. the primary energy requirement per unit of monetary output (Utrecht University, 2004).

5.5.1.1 Households

A number of input-output analyses linking energy requirements and household expenditure data for entire countries have been carried out since the early 1970s. The main results of these studies according to Munksgaard et al. (2005) were that:

- A substantial part of a household's energy requirements is constituted by non-energy commodities.
- Total energy requirements increase less than proportionally with income, which actually means that total energy intensity decreases with income. Regarding the initial research question this means that there is a decoupling trend of energy requirements and income.
- Per capita energy requirements decrease with the number of household members
- Urban households exhibit lower energy intensity than rural households.

Some results of the studies are discussed in more detail. First, we separately looked at the energy requirements and expenditures of households. The results of several countries are shown in Figure 5.29 and Figure 5.30. The energy requirement is expressed in GJ per average household per year, the expenditure in US dollars per year and average household.

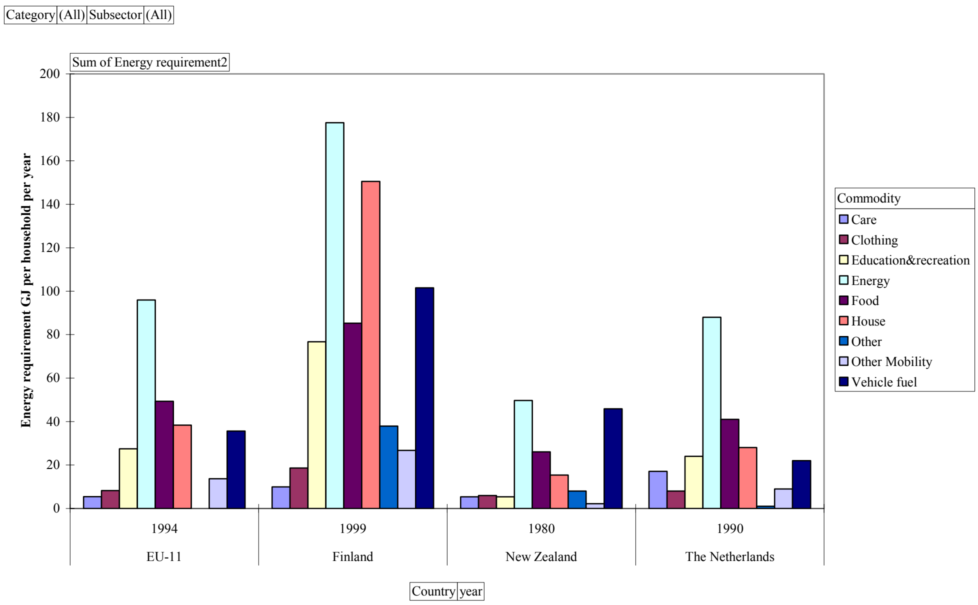

Figure 5.29. Energy requirements (GJ/household/yr) breakdown over various commodities (Vringer, 2005, Reinders et al., 2003, Mäenpää, 2005, Peet et al, 1985)

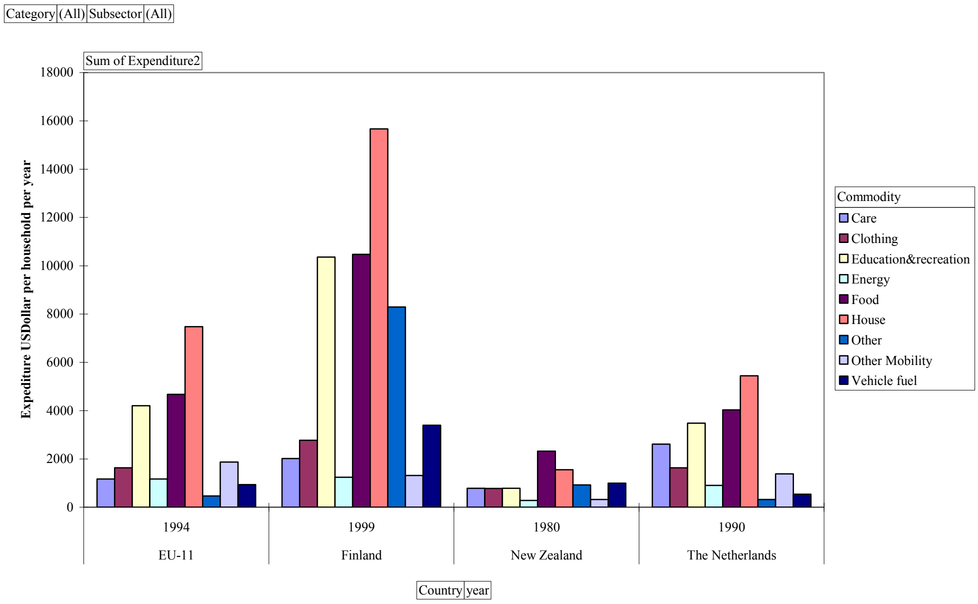

Figure 5.30. Expenditures (USdollar/household/yr) breakdown over various commodities (Vringer, 2005, Reinders et al., 2003, Mäenpää, 2005, Peet et al, 1985)

The main expenditure of an average household in developed countries concerns housing (rent, mortgage, maintenance, furniture). Also household money goes for a large extent to food, education and recreation. In contrast the expenditure for energy is low.

Secondly, within the input-output analysis the energy intensities of the various commodities are calculated. Several characteristic values in developed countries regarding energy intensities are presented in Table 5.1. Energy and vehicle fuel have, corresponding with their nature high energy intensities. The energy intensity of the human needs as food and house is somewhat higher than the energy intensity of the other commodities.

Table 5.1 Characteristic Energy intensities of various commodities in developed countries Sources: (Vringer, 2005), (Reinders et al., 2003),(Mäenpää, 2005), (Peet et al, 1985), (Lenzen, 1998)

	Energy intensity (MJ/USDollar)
Energy (heating, hot water electricity)	80-190
Vehicle fuel	30-50
Care	5-15
Clothing	5-10
Food	10-25
House	10-25
Education and recreation	5-20
Other mobility	5-20
Other	5-15

Finally, the calculated energy intensities hold information on the energy embodied in various commodities consumed in households. Figure 5.31 shows a comparison of breakdown of household energy requirements into nine commonly used categories of human needs (representing also other sectors).

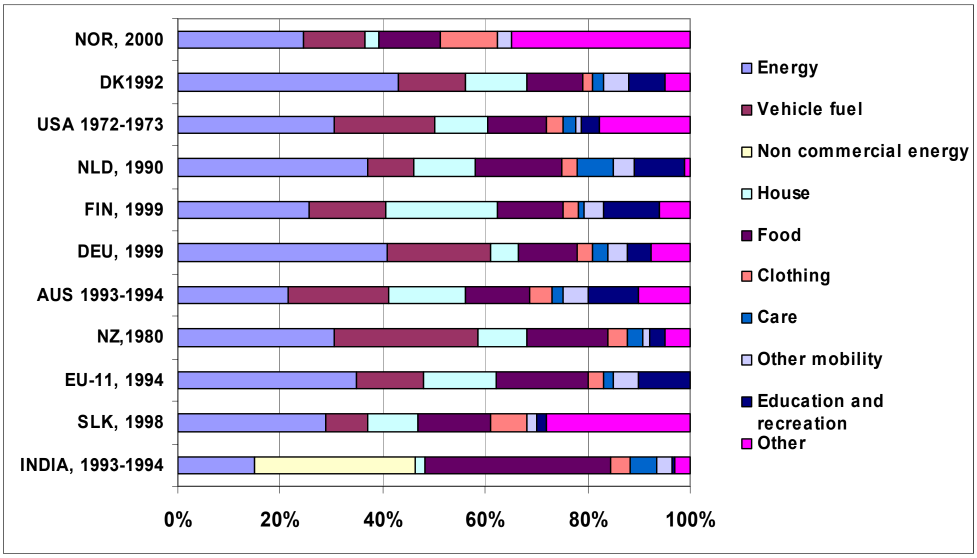

Figure 5.31. International comparison of household energy breakdowns (commodity breakdowns as percentage of the country total)

Sources: The Netherlands, NLD, 1990: (Vringer, 2005)
11 European Member States, EU-11, 1994 (Reinders et al., 2003)
Germany, DEU, 1999: (Federal Statistical Office of Germany, 1999)
Finland, FIN, 1999: (Mäenpää, 2005)
New Zealand, NZ, 1980: (Peet et al, 1985)
United States, USA 1972-1973: (Herendeen et al., 1981)
Denmark, DK, 1992: (Munksgaard and Petersen, 2001)[66]
Australia, AUS 1993-1994: (Lenzen, 1998)
India, India 1993-1994: (Pachauri, 2004)
Slovakia, SLK, 1998: (Korytarova and Hubacek, 2005)[67]
Norway, NOR, 2000: (Peters and Hertwich, 2004)[68]

The data were extracted from the references listed under Figure 5.31. It appears that the portion of direct energy requirements (vehicle fuel and energy in households (heating and electricity)) is around 50% in European countries. It is only 30% in Australia due to a warmer climate. Mobility makes up a larger part of the household energy requirements in Australia, New Zealand and the United States, because these countries are larger and/or less densely populated. The energy requirement for food consumption is considerable in all studied countries, i.e. around 15% of the energy requirement in households of developed countries and about 35% in India. In developed countries the energy requirements for housing, including furnishing, recreation and culture, are of significant importance. The commodities clothing, medical and personal care and other mobility (e.g. public transport) have a medium interlinkage with the household sector.

Non-commercial energy sources, largely fuel wood and other biomass, are still the main source of direct energy use in many developing countries. In India even today more than 80% of direct energy consumed in villages is from non-commercial sources. Urban households with a high income, however, have a different consumption pattern. Their direct energy comes mainly from commercial energy sources (Pachauri, 2004).

66 division made on CO_2 emissions

67 division made on CO_2 emissions and not all categories correspond with commodities, resulting in a large category others

68 division made on CO_2 emissions and not all categories correspond with commodities, resulting in a large category 'others'

5.5.1.2 Services sector

First of all, input-output energy analyses of the services sector are scarce. The outcome of Park and Chan, (1989) indicates that the intersectoral relationships between the manufacturing sector and services sector generally characterize asymmetrical dependence. Namely, the service activities tend to depend on the manufacturing sector as a source of inputs to a far greater extent than vice versa. The study of Gowdy and Miller (1987) takes a deeper looks into the effect of the energy price shock of 1973-1974. They find a substantial decline in energy intensity between 1972 and 1977 in the service sector. This is in contrast with the electricity use, which increased by about 9% in the same period.

To get an indication of interlinkages of the service sector with other sectors the monetary input-output tables of three countries i.e. Germany, USA and China are studied (OECD, 2001). The results are graphically presented in Figure 5.32, Figure 5.33 and Figure 5.34.

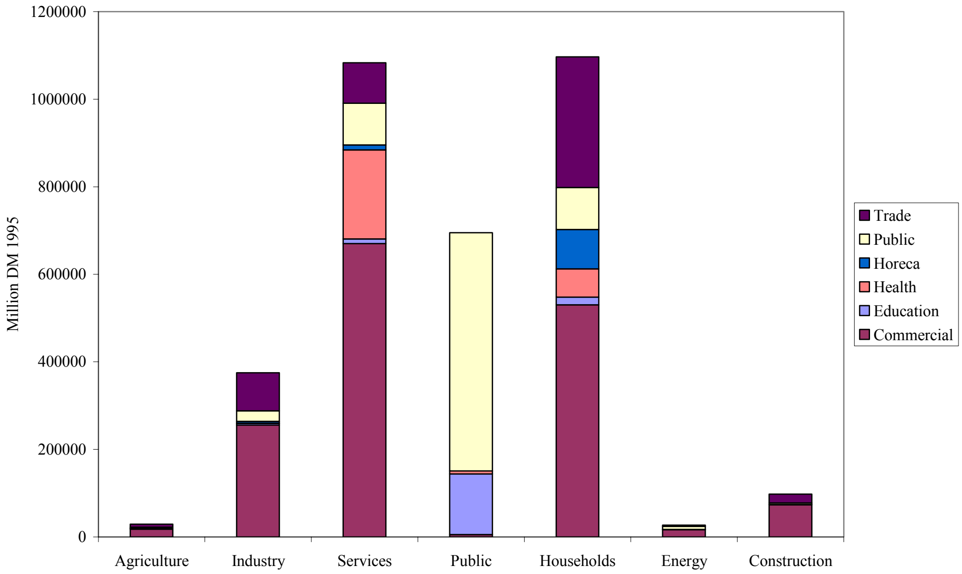

Figure 5.32. Monetary input from service sectors to all sectors, in Germany 1995 (OECD, 2001)

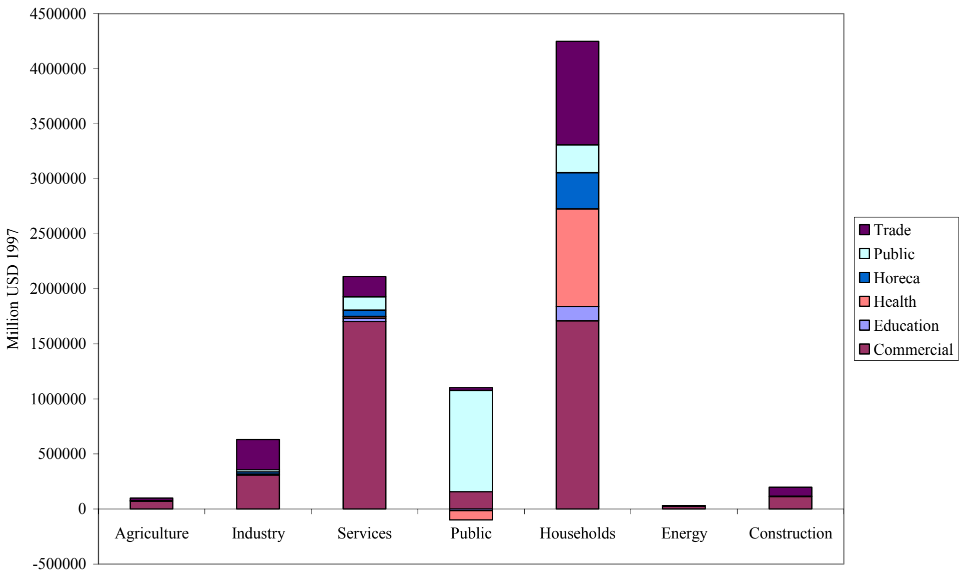

Figure 5.33. Monetary input from service sectors to all sectors, in the USA 1997 (OECD, 2001)

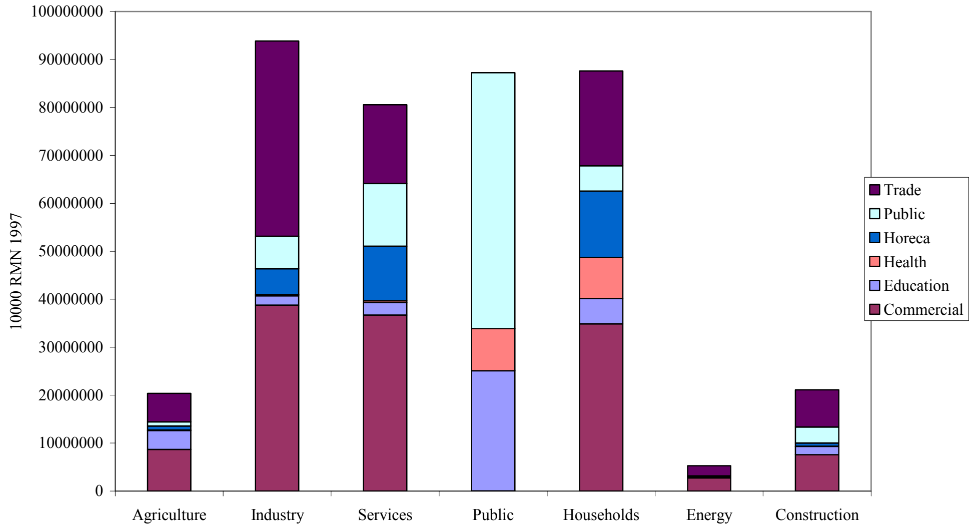

Figure 5.34. Monetary input received by other intermediate and final demand sectors from the service sector, China 1997 (OECD, 2001)

In developed countries (Germany and USA) a large share of the monetary output of the service sectors is delivered to the household sector (respectively 32% and 51%). Secondly, part of the output of the services sector is delivered as input to the services sector itself (Germany 32%, USA 25%). For some branches (finance and transport and storage), it even concerns a large internal monetary flow. For example the output of the finance sub sector is delivered for a large extent to the finance sub sector as well. The detailed research of the monetary output of the sector delivered to the non-services sectors shows that the construction, motor vehicles and the food sectors are of importance. For instance, products of the wholesale and retail, trade and repair sector are going to these sectors.
Thirdly, a considerable amount of deliveries from the services sector goes to the final consumption of the general government (Public sector) (Germany 20%, USA 12%). Only about a tenth of the monetary output of the service sector goes to the industry sector.

The monetary input-output table of China shows another picture, because the service sector delivers relatively much to the industry sector (about 24%), instead of being used for the final consumption of the households (about 22%) or the service sector itself (20%).

Time series of input-output tables of Germany, covering the period 1990 -2001, show that the input of services is received ever more from the service sector itself, instead of for instance the industry. In 1990 80% of the input comes from the services sector and 13% from the industry sector; in 2001 these percentages were 85% from services and 10% from industry, respectively.
Because of the lack of data about where the energy requirement of the service sector stems from, information about the life cycle analysis of buildings is taken into consideration as well. From several literature sources (Suzuki and Oka, 1998), (Schreuer et al, 2003), (Junnila, 2004) it appears that the main climate change impact of office buildings occurs within the operation phase, followed by the impact of building materials, maintenance and construction phase respectively. Climate change impact, within in buildings mainly CO_2 emissions, is a direct indication of the energy requirement of the sector.

Table 5.2. Climate change impact during building life cycle phase (Sources: Junnila, 2004, Suzuki and Oka, 1998, Schreuer et al., 2003)

Source	**Junnila, 2004**	**Suzuki and Oka, 1998**	**Schreuer et al., 2003**
Operation phase	80-85%	82%	93%
Within building materals	15%	15%	3%

Based on the available information the following conclusions can be drawn concerning the energy requirements of the services sector. The power production sector is the sector which probably has the most important interlinkage with the service sector, followed by the heat production sector. The building material sector has a medium interlinkage.

5.5.2 Input output table

Based on the findings in literature review (see paragraph 5.5.1.2) and expert estimations the most relevant influences between sectors are determined. The results are shown in Table 5.4. For the service sector only the commercial buildings are shown, because in case of the qualitative physical input-output there is only little information available (LCA studies).Therefore, in addition, the monetary output of the service sector to all sectors in several developed countries is summarized in Table 5.4.

Table 5.3. Qualitative Physical Input-Output Table by Sectors and Goods. (· weak interlinkage; ° medium interlinkage; • strong interlinkage)

Input / Output			Households	Commercial Buildings
Supply	1	Agriculture & Forestry	°	°
	2	Mining	.	
	3	Basic Metals	.	
	4	Basic Chemicals	.	
	5	Pulp & Paper	.	°
	6	Other Building Materials	°	°
	7	Fuel Production & Distribution	●	
	8	Electricity Production & Distribution	●	
	9	Food	●	°
	10	Fine Chemicals	.	
	11	Machinery	.	
	12	Electrical and Electronic Equipment	°	°
	13	Transport Equipment	°	°
	14	Other Industry	.	
	15	Construction	●°	°
	16	Trade and Retail	●°	= services
	17	Other Commercial Services	°	= services
	18	Public Services	°	= services
	19	Imports	°	= services

Table 5.4. Monetary Input-Output Table by Sectors and Goods. (· weak interlinkage; ° medium interlinkage; • strong interlinkage), sources USA, 1997 and Germany, 1995 (OECD, 2001)

Input \ Output			Intermediate Demand					Final demand	
			1	2	3	4	5		
			Agriculture & Forestry	Industry	Services	Energy	Construction	*Households*	*Public*
Supply	1	Trade & Retail		°	°			•	
	2	Commercial services		•	•		°	•	
	3	Public services			°				•
	4	Horeca						•	
	5	Health			°/•			°/•	
	6	Education*						•	•

* In case of education there is a strong interlinkage with households in the USA and with the public sector in Germany

Households

It appears from various studies that the energy production and the food sector have a strong interlinkage with the households sector. Construction and trade & retail might also be relatively important. These sectors deliver their output to fulfil food, housing, clothing and recreation needs which have essential shares in the total energy requirements. The sectors transport equipment, other commercial services and public services have a medium interlinkage with the households sector. These sectors deliver their goods to the households sector in order to fulfil basic human needs like 'other mobility'[69], health and personal care, education and recreation. Furthermore, based on literature and expert opinions it is assumed that agriculture & forestry, other building materials, electrical and electronic equipment also have a medium interlinkage with the households sector. Agriculture and forestry are related to the food and housing sector which have strong interlinkages. The sector other building material is one of the elements for the basic need housing. Electrical and electronic equipment is included in the category 'other'. Also from time series (see 5.4.1) it appears that households purchase ever more electronic appliances.

Services sector

It is more difficult to say something about the interlinkages of different sectors with the service sector, because the service sector itself is so diverse and there is little information available. The service sector is very heterogeneous and covers the wide range of activities in e.g. hospitals, offices, restaurants, shops, schools and so on. From the available studies it appears that the energy consumption during the operational phase of buildings is very important. This implies that the interlinkage of the services sector with the electricity production, fuel production and distribution sectors is strong. Furthermore, it is expected that commercial buildings have a medium interlinkage with the pulp and paper, building materials, machinery, electrical and electronic equipment and transport equipment sectors. This estimation is based on the building functions in the various services segments.

5.5.3 Summary of main findings

Households

Energy use of households can be divided in two parts; the direct energy use (e.g. fuels and electricity) and the indirect energy use (e.g. embodied energy in purchased goods and services). The portion of direct energy requirements (including vehicle fuel) is around 50% of total energy requirements in most developed countries. In countries with a warmer climate it can be less. The indirect energy use stems from various commodities consumed in households, of which food consumption is an important one. Also housing (building materials, furniture) and

[69] This basic human need often includes manufacture and maintenance vehicles and public transport.

clothing contribute significantly to the energy requirement of households. The energy requirements for education and recreation become more important when countries develop.

Services sector
The energy use of the service sector is less studied than the energy use in the household sector. Based on LCA studies it is clear that energy consumption during the operational phase (read direct energy use) is of much more importance than the energy use of building materials. From monetary input-output tables of two developed countries (USA and Germany), it appears that the deliveries of the services sector mainly go to the final consumption of households and the service sector itself. The input-output table for China shows that the service sector in China has a relative strong relation with the industry sector. Food, construction and transport are examples of relative essential sectors to which the service sector delivers its output.

5.6 Conclusions and recommendations

Today, forecasts and scenarios of the energy requirements of households and the service sector are frequently based on GDP and population growth rates. However, although population and GDP are potentially important drivers for energy use, other factors like behavior, physical activities and policy also play a role in the development of future energy use. Moreover, actual energy use is linked to the activities in these sectors, which may have a weaker or stronger relation to GDP. In this study we focused on the role of physical activities and their development with increasing levels of GDP or value added. The relationship between these physical activities, economic growth and underlying mechanisms has been studied in this assessment.

Households
From input-output analyses of households we conclude that a substantial part of households' energy requirements is fulfilled by non-energy commodities and indirect energy use (e.g., embodied energy in purchased goods and services). The indirect energy use comes from various commodities consumed in households, of which food consumption is the most important one. Also housing (building materials, furniture) and clothing contribute significantly to the energy requirement in households. The energy requirement for education and recreation is of some importance in developed countries.

Direct consumption of energy contributes to about half of the total energy use by households. The historic trend analysis of residential energy demand (energy consumption/cap versus GDP/cap) shows that growth of GDP outpaces the growth of energy requirements for most of the countries (Figure 5.6). The energy use in households is the result of several energy services performed within households, such as heating, cooking and lighting. So-called physical activities, like the floor space, number of persons and the number of appliances are driving forces behind the demand for energy. Therefore, we investigate the driving forces behind the typical patterns of energy requirements in several countries, focusing on physical activities.

For each physical activity the development with increasing GDP per capita is investigated. The hypothesis that saturation of physical activities will occur after a certain standard of living does hold for some indicators. There is a weak decoupling trend of the average dwelling area with GDP for all studied countries. The number of persons per dwelling is decreasing to what seems to be a saturation level of 2 to 2.5 persons per dwelling. This is a strong decoupling trend. The growth of average living area per capita, which is a combination of the dwelling area and number of persons per household, is slowing down. Although growth is slowing down the decoupling trend is not strong at all. With potentially slowing or even declining populations a stabilization of living area per capita might be an important parameter in future energy demand projections.

The hypothesis that saturation of physical activities will occur with increasing GDP does not hold for the ownership of electric appliances. Whereas some electric appliances experience saturation levels, overall we see that the number of appliances in households is (still) increasing. In other words, there is a coupling between ownership of electric appliances (and resulting energy use) and increasing GDP.

Services sector
The interaction of the service sector and other sectors, and the impact on total energy requirements, is difficult to assess. Based on LCA studies it is clear that energy consumption during the operation phase (direct energy use) is of much more importance than the energy use embodied in building materials used to construct office buildings. From monetary input-output tables of two developed countries (USA and Germany), it appears that the largest share of delivered goods of the services sector goes to the final consumption of households and to the service sector itself (i.e. trade). The input-output table for China shows that the service sector in China has a relative strong relation with the industry sector. About 24% of the monetary output of the Chinese service sector is delivered to industry. In Germany and the USA this is about 10%. Food, construction and transport are examples of relative essential sectors to which the service sectors deliver thier products.

The energy use of the service sector is studied less than the energy consumption in households. Also, data on relevant physical activities that influence the energy use are scarce (e.g. statistics on floor area of the service sector are scarce for many countries). We investigated the number of employees, office space per employee and the use of office equipment. The analysis shows that the number of employees working in the services sector increases with increasing economic growth. In countries with relatively high GDP levels, the share of the service sector in total GDP is relatively large. No general trends are observed on the development of floor area per employee with increasing services value added. On a country level sometimes more clear developments can be observed. In Italy and Japan for example the average office space per person grows with increasing value added of the service sector.

General recommendations
In general, it can be said that development of physical activities in the residential sector gives enough points of departure to include these indicators in energy modelling. For the household sector there is more empirical data that show how physical activities develop with increasing GDP compared to the services sector.

From the results we see that large differences exist in activity levels between countries. Although the investigation of country differences has not been a main objective of this study, we think it is important that these differences deserve further research, to enable the improvement of our understanding of the driving forces and the preparation of improved energy demand scenarios. As the study showed, the increased use of (new) appliances is one of the driving forces for increased energy use. Hence, it is important to get a better understanding of future development of the type and number of appliances, saturation levels, and (specific) energy use of appliances in various countries.

In this study the physical activities that influence the energy requirements of a sector are separately investigated. Although we made no attempt to aggregate the findings on activity level this might be useful for future research. It might for example be useful to study the aggregated effect of development of number of people per household, average dwelling area and average living space per capita on household energy requirements.

Future research on dealing with the relation of economic and physical growth should take other influences into account that felt outside the framework of this study. For instance, purchase and usage behaviour, energy prices, and impact of policies should be considered. Especially for the services sector, a better understanding of the impacts of intersectoral deliveries is needed. This can be achieved by further refining and improving of input-output analysis for the service sector and various segments thereof.

6 Discussion and Conclusions

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6.1 Relationships between physical and monetary growth of the economy

The central aim of this assessment project was to identify the relation between physical and monetary growth in four different economic sectors, i.e. (i) industry, (ii) transport, and (iii) services and households. Our research activities were mainly based on a literature review and were complemented by own data calculation.

For the total of 19 OECD countries, we found the share of the **industry sector** in the total GDP to decrease from roughly 27% in 1979 to 18% in 2002. This indicates that industrialized countries develop towards service economies with both the total service sector and the transport sector growing faster than per capita GDP. However, this finding does not mean that the absolute value added of the industry declines. Rather the opposite is true, as the value added of the industrial sector continues to increase but at slower rates than the total economic growth (around 5.5 % real growth per year of industry versus 7.3% growth of the total economy in the period 1979-2002).

This development is also reflected by the consumption of various bulk materials. While we find a general trend towards declining intensity of use with increasing GDP per capita, we identify at the same time a trend towards increasing absolute per capita materials consumption. These results indicate that the shift towards the service economy leads to weak decoupling between physical and monetary growth but not to absolute dematerialization, i.e. not to an absolute decline of materials consumption.

Our analysis of the industrial sector revealed a trend towards re-coupling between physical output and value added for paper and paperboard production and for cement production in South Asia and China. We furthermore identified a trend towards decoupling (i) between cement production and value added of the non-metallic minerals industries of North America and Europe and (ii) for aluminium production in the non-ferrous metals industry of China. For all other bulk material industries analyzed (i.e. wood production, feedstock use in the chemical industry, production of bricks, iron and steel, and aluminium production in the non-ferrous metals industry of North America, Europe, and South Asia) we were not able to identify robust trends towards either decoupling or re-coupling between monetary and physical activity. Based on this analysis, we therefore find no indication for a general trend towards decoupling between physical and economic growth in industry.

Unlike the industrial sector, both **passenger and freight transport** have been growing faster than GDP over the past decades. With rising income levels we observe (i) a trend towards faster passenger transport modes and (ii) a trend to specialized high-speed logistic freight chains (just- in-time delivery), along with reduced load factors, compared to traditional bulk oriented logistics. Although the energy efficiency of all transport modes for passenger and freight transport has increased over the past decades (partly as a consequence of energy conservation policies), the transport volumes have been growing substantially faster, resulting in an overall increase of energy use and CO_2 emissions.

As average income increased, the annual distance travelled in passenger transport rose by roughly the same proportion, especially in the private car sector. In developing countries people typically spend 3 to 5% of their income on transportation, i.e. mostly non-motorised and public transportation. At higher income levels in developed countries, this fraction tends to stabilise at 10 to 15%, with car ownership ranging from 0.4 car per capita in Europe and Japan, up to about 0.6 car per capita in the US (still growing). The available analyses indicate that people spend a rather constant part of their time on transport (~1-1.5 hours/day), regardless of income, social and geographical conditions.

For the total transport sector, we conclude that decoupling between passenger and freight transport and per capita GDP cannot be observed and is unlikely to occur in the near future as saturation in both passenger and freight transport is not yet occurring. The energy use of the transport sector will continue to increase. It is therefore likely that the transport sector becomes the major CO_2 emitter of all economic sectors in the next decades.

Next to the increasing demand for transportation also the need for other **services** increased markedly. The increasing complexity of modern economies stimulates activities in the service sector, i.e. health, education, finances, government. Linking the monetary growth of the service sector to physical activities is, however, complicated by the fact that data about physical activities in the service sector are scarce. In absolute terms, the number of employees in the service sector as a whole rose in all studied IEA-countries in the period of 1970-2000, while the amount of office space per employee (in m^2) appears to be relatively stable over time. Historical time series on the office space per employee show decoupling from value added per capita. The use of office equipment has increased significantly in the last ten to fifteen years. For example, in the US, both the ratio of computers per employee and per m^2 of office space increased in the nineties. Based on limited available information, it is expected that the amount of office equipment has not yet reached saturation. Demand for more comfort (indoor climate, electronic devices) and developments in the area of communication technology might further increase the amount of office equipments and as a consequence the energy demand of the service sector.

The data of developed countries indicate a trend towards re-coupling between the number of employees and the value added generated in the service sector. They also indicate recoupling between the use of office equipment and the value added generated in the service sector.

Households account for almost one third of the total worldwide final energy consumption. Next to economic growth (GDP per capita) and demographic growth (population), the average dwelling area, the number of persons per dwelling, the average living area per capita and the number of appliances per capita are the main drivers for energy consumption in households. In our analysis, we found evidence that total energy demand will level off at higher living standards, and that a decoupling of economic growth and total energy consumption in households is occurring. However, we could not find a uniform trend towards decreasing per capita total energy use in households, as countries that start at a relatively high (historical) level of energy use per capita tend to reduce their per capita energy demand with increasing GDP per capita (e.g. Denmark and Germany) while countries that have a relatively low residential energy use per capita at low GDP level like Japan, Finland and Norway continue to increase their energy use per capita. Although developed countries show very large differences in per capita energy use, a convergence towards similar levels of residential per capita energy use is observed.

For most countries the space heating energy intensity declines rapidly, and has a major impact on the total energy use. Declining energy use for space heating is caused by increased energy efficiency (e.g. insulation, energy efficient heating systems). As of 1970 the continued growth in absolute dwelling area with increasing GDP per capita is striking, despite large differences between individual countries regarding per capita dwelling area. However, as the average dwelling area per capita grows slower than per capita GDP, we observe a trend towards weak decoupling between growth of absolute dwelling area and GDP. We furthermore identified a general trend towards increasing living area per person as household occupancy decreases with increasing per capita GDP. The current trend in dwelling area development shows that although average dwelling size per capita is still growing, the growth is slowing or even stabilising in some developed countries. With potentially slowing or even declining population a stabilisation of total living area can be expected in the future.

In most developed countries the increase of energy consumption in households over the last decades is due to the increased electricity consumption of new appliances (even when some of it is offset by increased efficiency of major energy consuming appliances). The physical indicator ownership of electric appliances shows a re-coupling trend with GDP per capita.

Based on these core findings for industry, transport, services, and households, Table 6.1 presents stylized facts about the relationship between physical and monetary activity in the respective economic sector.

Table 6.1. Stylized trends for developments in selected economic sectors

Sector	**Value Added/ Physical production**	**Intensity of Use: Physical activity per cap / GDP per cap**	**Physical Activity per cap**
Industry			
Wood	**0**	**D**	**R**
Paper and Paperboard	**R**	**0**	**R**
Chemical feedstock use	**R**		
Polymers		**0/R**	**R**
Cement	**N**	**0**	**R**
Bricks	**0**	**D**	**0**
Ammonia		**D/0**	**0/R**
Crude Steel	**R/0**	**D/0**	**0/R**
Aluminium	**0**	**D**	**R**
Transport			
Passenger Transport		**0/R**	**R**
Freight Transport	**R**	**0/R**[1)]	**R**
Households			
Dwelling area		**R**	**R**
Living Area		**R**	**R**
Ownership of Electric Appliances		**R**	**R**
Service Sector			
Number of Employees		**R**	
Floor Area per Employee		**N**	**0/R**[2)]
Office Equipment			**R**[3)]

Legend: **D**-decoupling/de-materialization **0**-constant/no trend identified **R**-recoupling/(re) materialization **N**-diverse results

1) Constant ratio of freight transport to GDP per capita between 1970 and 1990, increasing ratio of freight transport to GDP per capita between 1990 and 2000
2) Development of floor area per employee
3) Development of number of computers per employee

As Table 6-1 shows, we observe for the majority of industrial bulk products either constant or declining intensity of use (e.g., wood, bricks, crude steel) while the intensity of freight and passenger transport as well as the physical indicators for household and service sector activity continue to increase (e.g., dwelling area, living area per person, or the number of employees in the service sector). In general, we observe increasing per capita physical activity for all three economic sectors, i.e., industry, transport, services (excluding transport) and households.

These findings are subject to uncertainties, partly due to questionable quality of some data. The identified trends have not been subjected to a sound quantitative statistical testing. To this end, a more rigorous statistical hypothesis testing via regression analysis should be applied (i) to fit idealized curves to the empirical data and (ii) to test the significance of the identified statistical trend.

Nevertheless the findings seem too important to be put aside with the argument of being subject to uncertainty. With regard to long-term developments, they raise the question about the *ultimate* level of saturation and – given the continued large gap between high-income countries and low-income countries – they may also point to the question whether the nearly exclusive focus on efficiency improvement by technological measures (as followed in the past) will be sufficient in order to realize a safe, secure and sustainable supply and use of energy. Depending on how this question will be answered in the years to come, this could entail substantial changes for policy making.

6.2 Assessing the Plausibility of the Economic Projections

The objective of this section is to use the insight gained in the sector analyses (Chapter 3-5) in order to assess whether economic projections as those used for model-based scenario analyses are plausible. To this end we have conducted a back-of-the-envelope calculation based on the following approach:

- We set out with stylized relationships, which reflect the dependency between the rise in value added of a given sector and the physical growth, thereby making use of the outcome of the literature survey and empirical analyses conducted for this study. These stylized relationships are representative for the development in the last 20 to 30 years and they are considered to capture sufficiently well also the dynamics in the next two decades.
- For the projected ratio between value added and the physical growth, we determine a *mean* value and we establish a wide range in order to account for the large uncertainties.
- By combining this information with value added projections until the year 2020 (as used in long-term energy and emission models) we project physical flows in the next two decades.
- We compare the *projected* physical flows with the *real* physical growth in the past and we then assess whether the projection in physical terms seems plausible.

While, at first glance, the approach taken may seem to be circular, this is not the case. It would be circular if exclusively information about the observed dynamics in the *past* were used. However, this is not the case since new information in the form of value added projections (i.e. *future* VA) is being made use of. Combining this *projected future* value added with historically derived relationships between physical flows and VA (ratios for the *past*) leads us to a projection of *future* physical growth. The projected physical growth is too low if the VA projections are too low and it is too high if the VA projections are too high. As we will discuss below, the latter (VA projections are too high) seems to be the case in the Scenario “Strong Europe”.

We applied this approach to three data sets for economic growth. The first represents the high economic growth scenario (IPCC A1), while the second (“Strong Europe”) is clearly lower and more in line with the development experienced in the last decades. The third scenario represents a case of low economic growth. All datasets used refer to Western Europe. The projected value added data for the first two scenarios originate from the WorldScan model and have been kindly provided by the Dutch Environment and Nature Plan Bureau (MNP) and the Dutch Central Planning Bureau (CPB) (personal communication with J. Bollen, MNP, June 2006 and with A. Lejour, CBS, June 2006). The ‘Low Growth’ scenario is an own estimate in which we simply assumed that the yearly growth rates would represent only one third of the values of the Scenario ‘Strong Europe’.

As shown in Table 6.2 the projected increase in physical flows between the years 2000 and 2020 are very substantial for Scenario IPCC-A1 and for the Scenario ‘Strong Europe’:
In these two scenarios, the physical flows for the bulk material industries[70] and for the metal

[70] Comprising
- Metals
- Printing, paper, and publishing
- Chemicals, rubbers and plastics, mineral products
- Other raw materials

industry increase by a factor of around 2.0 to 2.5 according to our *mean* estimate (first column under the heading of physical growth). For transport (commercial transport only), the physical flows (ton kilometres and passenger km) increase by a factor of approximately 2 to 3 according to our *mean* estimates for the scenarios 'IPCC-A1' and 'Strong Europe'. In contrast, the changes expected for the service sector (without transportation) are rather moderate, with *mean* estimates for absolute floor space growth between 1.2 ('Strong Europe') and 1.5 (IPCC A1).

The large increases in physical flows seem implausibly high for the *bulk* material industries if one takes into account that, in Western Europe:

- crude steel production has been roughly stable in the EU-15 in the last 30 years at a level of around 150 Mt respectively (in North America at around 110 Mt),
- total bulk materials production (in physical terms) has increased on average by 0.7% p.a. in the last 20 years in the EU (with some fluctuations), translating to a factor of a maximum of 1.15 for a period of 20 years (in North America the growth rate was much higher with 1.9% p.a. over the last 20 years, which translates to a factor of 1.45 over a 20 year period; however, this is still within the range if the Low Growth scenario, see Table 6.2).

The projected further developments for freight and passenger transport according to the Scenarios IPCC-A1 and for the Scenario 'Strong Europe' (see Table 6.2) are in line with the developments in physical terms in the past: in the last 30 years, both freight transport (by rail, trucks, air and ships) and public passenger transport (by bus, rail and air)[71] increased by a factor of 2 in Western Europe.

Similarly, the projected total floor space in the service sector (transportation excluded) according to Table 6.2 is consistent with the historical developments: in the last 30 years, floor space grew, depending on the individual country, by a factor of 1.5 to 2.5 in the (factor 1.1 to 1.8 in the last 20 years), which fits well with the projected ranges of the IPCC A1 scenario and the 'Strong Europe scenario'.

To summarize, the projections for the 'Low Growth' scenario shown in Table 6.2 seem quite realistic for the industry sector, while those for services and possibly also for transport may be too low.

Table 6.2. Projected physical growth for three scenarios for Western Europe in the period 1997 to 2020

	Scenario IPCC A1			Scenario 'Strong Europe'			Scenario 'Low Growth'		
	Value added increase in % p.a.	Physical growth over entire period (factor)		Value added increase in % p.a.	Physical growth over entire period (factor)		Value added increase in % p.a.	Physical growth over entire period (factor)	
		mean	range		mean	range		mean	range
Bulk material industries	3.7%	2.3	1.8 - 2.7	2.7%	1.9	1.5 - 2.2	0.9%	1.2	1.0 - 1.5
Metal industry only	4.1%	2.5	1.8 - 5.0	3.0%	2.0	1.4 - 4.0	1.0%	1.3	0.9 - 2.5
Transport	4.8%	2.9	2.5 - 3.2	3.3%	2.1	1.8 - 2.3	1.1%	1.3	1.1 - 1.4
Services (w/o transport)	3.2%	2.0	1.4 - 2.5	2.2%	1.7	1.2 - 2.0	0.7%	1.2	0.8 - 1.4

There are a few **caveats** that need to be considered when interpreting the outcome of the back-of-the-envelope calculation. As mentioned above stylized relationships are representative for the development in the last 20-30 years and they are considered to capture sufficiently well also the dynamics for the next two decades. There are essentially two ways (and combinations

71 It is important to note that passenger transport excludes travel with private vehicles but covers only commercial passenger transportation by bus, rail and air.

thereof), which could explain why the future trajectory for *bulk materials* could differ decisively from the past:

- Theoretically, the increase of the ratio of value added relative to the physical flows could be much higher in the future. Compared to today, this would mean that the physical quantities corresponding to the economic IPPC projections would be lower than those given in Table 6.2. This would make the economic projections for materials (but not for transport and neither for services) more plausible for the future. A large and unprecedented future increase of monetary relative to the physical flows may require major innovations, in terms of type and extent. While this is not impossible, one would expect such a development to be preceded by exceptionally large efforts in R&D, which, however, cannot be confirmed for most world regions today (and certainly not for bulk materials).
  Another possible trend that could lead to an increase of the ratio of value added relative to the physical flows would be that consumers move towards more and more expensive brands (Gucci and Versace, Mercedes and Maybach etc.). However, also the opposite trend is possible, if for example, high quality retailers (Albert Hein, delicatesse shops) get overrun by discounters (Lidl and Aldi; likewise for national airlines such as KLM and Air France versus budget airlines such as Ryanair and Easyjet).
- We argued above that, for *bulk materials*, the physical flows reported in Table 6.2 are too large when compared to the historical values. On the other hand, one could also argue that, in future, the renewal of the building stock will require much larger material quantities than currently consumed: The demolition rate of buildings currently stands at 0.2% (equivalent to a statistical lifetime of 500 years (EU, 1993)), resulting in an aging process of the built environment in Europe. At a given point in the future a wave of replacement and refurbishment may lead to higher levels of material use.

While, for *transport* and *services*, the projected physical quantities are plausible in view of historical developments, this consistency should not be over-interpreted. After all, the plausibility check by comparison with the dynamics of the last 20 years might be flawed due to the exceptionally strong increase of transportation which, (i) for *freight*, may reach saturation as a consequence of the slow-down of the globalisation process in production at a given point in future and (ii) for *passenger transport*, may reach limits as a consequence of demographic change.

In addition, the limitations and uncertainties pointed out towards the end of Chapter 3.4.3.2 should be kept in mind, even though they should be accounted for to a large extent by the wide ranges assumed in Table 6.2 for each of the three scenarios.

As a first conclusion, the back-of-the-envelope calculation (even though based on partly uncertain data) offers interesting new insights:

- It indicates that the economic projections for industry tend to be too high, while the economic projections for transport and for services seem to be in the right range. These conclusions are based on comparisons with the dynamics experienced in the three sectors studied in the last two to three decades. However, changes may occur in future which could make i) the projections for bulk materials more plausible than they seem now (due to renewal of the building stock and infrastructure) and ii) those for transport less likely (slowdown of globalisation and demographic change). On the other hand, such trend breaks are practically not mentioned in the description of baseline scenario projections (reference projections) as studied above. There is hence a good chance that they were not taken into account when the scenario datasets were established and that they should therefore not be considered when making comparisons with the back-of-envelope calculations.
- Only weak decoupling seems in sight, while the physical flows in absolute terms increase very substantially in the scenarios IPCC-A1 and ‘Strong Europe’. Even in the scenario ‘Low growth’, absolute decoupling is unlikely. This may indicate the need for targeted policies and measures.

One immediate question which these results raise are whether the implicit overestimation of the physical flows of bulk materials in the scenarios ‘Strong Europe’ and IPCC A1 (see Table 6.2) imply that also the energy requirements and the related emissions are overestimated. A first answer can be given simply by comparing the change in physical flows of bulk materials according to Table 6.2 with the energy requirements for the industrial sector according to the TIMER/IMAGE model for the scenarios ‘Strong Europe’ and IPCC A1 (these energy requirements were provided by MNP, however, only for the industrial sector as a whole and not for the various subsectors). In these two scenarios, the primary energy equivalents (in absolute terms) for the *total* industrial sector increased by a factor of 1.1 and 1.2 respectively between 1997 and 2020.

It can be concluded that energy use of the *total* industrial sector according to the TIMER/IMAGE model increases only very moderately, i.e. it is rather unlikely that the energy use is overestimated. This means: While the value added projections for the bulk material industries in combination with the EPIST analyses indicate an overestimation of physical growth (Table 6.2), the consideration of other effects in the TIMER/IMAGE model and/or the use of a different methodology seem to avoid an overestimation of energy use.

Further analysis about the plausibility of the energy projections is hampered by the lack of projected energy data at the level of individual industrial subsectors. Since 30-40% of the total industrial energy use (primary energy equivalents) is nowadays related to non-energy intensive sectors (e.g. automotive sector, machinery, electrical and electronic goods; the remaining 60-70% are related to the energy-intensive production of bulk materials), its further development has an important influence on total industrial energy demand.

To summarize, the analyses in this project indicate that the economic projections for industry tend to be too high but was not found that they lead to obviously implausible results for projected energy use in the TIMER/IMAGE model. While this assessment had to depend on readily available data (from the TIMER/IMAGE model; datasets from other models were not available), it has raised critical questions, which should be taken into account in future research (see also below). Due to the incomplete understanding it is at this stage not possible to derive recommendations for policy makers. However, if future research involving also other models used for IPCC projections cannot clarify sufficiently well the relationship between physical and monetary flows, this fact should be communicated to policy makers, because it could advocate a more precautionary policy style.

6.3 Future research trajectories

The original question for this assessment project was: To what extent does increased economic activity lead to increased activity in physical terms? This question is important as environmental impacts, like the anthropogenic greenhouse effect, are strongly related to the level of activities expressed in physical terms.

In the preceding chapters we studied the relation between monetary and physical activity for the main three economic sectors contributing to energy use and greenhouse gas emissions: *bulk* materials industry, transport, and the households and services sector. For these sectors, we were able to find empirical data for the relation between GDP per capita and the physical activity per capita.

One of the main findings of this assessment study is that the saturation hypothesis does, *in general*, not hold for the parameters studied in the respective economic sectors. The saturation hypothesis[72] assumes that with increasing GDP, human activity in physical terms will initially grow on a per capita basis, and then level off to a constant level per capita. We indeed found such a levelling-off for some types of human activity, e.g., for steel consumption, cement consumption, and household living area. In other cases, we rather found a development where the level of human activity follows the development of GDP, e.g., for freight transport, and for

[72] As long as GDP grows faster than population, the saturation hypothesis is stronger than the so-called dematerialization hypothesis. The (weak) dematerialization hypothesis claims that human activity in physical terms grows slower than GDP, which still makes it possible that per capita human activity increases.

the consumption of plastics and paper. An overview is given in table 6.1. Apart from these findings, Bringezu et al. (2004) and van der Voet et al. (2004) found saturation for the TMR (Total Material Requirements) and DMI (Direct Material Input) for selected, mainly industrialized countries. Their findings show, that there are indeed limits to physical growth, which, however, might not have been reached for individual materials at a less aggregated level of analysis (e.g., for plastics consumption) or for freight and passenger transport.

If we do not see saturation now, this does therefore not mean that we will never see saturation. In most of the cases we have studied the time series stretched over a period of 20 to 30 years, whereas we are interested to say more about future developments a century ahead. Indeed, in a number of cases, we do not see saturation now, but there are also obvious limitations (maximum per capita car ownership, personal time spend on travelling) that in the end will come into play in the future development of the related activity levels.

On the other hand, an important caveat in our analysis is that we look at a selection of human activities. These human activities may nowadays be responsible for the larger part of energy use and greenhouse gas emissions, but new activities will be added. E.g., even if the consumption of each individual material may stabilize on a per capita basis, the 'total' consumption of groups of materials may keep on increasing. The same goes for different transportation modes. This raises the problem of aggregation, e.g., if we wish to speak of the 'total' consumption of materials, we first need to be able to count them together, but we also need to be sure that we have included all relevant materials, including emerging materials that are still used in limited but not negligible quantities. One approach chosen is the concept of TMR and DMI. The problem with these parameters is, however, (i) that they account for the total mass flows resulting from anthropogenic activities, thereby attaching equal weights to all flows covered (e.g., eroded or excavated soils are treated equally as fossil fuel use or the consumption of scarce metals) and (ii) that they do not account for the specific environmental impacts related to the different material flows.

Two ways forward
Given these results, we propose two different ways forward to deepen the understanding of the link between physical and monetary activity of the economy; (1) deepening the current analysis and applying (2) a more extended approach, also taking into account intersectoral interactions.

1. The analysis in this report has shown clear patterns of development of human activity in relation to GDP. This suggests that this is a fruitful way to continue; it may be worthwhile to gather more of these data, for more countries, including developing countries and for more categories of human activity, including the non-energy-intensive industry, household appliances, and air transport.
   More important, however, is to find a theoretical basis for the developments observed. A further understanding may be achieved through econometric analysis in which not just one explaining variable (i.e., GPD per capita) is included, but different ones, depending on the type of activity observed. As an example, we found that the development of household living area per capita apparently depends on the population density. The relationship may be determined through econometric analysis. Similar relations may be observed for other human activity levels, but in all cases appropriate explaining variables need to be selected. Such analysis may reveal, if human activities level off, why they level off on different levels for different countries. Such extended analysis could provide parameter settings for those builders of long-term energy and climate models who want to include physical activity levels in their modelling system. Such inclusion may make the models more robust, or at least could serve as a reality-check of the outcomes in terms of energy use from the traditional energy-economic models.

2) A further, and theoretically richer, approach would be the explicit inclusion of the relation between the various developments. Although we have treated the three main sectors separately in this report, it is clear that they are interrelated. The steel consumption will depend, among others, on the number of cars, the size of freight transport will depend on industrial output (but quite differently for different products), home size will determine cement

and building brick production, but also transportation needs, etc., etc. Modelling all this would be mind-boggling. The standard approach to such complex set of interrelation is the input-output approach. Input-output data are widely available, but they are all in monetary terms. Converting these to physical units (for all the different types of human activity discussed!) would go beyond the capability of any research project of reasonable size.

An interesting way in between may be a hybrid approach. In such approach, one starts from the traditional input output framework and replaces the flows that are the most important determinants of energy use to physical flows. The picture remains complete as the monetary data can be used for all the other flows. This will cause the well-known errors, but for the overall picture these may remain small.

Note that a hybrid input-output matrix is only the framework. In addition the following is needed:

- ‘consumption functions’: to some extent in this approach the problem is shifted to the consumption side: one still needs to know how consumption (in physical terms) develops with GDP. However, this is probably a more robust approach, as on the consumption side there are more rigidities (population size, age distribution, time expenditure) that can make long-term projections more robust;
- technology parameters: for long-term scenarios the I/O-coefficients cannot be considered as fixed. For instance, the amount of steel, plastic, etc. needed per car, will change over time (and may change further due to external constraints, including those given by climate policy). So, material efficiency and material substitution effects should be included there.

Altogether, it makes this approach rather laborious, but it should be kept in mind that an incremental development is possible: a start can be made with a fully monetary input-output approach, and gradually the physical elements can be included.

Finally, it should be noted that the results obtained in the course of this assessment project can already be used to improve existing models for this as the quantitative relations that we found can be parametrized. Both routes as outlined above can be developed incrementally and used to further advance the parametrizations.

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Chapter 6: Conclusions

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APPENDICES CHAPTER 2

Appendix 2-A *Countries in the World Development indicators (WDI) 2004 set explored*.

DZA	Algeria
AGO	Angola
ARG	Argentina
AUS	Australia
BEL	Belgium
BOL	Bolivia
BFA	Burkina Faso
KHM	Cambodia
CAN	Canada
CHL	Chile
COL	Colombia
CIV	Cote d'Ivoire
CUB	Cuba
CZE	Czech Republic
ECU	Ecuador
EGY	Egypt, Arab Rep.
ETH	Ethiopia
FRA	France
DEU	Germany
GHA	Ghana
GRC	Greece
GTM	Guatemala
HUN	Hungary
ITA	Italy
JPN	Japan
KAZ	Kazakhstan
KEN	Kenya
PRK	Korea, Dem. Rep.
KOR	Korea, Rep.
MDG	Madagascar
MWI	Malawi
MYS	Malaysia
MLI	Mali
MEX	Mexico
MAR	Morocco
MOZ	Mozambique
MMR	Myanmar
NPL	Nepal
NLD	Netherlands
NER	Niger
PER	Peru
PHL	Philippines
POL	Poland
PRT	Portugal
ROM	Romania
SAU	Saudi Arabia
ZAF	South Africa
ESP	Spain
LKA	Sri Lanka
SDN	Sudan
SWE	Sweden
SYR	Syrian Arab Republic
TZA	Tanzania
THA	Thailand
TUR	Turkey
UGA	Uganda
UKR	Ukraine
GBR	United Kingdom
UZB	Uzbekistan
VEN	Venezuela, RB
VNM	Vietnam
YEM	Yemen, Rep.
ZMB	Zambia
ZWE	Zimbabwe

Total countries: 60. Total population in 2000: 2010 million persons.

The definition of Gross National Product (GNP). The Gross National Product (GNP) is the value of all the goods and services produced in one year in a given economy as expressed in the monetary System of National Accounts (SNA). If the goods and services for investment are substracted, the Net National Income (NNI) results. The national product can be defined from the production point of view: the sum of all value added; the consumption point of view: the sum of consumption expenditures (incl. government expenditures, gross capital formation and the transactions with abroad); and the income perspective: the sum of all incomes (wages, salaries, entrepreneurial income and all rents). The National Income consists of the rewards for all the factors of production - equal to the National Product. If the system is considered to be in accounting equilibrium within the given time period, the national product being the sum of all expenditures equals the national income consisting of all production factor rewards.

WDI 2004 data*.* Among the difficulties faced by compilers of national accounts is the extent of unreported economic activity in the informal or secondary economy. In developing countries a large share of agricultural output is either not exchanged (because it is consumed within the household) or not exchanged for money.

Agricultural production often must be estimated indirectly, using a combination of methods involving estimates of inputs, yields, and area under cultivation. This approach sometimes leads to crude approximations that can differ from the true values over time and across crops for reasons other than climatic conditions or farming techniques. Similarly, agricultural inputs that cannot easily be allocated to specific outputs are frequently ‘netted out’ using equally crude and ad hoc approximations.

Ideally, industrial output should be measured through regular censuses and surveys of firms. But in most developing countries such surveys are infrequent, so earlier survey results must be extrapolated using an appropriate indicator. The choice of sampling unit, which may be the enterprise (where responses may be based on financial records) or the establishment (where production units may be recorded separately), also affects the quality of the data. Moreover, much industrial production is organized in unincorporated or owner-operated ventures that are not captured by surveys aimed at the formal sector. Even in large industries, where regular surveys are more likely, evasion of excise and other taxes and nondisclosure of income lower the estimates of value added. Such problems become more acute as countries move from state control of industry to private enterprise, because new firms enter business and growing numbers of established firms fail to report. In accordance with the System of National Accounts (SNA), output should include all such unreported activity as well as the value of illegal activities and other unrecorded, informal, or small-scale operations. Data on these activities need to be collected using techniques other than conventional surveys.

In industries dominated by large organizations and enterprises, such as public utilities, data on output, employment, and wages are usually readily available and reasonably reliable. But in the service industry the many self-employed workers and one-person businesses are sometimes difficult to locate, and they have little incentive to respond to surveys, let alone report their full earnings. Compounding these problems are the many forms of economic activity that go unrecorded, including the work that women and children do for little or no pay. For further discussion of the problems of using national accounts data, see Srinivasan (1994) and Heston (1994).

Dollar conversion*.* To produce national accounts aggregates that are measured in the same standard monetary units, the value of output must be converted to a single common currency. The World Bank conventionally uses the U.S. dollar and applies the average official exchange rate reported by the International Monetary Fund for the year shown. An alternative conversion factor is applied if the official exchange rate is judged to diverge by an exceptionally large margin from the rate effectively applied to transactions in foreign currencies and traded products.

Definitions (WDI 2004)

• **Gross domestic product** (GDP) at purchaser prices is the sum of gross value added by all resident producers in the economy plus any product taxes (less subsidies) not included in the valuation of output. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Value added is the net output of an industry after adding up all outputs and subtracting intermediate inputs. The industrial origin of value added is determined by the International Standard Industrial Classification (ISIC) revision 3. • **Agriculture** corresponds to ISIC divisions 1–5 and includes forestry and fishing. • **Industry** covers mining, manufacturing (also reported as a separate subgroup), construction, electricity, water, and gas (ISIC divisions 10–45). • **Manufacturing** corresponds to industries belonging to ISIC divisions 15–37. • **Services** correspond to ISIC divisions 50-99. This sector is derived as a residual (from GDP less agriculture and industry) and may not properly reflect the sum of service output, including banking and financial services. For some countries it includes product taxes (minus subsidies) and may also include statistical discrepancies.

Appendix 2-B *The theory of dematerialization*

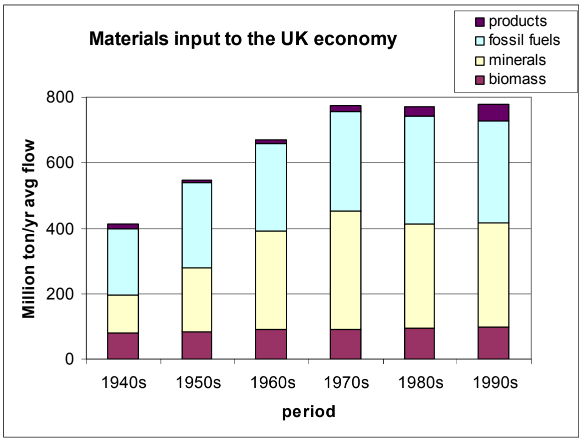
Richer with less resources? As early as the 1950s it was observed for the USA that the inputs of materials and semi-finished goods become relatively less important viz-à-viz non-material inputs such as labour, capital and services. In 1978 Malenbaum introduced the concept 'intensity of use' to draw attention to the phenomenon that over time (time-series) and across nations (cross-country) the use of minerals and energy per unit of GDP tends to rise and then fall. This bell-shape of the intensity-of-use curves has subsequently been called the IU-hypothesis and the theory of dematerialization. It has two postulates (Bernardini and Galli, 1993:433):

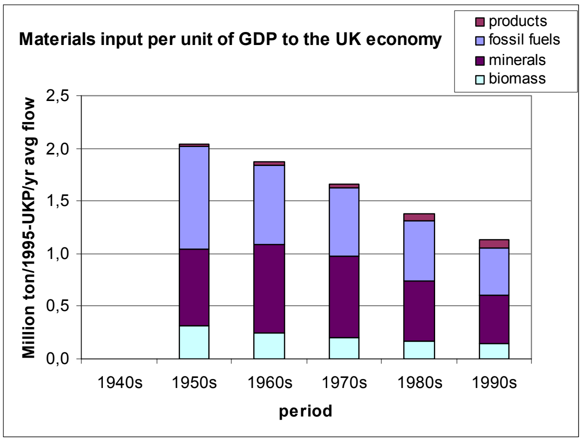
- The intensity of use of a given material (or energy) follows the same pattern for all economies, at first increasing with per capita GDP, reaching a maximum at about the same per capita GDP, and eventually declining; and
- The maximum intensity of use declines the later in time it is attained by a given economy.

The first postulate and some of the proposed explanatory mechanisms are graphically represented in the figure above. Among those mechanisms are:

- The life-cycle concept of materials: a reinforcing competition- and technology-driven growth loop stimulates demand by improving quality and lowering price, until market saturation is reached and a new competing materials with higher value added per unit mass take over;
- the build-up of infrastructures is a material-intensive growth phase, which has often been followed up by new but less material-intensive waves - the less industrialized countries in particular can benefit from the decline in material-intensity by having lower maxima ('leapfrogging');
- there is a continuous dynamic of innovation and substitution of one material for another, as a result of new applications and demands;
- recycling tends to increase with affluence, not only to extend resource availability but also to cope with solid waste problems.

An example of a straightforward calculation of material flows in an economy and of the 'dematerialization' associated with it is the analysis by Schandl and Schulz (2002). In the tradition of industrial ecology, they have quantified the flows of biomass, minerals, fossil fuels and products for the UK over the period of the 1940s to the 1990s. In absolute amounts they have remained constant since the 1970s (lefthand graph). It shows the transition from the biomass economy of the early 20th century to the fossil fuel economy ot the second half of the 20th century - and, again, the stagnation may be related to the rise of ICT. The material input per person has slightly declined. However, there has been a large decline in the materials input per unit of economic output (GDP - righthand graph). One may interpret this as a clear sign of decoupling: value is created at lower material throughput.





Dematerialization refers to the absolute or relative reduction of energy and materials used per unit of economical output (Bernadini and Galli 1993, Cleveland and Ruth 1999). It is closely related to the EKC concept (Appendix C). However, dematerialization does not focus on the total of environmental impacts but specifically on the intensity of use of materials and energy.

The intensity of use is defined as the ration of material use to the total output of the economy and can be expressed as:

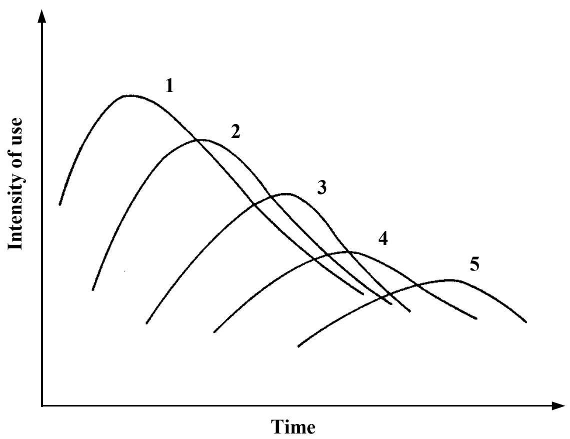
$$I_i = \frac{X_i}{Y}$$

with I being the intensity of use, X the material, Y the total economic output (GDP), and i the index for the specific material. The concept of intensity of material use can be also applied to the energy intensity of material use by adding energy requirements:

$$EI_i = \frac{E_i}{Y} = \sum_j \left(\frac{E_i}{X_i}\right)\left(\frac{X_i}{Y}\right)$$

with EI being the energy intensity of materials use and E the energy required for material i.

The theory of dematerialization consists of three postulates: (i) the intensity of use first increases with per capita GDP, it reaches a maximum at about the same per capita GDP for all countries and it eventually declines afterwards, (ii) the absolute maximum of the intensity of use decreases the later a country reaches the maximum point at a certain per capita GDP, and (iii) the intensity of use for materials or energy follow the same pattern for all economies.

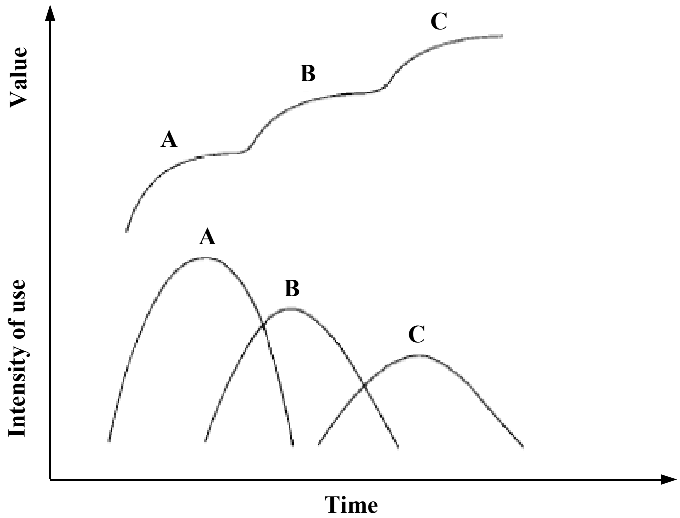


Theory of dematerialization: The maximum intensity of use (materials, energy, wastes) declines the later a country develops (Bernadini and Galli, 1993)

A common explanation for the ‘bell’ shaped curve of the intensity of use is given by the life cycle concept of materials: When new materials are introduced to the market, consumption rates are usually low and market potentials big. In this initial stage, consumption (and thereby production) of a certain material grows rapidly. Technological learning induced by market competition leads to improved production technologies and product quality and causes ultimately price cuts, which further stimulate market demand. As materials reach a mature state, markets become saturated and both, growth of production and consumption of a certain material decline to lower growth rates than GDP growth. At this stage of the material life cycle production and consumption might even decline in absolute terms due to market introduction of new and innovative materials comprising process, quality and price advantages. In this stage, emerging new markets for more sophisticated intermediate and final materials may cause a levelling off or even decline of intensity of use of the original material (Bernadini and Galli, 1993). The extent to which decoupling of materials use and economic growth in the industrial sector occurs, is therefore determined by the following factors:

- Shift of business activities (e.g. from material producers to service providers),
- Process innovation, i.e., the increase in the efficiency of energy and materials use (e.g., recycling, feedstock substitution, combined production of heat and power),
- Product innovation, i.e., the production of knowledge intensive commodities, typically characterized by a low ration of material content/value (e.g., cell phones and other electronics)
- Demand saturation,
- Changes in the structure of intermediate and final demand associated with
- Material substitution (e.g., metals by plastics)

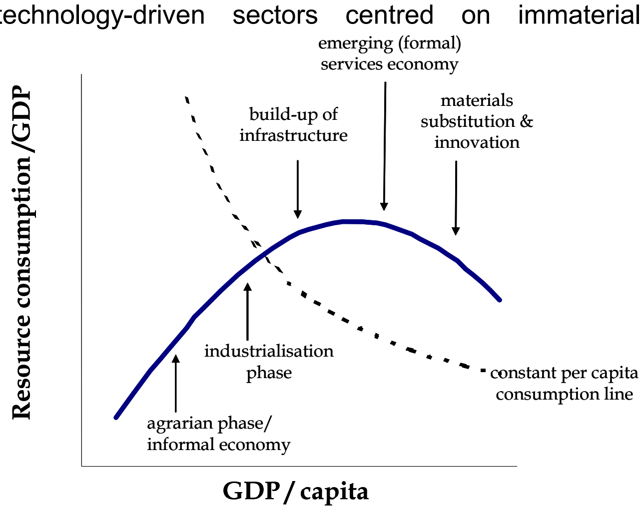
These factors might ultimately lead to transmaterialization, characterized by successive intensity of use curves for certain materials or energy displaying a trend towards increasing value per unit physical output and overall decreasing intensity of use over time.



The process of transmaterialization: New, high value materials replacing the old ones over time and subsequently leading to increase in value per unit product and decrease of intensity of use (Bernadini and Galli, 1993)

Both, the concept of EKC and the theory if dematerialization are often used to argue that relief of environmental pressure would inevitably result as a consequence of economic growth (Bringezu et al., 2004). However, given the theoretical background, a comprehensive empirical validation of these concepts is still missing. Empirical evidence of dematerialization is limited to a relatively small number of individual materials or to specific industries and bases mainly on qualitative assessment lacking thorough statistical and econometric analyses. To date there is still no compelling evidence that economical development shows strong decoupling from material and energy consumption (Cleveland and Ruth, 1999; Bringezu et al., 2004). Thus qualitatively correct, the concepts of dematerialization might quantitatively be an oversimplification (Bernardini and Galli, 1993). Furthermore, the concept of intensity of use is only indirectly linked to absolute material and energy consumption as decreasing intensity of use might well be associated to an overall increase of absolute material and energy consumption. Dematerialization as based on intensity of use is therefore necessary but not sufficient as sustainability indicator of the industrial sector.

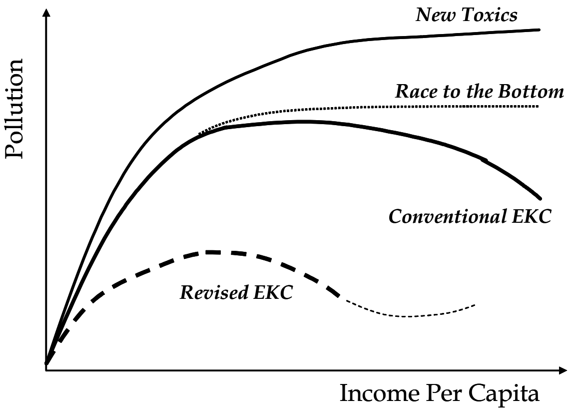
More in general, economic growth in affluent societies tends to come largely from sophisticated technology-driven sectors centred on immaterial factors (hygiene, safety, reliability, environmental quality, design etc.). But – does this mean that the theory of dematerialization is rigorously confirmed by observations? Unfortunately not. There are quite a few loopholes, which may make its use irresponsible. For instance, materials substitution usually implies the use of other materials (e.g., plastics) and the assumption of leapfrogging in less industrialized regions presupposes a functioning technical, financial and institutional setting. Bernardini and Galli concluded in 1993 that 'while qualitatively correct, the dematerialization model is quantitatively an oversimplification.' and 'the non-transferability of the development model across successive economic expansion phases increases the uncertainty in anticipated resource consumption levels' - a conclusion which still holds.



Appendix 2-C *The Environmental Kuznets Curve (EKC)*

Richer and cleaner? In 1955 the economist Kuznets suggested that income inequality will initially increase with rising income per capita, then decline – the previously discussed bell-shaped or inverted U-curve. Research at the World Bank did not find evidence for a Kuznets curve in a 73-country 1960-1990 corrected database [73]. Instead, the data seem to indicate that overall economic growth coincides with growth in the income of the poorest segments of society: the 'trickle-down percolator' hypothesis which states that economic growth will automatically lead to a decline in poverty.

In the early 1990s a Kuznets-type relationship was hypothesized between environmental degradation and income per capita - the 'green Kuznets curve' (Grossman and Krueger 1995). Early work for the World Bank Development Report in 1992 popularized this idea. For instance, Lomborg in his book *The Skeptical Environmentalist* (2001) uses the argument. Several researchers have investigated this hypothesis in an econometrically rigorous way.



Environmental Kuznets Curve (EKC): alternative views

(after Stern 2004 a.o.)

The concept of EKC concept expresses a hypothesized relationship between indicators of environmental pressure such as material/energy consumption or environmental degradation and the level of per capita income. The EKC hypothesis states that at the early stage of economic development absolute levels of environmental pressure increase with economic growth but beyond a certain threshold of per capita income the trend reverses. This ultimately leads to less environmental pressure as the economy continues to grow at higher levels of per capita income. Its validity rests on the assumption that (i) scale effects, (ii) structural changes and (iii) changes related to input mix, technology, and productivity offset over time the physical requirements and related emissions induced by economic growth. These changes ultimately result in a negative correlation between environmental pressure and economic growth.

The common method testing the relationship between environmental pressure and economic growth is to perform regression analysis for available panel data and a polynomial model for the EKC curve such as:

$$P_{i,t} = \alpha_{i,t} + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \beta_3 Y_{i,t}^3 + \beta_4 t + \beta_5 Z_{i,t} + e_{i,t}$$

where P is the environmental pressure, Y the yearly income, α a constant (e.g., the level of environmental pressure being independent from income), β the relative importance of the explanatory variables, t the time, Z the cumulative effect of other variables influencing environmental pressure, e the normally distributed error term and i and t being the indices for time and country of study (de Bruyn 1999). This model, however, lacks asymptotic properties, i.e. for any estimated value of β_1, β_2, β_3 environmental pressure could adopt indefinite positive or negative values. To avoid this problem, Stern (2004) suggests a logarithmic transformation of a simplified EKC model in the form of:

$$\ln P_{i,t} = \alpha_{i,t} + \beta_1 \ln(Y_{i,t}) + \beta_2 \ln(Y_{i,t})^2 + e_{i,t}$$

where ln is the natural logarithm.

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73 It was hypothesized that, apart from measurement issues, political mechanisms - such as voting by the poor for redistributive taxes - and financial mechanisms - such as credit markets - are explaining this outcome.

Many authors do not deny the existence of an inverted U-shaped relation for specific contaminants, environmental impacts on a local level, or simplified environmental indicators (e.g. total land use for agricultural purposes) but question the general applicability of the EKC concept on the overall environmental pressure. This is because empirical studies do often not appropriately account for replacements or shifts of environmental impacts (see Grossmann and Krueger, 1995). As Stern (2004) points out, the EKC is essentially an empirical phenomenon, despite the fact that EKC literature is econometrically weak and lacks a sound statistical analysis. This has caused lively discussion on the empirical evidence of EKC theory. After reviewing EKC studies, several authors conclude that EKC has neither been shown to apply to all pollutants nor to the total resource throughput of modern economies (Spangenberg, 2001, Stern, 2004). While applying statistical techniques, Perman and Stern (2003) found that the EKC does not exist. Spangenberg (2001) concludes that emissions of most pollutants and waste flows are monotonically rising with income and that the EKC hypothesis is only applicable for specific pollutants where pollution reduction strategies are related to point source end of pipe abatement. It is therefore questionable whether a simple and predictable relationship as it is proposed by the EKC per se exists between environmental impacts and per capita income. Consequently, although turning points can be identified for a number of environmental impacts and specific pollutants, the EKC hypothesis narrows the view on the relation between economic growth and the environment and should hence not be generalized as law of economic development (Spangenberg, 2001).

Thorough analysis shows that various hypotheses about the relationship between pollution and income can be defended on the basis of the available empirical data. For each of these, explanatory mechanisms have been suggested: economies of scale in abatement techniques, more strict regulation as people become more affluent, changing sector structure in the economy, changing trade patterns and others. Understandably, results of econometric analysis depend on how pollution is defined and measured and on the specification of proximate and underlying causes. Using urban pollutant concentration, for instance, leads to a different conclusion than using sulphur- or carbon dioxide emissions. There are also various statistical problems to be resolved. Stern (2004) concludes that ‘the only robust conclusion from the EKC literature appear to be that concentrations of pollutants may decline from middle income levels, while emissions tend to be monotonic in income’ and ‘the majority of studies have found the EKC to be a fragile model suffering from severe econometric misspecification… it seems unlikely that the EKC is an adequate model of emissions or concentrations.’ (Stern, 2004: 1426; 1431,1435).

Appendix 2-D *Input-output formalism and structural change*

The economic process can be represented as a series of transactions within a certain time period among identifiable/measurable subsets of societal actors, such as manufacturers, consumers etc. In its earliest form this is the input-output (I-O) representation introduced by Leontief. Its core matrix was the one with monetary deliveries between industrial sectors. In an attempt to link these data to physical flows, they have been widely employed in combination with material and energy flows to calculate the direct and indirect physical flows associated with monetary transactions and expenditures. The results of such analyses have yielded important insights in the relation between physical and monetary flows (see e.g., Hoekstra, 2003, Vringer, 2005). The original monetary I-O table (MIOT) is for this purpose split into a supply and use table and extended with details on environmental in- and outputs and on final demand categories [74]. If the units are, partly or wholly, physical - such as energy or mass but it can also be steelmass or watervolume or person-hours - the system is called a physical I-O table (PIOT). Many monetary and physical I-O tables have been constructed and used to investigate the phenomena of structural change and economy-environment interactions. An important application is the forward projection of the world economy on the basis of adjusted technical I-O-coefficients has been made by Duchin and Lange (1995).

Another extension of the conventional I-O table is the inclusion of information on the primary factors - such as details on the wage and age structure of the labour force - and on the final demand categories - such as demographic information on households and details on government expenditure categories (see e.g., Duchin and Hubacek, 2003). Such a Social Accounting Matrix (SAM) may be a good starting point to understand more in-depth how the economic structure is linking production and consumption. It may also provide a framework for the analysis of the value added in the labour involved in exchanges outside the formal monetary economy (illegal, criminal) and in households and the services done as part of the build-up and maintenance of 'social capital'. In such a way, rather intuitive notions such as about the importance of trust and job security for a socially stable society - and thus for sustainable development.

In principle, the I-O-formalism is most suitable to investigate the course of economic development, in particular its longer-term structural change. As has been discussed in paragraph 2, the question of structural change is still ambiguous - at least at the aggregate level at which it is often analysed. An in-depth analysis is hampered by lack of I-O-data for longer time-periods and sufficient sectoral detail - but even then the dynamics of economic development with its changing consumer habits, innovations, government regulations and trade patterns is a complex moving target.

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[74] The latter is an extension converts the I-O table into what is known as a social accounting matrix (SAM).

APPENDICES CHAPTER 3: SECTOR STUDY INDUSTRY

Appendix 3-A *Intensity of Use Curves and Per Capita Materials Consumption*

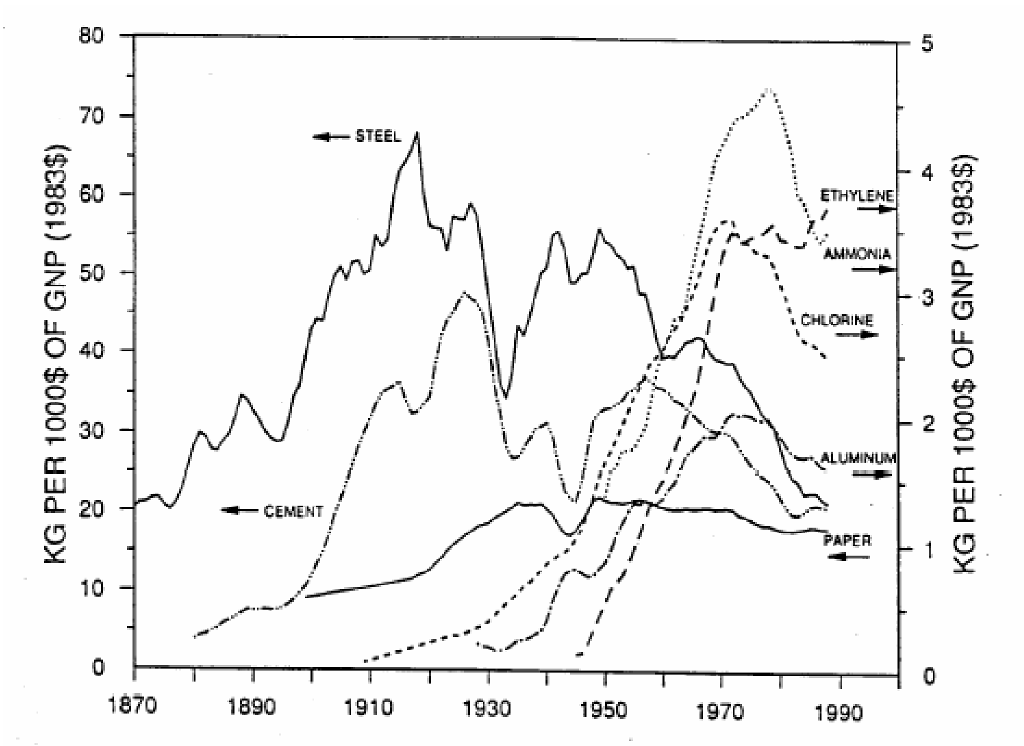

Figure 3-A.1. Intensity of use curves for bulk materials in the USA (Larson, 1991)

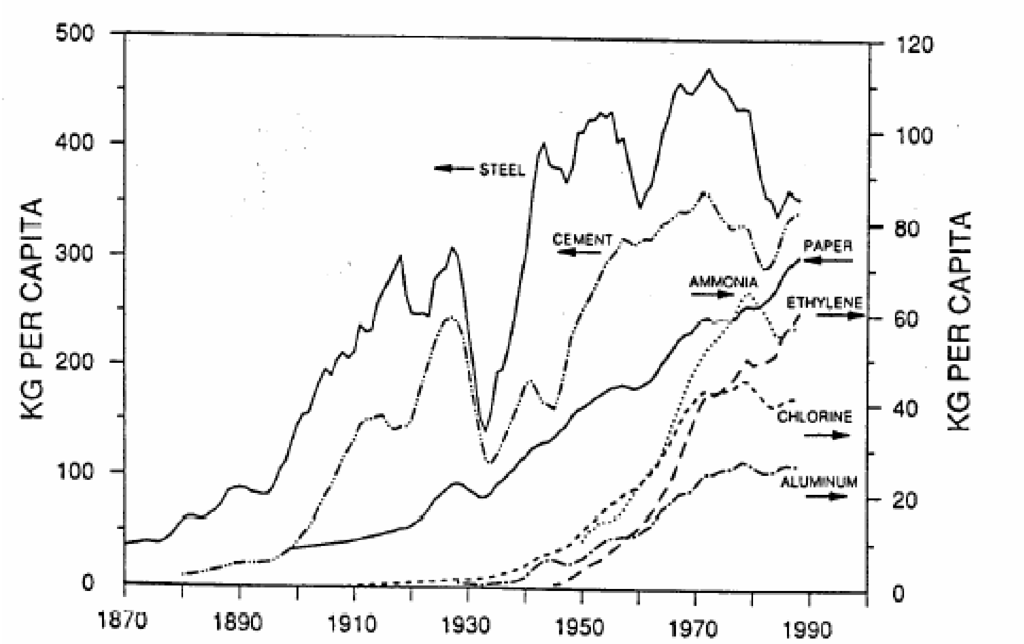

Figure 3-A.2. Per capita consumption of bulk materials in the USA (Larson, 1991)

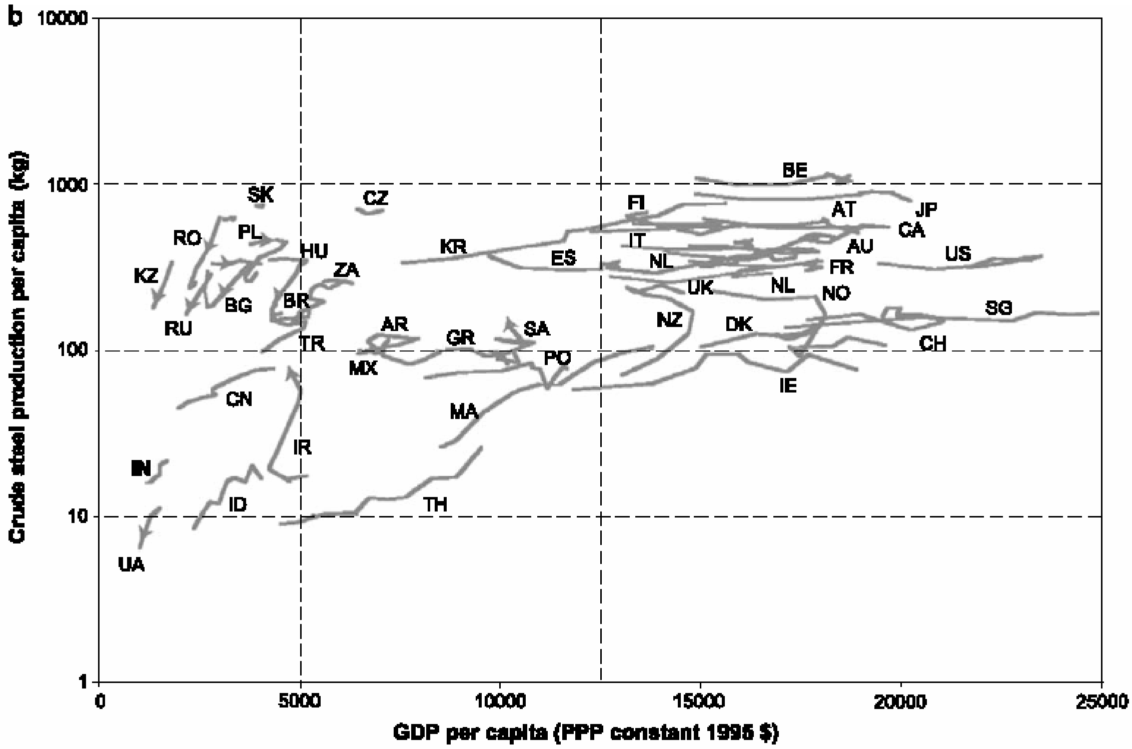

Figure 3-A.3. Per capita steel production (Groenenberg et al., 2005)

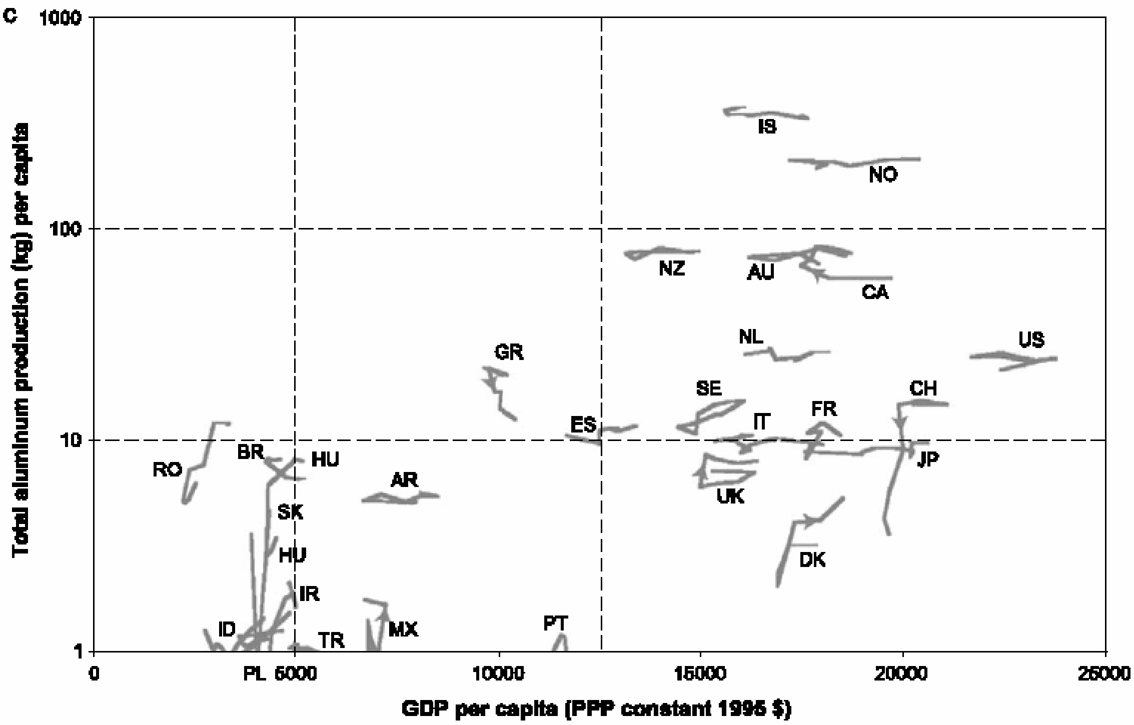

Figure 3-A.4. Per capita aluminium production (Groenenberg et al., 2005)

Appendix 3-B *Sector Classification*

Table 3-B-1. Economic sectors and countries covered by the GGDC data base (GGDC, 2005)

Number	Sector
1	Agriculture
2	Forestry
3	Fishing
4	Mining and quarrying
5	Food, drink & tobacco
6	Textiles
7	Clothing
8	Leather and footwear
9	Wood & products of wood and cork
10	Pulp, paper & paper products
11	Printing & publishing
12	Mineral oil refining, coke & nuclear fuel
13	Chemicals
14	Rubber & plastics
15	Non-metallic mineral products
16	Basic metals
17	Fabricated metal products
18	Mechanical engineering
19	Office machinery
20	Insulated wire
21	Other electrical machinery and apparatus
22	Electronic valves and tubes
23	Telecommunication equipment
24	Radio and television receivers
25	Scientific instruments
26	Other instruments
27	Motor vehicles
28	Building and repairing of ships and boats
29	Aircraft and spacecraft
30	Railroad equipment and transport equipment
31	Furniture, miscellaneous manufacturing; recycling
32	Electricity, gas and water supply
33	Construction
34	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
35	Wholesale trade and commission trade, except of motor vehicles and motorcycles
36	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
37	Hotels & catering
38	Inland transport
39	Water transport
40	Air transport
41	Supporting and auxiliary transport activities; activities of travel agencies
42	Communications

Table 3-B-1 (continued). Economic sectors and countries covered by the GGDC data base (GGDC, 2005)

Number	Sector
43	Financial intermediation, except insurance and pension funding
44	Insurance and pension funding, except compulsory social security
45	Activities auxiliary to financial intermediation
46	Real estate activities
47	Renting of machinery and equipment
48	Computer and related activities
49	Research and development
50	Legal, technical and advertising
51	Other business activities
52	Public administration and defense; compulsory social security
53	Education
54	Health and social work
55	Other community, social and personal services
56	Private households with employed persons
57	Extra-territorial organizations and bodies

Table 3-B-2. Manufacturing sectors and key products thereof covered by this analysis

ISIC rev 2 Code	Manufacturing Sector	Key Product
331	Wood and products of wood and cork	Wood
341	Pulp, paper, and paper products	Paper
35 (351+352)	Chemicals	Total feedstock use
36	Non-metallic mineral products	Cement, Bricks
37 (371+372)	Basic metals	Crude Steel, Aluminium

Appendix 3-C *Data Sources – Value Added Analysis*

Table 3-C-1. Data sources for physical production and value added of the respective industrial sectors

ISIC rev 2 Code	Manufacturing Sector	Physical Production, Time Period (Chateau at al., 2005)	Source of Value Added Data
331	Wood and products of wood and cork	North America: Wood (1979-2000) Europe: Wood of EU-33 (1979-2000) South Asia: Wood (1979-2000) China: Wood (1980-2000)	North America: GGDC (2005) Europe (Data for EU15): GGDC (2005) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
341	Pulp, paper, and paper products	North America: Paper and paperboard (1979-2000) Europe: Paper and paperboard of EU-33 (1979-2000) South Asia: Paper and paperboard (1979-2000) China: Paper and paperboard (1980-2000)	North America: GGDC (2005) Europe (Data forEU-15): GGDC (2005) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
351	Industrial Chemicals	North America: Total feedstock use (1979-2000)* Europe: Total feedstock use of EU-15 (1979-2000)* South America: Total feedstock use of India (1979-2000)* China: Total feedstock use (1985-2000)*	North America: UNIDO (2006) Europe (Data for EU-15): UNIDO (2006) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
352	Other Chemicals	North America: Total feedstock use (1979-2000)* Europe: Total feedstock use of EU-15 (1979-2000)* South America: Total feedstock use of India (1979-2000)* China: Total feedstock use (1985-2000)*	North America: UNIDO (2006) Europe (Data for EU15): UNIDO (2006) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
36	Non-metallic mineral products	North America: Bricks (1979-2000) Europe: Bricks of EU-33 (1979-2000)	North America: GGDC (2005) Europe (Data for EU-15): GGDC (2005)
36	Non-metallic mineral products	North America: Cement (1981-2000) Europe: Cement of EU-33 (1981-2000) South Asia: Cement (1981-2000) China: Cement (1981-2000)	North America: GGDC (2005) Europe (Data for EU-15): GGDC (2005) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
371	Iron and Steel	North America: Crude Steel (1979-2000) Europe: Crude Steel of EU-33 (1979-2000) South Asia: Crude Steel (1979-2000) China: Crude Steel (1979-2000)	North America: UNIDO (2006) Europe (Data for EU-15): UNIDO (2006) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)
372	Non-ferrous Metals	North America: Aluminium (1981-2000) Europe: Aluminium of EU-33 (1981-2000) South Asia: Aluminium (1981-2000) China: Aluminium (1987-2000)	North America: UNIDO (2006) Europe (Data for EU-15): UNIDO (2006) South Asia (Data for India): UNIDO (2006) China: UNIDO (2006)

* feedstock use data derived from IEA (2005)

Table 3-C-1 (continued). Data sources for physical production and value added of the respective industrial sectors

ISIC rev 2 Code	Manufacturing Sector	Unit of Value Added Data	Applied Deflators (Source)
331	Wood and products of wood and cork	North America: current US $ Europe (Data for EU15): current EUR South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators (GGDC 2005) South Asia (Data for India): 1995 US deflators (GGDC 2005) China: 1995 US deflators (GGDC 2005)
341	Pulp, paper, and paper products	North America: current US $ Europe (Data forEU-15): current EUR South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators (GGDC 2005) Europe (Data forEU-15): 1995 EU-15 deflators (GGDC 2005) South Asia (Data for India): 1995 US deflators (GGDC 2005) China: 1995 US deflators (GGDC2005)
351	Industrial Chemicals	North America: current US $ Europe (Data for EU-15): current US $ South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) South Asia (Data for India): 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) China: 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005)
352	Other Chemicals	North America: current US $ Europe (Data for EU15): current US $ South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) Europe (Data for EU15): 1995 EU-15 deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) South Asia (Data for India): 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005) China: 1995 US deflators for chemicals, ISIC rev 2 code 35 (GGDC 2005)
36	Non-metallic mineral products	North America: current US $ Europe (Data for EU-15): current EUR	North America: 1995 US deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005)
36	Non-metallic mineral products	North America: current US $ Europe (Data for EU-15): current EUR South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005) South Asia (Data for India): 1995 US deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005) China: 1995 US deflators for non-metallic mineral products, ISIC rev 2 code 36 (GGDC 2005)
371	Iron and Steel	North America: current US $ Europe (Data for EU-15): current US $ South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) South Asia (Data for India): 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) China: 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005)
372	Non-ferrous Metals	North America: current US $ Europe (Data for EU-15): current US $ South Asia (Data for India): current US $ China: current US $	North America: 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) Europe (Data for EU-15): 1995 EU-15 deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) South Asia (Data for India): 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005) China: 1995 US deflators for basic metals, ISIC rev 2 code 37 (GGDC 2005)