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Decoupling of CO_2 Emissions from Energy Intensive Industries

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Contents

Preface

This report was prepared by the Department of Policy Analysis at the National Environmental Research Institute (Denmark) as a contribution to the "Decoupling Project", initiated by the Working Group on Environment and Economics (WGEE) under the Nordic Council of Ministers. The members of WGEE are representatives from the Ministries of the Environment, and the Ministries of Economic Affairs and Finance in the Nordic countries.

Prof. Mikael Skou Andersen, together with Martin K. Enevoldsen and Anders Ryelund, are the authors of the report, while Carey E. Smith and Ann-Katrine Holme Christoffersen were involved in the editing.

The data compiled for the decoupling analysis was kindly provided by the Statistical Agencies of the Nordic countries. We would like to thank Agnes Nansen Urup, Klaus Balslev Pedersen and Casper Larsen, Statistics Denmark, Kari Grönfors, Matti Lång and Pihlaja Heikki, Statistics Finland, Niels Petter Skirstad and Dag Spilde, Statistics Norway; Niklas Notstrand, as well as Jonny Hall, Barbro Olsson and Maja Larsson, Statistic Sweden for their assistance and collaboration. We are also grateful for assistance from Eilev Gjerald and Marit Viktoria Pettersen, Norwegian Pollution Control Authority and Jarmo Vehmas, Turku School of Economics and Business.

Comments and suggestions on the report were provided by members of WGEE, but the final responsibility rests with the authors. It should also be noted that the Nordic governments do not necessarily support all views and considerations that appear in the report.

WGEE has expressed that the report provides useful data and information on the question of decoupling and CO_2 emissions, and hopes that the report will be well-received in this respect, by policy-makers, energy sector specialists and the general public alike.

More information on WGEE is available at the Nordic Council homepage at: http://www.norden.org/miljoe/Miljo-okonomi/sk/index.asp

Copenhagen, March 2006
Jørgen Schou, Chairman

Summary

The puzzling question remains whether environmental improvements are possible without sacrificing some degree of economic welfare. The concept of decoupling seems to suggest that this is indeed the case; that economic output can be increased, while at the same time the use of the environment as source and sink for economic activity can be decreased.

A classical article by Leibenstein (1966) provides an economic rationale for decoupling by establishing a distinction between ordinary allocative efficiency and the more subtle concept of "X-efficiency" (incentive-efficiency). Leibenstein suggests that much of the growth in the economy stems from improvements in incentives to perform better, rather than in improved allocation of productive factors. There is ample anecdotal evidence of attained productive improvements in energy efficiency to suggest that "free lunches" do indeed exist in certain circumstances. Leibensteins concept helps us understand why company energy-use is not always situated at the outermost bound of the productivity curve.

In this report we have investigated ten industrial sectors, both energy intensive and less energy intensive, to analyse whether decoupling between gross value added and carbon-energy emissions occurred during the 1990's and the extent to which any such decoupling can be explained by the incentives provided in terms of carbon-energy taxes in the Nordic countries.

For Norway, Denmark and Finland half or more of the industrial sectors experienced decoupling between economic growth and CO_2 emissions between 1990 and 2001. The predominance of coupling rather than decoupling in Sweden, on the other hand, appears to be related to the economic difficulties of the early 1990s in several industrial sectors. The time-series data suggests that sectors in economic decline have difficulties in adjusting to the incentives from carbon-energy taxation. Successful decoupling seems to require some level of economic growth to allow for renewal within process and energy technologies. This observation is in accordance with recent economic theories on endogenous growth.

The dataset employed for the analysis is unique in that sector-specific energy prices and taxes have been obtained. Previous analyses have relied on average energy prices and have neglected the existence of rebates and discounts for large energy consumers. Previous research has also been unable to account for the complex exemption schemes that characterise carbon-energy taxes for energy intensive industries. The data established here, as provided by the Statistical Services in the Nordic countries, allow us to improve the elasticity estimates, which are useful when considering the impact of price changes on energy consumption. The cross- and own

price elasticities are relevant not only for proper assessments of carbon-energy taxes, but also for any other price change, e.g. as caused by requirements for greenhouse gas emission permits or through market volatility.

In considering the impact of taxes on energy consumption and carbon emissions, an analytical approach has been employed whereby the impact of gross price changes – including taxes – on energy consumption has been analysed. In the panel regression analysis of the report a high explanatory power characterises the impact of price changes on energy consumption. The results are relatively uniform across the Nordic countries, indicating that the elasticities might be valid also for Finland, where sector-specific energy prices and taxes could not be established.

In the sectoral analysis statistically significant relations with a good explanatory power is found for the consumption of five fuels. The own-price elasticity of oil and coal, as well as of waste energy, are relatively high (-0,4 to -0,6), indicating that consumption of these fuels are highly price elastic. On the other hand electricity and gas were found to be somewhat less price elastic (-0,1 to -0.3). This is in accordance with previous studies that have reported modest price elasticities for electricity consumption. For gas the results are more surprising, but may relate to the long-term contracts typical for the fuel. Previous studies may have failed to separate out waste energy from gas. The results here indicate that creating a price advantage in favour of low-carbon waste energy forms is a sound CO_2-strategy.

The own price elasticity of energy factor demand is in the range of -0,35 to -0,44 for Norway, Sweden and Denmark, which indicates that carbon-energy taxes induce considerable reductions in energy consumption – either via shifts to labour demand, energy efficiency or through lower activity. The identified elasticities for energy factor demand are in line with other recent studies based on advanced panel regression econometrics. This evidence and the findings presented here mount to the conclusion that earlier reported energy factor elasticities of around –0,25 or less are underestimated.

Hence, by imposing CO_2 taxes (or quotas) that increase the real price of energy by, say, 10%, industrial energy consumption will be reduced by some 4%. On top of such reductions come fuel switches, that lower carbon emissions. The report provides fuel price elasticities, which allow for future calculations.

1. Introduction

On the occasion of the international 1988 Toronto conference on global climate change, governments in the Nordic countries were quick to react to the gloomy prospects of global warming by announcing unilateral policies to reduce CO_2 emissions as well as to decouple economic growth from use of fossil fuels. The Toronto conference recommended, as a first step, a 20% reduction in CO_2 emissions, an interim target that was adopted by several countries in the early 1990s. While the need for development of new energy technologies was obvious, economic instruments were believed to provide a first stimulus to the market to think in terms of alternatives to fossil fuels.

Finland was the first country to actually introduce a CO_2 tax, which became effective as early as 1990. However, in its 1989 proposal for environmental tax reform the Swedish government outlined an increase in energy taxation with a new separate tax on CO_2, which was introduced in 1991. Also Norway introduced a CO_2 tax in 1991, while Denmark, after obtaining EU approval, followed suit with a tax that became effective in 1993. (Iceland has access to geothermal energy and limits its use of fossil fuels to the transport sector).

The initial tax rates were low and many exemptions were introduced to avoid undesirable competitiveness effects, as countries outside the Nordic region hesitated in introducing similar measures. After a few years Sweden had to lower its rather high rate of combined carbon-energy taxation for industries. Denmark started to tax industrial CO_2 emissions only from 1993 cautiously, phasing in the tax rates gradually up until the year 2000. Despite the cautious approaches in the years immediately after introduction, CO_2 tax rates were gradually increased during the 1990s in the four Nordic countries where the taxation applied. This development was supported by the growing recognition of global warming as a pressing issue, and by the steady extension of carbon taxation in several other countries outside the Nordic region, including Germany, the Netherlands, UK, Poland, Italy, Slovenia and Estonia. The Nordic countries had managed to set an example, and others followed suit.

The Toronto conference initiated the political process that, via a series of negotiations, led to diplomatic agreement on the Climate Convention protocol in Kyoto in 1997. With the ratification of the Kyoto protocol by Russia the implementation of the reduction targets agreed for 2012 have now become binding. This means that member states are now carefully considering policies and measures available for CO_2 reductions, and are studying their properties as well as their economic implications. Not least, concerns about the relationship between improving competitiveness and improving carbon emission performance lie at the heart of policy-making.

The publication of this report from the "Decoupling Project" of the Working Group on Environment and Economics of the Nordic Council of Ministers is timely in view of these developments. The overall purpose of the Decoupling Project is to improve our understanding of the processes that may help decouple economic growth from environmental pressures and secure successful economy-environment integration. The present report addresses, in an ex-post perspective, the role and impact of the Nordic CO_2 taxes on industry, particularly energy-intensive industries. The main emphasis is on exploring the relationship between tax/price changes, on the one hand, and decoupling from CO_2 emissions on the other, while issues of competitiveness have not been investigated here.

With experiences from a full decade, time is now ripe for an all-Nordic assessment, providing insights on the elasticity of price changes and on possible barriers with regard to using price signals in energy markets. In a previous report (Andersen et al., 2001), individual evaluation studies from the Nordic countries were reviewed, but in this report a cross-Nordic analysis is provided, on the basis of a comprehensive database built for the purpose of the Decoupling Project.

To reap the full benefits from a market-oriented approach in climate change mitigation policy, our understanding of the interplay between price signals, market institutions and policies needs to be improved. Many of the standard assumptions on the impacts of using tax signals have been challenged in the policy debates over the past decade. This report intends to provide a firmer basis for such debates by exploring the data now available. However, before proceeding to the empirical analysis, the report provides a brief theoretical overview of the decoupling debate.

2. Decoupling, eco-efficiency and environmental taxation

Since Ernst Ulrich von Weizsäcker introduced the notion of *decoupling* (Weizsäcker, 1989; originally *delinkage*), the concept has achieved global recognition as a significant conceptualisation of successful economy-environment integration. The decoupling of environmental pressures from economic growth has become a desired policy outcome, whether in climate policy or in a wider context. The UK government, for instance, in its recent strategy paper on Sustainable Production and Consumption sets out a first set of *decoupling indicators* to measure progress on improved efficiency in material and energy use.

The OECD, which uses decoupling as a success criterion in its *environmental performance reviews* for member states, distinguishes between "absolute" and "relative" decoupling (OECD, 2002). Absolute decoupling refers to a development where the environmentally relevant variable is stable or decreasing, while the economic driving force (e.g. GDP) is growing. Relative decoupling is said to occur where the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variable. Decoupling is measured by means of the use of indicators which have an environmental pressure variable as numerator and an economic variable as denominator. Use of decoupling indicators frequently takes place within evaluations in the DPSIR framework (*Drivers-Pressures-State-Indicators-Response*).

Despite the extensive use of decoupling as an indicator for successful environmental performance, a remarkable absence of explicit analytical consideration of the causes and effects behind the emergence of decoupling in the settings where decoupling is observed, is evident. This project investigates the extent to which decoupling of carbon emissions from economic activity in energy-intensive industrial sectors has occurred in the Nordic countries. The project, moreover, seeks to reveal the nature of the role of carbon energy taxation in decoupling. Two main schools of thought dominate in the theoretical literature; one deterministic, which asserts that decoupling will result in any case due to internal transformation mechanisms in industrial society, and one more voluntaristic, which claims that decoupling is contingent upon specific policies and measures.

The existence of the environmental Kuznet's curve has been debated within the environmental economics literature. Kuznet's curve takes the shape of an inverted U; it implies that emissions in a country first increase with GDP, but then, after some time, decoupling occurs such that while GDP continues to increase, emissions are "decoupled" and decline.

The mechanism behind this curve is not generally stated explicitly, however, it is sometimes mentioned that preferences for more environmental goods, resulting from increased affluence, provide pressures to control emissions. Environmental Kuznet's curves have been identified, for instance, for sulphur dioxide. Much of the Kuznet's curve debate has focused on the implied relationship between "getting rich" and "getting clean" – whether an increase in GDP is a precondition for environmental improvement.

In the sociological literature, advocates of ecological modernisation theories (Huber, 1982; Mol, 1995; Mol and Sonnenfeld, 2002), tend to argue in a similar vein that decoupling will emerge *in any case,* as a result of the internal transformation dynamics of industrial society. Scarcity of environmental resources, including absorption capacities - "sinks" - forces actors to improve eco-efficiency, as well as to move forward to "leaner and cleaner" modes of production. Their position is supported by the improvement in energy and material intensities, observed in recent decades in many industrial sectors. The term ecological modernisation is used to denote a new phase in industrial modernisation; one with emphasis on more efficient and cleaner modes of production.

Critics concur with these perceptions and lament that decoupling represents, in fact, little more than business-as-usual within the contemporary market economy (cf. Hukkinen, 2003). The "lean-and-clean" principles of eco-efficiency are not inconsistent with the principles advocated by Henry Ford and F Taylor at the beginning of last century. Accordingly, these founding fathers of the industrialised economy focused not only on improving labour productivity, but, more broadly, on attaining, "the smallest *combined* efforts of human effort, plus *nature's resources* plus the cost for the use of capital in the shape of machines, buildings etc." (Taylor, 1911: 11-12). The utilitarian ethic of efficiency is merely extended to comprise the use of nature's resources, whether as an element in the production function or as a sink for its external effects.

The other more voluntaristic school of thought on decoupling finds its theoretical origins in the Porter hypothesis (Porter, 1991). The argument here is that in order to attain the improvements in efficiency, there is a need for regulators to intervene. Many adherents of the Porter hypothesis interpret it to imply that any type of environmental regulation can represent a driver for improved efficiency. However, Porter (1991), in fact, maintains that only incentive-based environmental regulation, which internalises external costs within the market, will be effective in achieving a decoupling from economic growth. The requirements for more efficiency in the use of nature's resources, whether in terms of prices or quotas, will spur the types of technological innovations that can pave the way for a process of decoupling. These, in turn, will feed back to improve the competitiveness of firms and sectors which have been able to innovate.

The notion of this "double dividend" forms the essence of the voluntaristic school of thought on decoupling. The double dividend is the hypothesis that it is possible to both improve the environment and to increase employment – the means for which must be the decoupling of economic growth from use of nature's resources. The double dividend argument, in fact, stems from Pearce (1991), who introduced the possibility of a *second* dividend from a carbon tax. The argument was that, while the environmental effects from carbon taxation were rather uncertain (due to the global increase in greenhouse gas emissions and, in any case, due to the long-term nature of the collective good in question), a more short-term second dividend would seem likely if carbon taxes would encourage manufacturers to improve efficiency by innovation. Attaching a price to using the atmosphere as a sink for gases from burning fossil fuels as part of economic activity would represent the lever to bring about decoupling.

Pearce's notion of decoupling links with a comprehensive body of literature on the use of economic instruments for the purposes of environmental policy-making. Conventionally, the use of both taxes and quotas (emissions trading) have been seen as means with identical properties, in that both instruments serve to establish a price on emissions which will help achieve decoupling. Recent contributions to the debate (Fischer, in press) do, however, distinguish between the innovative potentials of taxes and quota allowances, respectively. In the case of a uniform tax on emissions, an incentive arises for all polluters to continuously improve their technology so as to achieve the most efficient balance between abatement measures and tax payments. If a company in the front-line develops a new technology, it will be of interest to others. In the case of "grandfathered" allowances, however, there will be incentives that tend to counteract the adoption of new technologies by others. The total available quota is determined by the cap, so the availability of new and more effective technologies will depreciate the value of marketed allowances, causing the balance between abatement and price incentive to come to differ from that of the emissions tax.

Not withstanding potential differences between command-and-control arrangements, allowable quotas and environmental taxes, it seems fair to state, in terms of the decoupling debate, that it is the option of internalisation which provides the *prima facie* case for decoupling.

Whether there really is such a thing as a "free lunch", as is implied by the Porter hypothesis, is doubted by many economists (Porter & van der Linde, 1995). If such gains are worthwhile in the first place, why would firms not take advantage of them without regulation? What appear to be cost-savings in response to regulations will potentially be offset by full accounting of the transaction costs involved (e.g. for management, information gathering and reorganisation). There is also widespread scepticism as to whether it is really possible to achieve two targets with just one instrument, as such a possibility runs counter to established wisdom, that there needs to be one instrument for each target (cf. Tinbergen, 1952).

However, some suggestions have been put forward to explain how "win-win" situations might arise (Andersen and Dengsøe, 2002). Environmental performance may well be placed low in the attention hierarchy and public policies may help firms overcome internal coordination failures that hinder them in reaping the full benefits from more efficient operation. In this case, even a small tax would serve as a "reminder" to businesses to help shift some focus onto activities in the periphery of the conventional sphere of attention. That the double-dividend may actually be in need of a double instrument is implied by that part of the literature which advocates the earmarking of tax revenue for revenue recycling operations.

The problem with much of the debate on the double dividend hypothesis is that it narrows the debate on efficiency down to one of simply allocative efficiency. The proposal in the Delors white paper (CEC, 1993) to shift taxation from labour to pollution and natural resources, indeed, was conceived within a conceptual framework of improved allocative efficiency resulting from a change in input factors. However, what Porter and others seem to be addressing may be regarded rather as *incentive* efficiency.

In a landmark article, Berkeley economist Leibenstein (1966) proposed to distinguish so-called X-efficiency from traditional allocative efficiency. While allocative efficiency addresses the optimal combination of productive resources, X-efficiency addresses the optimal use of the individual factor of production. Leibenstein discussed whether labour was always used optimally, citing extensive evidence for productivity improvements achieved in the use of labour. The scope for such improvements would normally be assumed away by neoclassical theory's assumption of optimality and rationality in the management of firms. Yet, in the issue of monopoly regulation, the welfare improvements from X-efficiency could be justified theoretically and empirically to be of a much larger scale than simple allocative efficiency gains. Leibenstein provided a number of reasons why managers and employees would prefer not to produce at the outermost bound of optimality, e.g. to avoid the required effort and pain of full efficiency. "It is one thing to purchase or hire inputs in a given combination, it is something else to get a predetermined output out of them" (Leibenstein, 1966:408). The magnitude of the possible improvements in incentive efficiency is represented by an unknown factor X, the reason why Leibenstein introduced the concept under the label of X-efficiency. However, he suggested that X-efficiency accounts for a great deal of the unexplained residual in economic growth.

Much of the anecdotal evidence on inoptimal energy use in the management of firms cited in support of the Porter hypothesis is similar to the evidence on the use of labour that accumulated in the literature following

Leibenstein's hypothesis. There are several good reasons why companies would not be rational and optimal in their use of energy as an input factor, and these reasons go beyond simple transaction costs of gathering the necessary information and undertaking the required technical changes. They relate to the degree of slack in human behaviour and in company operations, and the failure to mobilise all the knowledge which is embedded in an organisation. Energy will be squandered away as long as prices are relatively modest compared with other input factors such as labour and capital, but once outside pressure is introduced the companies will be motivated to mobilise the knowledge and technology available so as to control unit costs. Out of such a process, the innovations may evolve which may improve economic efficiency and competitiveness.

When considering the differences between the Kuznet's curve argument and the Porter hypothesis more carefully, some overlap can be noted. In both cases decoupling is expected to occur. While the former ascribes such trends to autonomous market dynamics, the latter stresses more the need to manipulate price mechanisms through policy measures such as environmental taxation. When, in the following, the experiences of the Nordic countries with regard to CO_2 taxation are reviewed ex-post, the emphasis is on whether decoupling has been achieved as a result of such policies.

3. Methodological considerations

The present study focuses on decoupling in the manufacturing industry. The reason for such a focus is both the potential significance of successful economy-environment integration in this sector, as well as the considerable policy uncertainties in this sector regarding the impacts of energy price changes, whether from taxation, tradable quotas or world energy price increases. Households are numerous and similar, but industries are diverse and exposed to competition from abroad, so that a good understanding of how the energy market functions and can potentially be influenced seems to be a precondition for a successful development in this regard.

The study is based on a sectoral approach, where 10 energy-intensive and less energy-intensive sectors at NACE 3 digit level have been selected. The reason for the choice of a sectoral approach is found in the format of data available at statistical census agencies.

Decoupling is understood as the disconnection of the environmental pressure variable from the economic performance variable. As we are interested in decoupling mainly from a carbon tax perspective, the obvious environmental pressure variable is CO_2 emissions. The CO_2 emissions are fuel-dependent, however, so the CO_2 variable is a direct function of the fuel mix. For this reason it has been necessary to build the analysis on data for energy consumption. For economic performance, the usual choice of gross value added, which expresses the value of the commodities in monetary terms, is applied for the initial analysis.

Decoupling is in principle the dependent variable, but some difficulties arise. It follows from the previous section that there can be both relative and absolute decoupling, as well as inverse decoupling. The absolute figures for value added, energy consumption and CO_2 emissions fluctuate significantly across sectors and countries. In order to compare the differences in the development of these variables it is necessary to set up time-series index with a common base-year for these variables. This approach raises an additional problem. The achieved decoupling trends are to some extent base-year dependent. Whether - and in particular the extent to which - a particular sector can be said to have achieved a decoupling of environmental pressures from economic performance during the 1990s often depends critically on the base-year chosen for the analysis.

CO_2 intensity is the relationship between CO_2 emissions and gross value added. However, a reduction in CO_2 intensity is not a clear-cut indicator for a successful economy-environment decoupling - reduced CO_2 intensity can also reflect the simultaneous decline of both the environmental pressure indicator and the economic performance indicator.

Decoupling is not simple to operationalise, without losing information, and for this reason we shall consider the three variables of gross value added, energy consumption and CO_2 emissions in detail.

The independent variable affecting decoupling and of interest here is, in principle, CO_2 taxation, but as policymakers have frequently shifted between various types of energy tax and mixed energy taxes with CO_2 taxes, the independent variable becomes, in practice, the broader set of carbon-energy taxes. For instance, when Sweden introduced its CO_2 tax, the tax partly replaced previous energy taxes - so if the analysis neglected the previous level of energy taxation it would overstate the significance of the CO_2 tax. Finland has shifted between pure and mixed carbon-energy tax-bases during the 1990s, so that focus only on the pure CO_2 tax component would be highly biased.

The choice of carbon-energy taxes as the real independent variable has some repercussions with regard to the operationalisation of the dependent variable's environmental pressure component. The use of CO_2 emissions as environmental pressure variable is less meaningful when the independent variable is the combined level of carbon-energy taxation. As far as the basic dependent variable in the statistical analysis is concerned, it is mainly energy consumption which is employed. Since CO_2 emissions are calculated from the fuel mix in energy consumption there are few additional data needs, however, the dualistic character of the environmental pressure variable (CO_2 and energy use) is important to keep in mind.

The basic research question is how the possible impacts of carbon-energy taxation on energy consumption can be disentangled. Obviously it would be a complex task to disentangle the effects ex-post, as many other variables are at play.

First of all, there are impacts from price changes other than those caused by changes in carbon energy taxes. Oil prices go up and down as do electricity and other fuel prices, e.g. as a result of energy sector liberalisation. To control for such impacts it becomes necessary to study energy consumption as a function of price changes as a whole, including the effect from carbon-energy taxes, which is the approach adopted here. This is not a simple undertaking as energy prices, to some extent, vary between different consumers so that sector-specific energy prices need to be obtained for the complete analysis.

Once data have been established for such an analysis further questions and influences need to be considered. Energy is not a homogenous product, but consists of different types of fuels - analysis reduces the complexity to main categories including electricity, coal, natural gas, LPG, light fuel oil/gas oil, heavy fuel oil and waste. Prices fluctuate differently for different fuels, so both consumption and substitution effects will arise as a result of price changes.

In addition there are confounders such as;

- *Energy infrastructure:* The basic energy infrastructure (such as distribution grids for gas) which depends on political decisions and affects the options for companies to freely select their energy source.
- *Long term contracts on energy:* Energy supplies in industrial companies are often bought on contracts in order to decrease price and increase security of supply, which may prevent short-term adjustments.
- *Energy capital requirements:* The transformation process requires energy capital such as boilers, engines, electric motors, etc. and energy capital requirements depend on the physical characteristics of the energy source and the type of industrial process.
- *Composition of energy sources:* Some industrial sectors rely primarily on a narrow range of energy sources as these energy sources have some specific physical characteristics that make them particularly suited to use by these sectors.

Figure 3.1 below provides an overview of the relations apparent in influencing CO_2 emissions and ultimately economy-environment decoupling. The report is structured in accordance with its analytical structure.

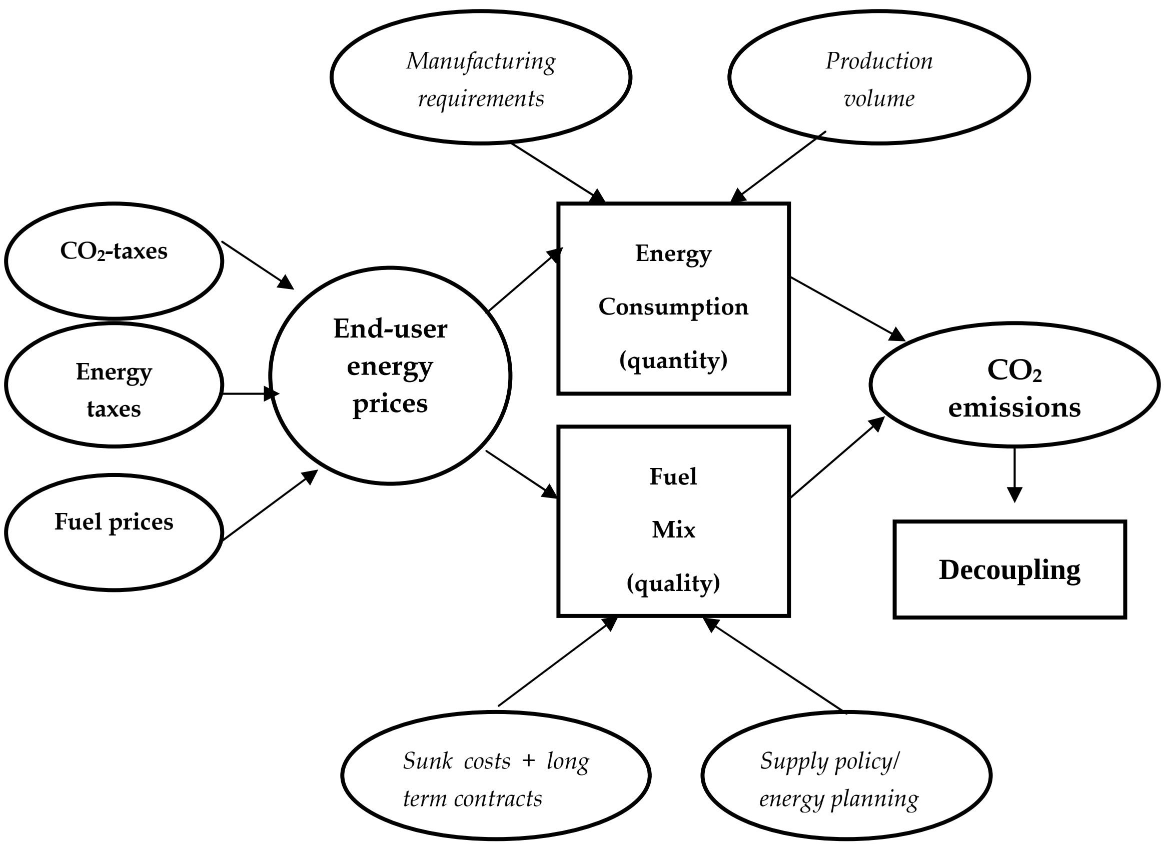

Figure 3.1. Overview of variables affecting CO_2 emissions and decoupling.

Chapter 4 provides a policy overview of CO_2 taxation policies for industries in each of the Nordic countries which have introduced this type of tax (Denmark, Finland, Norway and Sweden).

Chapter 5 presents the energy-intensive sectors selected for the analysis, and provides a benchmarking of their CO_2- and energy intensity, as well as an overview of fuel mixes sector by sector and country by country.

Chapter 6 plots the dependent and independent variables in a number of decoupling diagrams, sector by sector, with time-series from 1990-2001 - this provides a basic overview of the economic performance and the environmental pressure variables, the latter consisting of both energy consumption and CO_2 emissions.

Chapter 7 provides a panel-regression analysis of the relationship between price-changes and energy fuel consumption, with the aim of deriving own price and cross price elasticities

Chapter 8 concludes on the findings

4. CO_2 taxation in the manufacturing industry

4.1 Finland

The initial rate of Finland's 1990 CO_2 tax was low and uniform for most sectors. In 1993, the Finnish government doubled the tax rate as part of efforts to improve the Finnish economy. In the period 1994-96, the tax followed the "75/25-model", with 75% of the tax-base linked to the CO_2 content of fuels and 25% of the tax-base linked to the energy content. The European Commission raised various concerns over this system, in particular the treatment of imported electricity.

In 1997-98, the carbon energy-tax system was reformed to its present state. There is now a basic energy tax and an additional CO_2 tax. The CO_2 tax depends on the carbon content of fuels and has a rate of 17 EUR per tonne. For natural gas the rate is reduced to 50%. There is also a low rate for peat, of which the use is significant in some sectors. The basic energy tax differs according to fuel-type, but applies mainly to the transport sector and only marginally affects the manufacturing industry.

Since 1993/94, the tax has been consumption-based rather than tied to the primary sources of energy. Furthermore, the taxation of electricity changed fundamentally with the 1997-98 reform.

To protect the competitiveness of the manufacturing sector, the electricity tax for this sector is lower than for consumers in other sectors.

Part of the energy tax can be refunded for certain energy-intensive industries. If the excise taxes exceed 3.7% of the enterprise's value added, it is entitled to reclaim up to 85% of the excess amount paid, provided that this sum exceeds 50.000 EUR. In practice, the refund option is used mainly by the paper and pulp industry (about 10-12 companies).

All fuels used as raw materials are exempt from carbon-energy taxes.

4.2 Norway

Norway introduced a CO_2 tax in 1991 and the system has been relatively stable since.

The initial tax, with a rate of approximately 30 EUR, applied to the offshore industry and to the use of fuel oil. From 1992, the CO_2 tax was extended to coal. The effective rates for fuel oil and coal have been somewhat lower than the offshore-rate, about 139-183 NOK (18-24 EUR per tonne CO_2).

In the Norwegian system, the consumption of natural gas on the mainland is exempt from the CO_2 tax. Electricity is based on hydropower, and is not of relevance in relation to CO_2 taxation, however, a consumption tax does apply.

All fuels used as raw materials are exempt from carbon-energy taxes.

For the pulp production and fishmeal processing industries, the rates of the CO_2 tax are reduced by 50%.

A major reform of the energy tax system took effect in 1999. The energy taxes were converted to taxes relating to the CO_2 content of fuels, entailing certain adjustments (Nordic Council, 2002: 87).

4.3 Sweden

In 1991, Sweden introduced a CO_2 tax, which supplemented and partly replaced previous energy taxes. The CO_2 tax was uniform across sectors and fairly substantial, at around 33 EUR per tonne CO_2. This formed part of a comprehensive tax reform, which shifted the focus of taxes from labour to natural resources. A cap applied to carbon-energy taxation in energy-intensive industries, allowing for refunds if the tax burden exceeded 1.2% of sales value.

In 1993, the very high rates applied to the manufacturing industries were reduced considerably due to competitiveness concerns. The energy tax component was abolished and the CO_2 tax was reduced to 25% of the level for households, about 10 EUR per tonne. The ceiling was still in place, but applied to just 6 companies in 1996 in comparison with 112 in 1992. The six were mainly within the cement, lime and glass sectors.

From 1997, the rate was gradually increased again. From the year 2000, additional tax shifts from labour to energy taxation have been introduced. The implicit CO_2 tax rate for industry is now close to 20 EUR per tonne CO_2 or 30% of the rate for households.

The cap for energy-intensive industry has been lowered to 0.8% of sales value. The cap rule has been changed so that energy-intensive companies have to pay 24% of the tax rate on energy consumption above the cap. Above 1.2% of sales value, complete reimbursement takes place, however, only a handful of companies benefit from this exemption.

Fuels used as raw materials are generally exempt from carbon-energy taxes. Electricity production in Sweden, which is largely based on hydropower and nuclear power, is completely exempt from CO_2 taxes. For households, an energy tax applies, while industry is exempt from electricity tax in the period analysed in this study. In July 2004, however, a small energy tax was applied to industrial electricity consumption in Sweden.

Biofuels are exempt from energy and CO_2 taxes.

4.4 Denmark

Denmark was the last of the Nordic countries to introduce a CO_2 tax. After agreement in 1991, the tax took effect from 1992. Industry obtained concessions permitting a low rate in the first years of the tax, however, more comprehensive taxation was phased in for industry from 1996 with a new energy policy package. Currently, a rather complex system of tax rates is in place.

The initial rate effective for industry was about 4 EUR per tonne CO_2. From 1996, the standard rate for industrial processes was set to 7 EUR and then gradually increased further to 12 EUR per tonne CO_2 in 2000. Since 1996, taxes on energy used for industrial heating purposes, was also phased in. Industrial heating has been subject to the same tax level as households, about 80 EUR per tonne CO_2.

For a predefined list of energy-intensive industries, a lower rate of 3.3 EUR per tonne CO_2 applies for specific process purposes. This rate can be reduced even further to 0.40 EUR per tonne CO_2 for a 3-year period where formal energy agreements are reached with the national Energy Agency. About 30 industrial sectors, responsible for 1/3 of industrial energy consumption, are included on the energy-intensive list. In addition, a general clause allows any industry to benefit from agreed reductions, if the tax burden exceeds 3% of value added.

Also the standard rate for industrial processes can be reduced from 12 to 9 EUR per tonne CO_2 if energy agreements are entered into.

The number of agreements has been somewhat lower than expected. In 2001, 80 individual agreements and 3 sector agreements were in force. Nearly all agreements relate to energy-intensive industries.

The tax rates apply uniformly to the various fossil fuels employed by industry; only electricity is treated differently. Electricity is taxed according to the consumption level, while the fuels used to produce electricity are exempt from carbon and energy taxes. There is both an energy tax and a CO_2 tax on electricity.

Until 1995, industry was exempt from taxes on electricity as the taxes could be deducted via the VAT accounts. The CO_2 tax on electricity currently applies to industry, while the energy tax component can still be deducted. The rate of the CO_2 tax on electricity is 0.1 DKK per kWh or about 30 EUR per tonne CO_2. Despite the increased significance of windpower, around 83% of electricity production in Denmark still depends on fossil fuels.

Contrary to other Nordic countries, revenue from the Danish CO_2 tax has been recycled to support energy efficiency improvements. In the year 2000, 26% of the revenue was earmarked directly for such measures. From 2002, however, this support was abolished.

4.5 Comparison

It is difficult to draw general conclusions on the patterns of CO_2 taxation due to the particular peculiarities of the various national systems.

It appears that for the manufacturing industry, convergence has been around a tax level of about 20 EUR in Sweden, Norway and Finland. Denmark, with its more carbon-intensive energy sector, is well below this level, with a standard rate of about 12 EUR per tonne CO_2. Denmark also has the most comprehensive system of reductions. The rate for heating purposes, however, at 80 EUR per tonne CO_2, represents a deviation from the generally relatively low CO_2 taxation levels in Denmark.

There are several caveats to this attempt at generalisation;

Electricity: Before the EU Energy Taxation Directive Sweden and Norway have not taxed industrial consumption of electricity. This is partly due to the large share of non-fossil fuels in power production. In Finland and Denmark, where coal plays an important role in electricity generation, a consumption tax is levied. The consumption tax is levied pro rata implying that the primary use of fuels in this sector is not taxed. Fuels with lower rates or exemptions:

In Norway, consumption of natural gas on the mainland is exempt, but there is a 30 EUR tax on offshore emissions. In Denmark, the use of natural gas is exempt offshore, but taxed on the mainland.

In Finland, peat used as fuel is taxed with a low rate. Other countries do not appear to tax peat.

- Industrial sectors with reduced rates:

Sweden and Finland have placed caps on tax liability, but these only have implications for a limited number of companies - in Finland, the paper and pulp industry. In Norway, only two manufacturing industries have reduced rates; fishmeal processing and pulp production. In Denmark, on the other hand, reduced rates exist across the board for all energy-intensive companies.

- Fuels used as production input

In Norway, Denmark and Finland, fuels used as inputs to production processes are completely exempt. In Sweden, this is only the case in the metallurgical sector.

Figures 4.1 - 4.6 provide time-series for the CO_2 taxes for the 6 major fuel types used by the manufacturing industry.

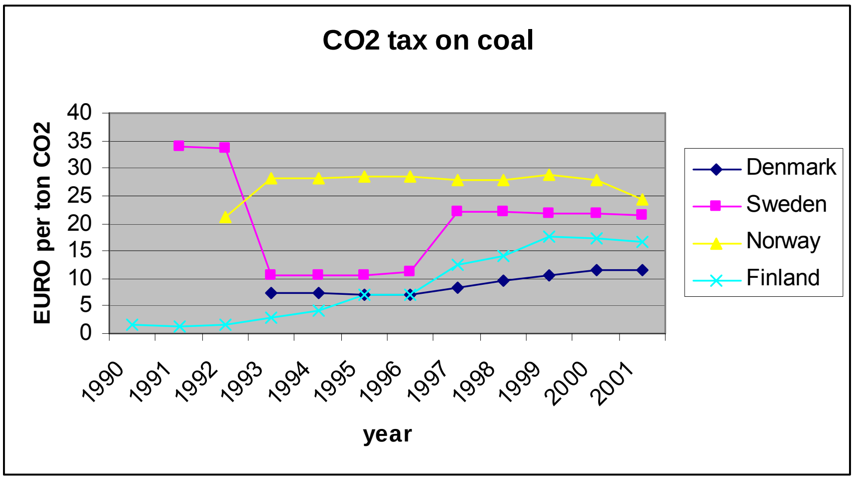

Figure 4.1 CO_2 taxes on coal and coke in the Nordic countries. 2000-prices.

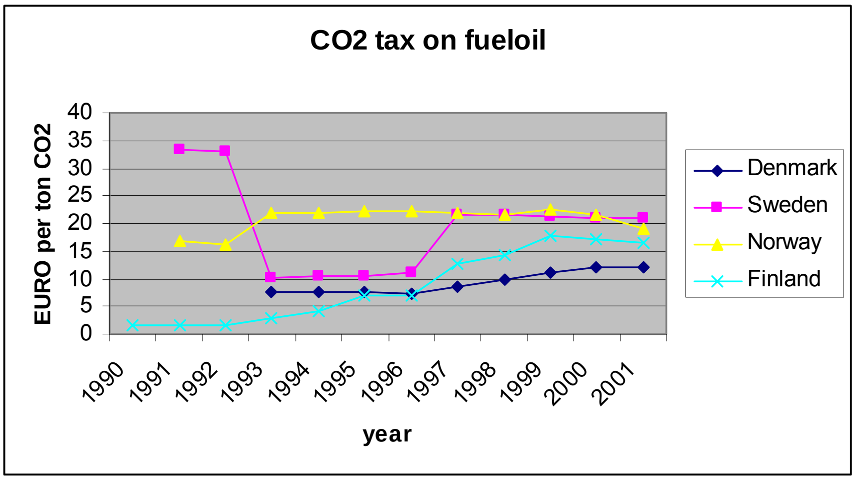

Figure 4.2 CO_2 taxes on fueloil in the Nordic countries. 2000-prices.

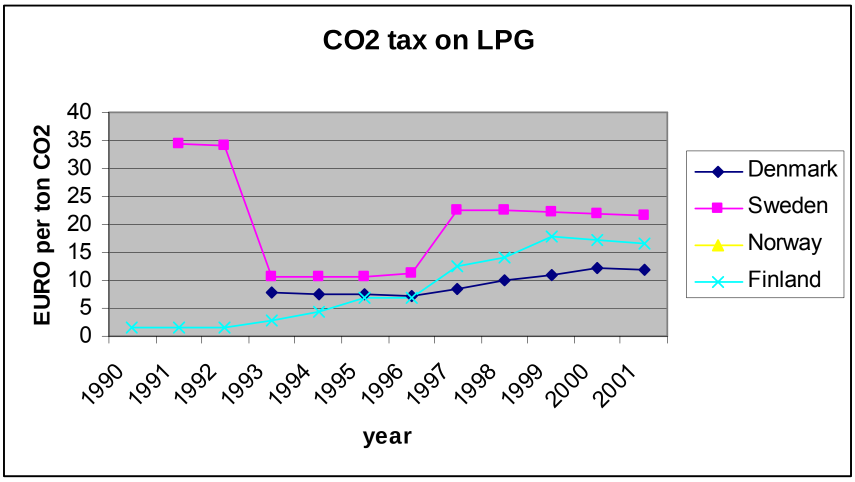

Figure 4.3 CO_2 taxes on LPG in the Nordic countries. 2000-prices.

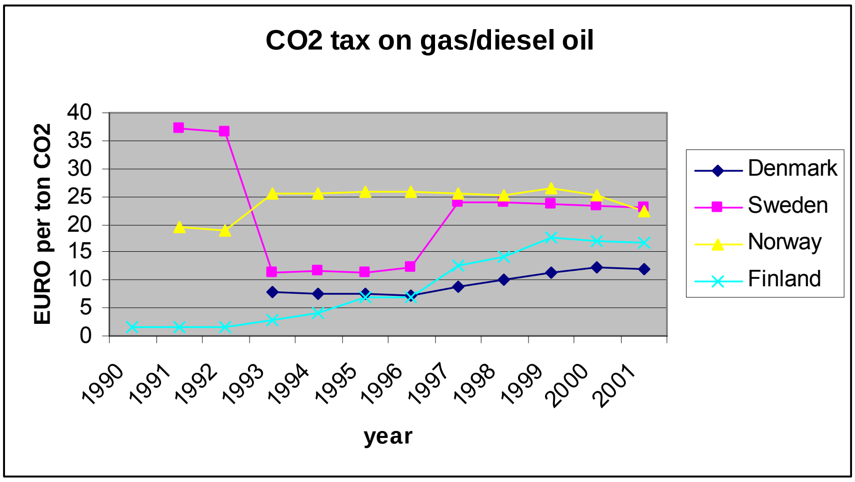

Figure 4.4 CO_2 taxes on gas/diesel oil in the Nordic countries. 2000-prices.

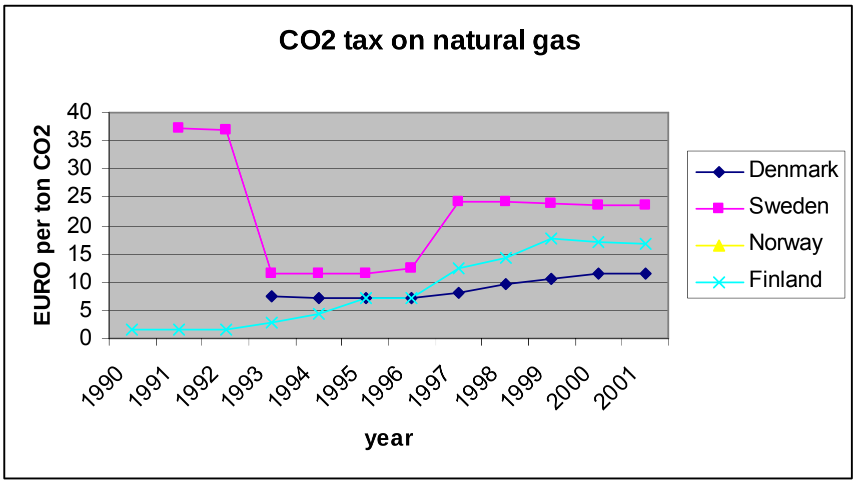

Figure 4.5 CO_2 taxes on natural gas in the Nordic countries. 2000-prices.

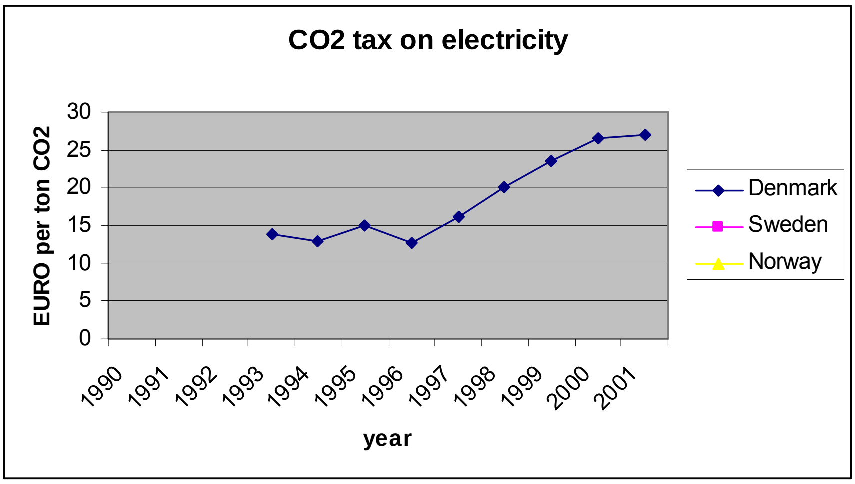

Figure 4.6 CO_2 taxes on electricity in the Nordic countries. 2000-prices.

5. Energy intensive sectors

5.1 Selection of industrial sectors for analysis

The industrial sectors selected for this study were identified so as to secure representation both of conventional energy-intensive industries and of energy-intensive sectors predominant in the Nordic region. In addition to the energy-intensive sectors, some reference sectors comprising less energy-intensive industries have also been identified so as to obtain a basis for comparison. In order to analyse decoupling, both physical data on energy consumption and economic data on gross value added is required.

The sectors have been identified at NACE 3-digit level. NACE is the sector classification established by Eurostat (see Commission Regulation 29/2002). The choice of the 3-digit level represents a compromise between the very broad sectors at 2-digit level, and the more detailed subsectors at 4-digit level. Although use of the NACE 4-digit level would allow the analysis to focus directly on important energy-intensive subsectors, the problem that arises in such an approach is that the statistical services are prevented from disclosing data at this level of detail due to reasons of confidentiality. In the Nordic countries, energy-intensive industrial sectors at NACE 4-digit level include so few individual companies, that disclosure of data would unveil the competitive position of particular firms.

Although the statistical services in the Nordic countries compile data according to Eurostat's NACE-classification methodology, they do not always make use of the most detailed level of disaggregation. This implies that at the 3-digit level industrial sectors are clustered when data is published. The clustering differs between economic and energy statistics as well as among countries. In selecting sectors that are to be compared across four Nordic countries, an inevitable loss of disaggregation occurs. One statistical service pools one set of 3-digit sectors under one label, while another statistical service pools 3-digit sectors slightly differently. In the end, the options for selecting industrial sectors for the analysis were narrowed considerably by different clustering practices by the various statistical services. Finland is still in the process of preparing release of figures at 3-digit level.

Since preference has been for analysis at 3-digit level, the sectors where most statistical services have released data were selected. For sector 202, data is pooled with data for 204.

Table 5.1 provides an overview of the 10 industrial sectors that are subject to analysis in this report. Six of these can be regarded as energy-intensive, while four are less energy-intensive sectors.

Table 5.1 Overview of industrial sectors – energy-intensive and other - included in the analysis

.152	Processing and preserving of fish and fish products*	Less energy-intensive
.201	Sawmilling and planing of wood	Energy-intensive
.202 .204	Manufacture of veneer sheets; manufacture of plywood, laminboard, particle board, fibre board and other panels and boards* Manufacture of wooden containers	Energy-intensive
.211	Manufacture of pulp, paper and paperboard*	Energy-intensive
.212	Manufacture of articles of paper and paperboard	Less energy-intensive
.241	Manufacture of basic chemicals*	Energy-intensive
261	Manufacture of glass and glass products*	Energy-intensive
.265	Manufacture of cement, lime and plaster[1]*	Energy-intensive
.281	Manufacture of structural metal products	Less energy-intensive
.361	Manufacture of furniture	Less energy-intensive

5.2 Energy intensity of the industrial sectors

Figures 5.2 and 5.3 provide an overview of energy intensities in the industrial sectors selected. Intensities are measured as the ratios to gross value added (GVA). The figures are for the year 2000.

Energy-intensive sectors are characterised here by an energy intensity above 4,000 GJ per million EUR in GVA. There are quite significant differences in the scale of energy-intensity, as some sectors range as high as 50,000 GJ per million EUR, whereas the average appears to be about 15,000 GJ per million EUR.

Energy-intensity appears to be more significant in Sweden and Norway than in Denmark. In most cases the energy-intensive sectors are less intensive when located in Denmark. The notable difference for sector 26.5, however, should be attributed to the different composition in Denmark.

[1] For Denmark data on value added for 265 is released only jointly with the sectors (263) Manufacture of ceramic tiles and flags; (264) Manufacture of bricks, tiles and construction products, in baked clay*; (267) Cutting, shaping and finishing of ornamental and building stone

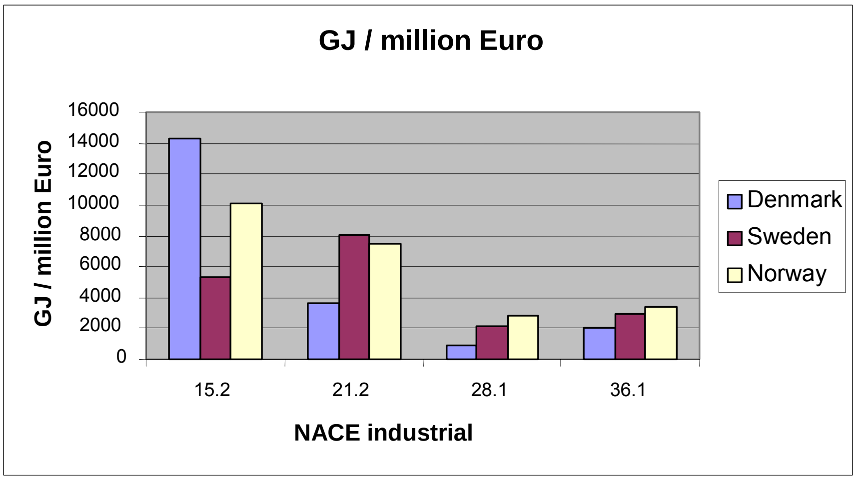

Figure 5.2 Less energy-intensive sectors: Energy intensity in GJ/million EUR of Gross Value Added in year 2000

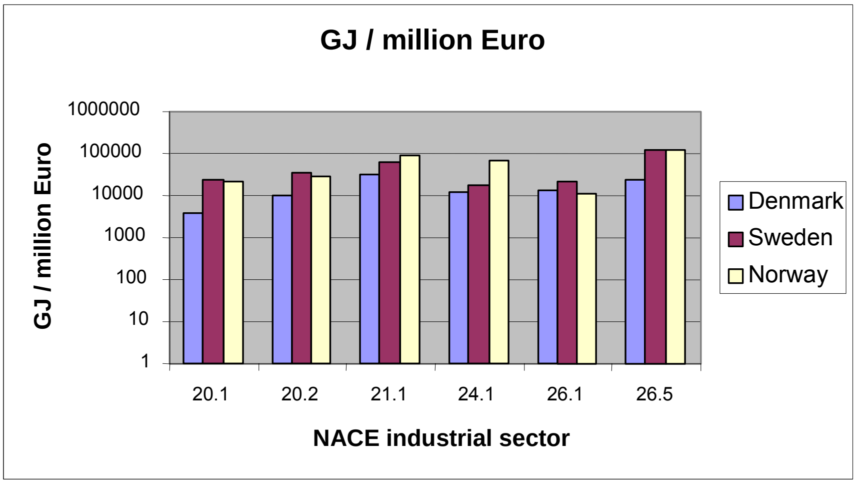

Figure 5.3 Energy-intensive sectors: Energy intensity in GJ/million EUR of Gross Value Added in year 2000 (NB: log scale)

For the less energy-intensive industries, there are energy-intensities as low as 800 GJ per million EUR (28.1). Also in the case of less-energy intensive sectors, the sectors located in Norway and Sweden tend to have higher intensities than the Danish. One exception is the fish processing industry.

It should be noted that the fish processing industry in Denmark is counted as an energy-intensive industry and, as such, can obtain reductions in CO_2 tax, whereas its energy-intensity is in fact well below the 4,000 GJ per million EUR threshold. Also in Norway, the subsector of fishmeal processing has obtained special treatment.

Sawmills (20.1) have different energy intensities; in Sweden and Norway, they are clearly energy-intensive, whereas in Denmark they are below the 4,000 GJ/million EUR threshold – and do not qualify for CO_2 tax reductions.

5.3 Carbon intensity of the industrial sectors

Carbon intensity has been calculated for all 10 sectors included in this study – see Figure 5.4. The carbon intensity has been calculated for each sector by adding up the CO_2 emission from each energy category and subsequently dividing the total CO_2 emission with the Gross Value Added. In this study the CO_2 emission for each energy category in each sector has been calculated by multiplying the carbon emission factor for each energy category in each country with the total consumption of this energy category. It should be noticed that the carbon emission factor for biofuels and waste, which are exempt from CO_2 taxation, has been set at zero as these energy sources can be categorized as CO_2 neutral. Significant structural changes have occurred in the production of electricity and heat during the research period. Better technology, more CHP and a shift in the mixture of primary energy sources used in the production of electricity and heat has affected and reduced the CO_2 emission factor for these energy categories. Especially the shift from coal and fuel oil to natural gas, waste, biofuel and other renewable sources like wind and hydro power has significantly reduced the CO_2 emission factor for electricity and heat. These structural changes in the production of both electricity and heat have been taken into account as an annual CO_2 emission factor has been calculated for each country for both electricity and heat.

Carbon-intensive industries are characterised here by a carbon-intensity above around 75 tonne CO_2 per million EUR in gross value added. Carbon-intensity also differs considerably between less carbon-intensive sectors and carbon-intensive sectors; the two sectors - pulp & paper and cement - range higher than 1,000 tons CO_2 per million EUR.

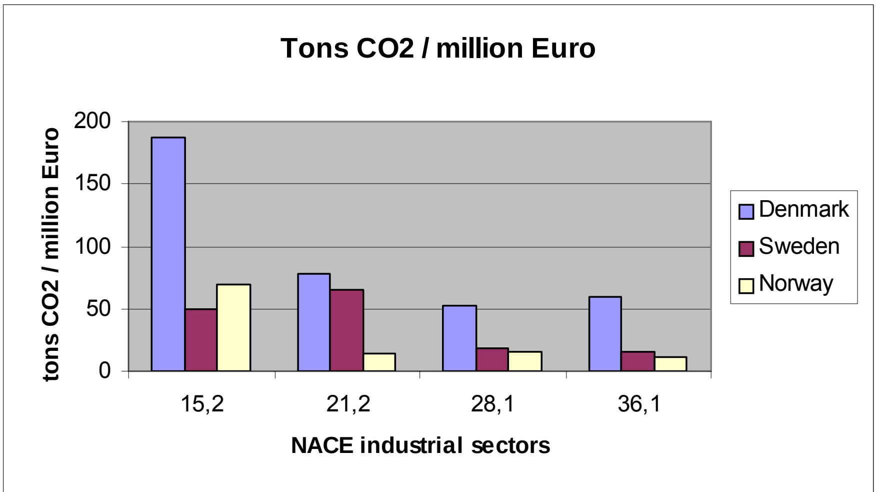

Figure 5.4 Less energy-intensive sectors: Carbon intensity in tonnes CO2/million EUR of Gross Value Added in year 2000.

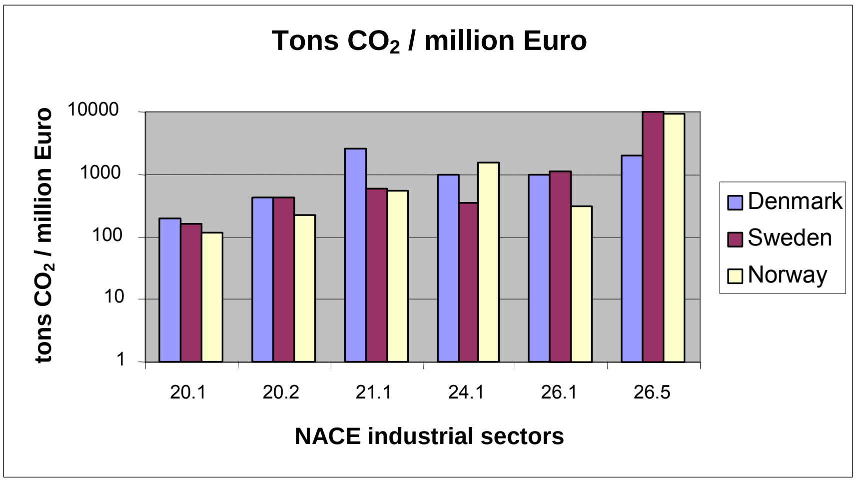

Figure 5.5 Energy-intensive sectors: Carbon intensity in tonnes CO_2/million EUR of Gross Value Added in year 2000 (NB: log scale)

Despite higher energy-intensities in Sweden and Norway than in Denmark, the pattern which emerges from Figures 5.4 and 5.5 is that carbon intensities in Denmark tend to exceed those of the other countries. This is most clearly the case for the less carbon-intensive group. Fish processing in Denmark is in fact so carbon-intensive that it exceeds the 75 tonne CO_2 per million EUR threshold, despite not being an energy-intensive industry.

However, in 4 of the 6 most carbon-intensive industrial sectors, either Sweden or Norway takes the lead with regard to carbon intensity, see Figure 5.5. Sweden has the highest carbon intensity in 21.1 (pulp & paper) and 26.1 (glass), whereas Norway has the highest carbon intensity in 24.1 (basic chemicals) and 26.5 (cement). Denmark has the highest intensities in the remaining two; 20.1 (sawmills) and 20.2 (veneer sheets etc.) – as well as in the fish processing industry, see above.

5.4 Fuel sources for energy consumption in the industrial sectors

The carbon intensities reflect different patterns in fuel consumption among the various industrial sectors. These are both related to the energy intensities and the energy supply structures in the various countries.

Table 5.2 provides an overview of the main fuel sources in each of the national industrial sectors. Where the main fuel source has changed between 1991 and 2001, this is indicated. The data is analysed in more detail in Section 6, however, an overview of the basic supply patterns is presented here.

The following patterns in fuel composition can be identified;

1) Coal dominates as fuel in the most energy-intensive sector, cement, this is the case in all the countries,
2) Electricity is the predominant energy source in the four less energy-intensive sectors: metal products, furniture, fish and paper products. The exceptions are the Danish fish and paper products sectors where gas dominates.
3) Biofuels are the predominant energy sources in sawmills and veneer sheets – in all the countries.
4) For the three energy-intensive sectors of glass, basic chemicals and pulp & paper, the main fuel supply differs. In Denmark gas is the main source, while in Norway it is electricity. In Sweden no single source dominates.

The main fuel sources have been remarkably stable between 1991 and 2001 in all three countries, although some changes can be noted;

- oil has been substituted with electricity in Sweden and Norway with regard to metal products and in Norway with regard to glass;
- oil and coal has been substituted with gas in Danish paper products, basic chemicals and pulp & paper;

These changes all represent a move towards less carbon-intensive fuels. To sum up, it can be observed that electricity is the predominant energy source in the 10 sectors selected for this analysis. In 13 of the 34 sectors (10 in DK, S, N and 4 in FI), electricity is the dominant energy source during the entire research period, while electricity is the dominant energy source in part of the period in 4 sectors. Bio-fuel is the dominant energy source during the entire research period in 8 sectors and is the dominant energy source in part of the research period in 2 sectors. For coal, these totals are 4 and 1, and for gas the totals are 3 and 2. Oil is not the most dominant energy source during the entire research period in any of the selected sectors, but in 3 sectors oil is the dominant energy source during part of the research period. It follows that oil, often praised as a vital energy source, in fact is only a supplementary fuel. Of the four main fuel sources, coal and gas are also by definition fossil fuels; electricity depends on the fuel mix, making it a fossil fuel-based energy source only in Denmark and Finland. Norway and Sweden rely on hydro and nuclear power for electricity production respectively.

Evidently, the choice of fuel source is related to the specifics of production in the sectors. The importance of biofuels in the wood-related industries comes from efforts to achieve efficiency in the use of waste and by-products. The significance of coal in the most energy-intensive sector, cement, appears to be related to the low cost per unit of GJ compared with other fuels as, relatively, coal is the cheapest energy source. It seems that there are scale effects which preclude industries with lower energy intensities from benefiting from the cheap coal; gas seems to dominate in the mid-energy-intensive industries, while electricity dominates in the less energy-intensive industries. Gas can be obtained at favourable prices by large industrial consumers on a contract basis, which implies that a certain level of consumption must be guaranteed to the gas suppliers. In addition, gas is only available in areas where the grid can reach. Electricity, however, is more flexible and can be tapped from the grid according to present demand, making it more attractive especially to less-intensive industrial sectors. There is, therefore, a logic relating to the physical properties of the fuel sources which explains why various fuels become main energy sources.

Table 5.2 Overview of the share of total energy consumption for the two principle energy sources in each sector

Sector	Year	Denmark		Sweden		Norway		Finland**	
15.2	1991	Gas 50.6	El 19.7	El 49.4	Oil 35.8	Oil 61.6	El 38.1		
	2000	Gas 57.8	El 14.5	El 42.9	Gas 38.7	El 47.3	Oil 45.6		
20.1	1991	Bio 72.3	El 17.7	Bio 77.4	El 17.2	Bio 58.1	El 28.7	Bio 58.5	El 24.8
	2000	Bio 46.3	El 36.9	Bio 58.8	El 25.4	Bio 67.8	El 25.5	Bio 50.6	El 35.8
20.2	1991	Bio 68.7	Oil 20.8	Bio 59.3	El 23.0	Bio 39.8	El 37.7		
	2000	Bio 53.6	Oil 32.5	Bio 48.8	El 37.4	El 48.2	Bio 39.1		
21.1	1991	Coal 30.5	Gas 27.9	Bio 60.6	El 30.4	El 45.4	Bio 37.9	Bio 51.5	El 24.7
	2000	Gas 42.1	Heat 36.7	Bio 56.9	El 31.4	El 47.2	Bio 39.8	Bio 58.2	El 27.6
21.2	1991	Gas 34.5	Oil 33.4	El 47.7	Oil 31.3	El 79.3	Oil 20.6		
	2000	Gas 106*	El 16.3	El 54.8	Gas 15.9	El 91.3	Oil 5.6		
24.1	1991	El 37.2	Oil 30.0	El 73.9	Gas 8.2	El 51.2	Bio 30.5		
	2000	EL 40.6	Gas 39.0	El 69.0	Gas 18.8	El 45.1	Bio 22.2		
26.1	1991	Gas 72.7	El 24.4	Gas 43.3	El 32.9	Oil 46.7	El 40.7		
	2000	Gas 69.9	El 27.9	Oil 41.1	El 27.6	El 57.5	Gas 35.5		
26.5	1991	Coal 57.5	Oil 19.6	Coal 78.0	El 11.2	Coal 75.2	El 16.0	Coal 43.1	Oil 26.7
	2000	Coal 66.8	Gas 20.1	Coal 67.4	Oil 20.0	Coal 70.1	Bio 15.7	Coal 33.1	Oil 23.6
28.1	1991	El 44.0	Oil 36.4	El 62.6	Oil 18.6	El 61.0	Oil 17.2	El 53.7	Oil 43.0
	2000	El 45.2	Gas 25.7	El 57.3	Oil 22.0	El 75.4	Oil 20.6	El 56.8	Oil 31.3
36.1	1991	Bio 49.2	El 31.8	El 54.5	Bio 20.6	El 68.6	Oil 20.2		
	2000	El 45.8	Bio 33.7	El 53.1	Bio 23.7	El 59.8	Bio 27.1		

* Sector 21.2 produces a substantial amount of heat to the public grid.
** Finnish data have only been available at a two-digit NACE level for a limited number of industries (20, 21, 26 and 28).

6. Decoupling patterns

The purpose of this section is to provide data on trends in energy consumption, carbon emissions and gross value added in the energy-intensive and less energy-intensive industries. The overview is entirely descriptive; analysis on the relationship between energy prices and energy consumption follows in Section 7.

6.1 Decoupling in coal-based energy-intensive industries

Figure 6.1 provides an overview of decoupling in the cement industry in Denmark, Norway and Sweden. This is the most energy-intensive of all the ten sectors included in this study, and the sector‘s most important source of energy is coal, which has the highest carbon content of all the energy sources.

In Denmark, relative decoupling between GVA and energy-CO_2 can be observed from 1993 to 1996. Energy consumption and CO_2 emissions are still increasing during this period, however, GVA is increasing more rapidly. Absolute decoupling can be observed from 1996 and onwards. From 1996 and onwards, energy consumption and CO_2 emissions decrease and, in the same period, GVA continues to increase. The appear-

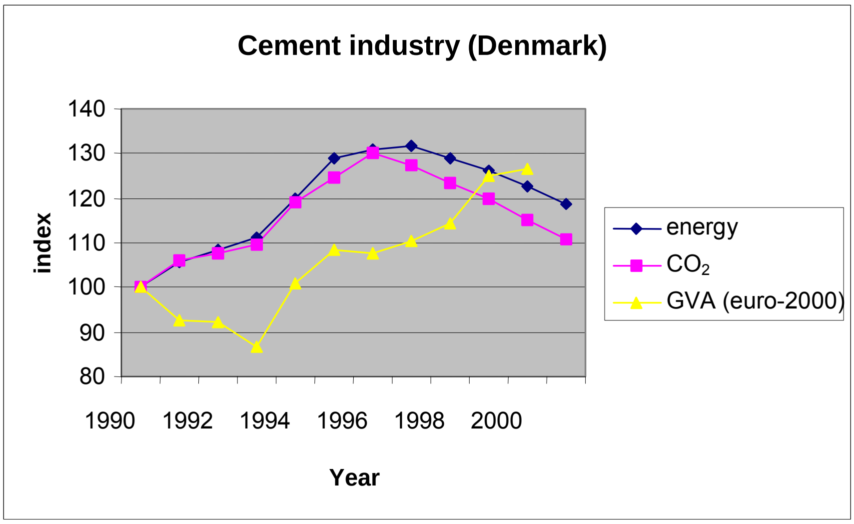

Figure 6.1a Cement Denmark – GVA, energy consumption and CO2 emissions

ance of the relative decoupling in 1993 seems to coincide with the introduction of the Danish CO_2-tax for the industry while the appearance of absolute decoupling in 1996 seems to coincide with changes in energy taxation for industries.

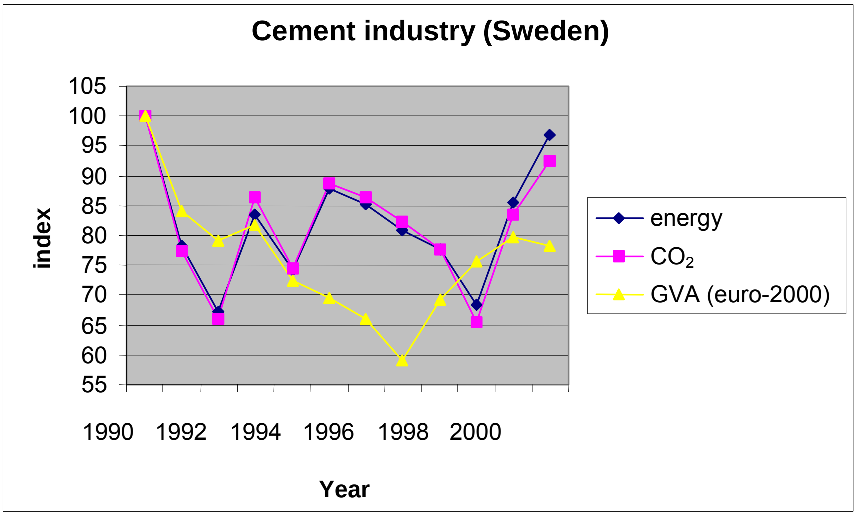

Figure 6.1b Cement Sweden – GVA, energy consumption and CO2 emissions

In Sweden, the cement industry has stagnated, with economic decline throughout most of the 1990's. Recent increases in energy consumption and CO_2 emissions net out a decoupling that occurred between 1997 and 2000.

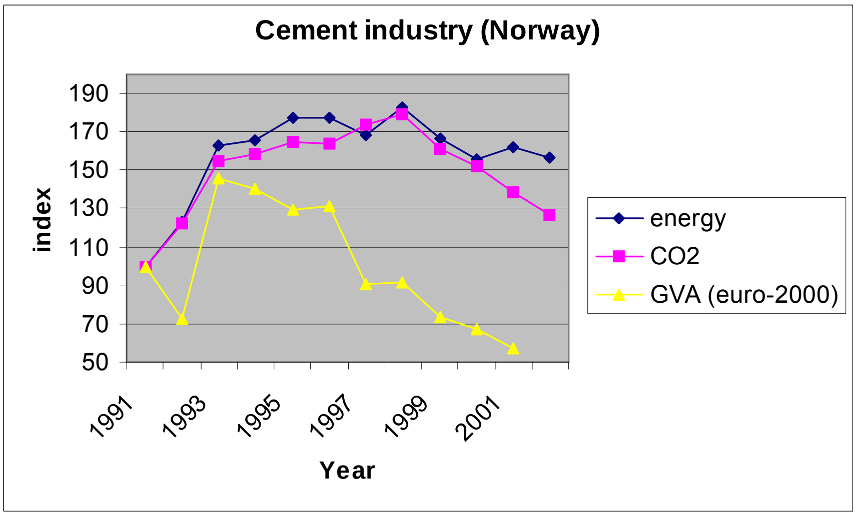

Figure 6.1c Cement Norway – GVA, energy consumption and CO2 emissions In

Norway, a strong *inverse* decoupling between gross value added and energy consumption can be observed from 1993 to 1998. Energy consumption and CO_2 emissions increase only slightly from 1993 to 1998, while GVA is decreasing rapidly causing a strong inverse decoupling. From 1998 through the rest of the period, energy consumption and CO_2 emissions decrease at approximately the same rate as GVA. Neither decoupling nor inverse decoupling can be observed during this period.

The development trends in the Finnish cement industry resemble the situation in Sweden. During the first half of the 1990's the entire non-metallic mineral industry suffered economic decline. During the second half of the period illustrated in Figure 6.1d., the situation changes. The second half of the period is characterised by a steady economic growth that exceeds the growth in both energy consumption and CO_2 emissions, thereby causing relative decoupling between value added and both energy consumption and CO_2 emissions.

In view of the high carbon-intensity in this sector in Norway and Sweden, the absence of carbon decoupling is surprising and warrants attention.

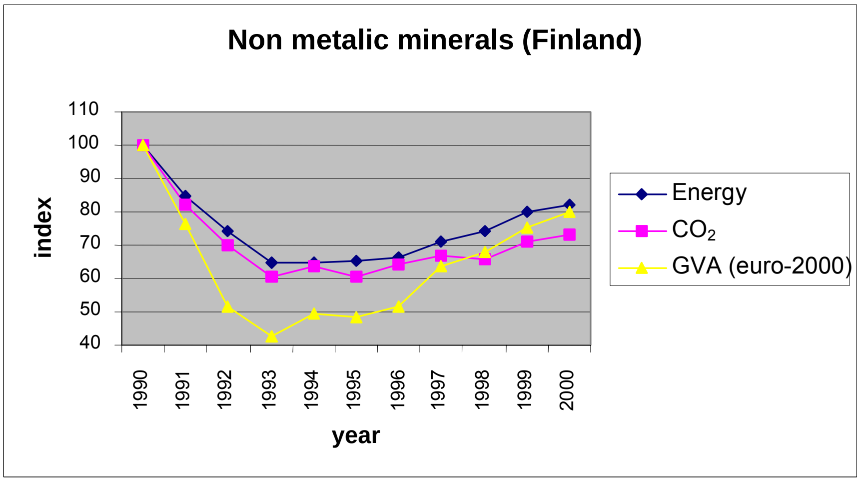

Figure 6.1d Non-metallic minerals. Finland – GVA, energy consumption and CO2 emissions

6.2 Decoupling in other energy-intensive industries

Pulp and Paper

Figure 6.2 below provides an overview of decoupling in the pulp and paper industries in Denmark, Norway and Sweden. A diverse energy supply structure is displayed by this sector, with gas dominating in Denmark and biofuels in Sweden and Norway.

In Denmark, absolute decoupling between GVA and both energy consumption and CO_2 emissions takes place, as well as, since 1996, decoupling between energy consumption and CO_2 emissions. The latter trend appears to reflect the fuel switch from coal to gas noted in Section 5.

In Sweden, the sector suffered economic decline in the early 1990's; still, energy consumption and CO_2 emissions have risen steeply and remain coupled, so that the net effect in the 1990s is a small *inverse* decoupling. This trend probably reflects that pulp and paper companies in Sweden have become suppliers of energy.

In Norway too, inverse decoupling is apparent, although mainly with regard to CO_2 and GVA. GVA and energy consumption remain more closely coupled, with a slight decoupling relationship. The increase in CO_2 emissions reflects a small increase in oil consumption during the period from 1994 to 1999. The share of oil in the total amount of energy increases from approximately 6% up to 17% during this period. As the sector largely relies on CO_2 neutral fuels, even a small shift in energy composition affects the CO_2 emission index significantly.

The situation in Finland is characterised by economic growth during the entire period. During most of the period there is close coupling between value added and energy consumption. From 1993 onwards, absolute decoupling can be observed between value added and CO_2 emissions and between energy consumption and CO_2 emissions.

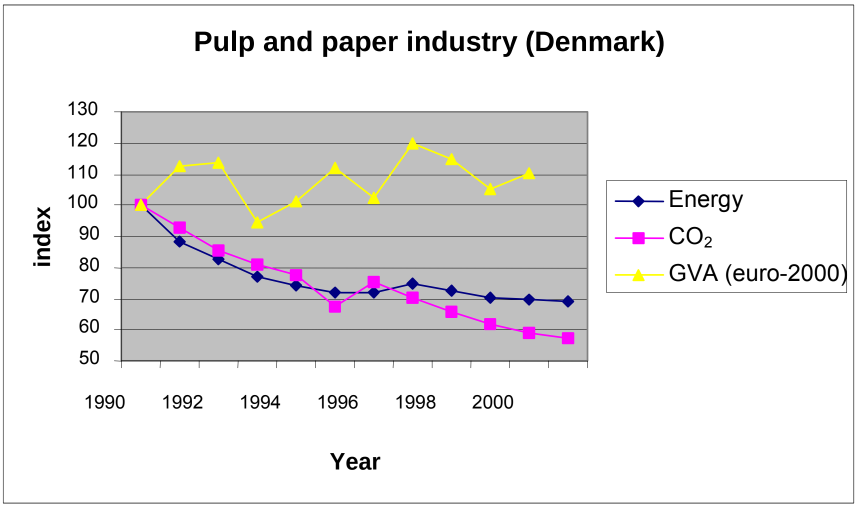

Figure 6.2a Pulp and paper Denmark– GVA, energy consumption and CO2 emissions

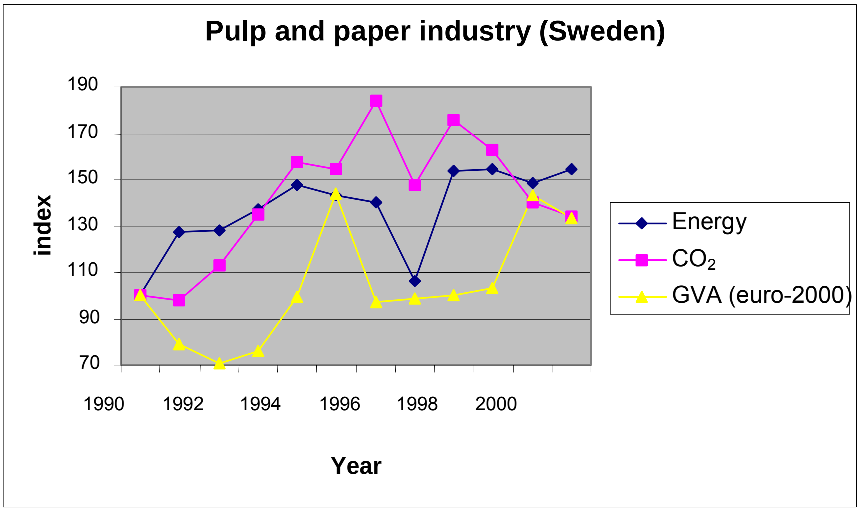

Figure 6.2b Pulp & paper Sweden – GVA, energy consumption and CO2 emissions

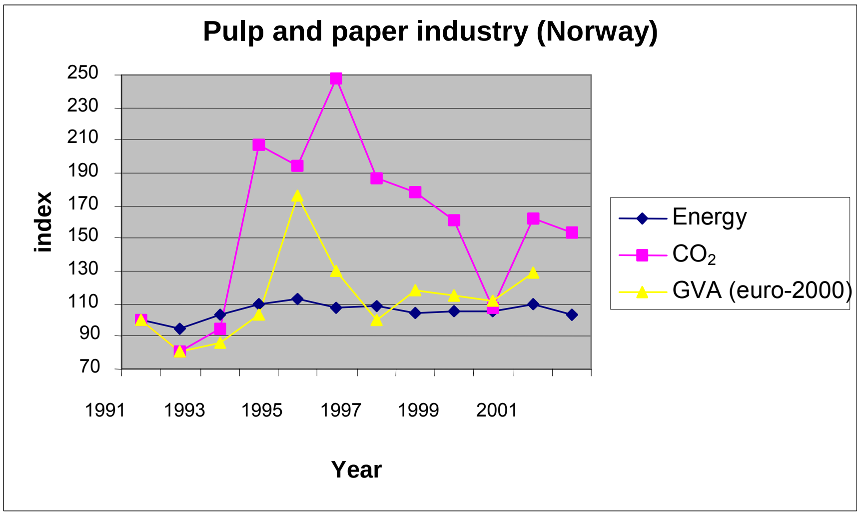

Figure 6.2c Pulp and paper Norway – GVA, energy consumption and CO2 emissions

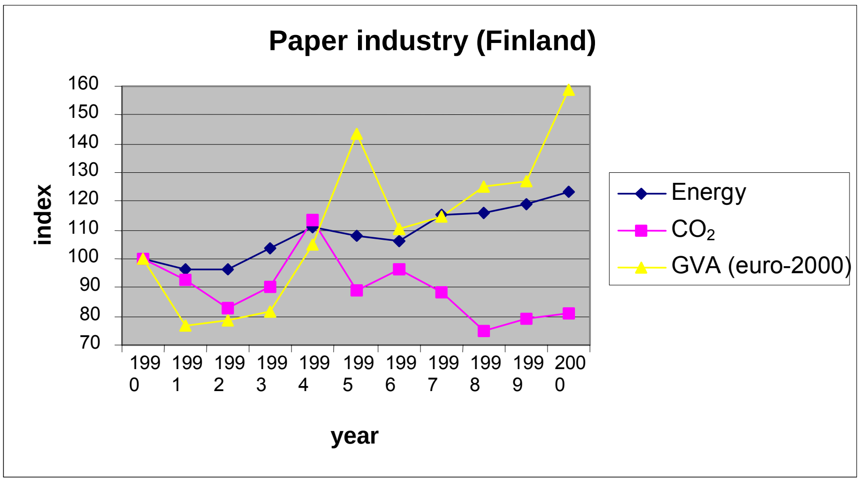

Figure 6.2.d Paper industry Finland – GVA, energy consumption and CO2 emissions

Basic chemicals

Figure 6.3 provides an overview of decoupling trends in the basic chemical industries in Denmark, Norway and Sweden. A diverse energy supply structure is displayed by this sector, with gas dominating in Denmark and electricity in Sweden and Norway.

In Denmark, the overall trend for the period as a whole can best be described as coupling between value added and both energy consumption and CO_2 emissions. Absolute decoupling between GVA and both CO_2 emissions and energy consumption can be observed in the period from 1993 to 1996. Developments in energy consumption and CO_2 emissions are relatively slight during this period in relation to the rapid increase in GVA. The appearance of decoupling seems to coincide with the introduction of the Danish CO_2 tax for the industry. From 1996, there is a general trend of coupling between GVA and energy consumption, while decoupling can be observed between energy consumption and CO_2 emissions. This decoupling reflects the substitution from oil to gas in the basic chemicals industry.

In Sweden, a general trend of absolute decoupling can be observed between GVA and energy consumption. Despite relatively stable energy consumption, CO_2 emissions remain coupled with GVA up to 1996. From 1996 onwards, absolute decoupling between GVA and CO_2 emissions can be observed. The development in CO_2 emissions is closely related to the composition of energy sources. From 1992 until 1996, CO_2 emissions increase while the level of energy consumption remains constant. The increase in CO_2 level is caused by an increase in gas and coal consumption. The rapid decrease in CO_2 emissions from 1996 is primarily a consequence of the phasing out of coal in the industry.

In Norway, a general trend of coupling between GVA, energy consumption and CO_2 emissions is seen until 1996. From 1996 onwards, GVA and energy consumption largely remain coupled, however, with regard to CO_2 emissions, inverse decoupling is apparent. The rapid increase in CO_2 emissions is caused by shift between energy sources in the chemical industry. The share of electricity and biofuels in total energy consumption decreases slightly while the share of gas increases. The shift from two energy sources with very small carbon emission factors to an energy source with a substantial carbon emission factor causes the observed CO_2 emission trend in Figure 6.3c.

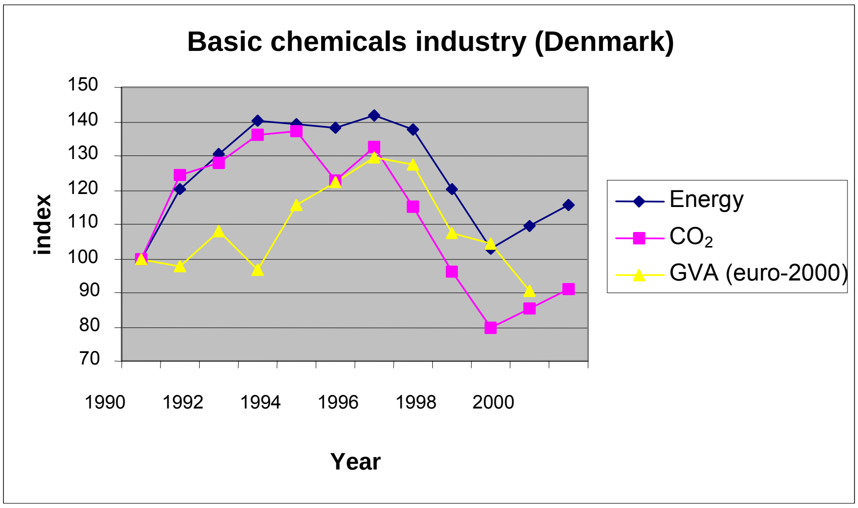

Figure 6.3a Chemicals Denmark – GVA, energy consumption and CO2 emissions

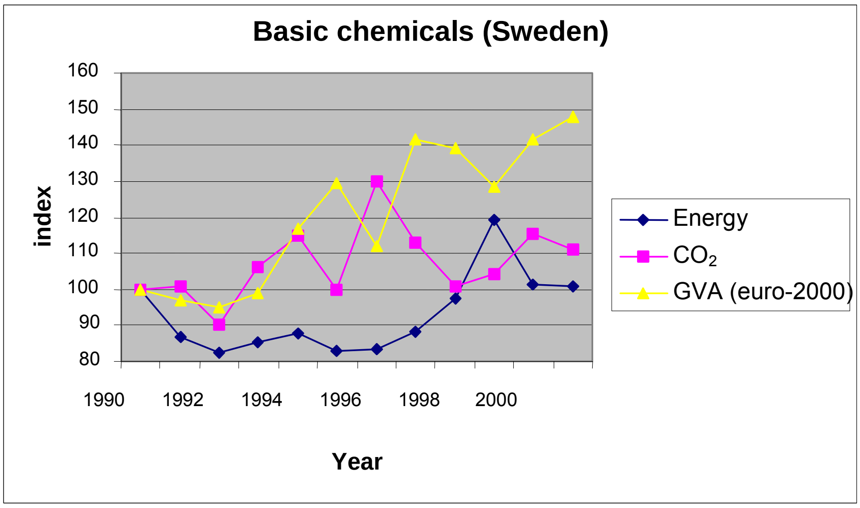

Figure 6.3b Chemicals Sweden – GVA, energy consumption and CO2 emissions

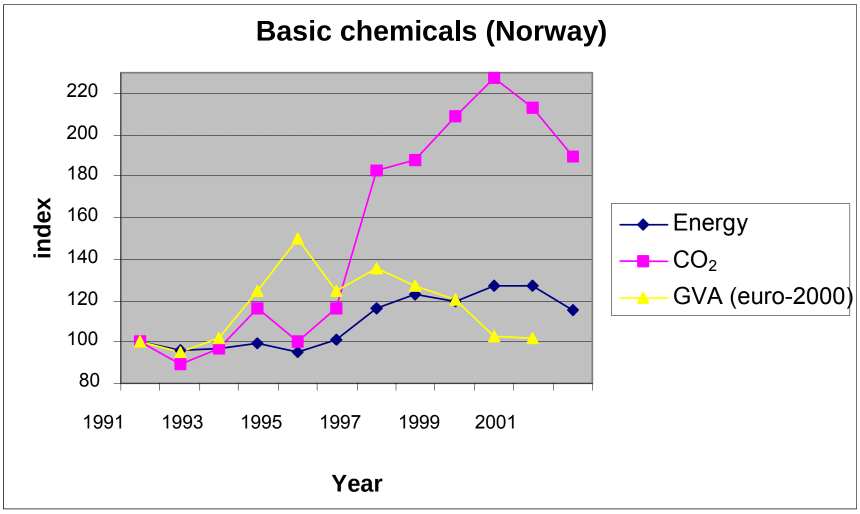

Figure 6.3c Chemicals Norway – GVA, energy consumption and CO2 emissions

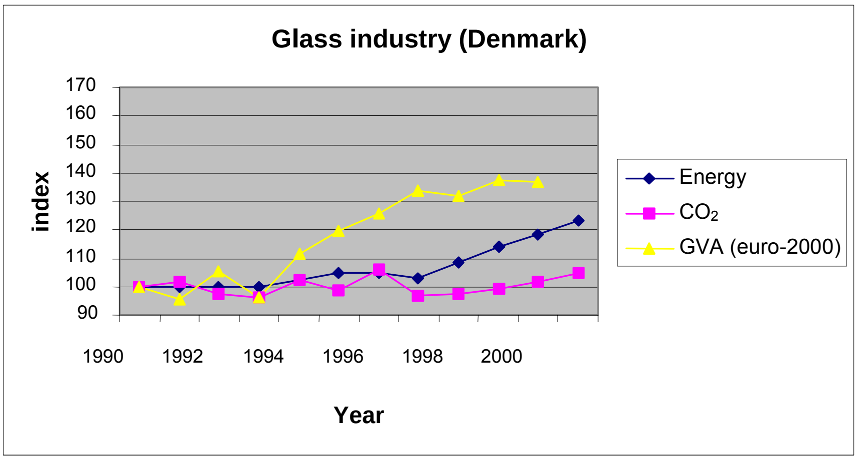

Figure 6.4a Glass Denmark – GVA, energy consumption and CO2 emissions.

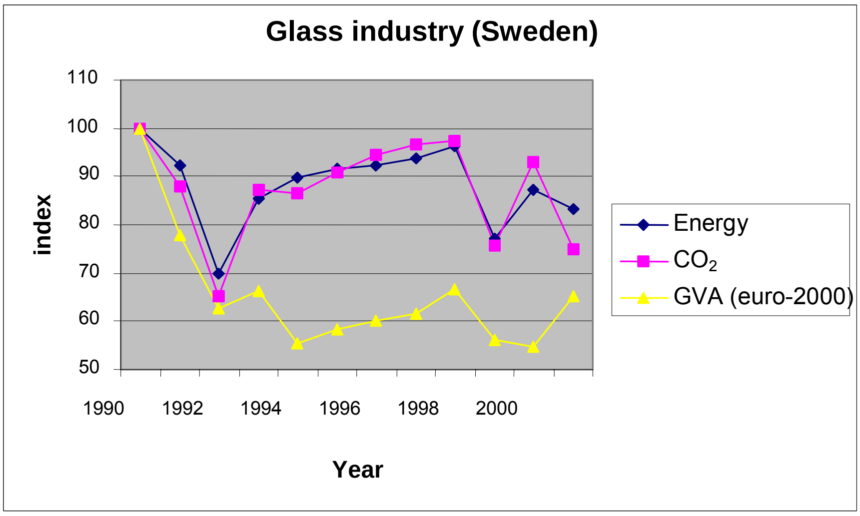

Figure 6.4b Glass Sweden – GVA, energy consumption and CO2 emissions

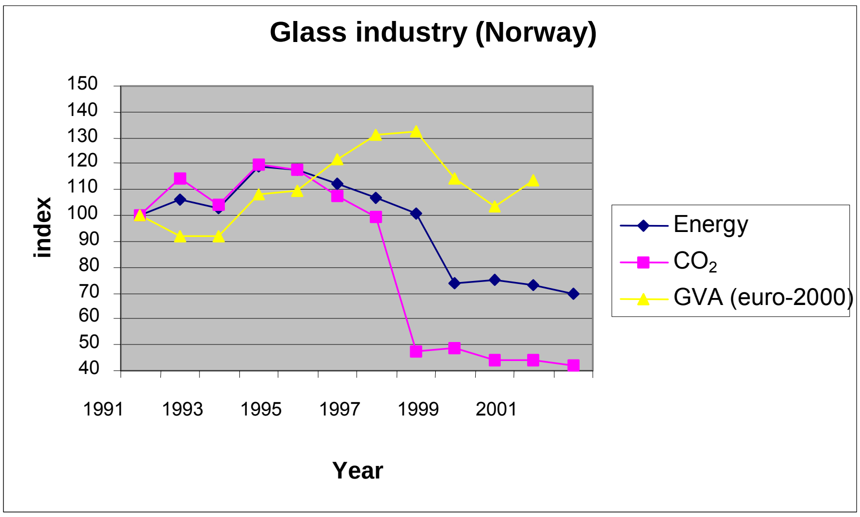

Figure 6.4c Glass Norway – GVA, energy consumption and CO2 emissions

Glass

Figure 6.4., below, provides an overview of decoupling in the glass industry in Denmark, Norway and Sweden. In this sector, gas dominates in Denmark and Sweden, while electricity is the main fuel in Norway.

In Denmark, absolute decoupling between GVA and both energy consumption and CO_2 emissions can be observed from 1993 and onwards. As has been pointed out in the description of the basic chemical industry and the cement industry, the appearance of decoupling in 1993 coincides with the introduction of the CO_2 tax for the industry in Denmark. Figure 6.4 also shows decoupling between energy consumption and CO_2 emissions from 1996 onwards.

In Sweden, the glass industry has been in economic decline. In the first three years of the observed period, there is close coupling between trends in GVA and energy-CO_2. However, since 1993 inverse decoupling between GVA and energy-CO_2 can be observed in Figure 6.4a.

The glass industry in Norway has not experienced the same economic decline as its Swedish counterpart. Until 1995, coupling between GVA, energy consumption and CO_2 emissions can be observed, however, from 1995 and onwards there is a general trend of absolute decoupling between GVA and both energy consumption and CO_2 emissions. The figure also shows decoupling between energy consumption and CO_2 emissions during the same period, reflecting the gas for oil substitution in this sector.

6.3 Decoupling in biofuel-dominated industries

Figures 6.5 and 6.6 provide an overview of decoupling in the biofuel-dominated industries - sawmills and veneer sheet production.

The decoupling trends in the biofuel-dominated industries are very country-specific. In both the Danish sawmill and veneer sheet industry, absolute decoupling between GVA and energy-CO_2 can be observed. Such decoupling trends cannot be observed in either Norway, Sweden or Finland. The overall tendency in Norway, Sweden and Finland for these two industries can best be described as coupling. Although considerable fluctuations for sawmills and veneer sheet manufacturers can be observed, the net result for the period 1990-2001 appears to be coupling rather than decoupling. In these industries, CO_2 decoupling is very sensitive to small changes in consumption of non-biofuels and needs to be interpreted with caution. The reader is referred to the annex detailing fuel switches between 1990 and 2001.

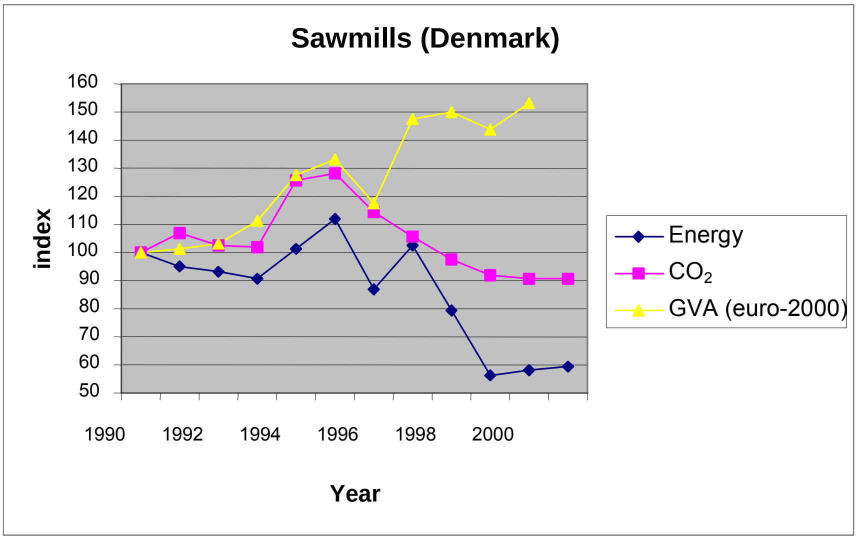

Figure 6.5a Sawmills Denmark – GVA, energy consumption and CO2 emissions

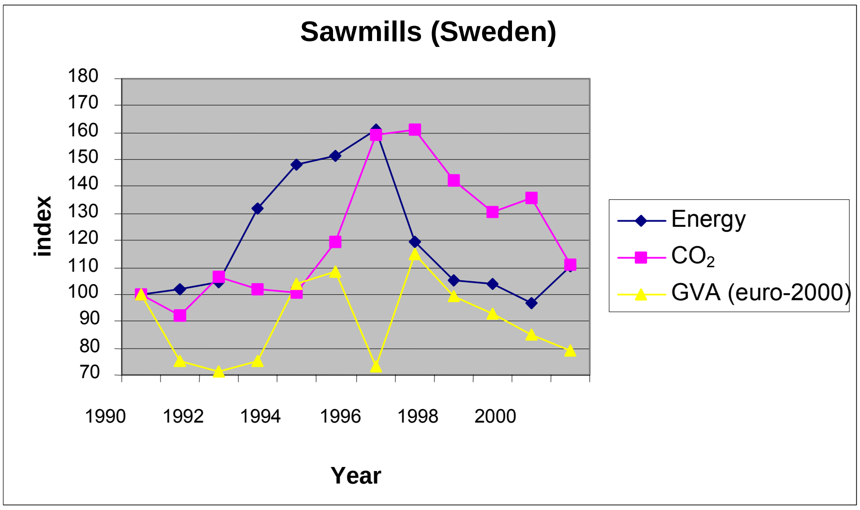

Figure 6.5b Sawmills Sweden – GVA, energy consumption and CO2 emissions

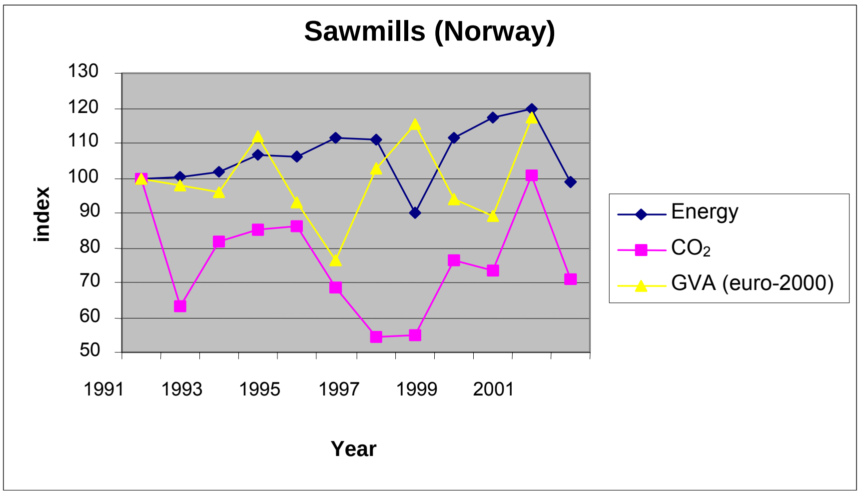

Figure 6.5c Sawmills Norway –GVA, energy consumption and CO2 emissions

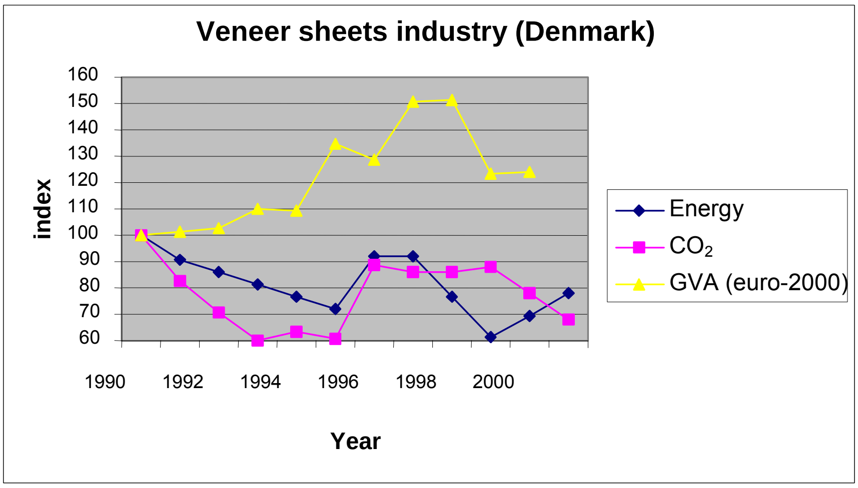

Figure 6.6a Veneer sheets Denmark–GVA, energy consumption and CO2 emissions

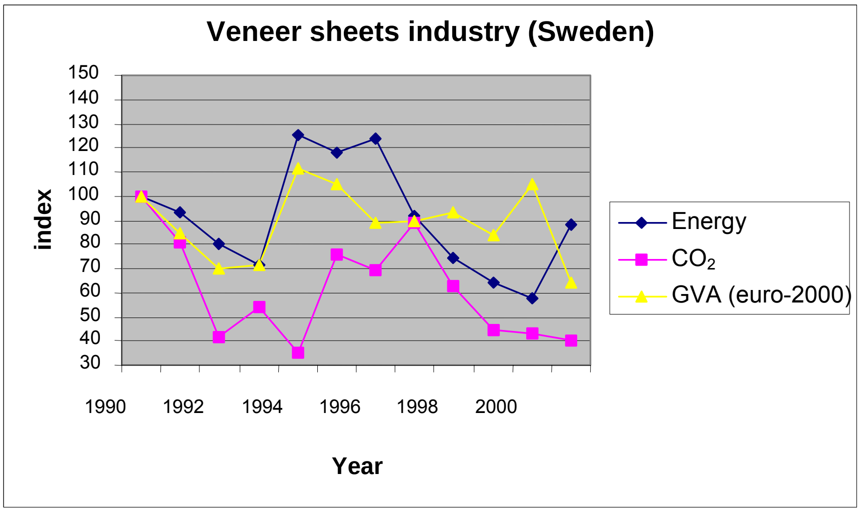

Figure 6.6b Veneer sheets Sweden–GVA, energy consumption and CO2 emissions

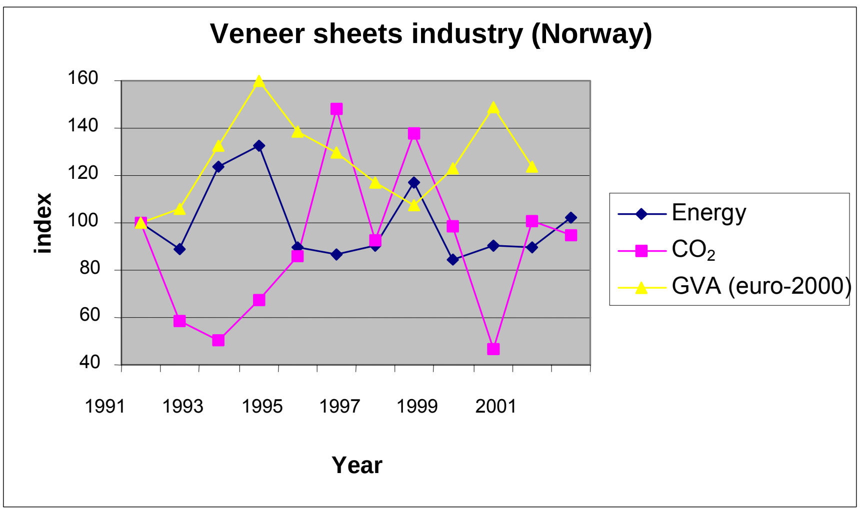

Figure 6.6c Veneer sheets Norway –GVA, energy consumption and CO2 emissions

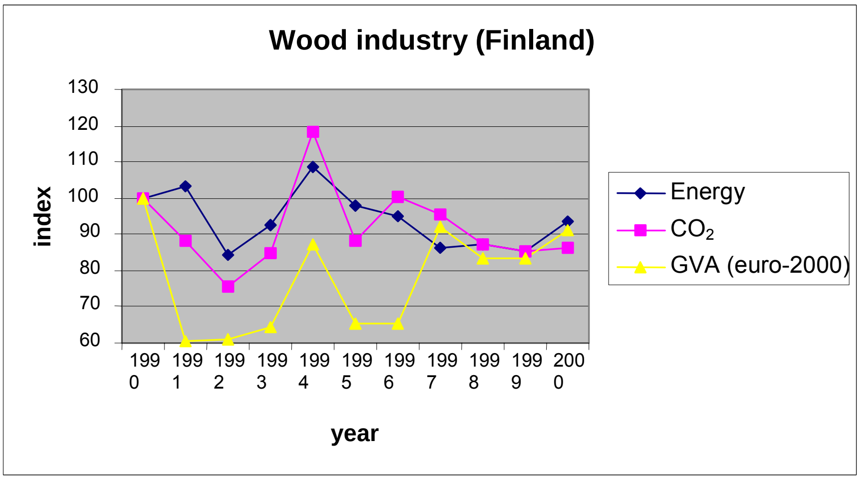

Figure 6.6d Wood industry Finland –GVA, energy consumption and CO2 emissions

6.4 Decoupling in less energy-intensive industries

In the four less energy-intensive industries (basic metals, furniture, fish industry and paper product industry), electricity dominates as the preferred source of energy. The Danish fish industry and paper product industry differ from the remainder of the less energy-intensive industries. In these two industries, both gas and electricity are important energy sources.

Basic metals

In Denmark, no significant decoupling can be observed between GVA and energy-CO_2. The most prominent trend in Figure 6.7a is significant decoupling between energy consumption and CO_2 emissions from 1996 onwards. This decoupling is primarily caused by more CO_2 efficient electricity production. The carbon coefficient for electricity decreases during this period and, as electricity is the dominating energy source in the metal industry, the change in the carbon coefficient has a significant impact on CO_2 emissions. In Sweden, the prominent trend during the entire period observed is a relatively close coupling between GVA, energy consumption and CO_2 emissions. In the Norwegian metal industry, there is also a close coupling between energy consumption and CO_2 emissions. However, a notable trend in the Norwegian metal industry is a significant absolute decoupling between GVA and energy-CO_2 from 1995 onwards. In the Finnish metal industry, there is a close coupling between energy consumption and CO_2 emissions during the entire period observed. Until 1997, there was also coupling between value added and both energy and CO_2. However, from 1997 onward, the dominating trend is inverse decoupling between value added and both energy consumption and CO_2 emissions.

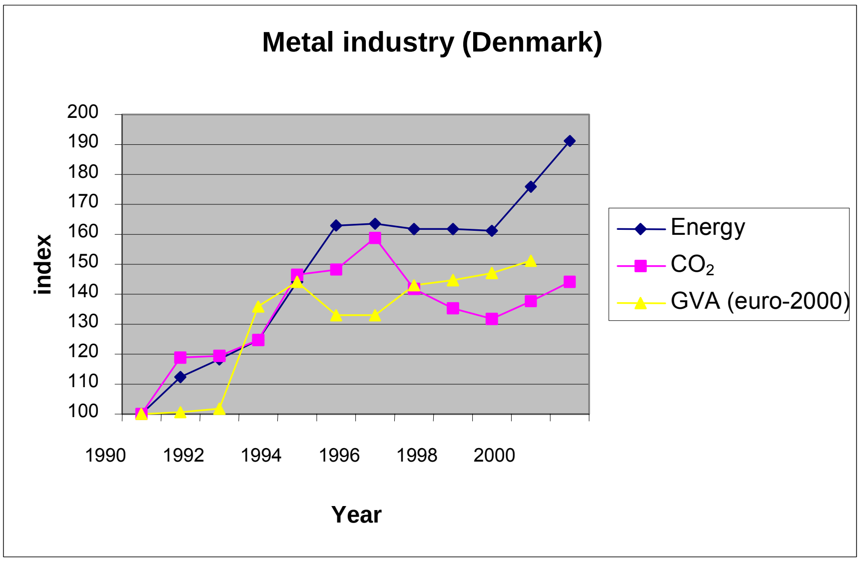

Figure 6.7a Basic metals Denmark – GVA, energy consumption and CO2 emissions

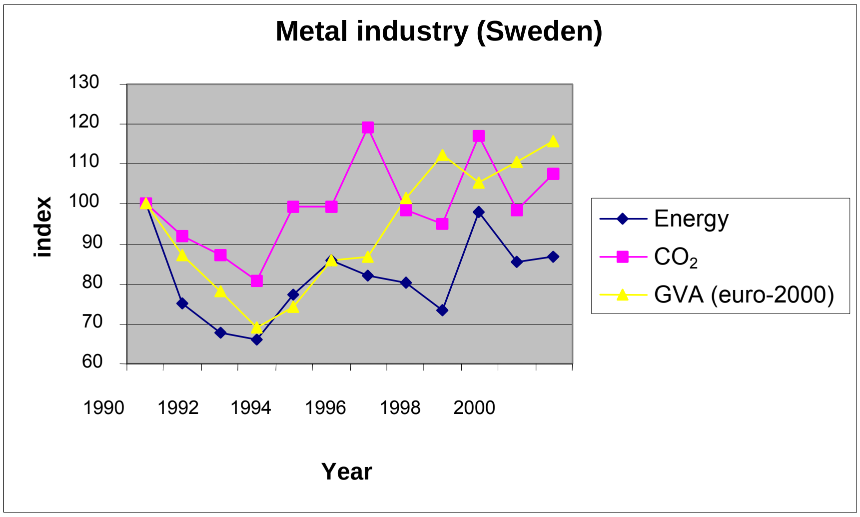

Figure 6.7b Basic metals Sweden – GVA, energy consumption and CO2 emissions

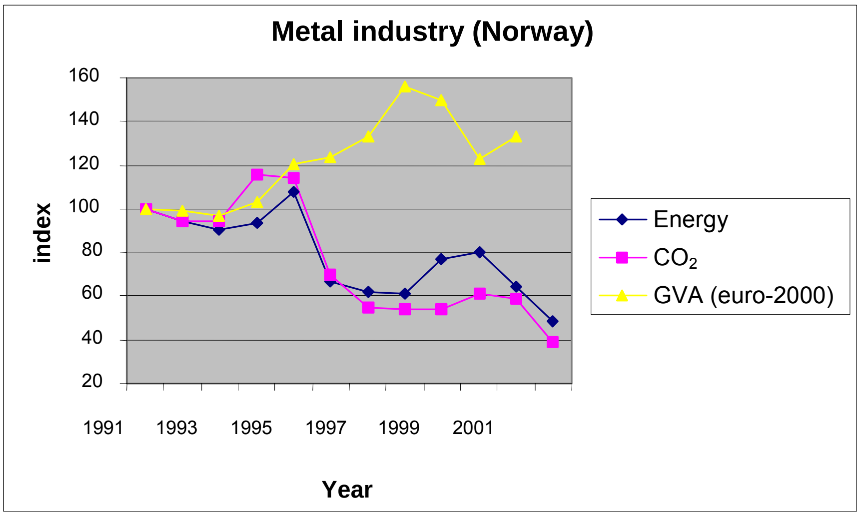

Figure 6.7c Basic Metals Norway – GVA, energy consumption and CO2 emissions

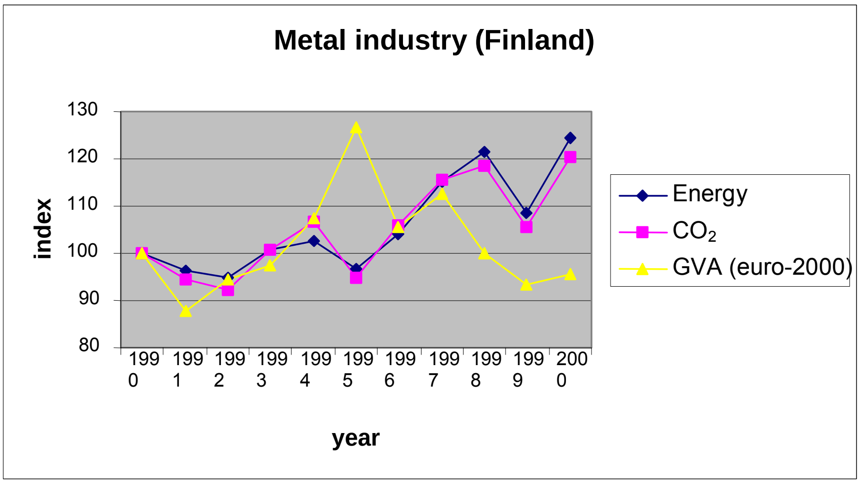

Figure 6.7d Metal industry Finland – GVA, energy consumption and CO2 emissions

Furniture industry

Until 1996, the prominent trend in the Danish furniture industry is a close coupling between GVA, energy and CO_2. From 1996 and throughout the rest of the period, a significant absolute decoupling between GVA and energy-CO_2 can be observed. Also in Sweden, the year 1996 marks a change in the relationship between GVA, energy consumption and CO_2 emissions. Until 1996, the dominant trend in Sweden is coupling between GVA and CO_2 emissions. However, from 1996 and onwards an absolute decoupling between GVA and CO_2 emissions can be observed. Once again, just as in Denmark and Sweden, the year 1996 marks a change within the Norwegian furniture industry. During the entire period observed, GVA and energy consumption are closely coupled. Value added and CO_2 emissions on the other hand are only coupled until 1996. From

1996 and onwards a strong decoupling between GVA and CO_2 can be observed in Figure 6.8c.

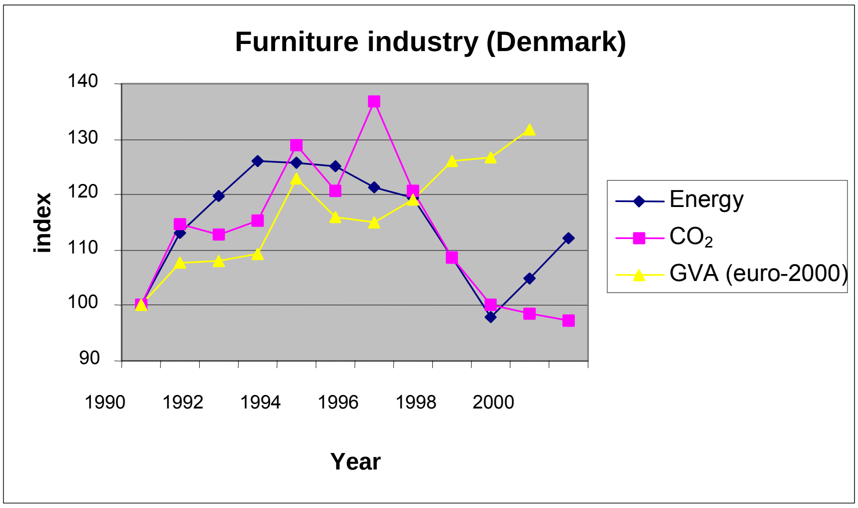

Figure 6.8a Furnitures Denmark– GVA, energy consumption and CO2 emissions

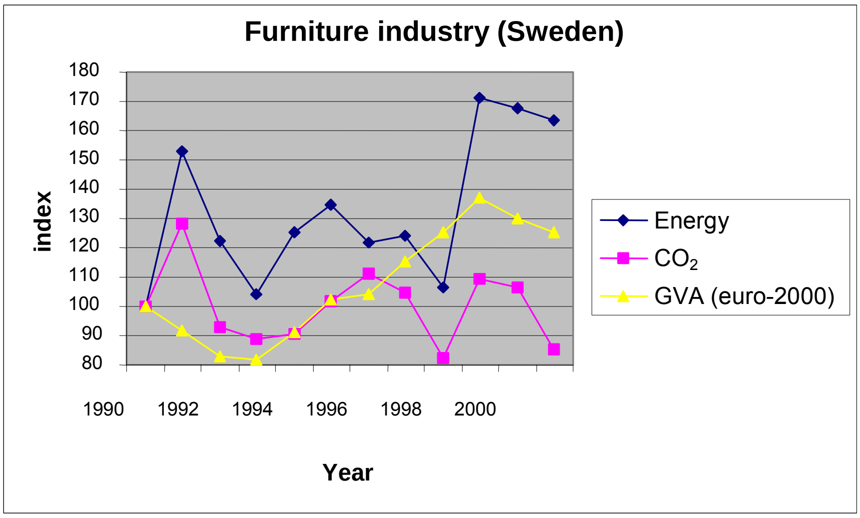

Figure 6.8b Furnitures Sweden– GVA, energy consumption and CO2 emissions

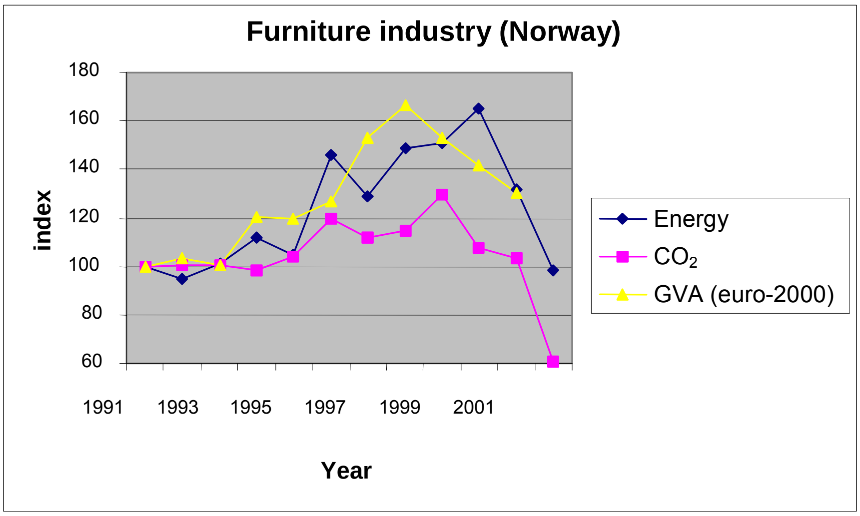

Figure 6.8c Furnitures Norway – GVA, energy consumption and CO2 emissions

Fish industry

In Denmark, two trends can be observed. Except for the period from 1991 to 1995, the development in GVA, energy and CO_2 is coupled. Until 1996, energy consumption and CO_2 emissions are closely coupled, but from 1996 onwards, decoupling between energy and CO_2 can be observed. The situation in the Swedish fish industry is marked by a significant inverse decoupling between GVA and energy-CO_2, especially in the period from 1992 to 1995. The overall trend in Norway is a coupling between GVA, energy and CO_2. Two deviations from this overall trend can be observed in Figure 6.9c. A relative decoupling between GVA and energy-CO_2 can be observed in the period from 1995 to 1998 and a decoupling between energy and CO_2 can be observed from 1998 and throughout the remainder of the period under observation.

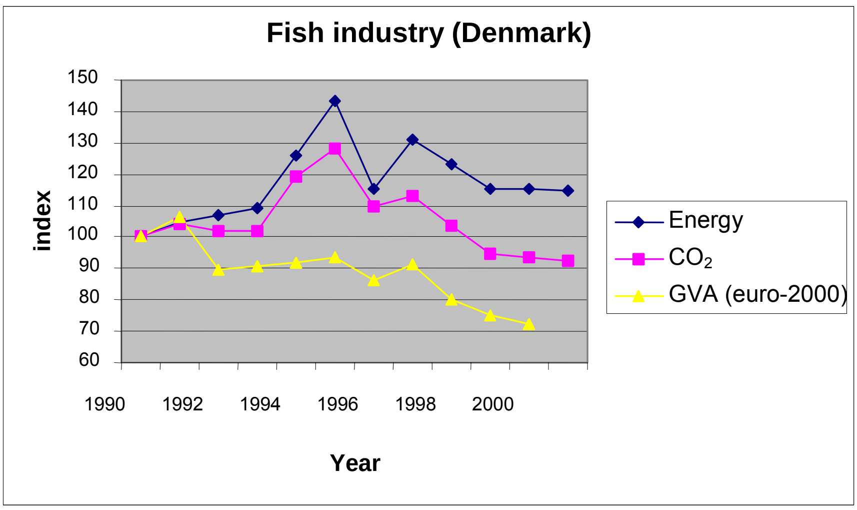

Figure 6.9a Fish Denmark – GVA, energy consumption and CO2 emissions

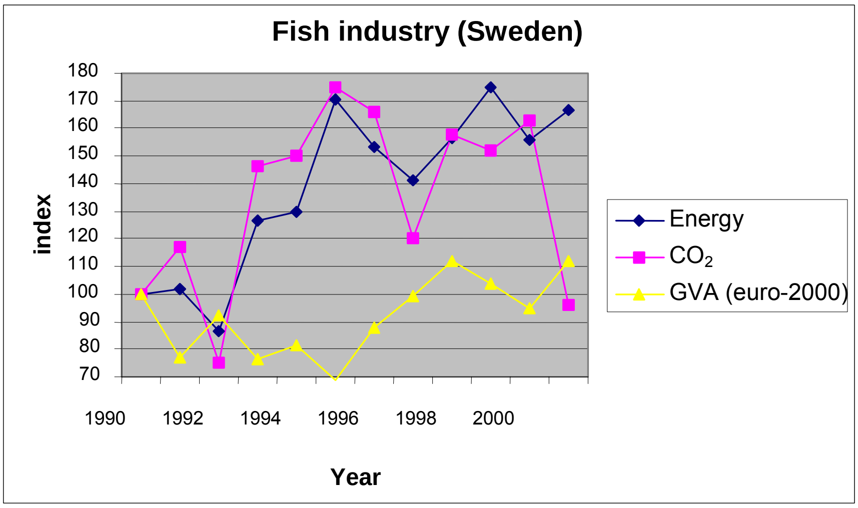

Figure 6.9b Fish Sweden – GVA, energy consumption and CO2 emissions

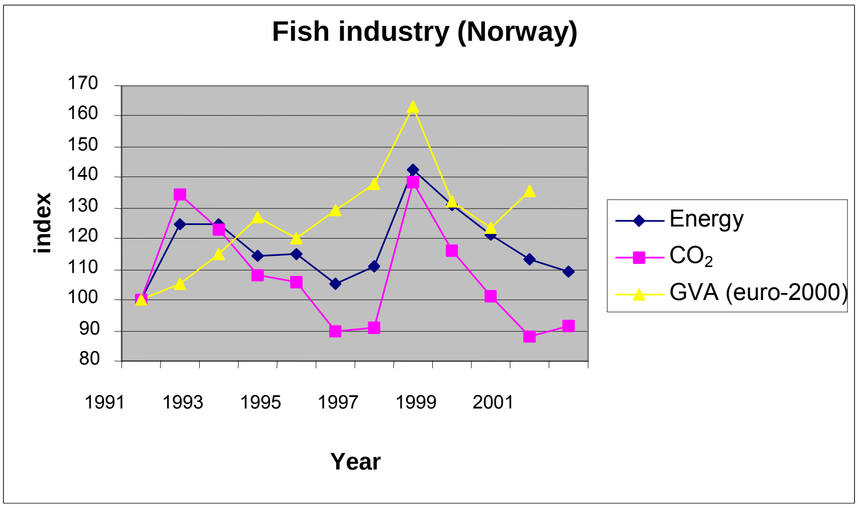

Figure 6.9c Fish Norway – GVA, energy consumption and CO2 emissions

Paper products

The overall trend in the Danish paper products industry is dominated by major fluctuations in energy consumption and CO_2 emissions in the period from 1996 onwards. These fluctuations make it difficult to interpret potential decoupling trends. In Sweden, energy and CO_2 is coupled during the entire period observed, whereas a significant inverse decoupling between GVA and energy-CO_2 can be observed from 1993 and onwards. In Norway, there are some major fluctuations in the CO_2 variable. Electricity is the all-dominating energy source in this sector and, at the same time, electricity in Norway has a very low CO_2 emission factor per GJ. Therefore, major fluctuations in the CO_2 variable will occur in response to even small variations in the consumption of CO_2 intensive energy sources such as oil, making it difficult to draw conclusions on the changing trends of such a variable. However, both energy consumption and value added have a gradual development. The two variables are coupled until 1997, whereas from 1997 onwards inverse decoupling between GVA and energy consumption can be observed between GVA and energy consumption.

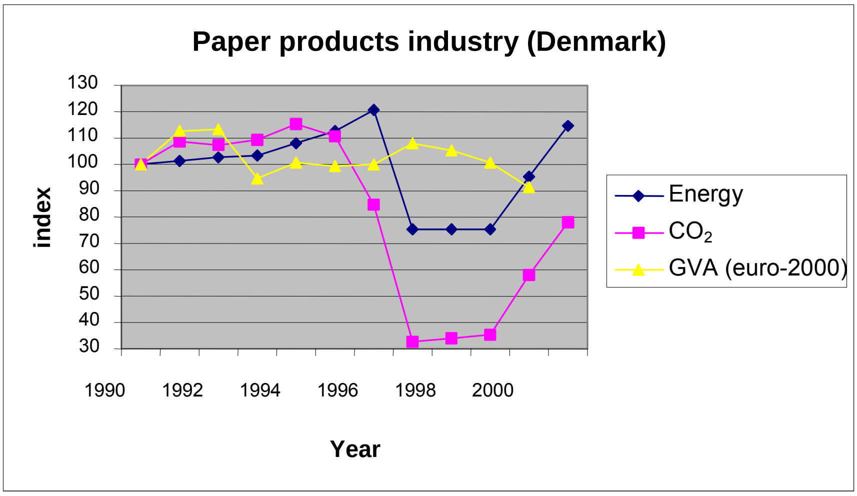

Figure 6.10a Paper prod. Denmark – GVA, energy consumption and CO2 emissions

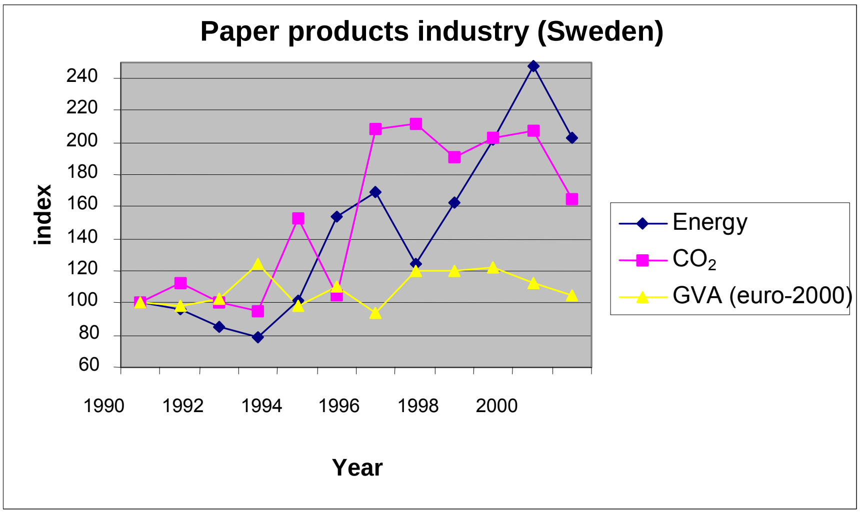

Figure 6.10b Paper prod. Sweden – GVA, energy consumption and CO2 emissions

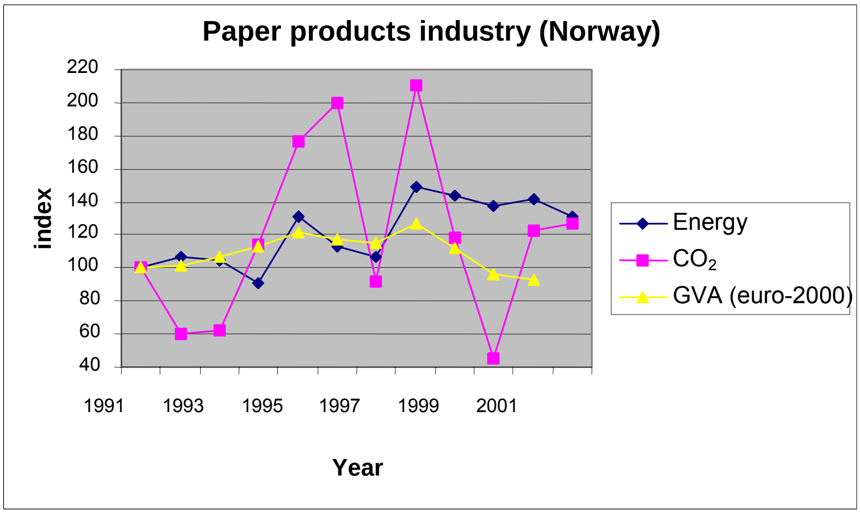

Figure 6.10c Paper prod. Norway – GVA, energy consumption and CO2 emissions

6.5 Decoupling overview

Table 6.1 provides an overview of decoupling trends in all sectors of the three countries. Several interesting patterns can be derived from this table.

Decoupling (either absolute or relative) between GVA and energy consumption occurs most frequently in Denmark (7 sectors). For Norway, the table records four sectors with GVA-energy decoupling and just one sector for Sweden and Finland, respectively. For the four most energy-intensive sectors, Norway and Sweden can record only one case of decoupling each, while decoupling can be observed in all four energy-intensive sectors in Denmark. Inverse decoupling with regard to GVA-energy occurs in four Swedish sectors, two Norwegian sectors and in only one Danish sector.

Decoupling (either absolute or relative) between GVA and CO_2 emissions also occurs most frequently in Denmark (7 sectors). For Norway, the table records GVA-CO_2 decoupling in six sectors and two sectors in Sweden and Finland, respectively. Norway and Sweden can record just one case each of GVA-CO_2 decoupling in the four most energy-intensive industries.

Inverse decoupling with regard to GVA-CO_2 occurs in three Swedish sectors and in three Norwegian sectors, whereas no overall inverse decoupling trends between GVA and CO_2 can be observed in the Danish and Finnish sectors. Coupling between GVA-CO_2 occurs in five Swedish sectors, three Danish sectors, two Finnish sectors and none of the Norwegian sectors.

The limited number of sectors, which experience decoupling in Sweden and Norway seems to be related to economic decline in particular sectors within these countries. Three of the four energy-intensive sectors in these two countries either suffered economic decline or experienced stagnating economic development in the 1990s. Sectors marked by strong economic decline are the cement industry, in both Norway and Sweden, and the glass industry in Sweden. In Denmark, however, only the chemical industry suffered overall stagnating economic development while the three other energy-intensive industries faced positive economic development.

The absence of decoupling in sectors with economic decline can be interpreted in the following way. Companies facing economic decline over several years suffer from a reduced ability to respond to normal competitive pressures and can, only with great difficulty, respond to changes in energy prices by making new investments in more efficient energy-capital. It is not necessarily productive output which declines in these companies, but their value added – and in the absence of income they may lack financial capacity to pursue more energy-efficient modes of production, other than pure "household-improvements".

Table 6.1 (Overview of decoupling trends in all sectors

		Denmark	Sweden	Norway	Finland
Metal	GVA-Energy	V	Ø	X	Ø
	GVA-CO_2	Ø	Ø	X	Ø
	Energy-CO_2	X	Ø	Ø	Ø
Furniture	GVA-Energy	X	V	Ø	
	GVA-CO_2	X	X	X	
	Energy-CO_2	Ø	V	X	
Fish	GVA-Energy	Ø	V	Y	
	GVA-CO_2	Ø	V	X	
	Energy-CO_2	X	Ø	X	
Paper products	GVA-Energy	Ø	V	V	
	GVA-CO_2	Ø	V	( )	
	Energy-CO_2	Ø	Ø	( )	
Sawmills	GVA-Energy	X	Ø	Ø	Ø
	GVA-CO_2	X	Ø	Y	Ø
	Energy-CO_2	V	Ø	Y	Ø
Veneer sheets	GVA-Energy	X	Ø	X	
	GVA-CO_2	X	Ø	X	
	Energy-CO_2	Ø	Ø	Ø	
Glass	GVA-Energy	X	V	X	
	GVA-CO_2	X	V	X	
	Energy-CO_2	X	Ø	X	
Basic chemicals	GVA-Energy	X	Y	Ø	
	GVA-CO_2	X	X	V	
	Energy-CO_2	X	Ø	V	
Pulp & paper	GVA-Energy	X	Ø	Ø	Ø
	GVA-CO_2	X	Ø	V	X
	Energy-CO_2	X	Ø	V	X
Cement etc.	GVA-Energy	X	Ø	V	Y
	GVA-CO_2	X	Ø	V	Y
	Energy-CO_2	Y	Ø	Ø	Y

X:Absolute decoupling
Y:Relative decoupling
Ø:Coupling
V:Inverse decoupling

6.6 Decoupling and CO_2-taxes

In Denmark, the CO_2 tax was introduced in 1991 and entered into force in 1992. However, production processes in industry were exempt from the tax during the first year. Therefore, it was not until 1993 that CO_2 taxes were applied to industrial processes. As noted earlier in the description of the energy-intensive industries, introduction of the CO_2 tax on industrial processes coincides with decoupling in all four energy-intensive industries. This characteristic is not evident from Figures 6.1a., 6.2a., 6.3a., and 6.4a., above, because the indexes are calculated with 1990 = index 100. When the figures are constructed with 1993 = index 100 as below, the appearance of decoupling upon introduction of the CO_2 tax in 1993 is pronounced.

However, a more rigorous analysis of the impact of CO_2-taxes on energy consumption and, ultimately, decoupling, requires that price elasticities are derived. They can then be employed to disentangle the effects of CO_2-taxes versus other price impacts in an ex-post analysis. Chapter 7 presents how such elasticities are derived and reach estimates that allow for future analysis.

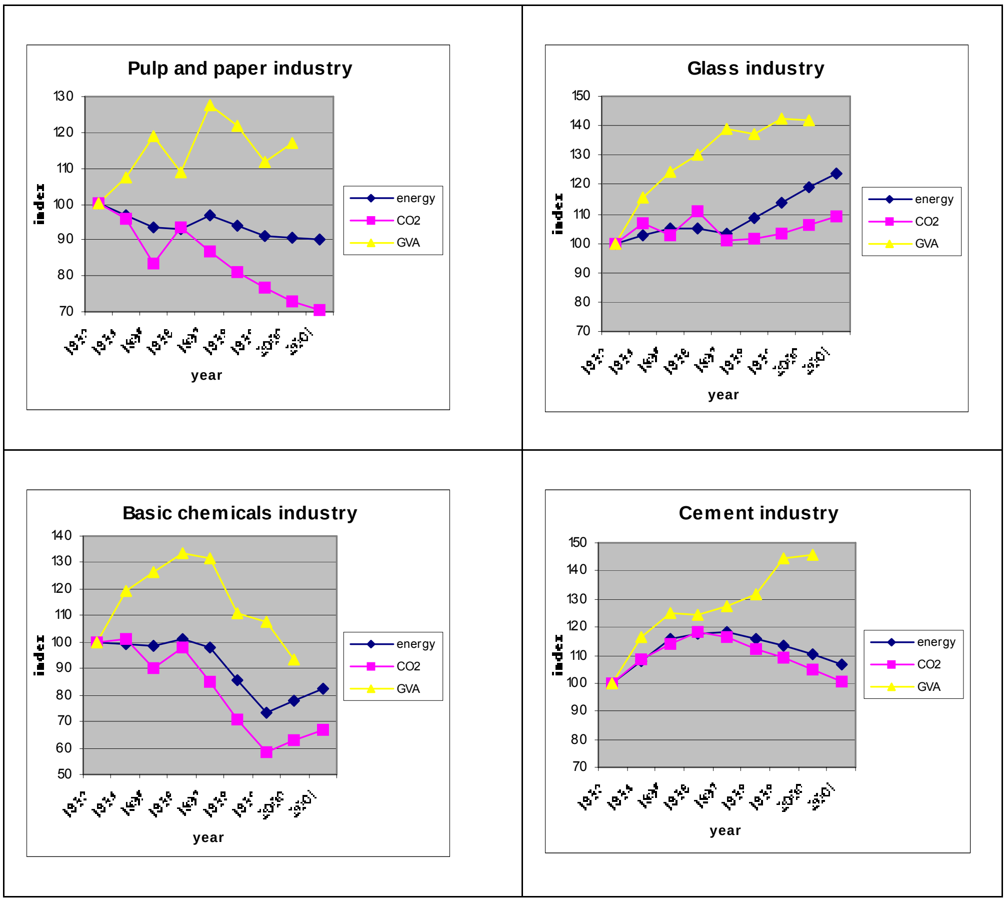

Figure 6.11 Decoupling in Danish energy-intensive industries

7. Panel regression analysis of price effects

7.1 Introduction

In order to explore the influences underlying the observed patterns of decoupling, referred to in Section 6, panel regression analysis has been undertaken to explain the relationship between changes in carbon-energy taxation and changes in energy consumption, and the results are presented below.

The relationship between energy consumption and energy prices is explored, looking at the combined effect of market price fluctuations and policy-induced price fluctuations arising from taxes. This is because companies are expected to react to net energy prices, rather than to taxes *per se*. CO_2 taxes and environmental taxes, in general, affect prices and, thereby, give companies an economic incentive to change to more environmentally-sound production processes, involving reductions in energy consumption. An investigation of the price effect on energy consumption implicitly represents, therefore, an investigation of the tax effect on CO_2 emissions. Analysis of this type sheds light on the particular impacts of CO_2 and energy taxes on energy consumption.

That energy prices influence energy consumption is an assertion with a strong intuitive appeal, and much of the policy reviewed in Section 4 rests on this assumption. Still, energy-intensive companies frequently remark that their energy demand is more or less inelastic, and that price changes lead to a decline in company competitiveness. The issue of impact is evidently one of price elasticity. By the means of appropriate econometric methods, the magnitude of the overall energy price elasticity and the respective fuel price elasticities can be estimated. The aim of this final chapter is to derive the various energy price elasticities that are necessary in order to estimate the impact of CO_2 taxes on energy consumption, and hence decoupling, in each of the Nordic countries.

The objective is achieved by carrying out panel regression analyses with respect to the collected sector-specific data on energy prices, energy consumption, value added and other relevant variables for the Danish, Swedish and Norwegian industry. The Finnish industry sectors are omitted from the analysis as no data exists on sector specific energy prices, which is a precondition for obtaining reliable estimates.

7.2 Panel regression analysis

When the data set to be analysed contains not only cross-sections (e.g. observations across different individuals, sectors, or countries at some point in time) but also repeated observations over time for each cross-section, panel regression analysis is the appropriate method. In our case, we have a panel data structure, where the cross sections (i.e. groups) are the respective industry sectors for which data were collected, and the time series are the annual observations between 1990 and 2003 for each industry sector.

In principle we have another layer of groups consisting of Denmark, Norway and Sweden. However, since we are more interested in the joint energy price elasticities that apply to each of the respective countries (and thus provides the basis for calculating the approximate effect of the national CO_2 taxes) than in pooled supranational elasticities for the entire data set, the obvious choice is to carry out separate panel regressions for each country.

7.3 Popular introduction to the applied methodologies

Having stated the basic reasoning for making use of panel regression analysis, this section is intented as a help to readers unfamiliar with quantitative statistical methods. Below we will provide a very brief overview of the basic steps and logic of the econometric analyses that we carried out in order to disclose the causal drivers behind the energy consumption and CO_2 emission patterns in Denmark, Norway and Sweden. The overview will make no use of mathematical symbols and will not go into details concerning the methodological challenges. Readers who want a real insight into the methodological foundation of the study are therefore recommended to jump to the following section 7.4 , while other readers that are mainly interested in the results and a very broad picture of how they were derived should read this section and then jump to section 7.7 and 7.8.

The basic challenge in panel regression analysis is to capture the effects that are specific to the cross-sections, that is, the individual industry sectors in this study. How to achieve this depends on what relations we are interested in explaining. Our general interest is to explain substitution between different fuels and energy forms, and to explain the overall trends in energy consumption. Energy prices, prices of other factor inputs and production demands are the central causes of such developments and the main concern of our study. Yet, there are also factors very specific to the individual sectors - for example capacity constraints, fixed capital investments, supply shortage in the region where the industry is situated, etc. There is no way in which we can grasp all the industry-specific energy demand factors in a general model. Fortunately, however, the panel regression method allows for ways to represent the joint effect of those individual factors so that they do no disturb the causal relationship among the general factors.

One way to do it is by way of the fixed effects model. In this model, the regression equation to be estimated includes a constant that varies from sector to sector. The constant represents the sum of all individual effects that apply to each respective sector. In this way the individual effects are separated from the energy price elasticities and other general factors for which separate regression coefficients are estimated. Another way is the random effects model, which is considered less relevant for this study (see section 7.4 for the theoretical argument). The presumption was confirmed in the empirical tests where estimations with the random effects model produced less reliable results than the fixed effects model.

In order to determine the general factors that account for overall energy demand and the relative demand for individual energy forms, it is necessary, in the first step, to take into account substitution elasticities between fuels, electricity and renewables and, in the second step, substitution elasticities at the higher level between energy and other production input factors (capital, labour and materials). Since the choice of one input type depends not only on the price of that input, but also on the price of all other inputs that the firm might use as a substitute (or complement), one need to estimate several demand equations simultaneously in order to find something that approximate the true own- and cross-price elasticities of demand.

Estimation of simultaneous equations are more complicated than individual equations, especially in a panel regression setting, but theoretical models and computer programs for estimation have been developed and put to frequent use for these purposes. In this study we used the translog model for modelling simultaneous energy demand equations at both levels, and the equations were thereafter estimated by the SUR method in the RATS software package (see sections 7.5-7.6 for further details or jump to directly to section 7.7 to learn about the results from the statistical estimations).

7.4 The applied panel regression method: theoretical basis

Panel regression analysis proceeds from considerations of how to impose restrictions on a model in which all parameters all allowed to vary freely across sections and time:

$$y_{it} = \alpha'_{it} + \beta'_{it} x'_{it} + u_{it} \qquad (7.1)$$

where y_{it} are the observations of the dependent variable at each cross section (i) at each point in time (t), α' it and β'_{it} are vectors of constants that vary across sections and time, x'_{it} is a vector containing the observations of each independent variable and u_{it} is the error term. Yet the unrestricted model is not statistically meaningful; all the parameters change with the observations at hand and hence we cannot draw any generalizations or inferences.

Compare this to the ordinary *pooled regression model* that imposes very tight restrictions on α and β parameters:

$$y_{it} = \alpha + \beta' x'_{it} + u_{it} \qquad (7.2)$$

Here there is only one overall constant α and a vector β of overall regression parameters for each independent variable in the *x*' vector.

If the pooled model adequately includes all thinkable *x* variables that have an impact on *y*, which might be the case under controlled experiments, the model would be applicable even to panel data structures. Standard statistical methods are sufficient for estimating the pooled model. However, in reality there are numerous individual factors that apply to each group, in our case the peculiarities of the specific industry sectors, which are not easy to capture by addition of new variables. Omitting these individual effects in the specification may lead to serious heterogeneity bias in the parameter estimates (Hsiao, 2003: 8ff).

This is where panel regression techniques enter the picture. By allowing the constant αi to vary across sectors (and perhaps also over time α_{it}) it is possible to control for the overall impact of omitted group specific (and time specific) variables. One could also allow the parameter estimates, for example the energy price elasticities, to vary between groups (β_i) without exhausting the possibilities for using panel regression techniques. But at least some dimension must be restricted in order not to fall back on the indeterminate model (7.1).

In order to assess the impact of CO_2 taxes on energy demand, we are interested in estimating the own price elasticity of energy demand along with the own- and cross price elasticities of the individual energy inputs (natural gas, oil products, coal, electricity, heat and bio fuels). Moreover, in order to discover the nature of decoupling, we are also interested in estimating the impact of economic growth on energy demand. There is every reason to expect that the respective industry sectors differ from one another with respect to structural aspects of energy demand and economic growth. It is impossible to include in the regression model all those underlying factors that account for these differences. Accordingly there is a strong presumption in favour of incorporating individual effects that adequately represents the omitted structural characteristics of each sector and thus provide for reliable estimation of the parameters of interest. It therefore came as no surprise, that every test we carried out in relation to the Danish Norwegian Swedish and panel data confirmed the existence of some kind of individual effects. In other words, the pooled regression model in which there is only a general constant α (7.2) was therefore ruled out, and so were the associated standard statistical methods.

The question of whether to allow the parameter estimates of the independent variables to vary between groups (β'_i), or to look for a vector of joint national parameter estimates (β) was determined *a priori* in the following way. In reality it is quite likely that energy price elasticities differ from sector to sector and even between the different companies within the sector. However, the central interest here is not the individual differences but the aggregate national effects, and these may be well represented by the joint energy price elasticities as long as we do not pool the sector data across nations (where national differences may arise due to, for example, hidden policy effects). In any case, the time dimensions of the included panel data sets are not long enough to generate an adequate vector of parameter estimates for each individual sector. Accordingly the panel regression analyses in this chapter centres around two models:

$$y_{it} = \alpha'_i + \beta' x'_{it} + u_{it} \qquad (7.3)$$

$$y_{it} = \beta' x'_{it} + (\alpha + u_i + \varepsilon_{it}) \qquad (7.4)$$

The first model is the fixed effects panel regression model. In this model, the omitted group specific structural variables are treated as fixed constants over time (α'_i). The second is the random effects model in which the individual effect is considered as a time invariant component in the error term, that is, a random disturbance (u_i) of the mean unobserved heterogeneity (α). Although both models incorporate individual effects stemming from omitted variables, the central difference is that the random effects model represents the individual effects by a random component in the error term and thus prohibits correlation between these individual effects and the regressor variables x'. By contrast, such correlation is not ruled out in the fixed effects models.

The great advantage of the random effects model is that, while fixed effect estimation implies a dummy vector α'_i = (d1, d2, …, dN) that expands with the number of groups thereby limiting the remaining degrees of freedom, an adequate error component model is sufficient for the estimation of the random effects model. Moreover, whereas it is natural to draw inferences from the panel data sample to the population in the case of the random effects model, this is more questionable in the fixed effects model that represents genuinely individual effects. However, two conditions must be met in order to justify the random effects model. First, the groups in the panel data set must be considered random draws from a common population. Second, and more important, the individual effects stemming from omitted variables as represented by the random disturbance must be uncorrelated with the included variables.

In our case, it is probably not right to see the included industry sectors as random draws. As would appear from the foregoing sections, there were also non-statistical reasons for choosing the sectors, and although the sample contains both energy intensive and energy extensive sectors, the former are clearly overrepresented. This is due to our interest in covering a major share of industrial energy consumption, but the chosen sectors do not also represent the major share of industry's value added. More important, it is not reasonable to assume that the omitted structural characteristics, for example production process requirements with respect to particular energy forms and factors that determine the growth potentials of the respective industry sectors, are uncorrelated with the employed regressor variables such as energy prices, wages, value added, etc. For these reasons we can decide, already on theoretical grounds that the fixed effects model is more suitable than the random effects model given the panel data sets that we work with. For a further the discussion of these matters, see Hsiao (2003: 41ff). Nevertheless, in the process of analysis, we also tried out random effects models, but in no cases did we find a better model fit, and in many cases the parameter estimates were much less realistic, than in the fixed effect models.

7.5 A translog system of simultaneous equations

Based on the microeconomic literature on production functions, a number of estimation methods for energy demand equations have been proposed, and most of them are, at least in principle, compatible with a panel regression structure. In this study we decided to apply a translog model of simultaneous energy equations. In accordance with the methodological suggestions, the model was applied over two steps, first to the demand for individual energy inputs (fuels, electricity, etc.) and thereafter to the overall demand for various factor inputs (energy, labour, etc).

The translog method is based on a second-order approximation to an arbitrary production function that places no restrictions on the elasticities of substitution (Christensen et al., 1971). On the assumption that the firm adapts instantly to price changes, the method allows for good predictions of the effects caused by changing energy prices on the overall demand for energy and the demand for various fuels that give rise to CO_2 emissions (see the survey in Atkinson and Manning, 1995). The translog cost function can be stated as follows:

$$\ln C = b_0 + \sum_h b_h \ln P_h + \tfrac{1}{2}\sum_h \sum_j b_{hj} \ln P_h \ln P_h + b_{\mathrm{Q}} \ln Q + \tfrac{1}{2} b_{\mathrm{QQ}} (\ln Q)^2 + \sum_h b_{h\mathrm{Q}} \ln P_h \ln P_{\mathrm{Q}} \tag{7.5}$$

where C is total cost, P_h denotes the price of the respective input factors, and b_h and b_{hj} the first-order and second-order parameters. By log differentiation of the cost function with respect to input prices ($\partial \ln C/\partial \ln P_h$), and using Shephard's lemma ($X_h = \partial C/\partial P_h$), we get the cost-minimizing input demand equations for the respective input factors (K, L, E, M) as a function of input prices and output:

$$\begin{aligned} S_{\mathrm{K}} &= b_{\mathrm{K}} + b_{\mathrm{KK}} \ln P_{\mathrm{K}} + b_{\mathrm{KL}} \ln P_{\mathrm{L}} + b_{\mathrm{KE}} \ln P_{\mathrm{E}} + b_{\mathrm{KM}} \ln P_{\mathrm{M}} + b_{\mathrm{KQ}} \ln Q \\ S_{\mathrm{L}} &= b_{\mathrm{L}} + b_{\mathrm{LL}} \ln P_{\mathrm{L}} + b_{\mathrm{LK}} \ln P_{\mathrm{K}} + b_{\mathrm{LE}} \ln P_{\mathrm{E}} + b_{\mathrm{LM}} \ln P_{\mathrm{M}} + b_{\mathrm{LQ}} \ln Q \\ S_{\mathrm{E}} &= b_{\mathrm{E}} + b_{\mathrm{EE}} \ln P_{\mathrm{E}} + b_{\mathrm{EK}} \ln P_{\mathrm{K}} + b_{\mathrm{EL}} \ln P_{\mathrm{L}} + b_{\mathrm{EM}} \ln P_{\mathrm{M}} + b_{\mathrm{EQ}} \ln Q \\ S_{\mathrm{M}} &= b_{\mathrm{M}} + b_{\mathrm{MM}} \ln P_{\mathrm{M}} + b_{\mathrm{MK}} \ln P_{\mathrm{K}} + b_{\mathrm{ML}} \ln P_{\mathrm{L}} + b_{\mathrm{ME}} \ln P_{\mathrm{E}} + b_{\mathrm{MQ}} \ln Q \end{aligned} \tag{7.6}$$

The demand for each input is expressed by its cost share S, that is, the total expenditure on that input divided by the firm's total cost. From the third equation we see that the firm's demand for energy depends on the price of energy (P_{E}), the prices of all other inputs (P_{K}, P_{L}, P_{M}), and the level of output (Q).

The above specification of the translog cost function and the factor demand equations can easily be extended to the sub-energy inputs by considering the following cost function:

$$C = F[P_{\mathrm{E}}(P_{\mathrm{E1}},...,P_{\mathrm{E}n})P_{\mathrm{K}}, P_{\mathrm{L}}, P_{\mathrm{M}}, Q] \tag{7.7}$$

Assuming that the aggregate price of energy (P_{E}) represents a homothetic sub-cost function, which is minimized one step before the overall cost function C is minimized, the elasticities of substitution with respect to the energy input prices ($P_{\mathrm{E1}},...,P_{\mathrm{E}n}$) do not depend upon the other factor prices (P_{K}, P_{L}, P_{M}). In other words, the sub-energy inputs are separable from capital, labour and materials. In that case, it suffices to consider a homothetic translog sub-cost function of the form:

$$\ln C_{\mathrm{E}} = b_0 + \sum_h b_h \ln P_h + \sum_h \sum_j b_{hj} (\ln P_h)(\ln P_j) \tag{7.8}$$

where h and j denote the respective sub-energy inputs (typically gas, oil, coal and electricity). For this sub-cost function, a system of demand equations can be specified for the respective fuels and electricity. The equations are similar to those in (7.6), except for the omission of the last Q-term. Later, we shall use such energy share equations to estimate the CO_2 intensity.

7.6 The equations used for estimating energy price elasticities

The question was how to fit the above translog model to the available panel data structure. We followed the suggested two-step logic by starting with the estimation of the sub-energy input demand equations.

In most studies the sub-energy inputs include natural gas, oil, coal, and electricity, but in recent years bio fuels have gained more importance, especially in the Nordic countries, and we therefore intended to add a demand equation for this category also. Moreover, although it is not used as much for process purposes as the other energy forms, heat is also important, and to some degree it is substitute for both electricity and fuels. The problem, however, is that the number of parameters to be estimated grows exponentially with the number of simultaneous equations. Rarely the data sets leave enough degrees of freedom to estimate more than three equations. Since it is common to drop the last equation in the translog system and derive it on the basis of the former, it means that demand can be estimated for no more than four energy inputs.

The approach taken here was to combine bio fuels and heat into one energy category called waste input. The justifications for combining those separate inputs into one category are the following. First, bio fuels, waste, and heat energy are to large extent industrial by-products. Moreover, heat energy often derive from combustion of bio fuels and waste, especially in the Nordic district heating sectors where many district heating plants are oriented towards producing electricity and heat from bio fuels and waste only. Hence common trends are expected in price developments and consumption patterns of bio fuels, heat and other waste energy. Moreover these types of energy inputs are much less CO_2 intensive than the traditional energy inputs (bio fuels and waste products are CO_2 neutral and whether heat is produced from fossil fuels or the two former, it is an energy efficient way of utilizing energy thus giving rise to lower CO_2 emissions).

Our panel data sets actually enabled simultaneous estimation of five demand equations for Denmark and Norway, but only four was necessary in Norway since natural gas hardly played any role. Four Sweden, where the time series had a length of only 7 years, compared to 12 for Denmark and Norway, four equations was the most we could do. Therefore natural gas was combined with waste (heat and bio fuels) into one overall clean fuel category for Sweden.

To avoid a singular covariance matrix, one equation must be dropped from the system, and for that purpose we selected the coal demand equation. By dividing all the prices in the remaining set of equations with the coal price, it is possible to omit that equation. The maximum structure, which was fully employed only in the Danish case, thus contained the following system of energy demand equations:

$$
\begin{aligned}
S_{\mathrm{G}_{it}} &= D'_{\mathrm{G}_i} + b_{\mathrm{GG}} \ln \frac{P_{\mathrm{G}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{GO}} \ln \frac{P_{\mathrm{O}_{it}}}{P_{\mathrm{C}it}} + b_{\mathrm{GE}} \ln \frac{P_{\mathrm{E}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{GW}} \ln \frac{P_{\mathrm{w}_{it}}}{P_{\mathrm{C}_{it}}} + T'_{\mathrm{G}_i} + \varepsilon_{it} \\
S_{\mathrm{O}_{it}} &= D'_{\mathrm{O}_i} + b_{\mathrm{OG}} \ln \frac{P_{\mathrm{G}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{OO}} \ln \frac{P_{\mathrm{O}_{it}}}{P_{\mathrm{C}it}} + b_{\mathrm{OE}} \ln \frac{P_{\mathrm{E}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{OW}} \ln \frac{P_{\mathrm{w}_{it}}}{P_{\mathrm{C}_{it}}} + T'_{\mathrm{O}_i} + \varepsilon_{it} \\
S_{\mathrm{E}_{it}} &= D'_{\mathrm{E}_i} + b_{\mathrm{EG}} \ln \frac{P_{\mathrm{G}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{EO}} \ln \frac{P_{\mathrm{O}_{it}}}{P_{\mathrm{C}it}} + b_{\mathrm{EE}} \ln \frac{P_{\mathrm{E}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{EW}} \ln \frac{P_{\mathrm{w}_{it}}}{P_{\mathrm{C}_{it}}} + T'_{\mathrm{E}_i} + \varepsilon_{it} \\
S_{\mathrm{W}_{it}} &= D'_{\mathrm{W}_i} + b_{\mathrm{WG}} \ln \frac{P_{\mathrm{G}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{WO}} \ln \frac{P_{\mathrm{O}_{it}}}{P_{\mathrm{C}it}} + b_{\mathrm{WE}} \ln \frac{P_{\mathrm{E}_{it}}}{P_{\mathrm{C}_{it}}} + b_{\mathrm{WW}} \ln \frac{P_{\mathrm{w}_{it}}}{P_{\mathrm{C}_{it}}} + T'_{\mathrm{W}_i} + \varepsilon_{it}
\end{aligned}
\qquad (7.9)
$$

where the demand for natural gas, oil, electricity and waste input is represented by the observed energy cost shares S_{G}, S_{O}, S_{E}, S_{W} for each industry sector at each point in time. The cost shares and thus energy demand are determined by the individual effects of each industry sector as represented by the dummy vector D'I, and the sector specific prices of the respective energy inputs at each point in time for which the b parameters express the effects that are used to calculate the energy price elasticities. Moreover, in this one-way fixed effect equation system we have also allowed for heterogeneous group trends that are a specific time trend applying to each industry sector as regards the demand for gas, oil, electricity and fuels. The trend vector T'_i represents the energy demand trends of the individual industry sectors. That dummy vector puts some extra strain on the degrees of freedom. For Sweden it could not be implemented, but in the two other cases it improved the model fit so much that there was little reason to attempt a dynamic formulation of the equations with all the extra difficulties it involves in the case of panel regression (see Arellano, 2003: 127ff). With two dummy vectors D'_i and T'_i, we had to drop one of the individual dummies in each equation in order to avoid a singular covariance matrix.

Our results indicated that industrial output in terms of value added had no systematic influence on the demand for sub-energy inputs and therefore it is omitted in the above specification. The equation system (7.9) was estimated with the 'nonlin' procedure in RATS software package that employs a GMM (general method of moments) estimator. From the conventional homogeneity restrictions that apply to the above set of equations – any column and row of b parameters sum to zero (cf. Greene, 2003: 368) – we derived the parameters for the omitted coal equation. Finally, on the basis of the b parameters and the average cost shares, the own-price and cross-price elasticities of the respective energy inputs were calculated in the following way:

$$
\eta_{hh} = \frac{b_{hh} + (S_h)^2 - S_h}{S_h} \quad \text{and} \quad \eta_{hj} = \frac{b_{hj} + S_h S_j}{S_h} \qquad (7.10)
$$

where η_{hh} denotes the own-price elasticity of demand for input *h* and η_{hj} the cross-price elasticity of demand for input *h* with respect to the price of input *j*.

In the next step we calculated an aggregate energy price index of for each industrial sector on the basis of the sector specific prices and consumption patterns of the sub-energy inputs. The aggregate energy price and energy consumption measures then enter the KLEM translog model in view of estimating the general own price elasticities of energy, labour, capital and materials along with the cross price elasticities between these factors inputs (according to the equation system in 7.6). However, in most cases it is very difficult to find adequate data indicators that measure the price and volume of capital and materials, and the difficulties compound when comparable indicators have to be collected for each industry sector in several countries. The available data were not sufficient for these purposes with respect to all three countries, and thus it was not possible to estimate the full set of KLEM equations in this study.

The normal way out of the problem is to estimate an aggregate energy consumption equation that includes on the right hand side a measure of the real price of energy, that is, current energy prices divided by the price deflator for value added. Since the price deflator for value added provides a gross representation of the overall development in factor costs, including labour costs, capital costs, energy costs and materials costs, the real price of energy thus contains information that is similar to relative prices that enter the KLEM specification. Other studies (for example, Bjørner & Jensen, 2002b; Enevoldsen, 2005) show that is has been possible to come up with energy price elasticities from the deflator adjusted equation that are almost as accurate as those derived form the full KLEM specification (and more accurate, in fact, than those KLEM estimates that are based on inadequate measures of capital and/or materials).

In our study we achieved reasonably good model fit with the deflator-adjusted equation. Yet, we found that even better estimates could be achieved by a limited LE version of the KLEM specification that includes only the labour and the energy equation. The LE specification assumes that labour and energy is separable from capital and materials. Although it has earlier been argued that materials are weakly separable from labour, capital and energy (Atkinson & Manning, 1995), it is questionable to extend this argument to capital also. However, since our interest centres on the price elasticity of energy demand (we are not interested in labour demand elasticity as such), the question is how much the former measure will be disturbed by omitting the capital equation. Not very much we argue, because the major substitution for energy, besides lower output, is labour input; there is no determinate result in the literature whether capital and energy are substitutes or complements (see the discussion in Berndt & Wood, 1979 and Griffin, 1981). Hence, unless one has really good data indicators of the capital components (which is rarely the case), a no less efficient estimate of the energy price elasticity can probably be obtained by omitting the capital equation. Moreover, the price deflator for value added is closely aligned with the costs of labour, and therefore the results of the LE specification will at least be within the broad lines of those from the deflator adjusted energy consumption equation.

In consequence, the translog model used in our estimation of the general energy price elasticity turned down to one energy cost share equation respectively one capital cost share equation (both of which include the requirements of the other by the dividing energy prices and labour costs):

$$S_{\mathrm{E}_{it}} = D'_{\mathrm{E}_i} + b_{\mathrm{EE}} \ln \frac{P_{\mathrm{E}_{it}}}{P_{\mathrm{L}_{it}}} + b_{\mathrm{EY}} Y_{it} + T'_{\mathrm{E}_i} + \varepsilon_{it} \quad (7.11)$$

$$S_{\mathrm{L}_{it}} = D'_{\mathrm{L}_i} + b_{\mathrm{LL}} \ln \frac{P_{\mathrm{L}_{it}}}{P_{\mathrm{E}_{it}}} + b_{\mathrm{LY}} Y_{it} + T'_{\mathrm{L}_i} + \varepsilon_{it} \quad (7.12)$$

where D'_i is the dummy vector of individual effects for each sector, T'_i is the vector of individual sector trends, $P_{\mathrm{E}it}$ are the observed energy prices, $P_{\mathrm{L}it}$ are the observed labour costs, and Y_{it} are the observed output levels measured by value added in constant prices. The b_{EE} and b_{LL} parameters are used along with the average factor cost shares SE and SL to calculate the own price elasticities of energy and labour (cf. 7.10). The cross price elasticities can be derived via the homogeneity assumptions: $b_{\mathrm{EE}}+b_{\mathrm{EL}}=0$, etc.

For estimation purposes we only need one of the two equations (7.11 or 7.12) as both contain the necessary information for deriving the inverse parameters applying to other. Such single panel data equations with fixed effects can be estimated by way of ordinary least squares regression.

7.7 Panel data sets

All estimations in this chapter are based on sector specific energy consumption and energy prices (detailed for each sub-energy input). Data were also collected at the NACE 3-digit level for value added in constant and current prices, employment and labour costs. These conditions were only met for a subset of the industry sectors selected for consideration. For Denmark, data were available for the full set of years 1990-2001. For Norway data starts from 1991, but one additional year was included in the end to enable the same length of time series as in Denmark. The Swedish data were much more limited at the outset, but after a special request Statistics Sweden provided us with a new energy data set covering the years 1997-2003. Table 7.1 provides an overview over the sectors that are included in the respective data sets.

It appears from the table that the Danish and Norwegian data sets are roughly similar, while the Swedish data set is smaller, containing the majority of the very energy intensive industry sectors, but no sectors in the wood industry for example, and a shorter and slightly more up-to-date time period.

Although the necessary data were generally available at the NACE 3-digit level for all sectors in Table 7.1, there were a few exceptions, especially with respect to the prices of some energy products. For example bio fuels are reported to have the same price level for all Danish industry sectors and with respect to coal products prices are also reported to be quite homogeneous among the sectors. This probably reflects a lack of knowledge regarding the exact prices, but the assumptions nevertheless appear to be quite reasonable. For some of the Norwegian and Swedish sectors, price data were missing for a few energy products. In these cases we followed the example of Statistics Denmark; we simply used the price developments in similar sectors within the country. Overall the best model fit was achieved with the Danish panel data set, which might indicate that the Danish energy consumption and energy price data are more accurate than those for Norway and Sweden.

Table 7.1 The cross section and time dimensions of the three panel data sets

Sector (NACE 3-digit):	Denmark 1990-2001	Norway 1991-2002	Sweden 1997-2003
15.1 Meat industry	√		√
15.2 Fish industry	√	√	
20.1 Sawmilling and wood plaining	√	√	
20.2 Veneer sheets, boards, panels	√	√	
20.4 Wood containers		√	
21.1 Pulp and paper industry	√	√	√
21.2 Paper and cardboard articles	√	√	√
24.1 Basic chemicals industry	√	√	√
24.4 Pharmaceuticals industry	√		√
26.1 Glass industry	√	√	√
26.2 Fine ceramics industry		√	
26.5 Cement, lime and plaster	√	√	√
27.1-27.3 Basic ferrous metals	√		√
27.4 Basic Non-ferrous metals	√		√
28.1 Metal constructions industry	√	√	
36.1 Furniture industry	√	√	

7.8 Results

In this section we report the results obtained from estimating the models that were specified in section 7.4. The first subsection analyses results from first step estimation of the sub-energy demand equations, while the second subsection analyzes the results obtained in the next step from the general factor demand equations.

7.8.1 Estimation results from the sub-energy input equations

For Denmark, there were sufficient degrees of freedom and sufficient positive consumption of all major energy types to estimate the full set of equations specified in (7.9). The full set of equations required the estimation of no less than 124 parameters including 56 dummy constants and 52 trend constants. See Table 1-4 in Appendix 1 for the estimated *b* parameters, the linear trends and the model statistics for each demand equation. In order to save space, the dummy constants (individual effects) - most of which are highly significant - are not reproduced in the tables. The model fit for Denmark was very good with an adjusted R^2 of, respectively, 0.91, 0.84, 0.91 and 0.93 for the gas, oil, electricity and waste equations. The Durbin-Watson statistics gave no indication of serious autocorrelation (no values approximate 0 or 4), and there was no evidence of heteroskedacity in the residual plots. All the *b* parameters used for calculating own price elasticities were highly significant and all cross price b parameters, except for the relation between oil and gas, respectively oil and waste, were also significant.

When comparing the panel regressions of the Danish data with those of the two other countries we see that the basic model statistics are almost as good for Norway and Sweden and the same goes for the residual plots. For the Swedish oil equation, the adjusted R^2 is only 0.73, but the unadjusted R^2 (not reported in the tables) is still as high as 0.95 and the parameter values are well in line with those of the two other countries (cf. Table 2, Appendix 1). All in all there are more insignificant *b* parameters for Norway and Sweden than for Denmark, which indicate that the best model fit has been achieved for Denmark. Yet the own price elasticity related *b* parameters are also quite significant in Norway and Sweden and so are some of the cross price parameters.

There is clear evidence of heterogeneous trends; many sectors have followed significant energy conversion patterns irrespective of price fluctuations in the period since 1990. In Denmark, a number of energy intensive sectors have steadily increased the cost share of natural gas while the oil cost share has been declining in most sectors throughout the period (see Table 1 and 2). For example the T_{G8} coefficient of 0.0106 means that the natural gas cost share is characterized by an autonomous growth trend of 1.06%age points per year within the basic chemicals sector. Natural gas is hardly used in Norway (the basic chemicals sector is the only exception) and therefore the natural gas equation has been omitted for that country. The oil trends within the Norwegian industry sectors are very mixed; the absence of an overall declining trend might be a reflection of Norway's unique access to oil resources. For Sweden no sectors trends were calculated since the panel data set leaves too few degrees of freedom for that purpose.

For electricity the picture is more mixed. The wood industry sectors and the glass industry in both Norway and Denmark are generally characterized by a steady increase in the electricity cost share, but for the other sectors there are movements in opposite directions. A very strong negative trend is seen in relation to Danish paper and cardboard products, presumably due to an extraordinary focus on self-generated electricity arising from the installation of gas-fired CHP plants within that sector. The muddy general picture is a consequence of opposing forces. On the one hand, structural changes in industrial production entail increasing demand on electricity and, on the other, environmental policy and CHP programmes discourage electricity demand. For waste energy input the trends are also mixed, which is a little surprising in view of the official policy emphasis on instruments – on top of CO_2 taxes – that are supposed to provide additional incentives for cleaner energy inputs (see next section for a further discussion of the policy implications).

The above trends should be seen as autonomous developments over and above the trends that result from price fluctuations. In all three countries, however, the central policy stimuli are in the form of CO_2 taxes, the effects of which are embedded in the price factors. The price elasticities applying to sub-energy inputs are reported in Table 7.2. All own-price elasticities have the expected negative sign. Waste energy (heat and bio fuels) appears to be the most price elastic: For Denmark, a one per cent price drop leads to more than a half per cent increase in consumption, and for Norway the same price reduction invokes 0.62% higher consumption. The results indicate that creating a price advantage in favour of low-carbon waste energy forms is a sound CO_2 policy strategy.

Table 7.2 Own-price elasticity of demand for sub-energy inputs

	Denmark	Norway	Sweden
η_{gg}: Natural Gas	-0.11	nc	(-0.12) ¤
η_{oo}: Oil products	-0.42	-0.55	-0.57
η_{cc}: Coal products	-0.37	-0.57	-0.59
η_{ee}: Electricity	-0.10	-0.28	-0.16
η_{ww}: Waste energy	-0.51	-0.62	see ¤

nc: Not calculated
¤ Natural gas and waste energy is combined into one clean fuel category

Oil and coal products are also relatively price elastic, especially in Norway and Sweden. The credibility of estimates is strengthened by the rather similar values across countries. On the other hand, natural gas and electricity are found to be very inelastic. The own-price elasticity of electricity demand ranges between -0.10 and –0.28 for the three countries, with the lowest estimate being reported for Denmark. Other studies have also found that electricity is rather insensitive to price changes (see e.g. Bjørner & Jensen, 2002a). Our findings support the view that CO_2 taxes will have only a limited influence on electricity consumption because, in many production processes, there is no adequate substitute for this high-order energy form. Arguably, it is a more rational strategy to reduce the CO_2 intensity of public electricity generation by setting requirements or providing incentives for cleaner energy input into the power stations. Yet, it is interesting to note that in Norway there seems to more scope for price-induced changes in electricity demand than in the two other countries.

It was more surprising to find that natural gas demand is very inelastic. The figures for Denmark and Sweden are -0.11 and –0.12. However, the elasticity estimates are not entirely comparable as the Swedish is based on a combination of natural gas and waste energy. In fact, by estimating the Swedish equation with natural gas only, we obtain a much higher own-price elasticity estimate, but then it is not significant. In Denmark, if we omit the fourth waste equation from the translog system, we also get a higher elasticity estimate for natural gas.

Table 7.3 Cross-price elasticity of demand for sub-energy inputs

	Denmark	Norway	Sweden
η_{go}	0.11	nc	(0.01) ¤
η_{gc}	0.03	nc	(0.04) ¤
η_{ge}	-0.04	nc	(0.07) ¤
η_{gw}	0.01	nc	see ¤
η_{og}	0.23	nc	(0.01) ¤
η_{oc}	-0.09	0.48	0.14
η_{oe}	0.20	0.07	0.41
η_{ow}	0.01	0.00	see ¤
η_{cg}	0.25	nc	(0.08) ¤
η_{co}	-0.35	0.01	0.31
η_{ce}	0.35	0.50	0.21
η_{cw}	0.11	0.06	see ¤
η_{eg}	-0.02	nc	(0.02) ¤
η_{eo}	0.04	0.17	0.12
η_{ec}	0.02	0.07	0.03
η_{ew}	0.06	0.04	see ¤
η_{wg}	0.03	nc	see ¤
η_{wo}	0.09	0.15	see ¤
η_{wc}	0.03	0.44	see ¤
η_{we}	0.37	0.03	see ¤

nc: Not calculated
¤ Natural gas and waste energy is combined into one clean fuel category

We suggest the tentative conclusion that earlier studies have overestimated the price elasticity of natural gas, precisely because waste energy demand has not been taken into account. The cross-price elasticities for Denmark (see Table 7.3) indicate that there is little substitution between natural gas and waste energy. Consequently, if a lower price of both natural gas and waste energy invokes higher demand (but more so in the latter case), ignoring the waste demand may lead us to ascribe a greater demand effect to natural gas than is actually the case. There are also practical reasons why natural gas demand might be inelastic. First, natural gas is often purchased on the basis of long-term contracts. Second, massive investments in gas-fired CHP installations during the 1990s have imposed new rigidities.

Table 7.3 reports the cross-price elasticities of sub-energy demand. All but four have the expected positive sign, and approximately 6 out of 10 are significant (cf. the associated parameter estimates in Table 1-4,

Appendix 1). There is evidence from all three countries of substitution between coal and electricity, respectively, oil and electricity, as relative prices change. Moreover, in Denmark, there is considerable substitution between electricity and waste and, in Norway, between coal and waste.

7.8.2 Estimation results from the general factor input equations

In Section 7.4 we argued in favour of using a limited LE specification of the translog model in order to estimate the own-price elasticity of energy demand vis-à-vis other factor inputs. The simultaneous estimation of energy and labour cost shares on the basis value added and factor prices (cf. equation 7.11 and 7.12) turned out very satisfactory for all three countries. Since all operations could be reduced to one equation, either (7.11) or (7.12), there were enough degrees of freedom to allow for heterogeneous trends even in the Swedish case.

Table 5 in Appendix 1 lists the parameters and model statistics that resulted from OLS estimation of (7.11). Again the fixed effects constants, one for each sector, are omitted from the list, while the more interesting individual trends are reported. The model statistics is extremely good for all three countries (almost all of the variance is being accounted for) and, again, there is no alarming evidence of autocorrelation. The marginal improvement in R^2 compared to the simultaneous sub-energy input equations is probably due to fewer parameters and thus more degrees of freedom.

The energy price parameter b_{EE} is highly significant for all three countries thus indicating that reliable energy and labour price elasticities can be derived from the model. However, the industrial output parameter b_{EY} (value added in constant prices) only has a very significant influence on the Danish energy cost share compared to a vaguely significant influence for Norway and not significant for Sweden. The significantly negative parameter estimate for Denmark indicates that energy demand decreases with economic growth, while labour demand increases. Hence, the Danish evidence for period 1991-2001 indicates that economic growth induces a substitution from energy towards labour. In Norway a moderate opposite tendency shows. However, without the capital (and materials) equation it is difficult to say whether the output effects are real; after all, we usually expect increasing substitution towards capital as the economy grows.

Many sectors show a significant autonomous trend towards an increasing energy cost share over the period. This is especially the case in some of the very energy intensive sectors, most notably cement production, paper and pulp production and basic chemicals. In these sectors, structural changes have obviously occurred resulting in fewer employees and more energy for intensive processes.

Fortunately, the three Nordic countries have countered this tendency by imposing CO_2 taxes that works in the opposite direction. Table 7.4 reports the own price elasticity of energy and labour derived from the parameter estimates in Table 5. Although the overall energy demand is not very elastic, our findings of highly significant and rather homogeneous own-price elasticities in the range of -0.35 to -0.44 for Norway, Sweden and Denmark clearly indicate that, besides from shifting energy demand towards more environment-friendly fuels, the CO_2 taxes also induce considerable reduction in energy consumption (either qua shifts to labour demand, energy-efficiency improvements or lower activity). By imposing CO_2 taxes that increase the real price of energy by, say, 10%, industrial energy consumption will, on average, be reduced by some 4%.

Table 7.4 Own price elasticity of factor input demand

	Denmark	Norway	Sweden
η_{EE}: Energy	-0.38	-0.35	-0.44
η_{LL}: Labour	-0.21	-0.28	-0.34

Apparently, the price elasticity of energy demand is somewhat higher in Sweden compared to Denmark and Norway. It indicates that CO_2 taxes will be even more effective in a Swedish context. That Norway experiences marginally lower energy price elasticity than Denmark may come as a surprise in view of the relatively higher price elasticities of the sub-energy inputs in Norway. But the interpretation is simply that substitution between sub-energy inputs is more outspoken in Norway than in Denmark, while this is not the case with respect to the general factor inputs.

The own-price elasticity of labour demand is estimated to –0.21, -0.28 and –0.34 for the three countries, which appears to be quite realistic (the statistical significance is the same as for energy as η_{LL} is simply based on the inverse of b_{EE}). It is fully expected that labour demand is more price inelastic than energy demand given the limited flexibility of hiring and firing people.

The main problem with the model estimates of (7.11) and (7.12) is that they are not dynamic. Cointegration studies of Danish energy demand have shown that it takes approximately four years before industrial energy demand fully adapts to a given change in energy prices (Bentzen and Engsted, 1993; Enevoldsen, 2005, chp. 10). In theory, the static translog model actually does in fact estimate the long-term price elasticity, but the lack of dynamic simulation of course implies a risk that it is biased in some way. Yet, our estimate of –0.38 for Denmark appears to be well in line with the findings of dynamic and other recent studies. Enevoldsen found a long-term price elasticity of –0.48 for aggregate industrial energy demand over the period 1958-2000, but also found that the elasticity tended to be (numerically) lower than –0.40 in the period from 1973-2000 (ibid.). Bjørner & Jensen (2002b) carried out a panel regression study of energy demand among Danish industrial firms over the period 1988 to 1997, and their best joint estimate of the energy price elasticity is –0.44. In sum, recent evidence and our findings mount to the conclusion that the earlier reported elasticities of around –0.25 or less (see e.g. Thomsen, 1995; Danmarks Statistik, 1997; Andersen et al., 1998) are underestimated.

7.9 Other potential factors and omitted variables

Above we have provided convincing evidence that value added and the price of energy, labour and the relative prices of the sub-energy inputs are the central determinants of the level of energy consumption and the energy mix, and thus CO_2 emissions.

We also found evidence of autonomous trends in the consumption of fuels and other energy forms that are not accounted for by the above mentioned factors, but which are nevertheless important in understanding decoupling. A part of the autonomous development may be explained by underlying political factors that were not included in this study such as for example subsidies for CHP and specific energy carriers that provide direct or indirect incentives to use some energy inputs before others. For example, during the 1990s, the Danish energy subsidies increasingly favoured consumption of natural gas and wood chips, especially for CHP purposes (Enevoldsen, 2005, ch. 9). Yet, a substantial part of the autonomous development owes to the logic of technological progress and other structural changes with no obvious relation to policy instruments.

An important event that has not figured directly in the panel regression equations is the European energy market liberalization. However, the major implication of energy market liberalization is the impact on electricity prices which is fully included in our analysis as it contributes to the own-price and cross-price elasticities of electricity demand. Of course it is an interesting question whether energy market liberalization has contributed to decoupling or not.

The question has not been pursued in this analysis, although the statistical results may be put to such use by first investigating the magnitude of energy price changes caused by the energy market liberalization and thereafter using the derived price elasticities to calculate the consequences on energy consumption and CO_2 emissions. A remaining question is whether there are other relevant effects of energy market liberalization than changing energy prices. For example, energy forms such as natural gas that were only available is some regions and for some sectors before liberalization, may now be supplied more widely thus affecting the elasticities of substitution. However, to our knowledge no such developments have taken place. The expansion of the natural gas grid, for example, is more closely related to political programmes.

Finally, there are all sorts of industry-specific factors such as demand patterns for energy-intensive goods, production process requirements, fixed capital assets, capacity constraints, structural changes in production etc. However, it is important to restate the earlier assertion that an expression for the joint effect of such particular dynamics is provided by the sector-specific constants in the fixed effects panel regression model. To the extent that the model estimations has been adequately specified, we need not worry that the omission of the industry-specific factors has a decisive influence on the relationship that we detect among the general factors. The results we obtained clearly indicate that the employed fixed effects models did their job quite well. So although the derived constants do not tell us what the industry-specific black boxes contain, they are sufficient for control purposes. Moreover, the industry-specific autonomous trends that we included in the models further contributes to controlling for individual factors with a linear pattern and thus provide for "cleaner" estimates of the central causal factors that affect all industries.

7.10 Conclusion

In this chapter, we investigated the factors that contribute to decoupling of economic growth and CO_2 emissions qua econometric analysis of overall energy demand and the demand for sub-energy inputs (the energy mix). The conclusion is that decoupling primarily owes to three factors:

1. increases in the price of energy relative to the price of labour and other input factors caused either by market developments or political instruments such as the introduction of energy/CO_2 taxes or cuts in labour taxes,
2. changes in relative energy prices in favour of low-carbon energy forms that arise as a consequence of either market developments or political instruments such as CO_2 taxes,
3. autonomous developments that reflect structural changes towards less energy-intensive products,/production processes and energy forms with lower carbon content. To the extent that these developments are the result of political instruments (other than taxes) such as for example subsidies for CHP production, they are not autonomous in the usual sense. Instead they are political factors which this study has not accounted for.

The statistical analyses provided clear evidence that energy taxes and especially CO_2 taxes will be an important instrument for decoupling of economic growth and CO_2 emissions. The high own-price elasticities of energy demand in the range of -0.35 to -0.44 for Denmark, Norway and Sweden show that taxes will encourage considerable reductions in the overall energy consumption. The finding of rather high energy price elasticities is in line with other recent studies of Danish energy demand which generally report higher elasticities than older studies based on less advanced methods.

The own- and cross price elasticities applying to the individual fuels also indicate considerable opportunities for shifting the energy mix towards a lower CO_2 intensity. In particular, we undertook a pioneering analysis of substitution between fuels and waste energy forms (heat and bio fuels) that are characterized by low CO_2 emissions, or even CO_2 neutrality as regards bio fuels. The analysis showed that waste energy is very price sensitive. Accordingly, CO_2 taxes that change the relative prices in favour of energy forms with low CO_2 emissions, i.e. natural gas and waste energy, will reduce the CO_2 intensity mainly trough substitution towards waste energy.

On the other hand, our study confirmed earlier findings that the demand for electricity is very inelastic, that is, CO_2 taxes will have only limited effects with respect to reducing electricity consumption. Moreover, increasing electricity consumption figured as an autonomous trend in most industry sectors. This is especially problematic in the case of Denmark where electricity is mainly produced from coal which, after conversion losses, makes it the most CO_2 intensive energy form. But it is also a problem in Norway and Sweden, where marginal electricity (i.e. the last units of demand) is also generated by coal-fired power plants. So with respect to electricity, other instruments than end-user taxes should take priority, especially taxes directed towards the energy input of power plants.

8. Conclusions

There has been widespread debate over the concept of decoupling in the preceding decade. There is a saying that “beloved children have many names”. This would seem to also apply to decoupling, which some refer to in terms of environmental Kuznet's curves, while others talk about ecological modernisation and others refer to the Porter hypothesis and the potential double dividends from successful economy-environment interactions.

Most approaches seem to imply that decoupling needs to be stimulated by the policy system, although some observers are more optimistic about the inherent dynamics of the market economy. Still, even adherents to the Kuznet’s curve theorem, which attributes decoupling to the transformation of changes in preferences for environment goods, would not be hard pressed to agree that such changes translate into altered government interventions.

The puzzling question remains whether environmental improvements are possible without sacrificing some degree of economic welfare. The concept of decoupling seems to suggest that this is indeed the case; that economic output can be increased, while at the same time the use of the environment as source and sink for economic activity can be decreased. Many economic observers are sceptical and deny the existence of this “free lunch”. The usual question posed is that if this was possible, why would it not have happened already. The classical article by Leibenstein (1966), mentioned in Section 2 of the report, provides an economic rationale for decoupling by means of a distinction between ordinary allocative efficiency and the more subtle concept of X-efficiency. In short, Leibenstein found a great many reasons why company-workers would not be performing at the outermost curve of productive efficiency. Leibenstein suggested that much of the growth in the economy stems from improvements in incentives to perform better, rather than in improved allocation of productive factors. It appears that similar reasons can be provided for understanding why company energy-use is not always situated at the outermost bound of the productivity curve, and there is ample anecdotal evidence of attained productive improvements in energy efficiency to suggest that “free lunches” do indeed exist in certain circumstances.

In this report, the manufacturing sector has been investigated to analyse whether decoupling occurred during the 1990s in the Nordic countries, and the extent to which such decoupling can be explained by the incentives provided in terms of carbon-energy taxes. The analysis focuses on 10 industrial sectors, of which five are energy intensive and five are less energy intensive. In the case of Finland, the analysis is limited to four sectors as data has not been released at the same level of detail as for the other countries. Some way is gone to clarify the occurrence and magnitude of decoupling as well as to explain the relationship with economic growth. However, the issues are complex, so while the report serves as a contribution to the puzzle surrounding the issue of decoupling, it does not manage to go all the way in disentangling cause and effect.

Finland, Sweden, Norway and Denmark have practised carbon-energy taxation since the early 1990s, partly for fiscal reasons, and partly as a potential stimulus to decouple carbon emissions from economic growth. Tax rates for CO_2 are highest in Sweden and Norway, at around 20-25 EUR per tonne CO_2, and lower in Finland (17 EUR per tonne) and Denmark (13 EUR per tonne CO_2), with many exemptions and special clauses in operation. The industry sectors in Sweden and Norway are generally less carbon-intensive, so the tax burden differences are subtle.

From 1990-2001 a decoupling (absolute or relative) between economic growth and CO_2 emissions can be found for seven sectors in Denmark, for six in Norway and for two in both Sweden and Finland. However, an inverse decoupling with more CO_2 per unit of gross value added can be noted in three sectors in Norway and Sweden. Finally, a coupling between GVA-CO_2 occurs in 5 Swedish sectors, 3 Danish sectors and 2 Finnish sectors.

There are notable differences between countries and sectors. The pulp and paper industry and sawmills in Denmark have achieved a high rate of decoupling, while little or no decoupling has occurred in these sectors in the other Nordic countries. The reason might be that biofuels and other non-fossil fuels make up a large proportion of the fuel mix in these sectors in Sweden, Norway and Finland, and hence that the incentive provided by CO_2 taxes to reduce energy consumption has been much more modest than in Denmark, which relied mainly on fossil fuels.

The overall figures on decoupling are sensitive to the base-year chosen, and, due to differences in the fuel mix, are also uninformative with regard to the importance of carbon-energy taxes for decoupling.

In considering the impact of taxes on energy consumption and carbon emissions, an analytical approach has been employed whereby the impact of gross price changes – including taxes - on energy consumption and the related carbon emissions has been analysed. One reason for focusing on energy consumption, rather than on carbon emissions per se, is the mix of carbon and energy taxes which decision-makers have employed.

The dataset employed for the analysis is unique in that sector-specific energy prices and taxes have been obtained. Previous analyses have relied on average energy prices and have neglected the existence of rebates and discounts for large energy consumers. Previous research has also been unable to account for the complex exemption schemes that characterise carbon-energy taxes for energy intensive industries. The data established here, as provided by the Statistical Services in the Nordic countries, allow us to improve the elasticity estimates, which are useful when considering the impact of price changes on energy consumption. The cross- and own price elasticities are relevant not only for proper assessments of carbon-energy taxes, but also for any other price change, e.g. as caused by requirements for greenhouse gas emission permits or through market volatility.

In considering the impact of taxes on energy consumption and carbon emissions, an analytical approach has been employed whereby the impact of gross price changes – including taxes - on energy consumption has been analysed. In the panel regression analysis of the report a high explanatory power characterises the impact of price changes on energy consumption. The results are relatively uniform across the Nordic countries, indicating that the elasticities might be valid also for Finland, where sector-specific energy prices and taxes could not be established.

In the sectoral analysis statistically significant relations with a good explanatory power is found for the consumption of five fuels. The own-price elasticity of oil and coal, as well as of waste energy, are relatively high (-0,4 to -0,6), indicating that consumption of these fuels are highly price elastic. On the other hand electricity and gas were found to be somewhat less price elastic (-0,1 to -0.3). This is in accordance with previous studies that have reported modest price elasticities for electricity consumption. For gas the results are more surprising, but may relate to the long-term contracts typical for the fuel. Previous studies may have failed to separate out waste energy from gas. The results here indicate that creating a price advantage in favour of low-carbon waste energy forms is a sound CO2-strategy.

The own price elasticity of energy factor demand is in the range of -0,35 to -0,44 for Norway, Sweden and Denmark, which indicates that carbon-energy taxes induce considerable reductions in energy consumption – either via shifts to labour demand, energy efficiency or through lower activity. The identified elasticities for energy factor demand are in line with other recent studies based on advanced panel regression econometrics. This evidence and the findings presented here mount to the conclusion that earlier reported energy factor elasticities of around –0,25 or less are underestimated.

Hence, by imposing CO_2 taxes (or quotas) that increase the real price of energy by, say, 10%, industrial energy consumption will be reduced by some 4%.[2] On top of such reductions come fuel switches that lower carbon emissions. The report provides fuel cross-price elasticities, which allow for future calculations.

[2] In a detailed assessment of the Danish CO2-tax Enevoldsen (2005) found a 10% reduction in CO2-emissions from industry, half of which was a fuel switch and half of which was a reduction in energy consumption.

Appendix 1

Table 1. Parameters and model statistics for the natural gas equation

	Denmark	Norway	Sweden
Parameters:			
b_{gg}	0.1454***	nc	0.1082*** ¤
$b_{go} = b_{og}$	0.0016	nc	-0.0240 ¤
$b_{ge} = b_{eg}$	-0.1305***	nc	-0.0782*** ¤
$b_{gw} = b_{wg}$	-0.0174***	nc	nc
T_1, sector 151	0.0034	-	nc
T_2, sector 152	0.0087**	nc	-
T_3, sector 201	-0.0070*	nc	-
T_4, sector 202	-0.0074*	nc	-
T_5, sector 204	-	nc	-
T_6, sector 211	dropped	nc	nc
T_7, sector 212	0.0442***	nc	nc
T_8, sector 241	0.0106***	nc	nc
T_9, sector 244	-0.0027	-	nc
T_{10}, sector 261	-0.0007	nc	nc
T_{11}, sector 262	-	nc	-
T_{12}, sector 265	0.0029	nc	nc
T_{13}, sector 271-273	-0.0017	-	nc
T_{14}, sector 274	0.0116***	-	nc
T_{15}, sector 281	-0.0003	nc	-
T_{16}, sector 361	0.0041	nc	-
Model statistics:			
Observations (*N**T*)	168	nc	63
Equation parameters	4*31	nc	3*12
Adjusted R^2	0.912	nc	(0.854)¤
Durbin-Watson Statistics	1.229	nc	(1.460)¤

nc: Not calculated
***Signifcant at the 99% confidence level
** Signifcant at the 95%level
* Signifcant at the 90%level
¤ Natural gas and waste energy is combined into one clean fuel category

Table 2. Parameters and model statistics for the oil equation

	Denmark	Norway	Sweden
Parameters:			
b_{oo}	0.0503***	0.0517***	0.0449*
$b_{og} = b_{go}$	0.0016	nc	-0.0240 ¤
$b_{oe} = b_{eo}$	-0.0381***	-0.0335	-0.0319*
$b_{ow} = b_{wo}$	-0.0017	-0.0071	see ¤
T_1, sector 151	-0.0063***	-	nc
T_2, sector 152	0.0014	-0.0066*	-
T_3, sector 201	0.0006	0.0034	-
T_4, sector 202	0.0056***	0.0060***	-
T_5, sector 204	-	-0.0231***	-
T_6, sector 211	dropped	dropped	nc
T_7, sector 212	-0.0061**	-0.0007	nc
T_8, sector 241	-0.124***	0.0024	nc
T_9, sector 244	-0.0087***	-	nc
T_{10}, sector 261	-0.0045*	-0.0218***	nc
T_{11}, sector 262	-	0.0127***	-
T_{12}, sector 265	-0.0095***	0.0029	nc
T_{13}, sector 271-273	-0.0043**	-	nc
T_{14}, sector 274	-0.0130***	-	nc
T_{15}, sector 281	-0.0096***	-0.0027	-
T_{16}, sector 361	-0.0072***	-0.0002	-
Model statistics:			
Observations ($N*T$)	168	144	63
Equation parameters	4*31	3*27	3*12
Adjusted R^2	0.840	0.915	0.732
Durbin-Watson Statistics	1.305	1.572	1.341

nc: Not calculated
***Signifcant at the 99% confidence level
** Signifcant at the 95%level
* Signifcant at the 90%level
¤ Natural gas and waste energy is combined into one clean fuel category

Table 3. Parameters and model statistics for the electricity equation

	Denmark	Norway	Sweden
Parameters:			
b_{ee}	0.1918***	0.0584*	0.1420***
$b_{eg} = b_{ge}$	-0.1305***	nc	-0.0782*** ¤
$b_{eo} = b_{oe}$	-0.0381***	-0.0335	-0.0319*
$b_{ew} = b_{we}$	-0.0176**	-0.0182*	see ¤
T_1, sector 151	0.0013	-	nc
T_2, sector 152	-0.0112***	0.0107**	-
T_3, sector 201	0.0208***	0.0052	-
T_4, sector 202	0.0180***	0.0162***	-
T_5, sector 204	-	-0.0074*	-
T_6, sector 211	dropped	dropped	nc
T_7, sector 212	-0.0417***	0.0069	nc
T_8, sector 241	0.0000	-0.0127***	nc
T_9, sector 244	0.0128***		nc
T_{10}, sector 261	0.0114***	0.0198***	nc
T_{11}, sector 262	-	-0.0146***	-
T_{12}, sector 265	0.0022	-0.0069	nc
T_{13}, sector 271–273	0.0058*	-	nc
T_{14}, sector 274	0.0026	-	nc
T_{15}, sector 281	0.0022	0.0039	-
T_{16}, sector 361	0.0079**	-0.0066	-
Model statistics:			
Observations (*N***T*)	168	144	63
Equation parameters	4*31	3*27	3*12
Adjusted R^2	0.906	0.902	0.910
Durbin-Watson Statistics	1.258	1.634	1.451

nc: Not calculated
***Signifcant at the 99% confidence level
** Signifcant at the 95%level
* Signifcant at the 90%level
¤ Natural gas and waste energy is combined into one clean fuel category

Table 4. Parameters and model statistics for the waste equation

	Denmark	Norway	Sweden
Parameters:			
b_{ww}	0.0362***	0.0272***	see Table 1
$b_{wg} = b_{gw}$	-0.0174***	nc	see Table 1
$b_{wo} = b_{ow}$	-0.0017	-0.0071	see Table 1
$b_{we} = b_{ew}$	-0.0176**	-0.0182*	see Table 1
T_1, sector 151	0.0018	-	nc
T_2, sector 152	-0.0005	-0.0049	-
T_3, sector 201	-0.0145***	-0.0090***	-
T_4, sector 202	-0.0150***	-0.0205***	-
T_5, sector 204	-	0.0302***	-
T_6, sector 211	dropped	dropped	nc
T_7, sector 212	0.0028	-0.0074*	nc
T_8, sector 241	0.0022	0.0122***	nc
T_9, sector 244	-0.0008	-	nc
T_{10}, sector 261	-0.0071***	0.0016	nc
T_{11}, sector 262	-	0.0021	-
T_{12}, sector 265	0.0002	0.0054	nc
T_{13}, sector 271-273	0.0000	-	nc
T_{14}, sector 274	-0.0003	-	nc
T_{15}, sector 281	0.0070***	-0.0034	-
T_{16}, sector 361	-0.0047**	0.0060*	-
Model statistics:			
Observations ($N*T$)	168	144	see Table 1
Equation parameters	4*31	3*27	see Table 1
Adjusted R^2	0.934	0.895	see Table 1
Durbin-Watson Statistics	1.704	1.512	see Table 1

nc: Not calculated
***Signifcant at the 99% confidence level
** Signifcant at the 95%level
* Signifcant at the 90%level

Table 5. Parameters and model statistics for the energy share equation

	Denmark	Norway	Sweden
Parameters:			
b_{EE}	0.0651***	0.0837***	0.0777***
b_{EY}	-0.0509***	0.0182*	-0.0095
T_1, sector 151	0.0028**	-	-0.0017
T_2, sector 152	-0.0005	-0.0027*	
T_3, sector 201	-0.0043***	0.0022	-
T_4, sector 202	-0.0027*	-0.0065***	-
T_5, sector 204	-	0.0055***	-
T_6, sector 211	0.0090***	0.0037***	0.0115***
T_7, sector 212	0.0006	0.0030**	0.0020
T_8, sector 241	0.0004	0.0093***	0.0146***
T_9, sector 244	0.0062***	-	0.0022
T_{10}, sector 261	0.0044***	-0.0077***	0.0084**
T_{11}, sector 262	-	0.0040**	-
T_{12}, sector 265	0.0147***	0.0099***	0.0197***
T_{13}, sector 271-273	-0.0014	-	0.0096***
T_{14}, sector 274	-0.0004	-	-0.0061
T_{15}, sector 281	0.0008	-0.0042***	-
T_{16}, sector 361	-0.0001	0.0022	-
Model statistics:			
Observations ($N*T$)	168	144	63
Equation parameters	30	26	20
Adjusted R^2	0.988	0.992	0.990
Durbin-Watson Statistics	1.440	1.355	2.532

***Signifcant at the 99% confidence level
** Signifcant at the 95%level
* Signifcant at the 90%level

References

Andersen, F.M., Jacobsen, H.K., Morthorst, P.E., Olsen, A., Rasmussen, M., Thomsen T. & Trier P. (1998), 'EMMA: En energi- og miljørelateret satellitmodel til ADAM', Nationaløkonomisk Tidsskrift, No. 136, pp. 333–49.

Andersen, M.S., Dengsøe, N. & Pedersen, A.B. (2001): An Evaluation of the Impact of Green Taxes in the Nordic Countries. Nordic Council of Ministers. – TemaNord 2001:566: 114 pp.

Andersen, M.S. & Dengsøe, N. (2002), A Baumol-Oates Approach to Solid Waste Taxation. – Journal of Material Cycles and Waste Management 4: 23–28.

Arellano, M. (2003), Panel Data Econometrics, Oxford: Oxford University Press.

Atkinson, J. & Manning, N. (1995), 'A survey of international energy elasticities', in T. Barker, P. Ekins and N. Johnstone (eds), Global Warming and Energy Demand, London and New York: Routledge, pp. 47–105.

Bjørner, T.B & Jensen, H.H. (2002a), 'Interfuel Substitution Within Industrial Companies – An analysis based on panel data at company level 2002', The Energy Journal , Vol. 23, No. 2, pp. 27–50.

Bjørner, T.B & Jensen, H.H. (2002b), 'Energy Taxes, Voluntary Agreements and Investment Subsidies – A micro panel analysis of the effect on Danish industrial companies' energy demand 2002', Resource and Energy Economics, Vol. 24, No. 3, pp. 229–249.

Berndt, E.R. & Wood, D.O. (1979), 'Engineering and econometric interpretations of energy–capital complementarity', American Economic Review, Vol. 69, No. 3, pp. 342–54.

Bentzen, J. & Engsted, T. (1993), 'Short- and long-run elasticities in energy demand', Energy Economics, Vol. 15, No. 1, pp. 9–16.

CEC (1993), Competitiveness, employment and growth – Delors whitepaper, Brussels.

Christensen, L.R., Jorgensen D.W. & Lau, L.J. (1971), 'Conjugate duality and the transcendental logarithmic production function', Econometrica, Vol. 39, pp. 255–66.

Commission Regulation 29/2002 – NACE codes.

Danmarks Statistik (1997), Energi- og Emissionsmodeller til ADAM (Energy and Emission Models for ADAM), Udarbejdet af Danmarks Miljøundersøgelser, Forskningscenter Risø og Danmarks Statistik, Danmarks Statistik.

Enevoldsen, M. (2005), The theory of environmental agreements and taxes: CO_2 policy performance in comparative perspective, Cheltenham: Edward Elgar.

Fischer, C., in press, The Effects of Emissions Trading and Other Climate Policies on Innovation, in Bernd Hansjürgens, ed., Climate policies in the US and Europe, Cambridge University Press.

Greene, W.H. (2003), Econometric Analysis, 5th edition, Upper Saddle River, NJ: Pearson Education, Prentice Hall International Edition.

Griffin, J.M. (1981), 'Engineering and econometric interpretations of energy–capital complementarity: Comment', American Economic Review, Vol. 71, No. 5, pp. 1100–104.

Huber, J. (1982), Die verlorene Unschuld der Ökologie, Frankfurt a.M.: Fischer Verlag.

Hukkinen, J. (2003), From groundless universalism to grounded generalism: improving ecological economic indicators of human – environmental interaction, Ecological Economics 44, 11–27.

Hsiao, C. (2003), Analysis of Panel Data, 2nd edition, Cambridge: Cambridge University Press.

Leibenstein, H. (1966), Allocative efficiency vs. "X-efficiency", American Economic Review, 56:3, 392–415.

Mol, A. (1995) The refinement of production: ecological modernization theory and the chemical industry, Utrecht: van Arkel.

Mol & Sonnenfeld, (2002), Ecological modernisation, American behavioural Scientist 45(9), special issue

Nordic Council, (2002), The Use of Economic Instruments in Nordic Environmental Policy 1999–2001, TemaNord 581, Copenhagen.

OECD, (2002), Sustainable development: critical issues, Paris.

Porter, M. (1991), Americas green strategy, Scientific American, April issue, p. 96.

Porter, M. & van der Linde, C. (1995): Toward a new conception of the environment-competitiveness relationship, Journal of Economic Perspectives, 9:4, 97–118.

Pearce, D. (1991), The role of carbon taxes in adjusting to global warming, The Economic Journal 101, 938–948.

Taylor, F.W. (1911), The principles of scientific management, New York: W.W. Norton.

Thomsen, T. (1995), 'Faktorefterspørgsel på kort og langt sigt', Nationaløkonomisk Tidsskrift, Vol. 133, No. 1, pp. 52–65.

Tinbergen, J. (1952), On the theory of economic policy, Amsterdam: North Holland Press.

von Weizsäcker, Ernst Ulrich, (1989), Erdpolitik: Ökologische Realpolitik an der Schwelle zum Jahrhundert der Umwelt, Darmstadt: Wissenschaftliche Buchgesellschaft.

Dansk sammenfatning

(Danish Summary)

Det er fortsat et interessant spørgsmål, om miljømæssige forbedringer er mulige, uden at de medfører et vist tab af økonomisk velfærd. Begrebet ”afkobling” (decoupling) antyder, at det bestemt er muligt at det økonomiske output kan forøges, mens anvendelsen af miljøet som ressource og skraldespand i forbindelse med økonomisk aktivitet reduceres.

En klassisk artikel af Leibenstein (1966) giver et økonomisk rationale for decoupling ved at opstille en sondring mellem almindelig allokeringsefficiens (fordelingsmæssig efficiens) og det mere raffinerede begreb ”X-efficiens” (incitaments-efficiens). Leibenstein argumenterer, at en stor del af væksten i økonomien skyldes forbedringer i incitamenter til at præstere bedre frem for forbedret fordeling af produktionsfaktorer. Der findes tilstrækkelig anekdotisk viden om opnåede produktionsmæssige forbedringer til at sandsynliggøre, at det faktisk under visse omstændigheder er muligt at opnå miljømæssige forbedringer, uden at det koster noget. Leibensteins begreb hjælper os til en teoretisk forståelse af, hvorfor virksomheders energiforbrug ikke altid er placeret ved produktionskurvens yderste grænse.

I denne rapport har vi analyseret ti industrielle sektorer – både energi-intensive og mindre energi-intensive – for at undersøge, om der gennem 1990’erne forekom decoupling mellem bruttoværditilvækst og CO_2-udledning, og i hvilken grad en sådan decoupling-effekt kan forklares ved ændringer i energipriserne, herunder de incitamenter, som CO_2- og energiskatter skaber i de nordiske lande.

I Norge, Danmark og Finland oplevede mere end halvdelen af industrisektorerne decoupling mellem økonomisk vækst og CO_2-emissioner fra 1990 til 2001. Overvægten af coupling frem for decoupling i Sverige synes derimod at hænge sammen med økonomiske vanskeligheder i flere af de svenske industrisektorer i starten af 1990’erne. Tidsseriedata antyder, at sektorer, der er i økonomisk nedgang, har vanskeligt ved at tilpasse sig incitamenterne fra CO_2- og energibeskatning. Decoupling synes at kræve et vist niveau af økonomisk vækst, der giver plads til fornyelser indenfor produktionsmåder og energiteknologier. Denne iagttagelse er i overensstemmelse med nyere økonomiske teorier om endogen vækst.

Analysens datasæt er unikt, idet sektorspecifikke energipriser og skatter er indsamlet. Tidligere analyser har anvendt gennemsnitlige energipriser, og har derfor set bort fra de rabatter og fradrag, der findes for de store energiforbrugere. Tidligere analyser har desuden ikke været i stand til at tage hensyn til de komplekse fritagelsesordninger, der præger CO_2- og energiskatter for energi-intensive industrier. Det datamateriale, der her er tilvejebragt fra statistiske bureauer i de nordiske lande, giver grundlag for at forbedre de elasticitets-estimater, der anvendes ved vurderinger af prisændringers betydning for energiforbruget. Krydspris- og egenpris-elasticiteterne er ikke alene relevante ved fastsættelsen af passende energiskatter, men også ved enhver anden prisændring, som for eksempel skyldes krav om tilladelser til udledning af drivhusgasser eller markedsomskiftelighed.

Rapportens regressionsanalyse af paneldata viser, at prisændringernes betydning for energiforbruget har en høj forklaringskraft. Resultaterne er relativt ensartede mellem de nordiske lande, hvilket indikerer, at elasticiteterne formentlig også kan antages at have gyldighed for Finland, hvor det ikke har været muligt at indsamle sektorspecifikke energipriser og skatter.

I sektoranalysen er der fundet signifikante sammenhænge med god forklaringskraft for forbruget af fem brændstoffer. Priselasticiteten for olie og kul er, som det også gælder for affaldsenergi, relativ høj (-0,4 til -0,6), hvilket indikerer, at forbruget af disse brændstoffer er særdeles priselastisk. Elektricitet og gas findes derimod at være noget mindre priselastisk (-0,1 til -0,3). Dette er i overensstemmelse med tidligere studier, der har rapporteret beskedne priselasticiteter for elektricitetsforbruget. Resultaterne for gas er mere overraskende, men kan hænge sammen med de langsigtede kontrakter, der typisk findes for dette brændstof. Tidligere studier kan have undladt at adskille affaldsenergi fra gas. Resultaterne her viser, at det er en fornuftig CO_2-strategi at skabe en prisfordel til fordel for affaldsenergiformer med lavt kulstofindhold.

Priselasticiteten for efterspørgsel på energifaktorer ligger mellem -0,35 og -0,44 for Norge, Sverige og Danmark, hvilket indikerer, at CO_2-energiskatter kan medføre betydelige reduktioner i energiforbruget – enten gennem skift til efterspørgsel på arbejdskraft, øget energieffektivitet eller lavere aktivitet. De elasticiteter for efterspørgsel på energifaktorer, der er bestemt her, er på linje med andre nyere studier baseret på avanceret panel-regressions-økonometri. Disse studier og resultaterne, der er præsenteret her, leder frem til den konklusion, at tidligere rapporterede energifaktor-elasticiteter på omkring -0,25 eller mindre er underestimerede.

Ved at pålægge CO_2-skatter (eller kvoter), der øger energis reelle pris med for eksempel 10%, reduceres det industrielle energiforbrug dermed med cirka 4%. Dertil kommer brændselsskift, der mindsker udledningen af CO_2. Rapporten præsenterer værdier for brændslers krydspris- og egenpriselasticiteter, der kan anvendes ved fremtidige beregninger.