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SUMMARY

Various different approaches have been proposed to allocate commitments regarding greenhouse gas emission mitigation for different countries. One of them is the Contraction and Convergence approach, which defines emission permits on the basis of converging national CO_2 emission rates to an equal level, which is based on per capita emissions under a contracting global emission profile. In this approach an equal per capita emission level of about 1.8 tons of CO_2 should be achieved by all countries by a designated year. As a result, many developing countries could continue to increase their emission level whereas the industrialized countries would have to reduce their emissions quite dramatically. This regime would be a shift away from the present approach and would move towards defining commitments for all parties and their evolution over the long term.

The paper explores the issue of future burden sharing for the European Union member states as well as other large carbon dioxide emitters (USA, China, Japan etc.) and selected developing countries.

The aim of this paper is to analyze what one potential future allocation scheme, the Contraction and Convergence approach, might mean for the examined countries. That has been done by making an analysis of the historical rates of CO_2 emission intensity. Those rates were then compared to more recent CO_2 emission intensity trends. The research then analysed the rate of CO_2 emission change required by different countries in order to reach the Contraction and Convergence target of equal emissions per capita. Additionally, the amount of CO_2 emissions per country was decomposed into different explanatory effects, which are also analysed in this paper. For that it was assumed that the CO_2 intensity of a country depends on energy and production technology, the fuel shares of the primary energy supply and the economic production structure.

The development of emission intensities for the selected countries has been calculated and the results show that trends in most industrialised countries, after the oil crises, could lead to the Contraction and Convergence target. However, the trends in the 1990's have usually not been sufficient due to weaker energy policy measures. The industrializing countries of Southern Europe, South-East Asia and Latin America will have to lower their CO_2 intensity trends significantly to reach the Contraction and Convergence target, while some developing countries can increase their CO_2 intensity.

1. INTRODUCTION

The paper deals with Post-Kyoto burden sharing questions for industrial and developing country partners. According to the IPCC there is a need for a 50 to 70 % reduction in greenhouse gases (GHGs) in order to stabilise the CO_2 content in the atmosphere at a level, which will not dangerously interfere with the climate system. To achieve these reductions targets have to be accepted for the different stakeholders and actors.

In the United Nations Framework Convention on Climate Change (UNFCCC) reduction commitments on GHGs were given to industrialised countries (Annex 1 Parties) only. A key feature of the Kyoto Protocol is that it includes legally binding GHG emissions targets for Annex 1 Parties totalling a reduction of 5.2 % from 1990 levels between 2008 and 2012 (UNFCCC, 1997).

One of the key policy issues in the evolution of the Framework Convention on Climate Change (FCCC) is the involvement of developing countries (non-Annex I Parties). While their emissions presently constitute only a minor part of global GHG emissions, it is expected that within a number of decades their emissions will outgrow those of the industrialised countries. The annual emissions of developing countries are growing so rapidly that even if industrialised countries meet their Kyoto targets, annual global emissions are projected to increase (IEA, 2002). Under the current climate negotiations, developing countries do not have binding commitments to reduce GHG emissions.

However, developing countries stressed that given their historically low emissions the industrialised countries should bear primary responsibility for the climate problem and should be the first to act. This was formally recognised in the FCCC in 1992, which states that developing and developed countries have "common but differentiated responsibilities" (UNFCCC, 1992). This principle is well established, but it is clear that the ultimate objective of the UNFCCC can only be met if all countries eventually participate.

The paper is structured as follows. Chapter two discusses the contraction and convergence approach. Chapter three covers the data used and the research methodology. In chapter four, the results of the quantitative analysis of the C&C approach and the decomposition analysis of selected countries are presented. Chapter five summarises the key results and discusses policy options.

Climate policy targets

Various options for potential future targets (Philibert and Pershing, 2001) have been introduced to meet the ultimate objective of the climate change convention by all countries. In addition, many approaches (Berk and den Elzen, 2001; den Elzen, 2002; Torvanger and Godal, 1999; Metz et al., 2002) have been proposed for distributing commitments with respect to the climate mitigation of different countries (Luukkanen & Kuntsi, 2003). The assumption in this paper is that any future climate policy regime will be based on the quantification of absolute emission allowances for each party as well as emission trading. The different types of policy targets that are briefly discussed here are fixed, dynamic, non-binding and dual targets.

The Kyoto target is an example of a type called fixed targets. These targets are fixed at a certain emission level, which is defined on the basis of historical emissions in a certain base year, which is for most countries 1990. For example, the target for Finland is 0 % change from the 1990 emission level. This type of target does not take into account the uncertainty of future trends. If, e.g. the GDP of a country decreases (as in ex-socialist countries in the 1990's) or increases rapidly, the activities required to achieve the targets vary considerably. In this approach the uncertainty of costs related to the mitigation activities may be considerable. One clear advantage of the approach is that a certain environmental outcome can be achieved, i.e. the reduction of emissions to the predetermined level.

In dynamic targets the allowable emission level for countries is a function of GDP. The functional form can be linear or non linear. One possibility is to determine the level of emissions to be a certain intensity factor multiplied by GDP to the power of α. When the allowable emission level depends on the rate of economic growth the uncertainty related to the costs of mitigation activities is reduced. The weak point of this type of dynamic target is that it does not guarantee a certain environmental outcome.

One possible approach could be to define non-binding targets especially for developing countries. In this approach there would be no sanctions for non-compliance. There can, however, be an incentive to reduce emissions, if, in a case where the emissions are lower than the target, there is the possibility of selling.

A dual target is a combination of dynamic and non-binding targets. In this approach the compliance target defines the level, where sanctions would be introduced. This can be defined as a function of GDP. The selling target, which is lower than the compliance target, defines where the option for selling takes place. The difference between these two targets defines an area, which takes into account the uncertainty involved in the future development.

Differentiating commitments

One of the most contentious issues of the differentiation of (future) commitments is ‘who should contribute when and how much to mitigate global climate change and to the costs resulting from adaptation measures’. The concerns of equity and efficiency are important in the evaluation of the possible burden sharing models, which determine emission commitments for different countries. All in all, it is not an easy task to find a model, which will satisfy all parties. In the following paragraphs some of the most interesting methods and models used to differentiate commitments are briefly described. That lays the foundation for discussing whether these targets should be set for different countries (which are the partners of the Climate Convention), or not, or for the companies (which are the main emitters of the GHGs), or for the final consumers of products and services.

The Brazilian Proposal distributes emission reductions to Annex I Parties based on their regional contribution to temperature increase based on their historical emissions (since 1890). The burden is shared between industrialised countries on the basis of the cumulative temperature change they have caused, i.e. effective emissions. According to this proposal, countries with a longer history of industrialisation and hence a bigger responsibility would be required to make larger reductions, while those that have industrialised relatively late would have to reduce less. The reduction target for United Kingdom would be 63.3 % whereas for Greece it would only be 7.5 % (UNFCCC, 1997).

The American Pew Center has presented criteria (responsibility, standard of living, opportunity) in order to group countries into three tiers (high, middle, low) with different levels of action required ('must act now', 'should act now, but differently', could act now'). The tiers are meant to act as indicative groupings for further negotiations. (Claussen & McNeilly, 1998.)

In the *Multi-stage approach* a gradual increase in the number of parties involved and their level of commitment (no commitments; de-carbonisation; the stabilisation of emissions; burden sharing) takes place according to participation and differentiation rules (den Elzen et al, 2002).

One method used in burden sharing proposals is the *Triptych approach*, which is a sector and technology-oriented approach that accounts for differences in national circumstances such as population size and growth, standard of living, economic structure and the fuel mix for the generation of power. The Triptych approach is a sector approach that distinguishes three categories of emissions, which correspond to three groups of economic sectors: the energy intensive industry, the power producing sector and the domestic sectors. When accounting for varying national circumstances, different criteria are used for each of the three categories to calculate sectoral allowances. (Phylipsen et al, 1998; Groenenberg et al, 2001.)

The Multi-sector convergence approach has many similarities with the region-oriented triptych approach, but has a global coverage. Also, the multi-sector convergence approach contains more sectors than the triptych, which makes it highly flexible and allows more country-specific circumstances to be taken into account. (Ringius et al, 2000.)

A fair amount of attention is also given to the different models which revolve around the concept of the environmental space and per capita entitlements, including *Contraction and Convergence*, which is perhaps one of the most comprehensive models devised so far. This paper introduces the Contraction and Convergence burden sharing model in the second chapter. The Contraction and Convergence approach tries to use objectively defined criteria for the differentiation of commitments and tries to factor in equity.

The National Institute of Public Health and the Environment (RIVM) in the Netherlands has developed an interactive analytical computational framework for linking the evaluation of different approaches for the differentiation of future commitments to global climate protection targets. The FAIR (Framework to Asses International Regimes for the differentiation of commitments) model can be used to quantitatively explore a wide range of climate policy options for international burden sharing and to evaluate the consequences of different approaches to the differentiation of future commitments. The model includes approaches that have gained policy attention, e.g. the Brazilian proposal, Contraction & Convergence (GCI), Global Compromise (Benito Müller), the Triptych approach (UU), the Emission Intensity Targets approach.

The FAIR model includes three modes for evaluating international commitment regimes. The first is 'increasing participation' so that the number of parties involved and their level of commitment gradually increases according to participation and differentiation rules (such as per capita income, or per capita emissions). The second is 'convergence', where all parties participate in the burden-sharing regime with emission rights converging to equal per capita levels over time. The third is 'triptych': different burden sharing rules are applied to different sectors (the convergence of per capita emissions in the domestic sector, efficiency and de-carbonization targets for the industrial and power generation sectors). The three modes in FAIR, i.e. increasing participation, convergence and triptych combine both different principles of equity as well as most of the other dimensions of regimes. (FAIR-model, downloadable at http://www.rivm.nl/fair/)

Equity

Many discussions on international burden sharing in the field of climate change focus on principles for distributional fairness or equity. Burden sharing negotiations involving both industrialized and developing countries can be seen as an interactive process where proposals for the differentiation of commitments are put on the negotiation table. Then details of the proposals are negotiated and the parties, in particular the developing country parties, decide if they are willing to accept a burden sharing arrangement and take on the resulting abatement commitments (see for example the discussion in Berk and den Elzen, 2001). In climate change policy the equity of negotiations procedures, equity of implementation procedures and the equity of consequences have to be considered.

The crucial question is whether the parties accept the future contract or not. If the parties perceive the proposal as equitable it is likely that they commit themselves to the targets set. It is important that the parties acknowledge the commitments and rules as justified in relation to the responsibility, the financial investments, the possibilities for mitigating climate change and the measures already carried out. The differentiation of commitments is an issue related to technical capabilities, economic costs and normative aspects such as responsibility and the equity of rights.

The chosen burden sharing rules should according Torvanger & Ringius be based on at least one of the three principles of fairness: need, capacity, or 'guilt'. According to the 'guilt' principle, the costs of carrying out measures to alleviate the climate problem - i.e. the abatement costs - should be distributed in to the degree to which actors are responsible for the climate problem. The first principle would distribute the costs in accordance with actors' legitimate need for economic and social development, whereas the second principle would distribute the cost in accordance with actors' ability or capacity to reduce greenhouse gas emissions (where a conventional yardstick is wealth measured as GDP per capita). According to Torvanger & Ringius in order to receive widespread policy feasibility and political acceptability, any model intended to have an impact would probably need to combine at least two, and preferably three, of these principles. (Torvanger & Ringius, 2000.) Most proposals for a 'fair' distribution of emissions centre on the idea of either equal emissions per capita or allocations based on incremental changes to national baseline emissions (current or projected) (Grubb et al, 1999).

This paper concentrates on the Contraction and Convergence (C&C) approach which is based on equal per capita emission rights and concedes individuals' equal rights to pollution permits. The approach has a long-term perspective with respect to the distribution of rights and duties and their evolution over time. The C&C approach of the Global Commons Institute defines emission permits on the basis of a convergence of per capita emissions under a contracting global emission profile. Important policy variables in this approach are the level of contraction of global emissions, the convergence year, the rate of convergence and the extent to which population growth is accounted for. Under C&C, all countries would collectively agree an annually reviewed target for a stable atmospheric concentration of CO_2 in the atmosphere, and then work out the rate at which emissions must contract in order to reach it.

2. THE CONTRACTION AND CONVERGENCE APPROACH

The C&C approach is an interesting application of environmental space, which has a long-term perspective with respect to the distribution of rights and duties and their evolution over time. Therefore it is suitable for supporting long term climate policy development. This approach was developed by an English organisation called the Global Commons Institute (GCI) to avert the devastating CO_2 emission trends that are developing. This type of regime defines emission permits on the basis of a convergence of per capita emissions under a contracting global emission profile. In the per capita Convergence approach all parties participate in the emission-control regime (in the post-Kyoto period), with per capita emission permits converging to equal per capita levels over time (den Elzen, 2002).

Therefore, instead of focusing on the question of how to share the emission reduction burden, it starts from the assumption that the atmosphere is a global common to which all are equally entitled (den Elzen, 2002). The differentiation of future commitments thus concerns the equitable allocation of emission rights or permits. By way of "compromise" between ideal and reality, the approach allows for a transition period during which per capita emission allowances converge from a status quo to equal per capita levels. Key policy choices relate to the duration of the transition period and accounting for population growth. A long transition period (late date of convergence) is to the disadvantage of developing countries since it results in less (cumulative) emission permits over a defined period of time. This is particularly true when global emissions contract, making the "compromise" less fair (Berk and den Elzen, 2001).

Under C&C approach, all countries would collectively agree an annually reviewed target for a stable atmospheric concentration of CO_2 in the atmosphere, and then work out the rate at which emissions must contract in order to reach it. After choosing the concentration target, a global carbon budget would then be devised accordingly. To stay within the budget, emissions have to be reduced gradually. This is the contraction part of the model. Annual limits that decrease in stages up to the target year will thus be set for the global level of emissions. The aim of the gradual contraction is to avoid both unrealistically drastic annual reductions and over-production in the beginning, which would necessitate temporary net negative emissions in the future. Eventually, emissions will reach a much lower than current level (Global Commons Institute, 1996).

The convergence part of the proposal means that each year's global emissions budget is shared out amongst the nations of the world so that every country converges on the same allocation per inhabitant by an agreed date. The industrialized countries whose emissions per capita are clearly above the sustainable level would reduce their emissions while developing countries under that level would be allowed to increase their emissions (Global Commons Institute, 1996). Countries unable to manage within their shares would be able to buy the unused parts of the allocations of other countries.

The need for a specific concentration target to be set is absolutely critical. Indeed, there should be a clear global trajectory towards a specific level of CO_2 in the atmosphere. Thus, the level of contraction and timing of convergence should be negotiated on the basis of the precautionary principle. Suggestions for emissions reductions are well known and convergence should be achieved by the medium term in order to satisfy legitimacy.

Many leaders from government, business and environmental organisations support this method as a realistic framework within which the international community can take the necessary action to solve the critical problem of climate change. The C&C approach has been adopted as the basis for future negotiations by India and China, as well as many of the African countries (Meyer, 2001).

The C&C proposal would involve sharing out each year's ration of a global emissions budget so that every country converges on the same allocation per inhabitant by an agreed date. An international trading scheme would allow countries to buy and sell unused allocations from other countries. Since developing countries have much lower per capita emissions than the developed world, convergence at equal per capita emissions rates would allow developing countries to sell their surplus emissions to the developed world at a profit. This trading would also help to establish clean technologies, especially in the South. The South would have a clear incentive to reinvest the proceeds of its permits sales into zero emissions technologies, since this would allow it to continue to sell permits. At the same time, businesses would benefit from a long-term framework that would allow them to plan effectively their capital investment in clean technology, which, in theory, would become a vast growth sector.

But there are potential drawbacks. First of all, per capita entitlements are criticised as they do not address international equity. Different countries have different needs: people in cold countries need more energy to keep warm, while those in sparsely populated countries need more energy for transport. Similarly, people in warm countries could need more energy for air conditioning. Thus, it is argued that in a way the C&C approach would be unfair.

Another concern is that it would give a large share of emission permits to a very small number of countries, to those countries with the largest populations, which could potentially collude to maintain an artificially high price.

Per capita entitlements can also be criticised as they would encourage countries to retain high population growth rates. However, it is doubtful whether entitlements would really create an incentive for high population growth, but the problem is easy to solve: population levels used for calculating countries' emission quotas could be frozen after a given population cut-off year. Per capita entitlements do not as such address intranational equity, but nor does the current UNFCCC framework (Lammi & Tynkkynen, 2001). Furthermore, the C&C approach is criticised as it ignores historic emissions. Countries with a large historic responsibility could be required to reduce more emissions than others.

It is also argued that per capita entitlements are unrealistic. Entitlements may seem unrealistic for the time being, but they enjoy relatively widespread support already now. As ample difficulties with the Kyoto Protocol have shown, the realism of conventional wisdom may be doubted as well. This would become even more apparent if developing countries were asked to take on emission targets based on grandfathering (Lammi & Tynkkynen, 2001).

One problem related to C&C approach is that while it has made recurring appearances in international negotiations, it is yet to be put on the official agenda. Furthermore, as C&C approach would mean early emission limitations for many Southern countries and also reductions in the foreseeable future, it is questionable whether C&C approach can ever garner enough support either from the North or the South. Another, more fundamental drawback of using a formula of this sort is that it would be resisted by many countries, particularly those required to make rapid, dramatic cuts in emissions.

This is not to say that there is anything inherently wrong with the Contraction and Convergence approach, rather this underlines the complexity and difficulty of the whole issue. However, GCI argues that there can be no solution to climate crisis without the two key elements: contraction as an ecological sustainability tool and convergence as equity (Lammi & Tynkkynen, 2001). If Southern countries refuse to participate in limiting emissions, a catastrophic climate change cannot be averted. However, Southern governments would be foolish to accept burden sharing that is inherently inequitable; thus equity is a prerequisite for a workable solution. Therefore, the C&C approach presents a global solution to a global problem. It is also a comprehensive model with rationally defined targets.

The C&C approach also includes an efficiency component because emission trading will lead to decisions to cut emissions first in those places where it is most economic. The approach does not contain any sectoral efficiency measures, which may be seen as a shortcoming. In addition the approach does not have any compensation measures for different national circumstances (climate, natural resources, etc.) or for the adaptation burden, which may be regarded as not meeting the equity criteria.

Done well, C&C could provide a framework for a genuine, equitable, long-term solution to climate change, which reduces political risks and provides businesses and investors with the sort of predictable framework they prefer. But if agreement is hard to reach, it might serve to highlight injustices and end up exacerbating tensions.

3. DATA AND METHODOLOGY

Data

The data used for the analysis was mainly taken from IEA statistics (IEA, 2003a, b, c). The IEA sectoral approach contains the total CO_2 emissions from fuel combustion as calculated using the IPCC sectoral approach. Emissions calculated using this approach only include emissions if the fuel has actually been combusted. The GDP data for the years from 1960 to 2001 is taken from IEA Statistics (IEA 2003a). The GDP data has been compiled for individual countries at market prices in local currency and annual rates. The data have been scaled up or down to the price levels of 1995 and then converted to US dollars using the yearly average 1995 purchasing power parities. For the calculation of the economic development of the selected countries we have used the estimates in Table 3.1.

The CO_2 future emissions are estimates made by the Global Commons Institute (Global Commons Institute, 2003) for different countries. The estimates indicate the rate of change required to reach the C&C target of 1.8 tons of CO_2 per capita by 2040, based on the concentration target level of 450 ppmv[1] of CO_2 by 2100 (Global Commons Institute, 1998). The slight differences in the IEA's and GCI's data for past CO_2 emissions caused some "jumps" in the intensities of some countries between 2001 and 2002.

The main source of the 1960 to 2001 population data is from the OECD (IEA, 2003a). The population growth rates with a medium variant from 2002 to 2050 are from the United Nations (UN, 2003). The data for the primary energy supply figures is taken from the IEA's Energy Balances.

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1 ppmv = parts per million by volume, a measure of gas concentration

For the analysis we have calculated the required change in the CO_2 intensities of the selected countries in order to achieve the contraction and convergence target of 1.8 tons of CO_2 per capita in the year 2040. The carbon dioxide emission intensity of the economy describes how many tons of CO_2 emissions are emitted per one dollar of economic output of the nation measured as GDP (CO_2/GDP). A decrease in energy intensity indicates that less CO_2 emissions are produced for the same economic output.

The changes in emission intensity result from technological changes in energy and production technology (e.g. changes in energy efficiency), changes in the shares of fuels used for energy (e.g. a shift from coal to gas) and changes in the economic production structure (e.g. a shift towards a service economy). The required change in emission intensity to achieve the emission target indicates the required structural changes in the production system and, hence, the level of difficulty to be overcome to achieve the target. In most industrialised countries the emission intensities have been declining as can be seen in the Figures in Chapter 4.

The purpose of this study is to analyse the potential changes that are needed in the emission intensities of the selected countries in order to achieve their contraction and convergence targets. We have calculated the required future development of CO_2 intensities by dividing the future emissions, produced with the C&C model, by the estimated future GDP. For future GDP growth rates we have used IIASA's and the World Energy Council's joint study (Nakicenovic et al. 1998). We have also used the growth rates of the middle scenario B of the WEC's study of the world's different regions. The growth rates are given in Table 3.1. In addition, we have carried out a sensitivity analysis using the fast and slow growth scenarios of the WEC study.

Table 3.1. Economic growth rates from 2002 to 2050, in percentages per year, for different world regions. Source: Nakicenovic et al. 1998.

Region	2002-2020	2020-2050
North America	2.0	1.3
Western European Union	1.9	1.3
Pasific OECD	1.5	0.9
Eastern Europe	0.9	3.6
Former Soviet Union	0.7	3.8
Centrally Planned Asia	5.0	4.0
South Asia	3.5	3.5
Other Pacific Asia	4.4	3.1
Middle East	3.3	3.0
Africa	3.0	3.5
Latin America	3.0	2.8
World	2.2	2.0

The Advanced Sustainability Analysis

The Advanced Sustainability Analysis (ASA) is a mathematical information system developed by the Finland Futures Research Centre. It can be used to analyse macro-economic development from different sustainability points of view (Kaivo-oja et al, 2001a; 2001b; Malaska et al, 2003; Vehmas et al, 2003; Kaivo-oja, 2004). ASA focuses on analysing changes in environmental stress (ES) or social welfare (WF), which are measured with different indicators. ASA is different from other sustainability analysis methods such as "ecological foot-print" or "ecological rucksack", which strive to provide an absolute measure of the state of environmental sustainability. ASA deals with environmental, social and economic dimensions of sustainability, but it reveals only information about the direction of change, i.e. whether it is moving towards or away from sustain-ability. This makes ASA a more practical tool for policy analysis. ASA has been used to measure and analyse several sustainability-related phenomena such as the dematerialization of production, the immaterialization of consumption, rebound effects, sustainable economic growth and sustainable technology development rates.

ASA's method is to use a complete decomposition analysis in order to divide the total ES or WF change into different components, which are called factors. The sum of all identified and decomposed factors is equal to the total ES or WF change. Different decomposition techniques have been developed mainly in the field of energy studies for modelling changes e.g. in energy use or energy intensity (Rose & Casler, 1996; Ang & Zhang, 2000; Ang, 2004). The main features of ASA include applying the decomposition technique into environmental stress (ES) or social welfare (WF) indicators and interpreting the decomposed factors as indicators either advancing or threatening sustainability. The complete decomposition method used in this study is described in detail in Appendix 1.

The ASA carried out in this study identifies five different factors behind the change in CO_2 emissions from fuel combustion (see Figure 3.1.). The factors are described and interpreted in the following way. The starting points for interpreting the bars presented in Figure 3.1 are that (1) three different time periods with the same base year of 1973 are represented in the same picture. Each time period has a different colour in each bar set. (2) Each factor affecting the change in CO_2 emissions during each time period is presented in a set of bars. (3) The sum of all factors equals the total change in CO_2 emissions from fuel combustion and is presented in the last set of bars labelled "Total".

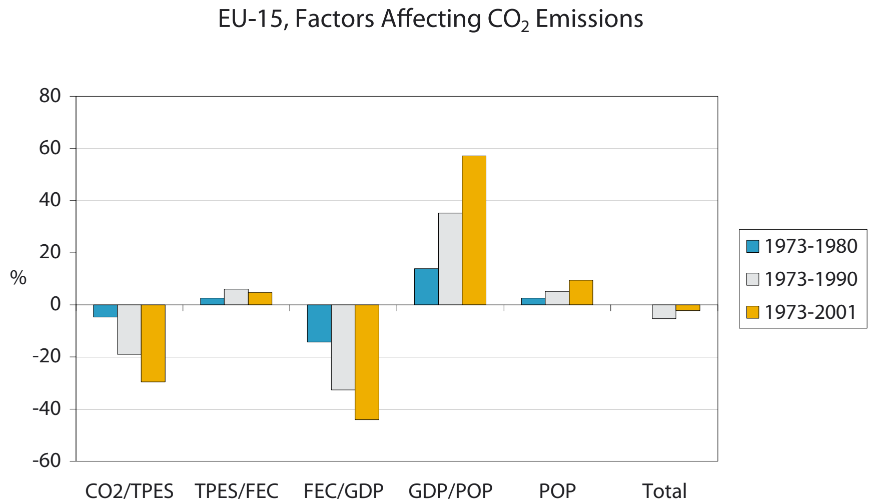

Figure 3.1. The effects affecting CO_2 emissions in The European Union (EU-15) during the periods 1973-1980, 1973-1990 and 1973-2001.

Identifying the factors behind change in CO_2 emissions from fuel combustion is based on the partition presented in the following equation:

$$CO_2 = \frac{CO_2}{GDP} \times GDP$$

$$CO_2 = \left(\frac{CO_2}{TPES} \times \frac{TPES}{GDP} \right) \times GDP$$

$$CO_2 = \left(\frac{CO_2}{TPES} \times \left(\frac{TPES}{FEC} \times \frac{FEC}{GDP} \right) \right) \times GDP$$

$$CO_2 = \left(\frac{CO_2}{TPES} \times \left(\frac{TPES}{FEC} \times \frac{FEC}{GDP} \right) \right) \times \left(\frac{GDP}{POP} \times POP \right)$$

where

CO_2	=	carbon dioxide emissions from fuel combustion;
GDP	=	gross domestic product in real prices;
TPES	=	total primary energy supply (including all fuels and other forms of primary energy, i.e. before the combustion process and transfer and distribution of electricity or heat;
FEC	=	final energy consumption, i.e. the consumption of energy carriers such as district heat and electricity, and fuels used in residential heating and transport;
POP	=	the country's population.

As a result, five different factors contributing to the change in CO_2 emissions are identified in a way that their sum is equal to the total change. For the three time periods studied, all factors are calculated as a percentage of the base year (1973) value. Each bar describes the amount of corresponding factor contributing to the change in CO_2 emissions during the studied time period.

The first factor, CO_2/TPES-factor, refers to the contribution of the change in the CO_2 intensity of the entire energy system that has been influenced by a switch from one energy form to another. Negative values for this factor in Figure 3.1 imply a switch from fuels with a high carbon content to energy sources with a lower carbon content, e.g. from coal to natural gas or nuclear power. Positive values would imply an increasing effect on CO_2 emissions due to the opposite type of fuel switch.

The second factor, TPES/FEC-factor refers to the efficiency of the energy transformation system, i.e. efficiency in transforming primary energy into different energy carriers such as electricity or heat. This can be influenced by e.g. a switch from fuel use to electricity or vice versa, or technological changes in fuel combustion. Positive values for this factor in Figure 3.1 imply an increasing use of electricity instead of other energy sources. Negative values would imply an opposite change of direction, i.e. technological changes such as a switch to combined heat and power (CHP) production instead of separate heat and electricity production.

The third factor, FEC/GDP-factor, refers to the energy intensity of the whole economy. This can be influenced by several factors, such as changes in the industrial structure from energy intensive to less energy intensive industrial branches, a shift from industrial production towards services in terms of GDP shares, or technological development inside energy- consuming fields of the economy. Negative values for this factor in Figure 3.1 imply that European countries have decreased their energy intensity due to the reasons provided above. Positive values would imply an increasing CO_2 emissions effect due to changes in the direction of a more energy intensive structure of the economy.

The fourth factor, the GDP/POP-factor refers to the amount of economic activity per capita which can be influenced foremost by economic growth. The positive values for this factor in Figure 3.1 imply that continuous economic growth per capita has increased CO_2 emissions. Negative values would imply a decreasing effect on CO_2 emissions due to a decrease in GDP per capita.

The fifth factor, the POP-factor refers to changes in the population figure brought about by birth and death rates as well as by international migration. The positive values for this factor in Figure 3.1 imply that quite a slow population growth has slightly increased CO_2 emissions from fuel combustion in the European Union. Negative values would imply a decrease in the effect of CO_2 emissions due to a decrease in the population.

The last set of bars in Figure 3.1 shows the total change of CO_2 emissions in the EU-15 countries as a sum of the five factors presented above. Between the years 1973 and 1980 the absolute CO_2 emissions from fuel combustion did not change. During the time periods 1973-1990 and 1973-2001 emissions have slightly decreased as a result of a switch towards energy sources that include less carbon as well as structural changes in the economy, such as the switch towards a less energy intensive industry and an increase in services. These factors have compensated for the factors of population growth, an increase in GDP per capita and the increasing use of electricity, which all tend to increase CO_2 emissions.

4. THE QUANTITATIVE ANALYSES OF EMISSION INTENSITY CHANGE AND A DECOMPOSITION ANALYSIS FOR SELECTED COUNTRIES

Emission intensity changes

The CO_2 emissions of an economy can be defined with the aid of the CO_2 intensity of production and the production volume

$$CO_2 = \frac{CO_2}{GDP} GDP$$

where CO_2 means the amount of carbon dioxide emissions, and GDP is the Gross Domestic Product and the CO_2 intensity of the economy is defined as the CO_2 emissions divided by the Gross Domestic Product, GDP.

$$CO_2 \,\text{int} = \frac{CO_2}{GDP}$$

where CO_2 int means carbon dioxide intensity.

The future development of CO_2 emissions in a country can be defined by the estimated CO_2 intensity of the future and the estimated GDP growth. The changes in CO_2 intensity depend on several factors, but the general development path of an industrialising nation has been increasing intensity in the industrialization phase and decreasing intensity when the economy shifts more towards a service sector dominated system. The changes in CO_2 intensity in Italy indicate this general development trend (see Figure 4.1).

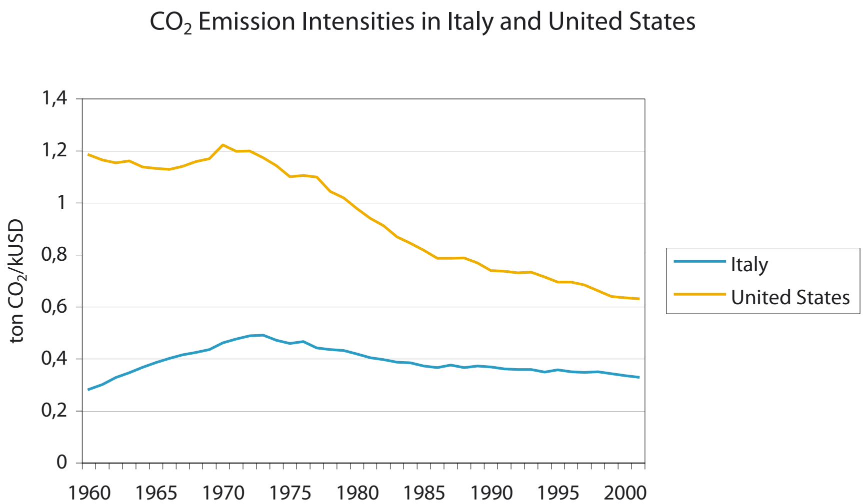

Figure 4.1. Changes in the CO_2 intensity of the economies of Italy and the USA from 1960-2001 (Source: IEA 2003a).

A falling trend in CO_2 intensity after the first oil crisis in 1973 can be seen in most industrialized countries. In some countries the trend of decreasing intensity started even before the oil crisis as can be seen in Figure 4.1 for the USA.

The level of the CO_2 intensity of the economy depends strongly on the production structure and the energy sources that are used. The transport sector can have an important effect on the level of the CO_2 intensity in countries, especially those with a high share of private car based passenger traffic and truck dominated freight transport. The transport sector is discussed in more detail in Chapter 4.11.

In the so called Newly Industrialized Countries (NIC) the trend of growing CO_2 intensity can be clearly seen as is indicated in Figure 4.2 for Thailand and Malaysia. In relation to the Contraction and Convergence model this can be seen as a problem since the model does not take into account responsibility for historical emissions.

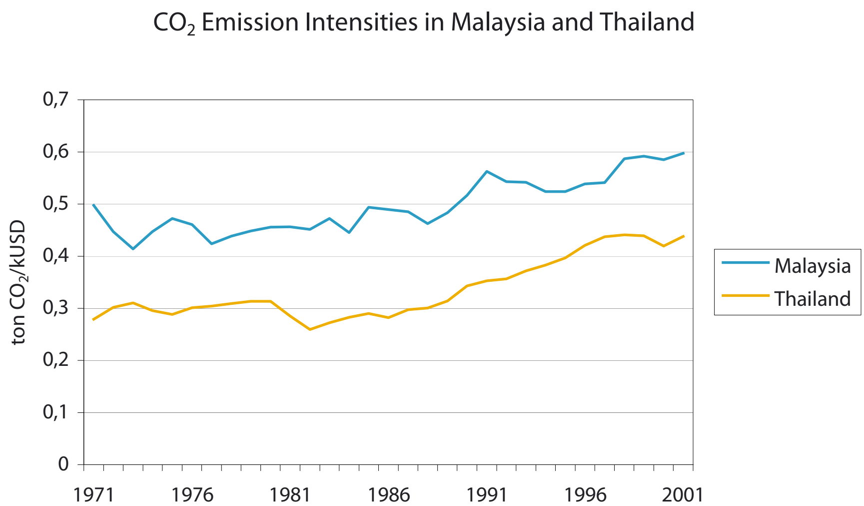

Figure 4.2. Changes in the CO_2 intensity of the economies of Thailand and Malaysia from 1971-2001 (Source: IEA 2003a).

We have calculated the future development of the CO_2 intensities of selected economies in order to analyse the likelihood of achieving the C&C target of 1.8 tons of CO_2 per capita in 2040 and to see what this requires, in terms of action, from different countries. We have downloaded the future emission projections from the C&C web site and calculated the future development of GDP based on the middle scenario of the WEC report "Global Energy Perspectives" (see Nakicenovic et al 1998). Based on this data we have calculated the required development paths for the CO_2 intensities in the different economies.

In addition we have analysed the past trends of CO_2 emissions and primary energy use for the selected countries. The decomposition analysis thus provides the means to assess the different factors that have contributed to the changes in the emission amounts.

Japan, USA and EU15

The past development and the required future changes in the CO_2 intensity of the economies of the USA, Japan and the EU15 are shown in Figure 4.3.

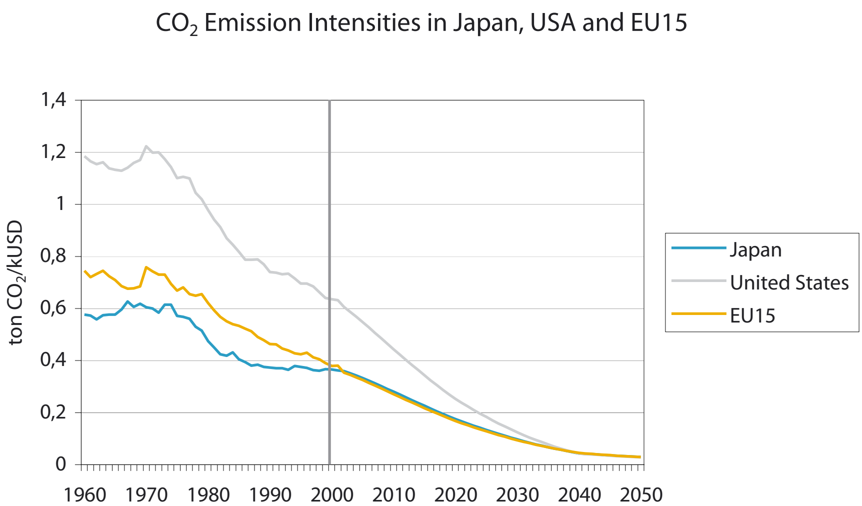

Figure 4.3a. Changes in the CO_2 intensity of the economies of Japan, the USA and the EU15 from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

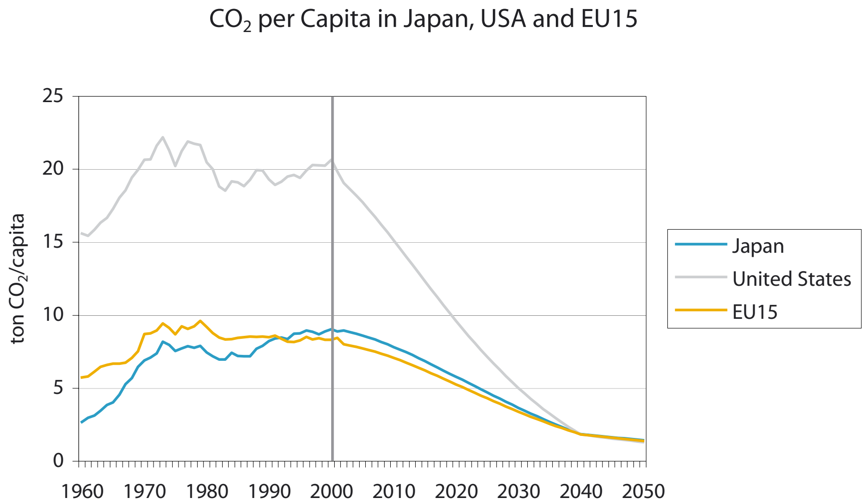

Figure 4.3b. Changes in the CO_2 emissions per capita of the economies of Japan, the USA and the EU15 from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

The required future development for CO_2 intensities for Japan, the USA and the EU15 seems not to be too unrealistic. The sharp decrease in intensity after the first oil crisis was due to the increased efficiency of their energy use, plus a shift from oil to energy sources of lower carbon content. However, it was mainly due to a structural shift in the production structure, which led to lower energy intensities in their economies. This can be seen in the results of the decomposition analysis shown below.

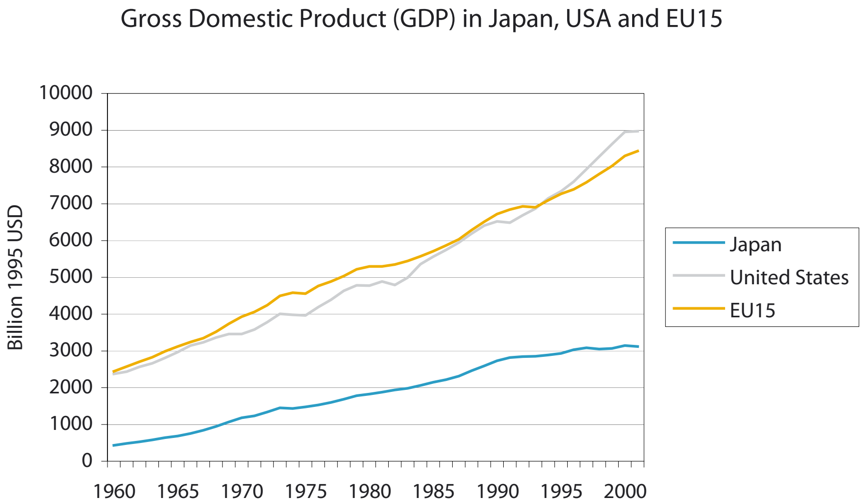

Figure 4.4. *The growth of Gross Domestic Product (GDP) in Japan, USA and EU15 between 1960 and 2001 (in PPP 1995 US$) (Source: IEA 2003a).*

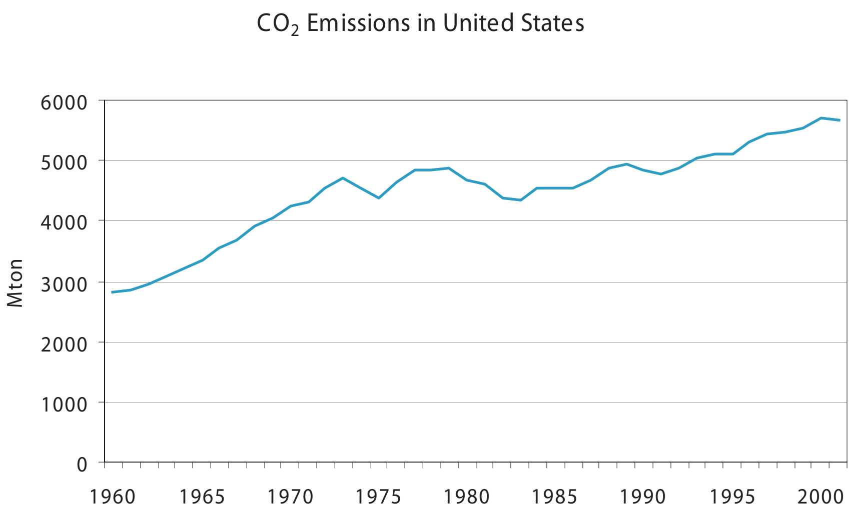

Figure 4.5a. *CO_2 emissions in the USA from1960-2001 (Source IEA 2003a, b).*

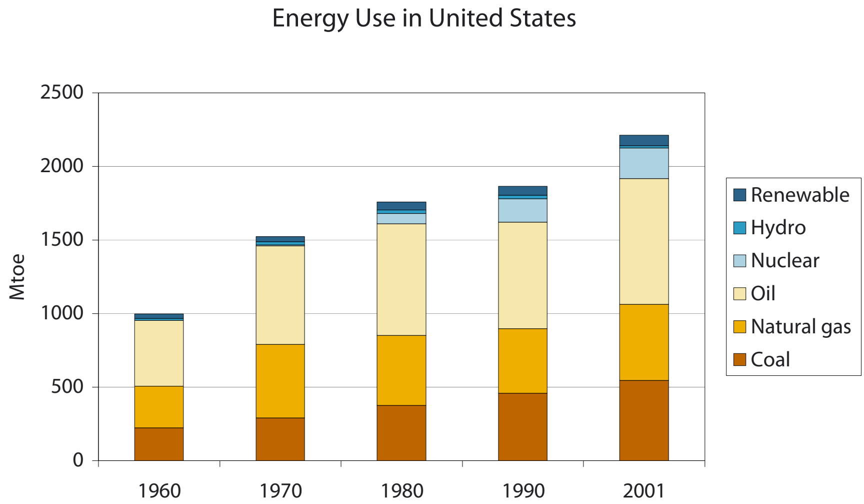

Figure 4.5b. Primary energy use in the USA from1960-2001 (Source IEA 2003a, b).

In the USA the decarbonisation of the economy was quite rapid in the 1970's and 1980's, but development in the nineties has not been as successful. The changes in the fuel mix for energy production can be seen as one factor contributing to intensity change. The levelling off of the use of oil in 70's and 80's together with the increased use of nuclear energy explain the slow growth of CO_2 emissions. In the 1990's the use of oil has rose considerably in the USA increasing CO_2 emissions and lowering the rate of reduction of the CO_2 intensity of the economy.

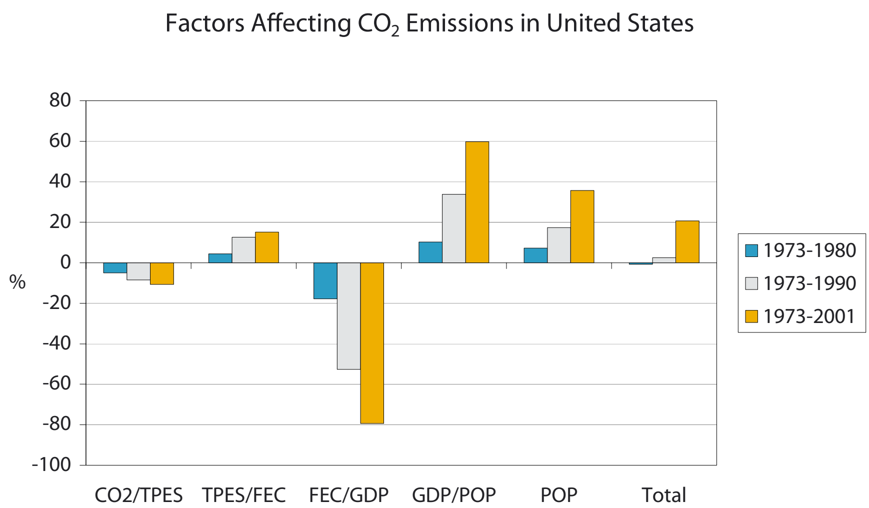

Figure 4.6. A decomposition analysis for the factors affecting CO_2 emissions in the USA from 1973 to 2001.

The decomposition of the US's CO_2 emissions according to different factors is shown in Figure 4.6. In this figure the changes in CO_2 emissions are shown in comparison with the year 1973. The first factor CO_2/TPES indicates the fuel shift in the total primary energy supply (TPES). The fuel shift has contributed to about a 10 % decrease in emissions in 2001 compared to the level of 1973. The second factor, TPES/FEC (Final Energy Consumption), indicates the change in the efficiency of the energy transformation chain. In this case efficiency has decreased, due to the increased share of electricity in FEC increasing CO_2 emissions by 17 % in 2001. The third factor, FEC/GDP, indicates the energy intensity of the production system. This has decreased considerably due to the increased share of services and the decreased share of heavy industry in the economy. The structural shift in the economy has decreased CO_2 emissions by 80 %.

The fourth factor, GDP/POP, indicates the effect of the increase in per capita production. This factor has increased emissions by 60 %. The fifth factor, POP, shows the effect of an increasing population on CO_2 emissions. In the USA the population growth effect has been about 35 %.

The total change in the US's CO_2 emissions is the sum of the five effects, which is about a 20 % increase between 1973 and 2001.

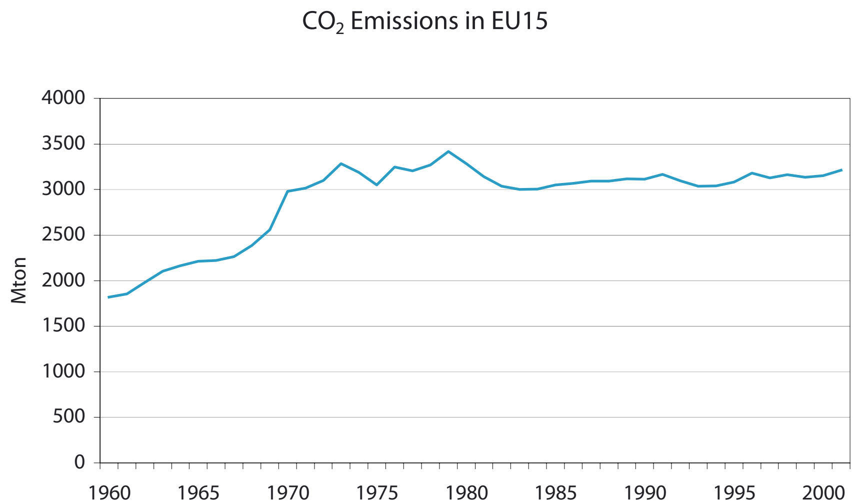

Figure 4.7a, CO_2 emissions in the EU15 from1960-2001 (Source IEA 2003a, b).

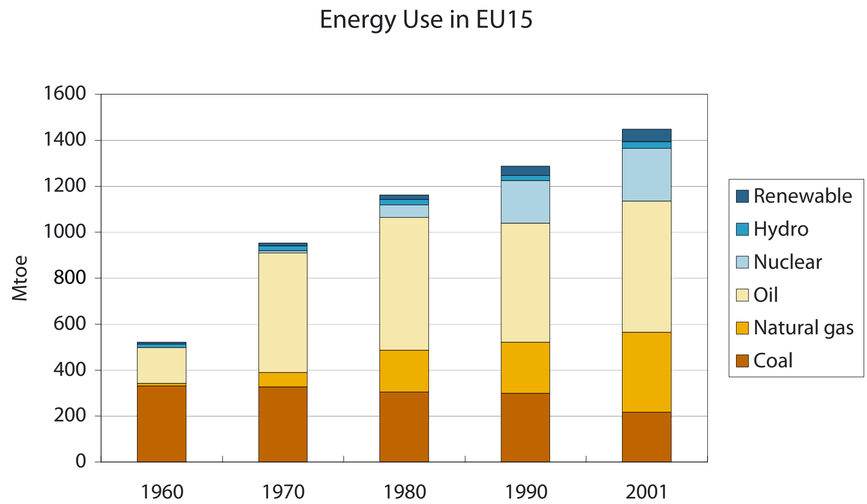

Figure 4.7b. Primary energy use in the EU15 from 1960-2001 (Source IEA 2003a, b).

In the EU15 the growth of energy use has been faster than in the USA, but the shift in fuel use has been larger resulting in the stabilisation of CO_2 emissions after 1973. The shift from coal to gas has been remarkable and the increase in nuclear production considerable.

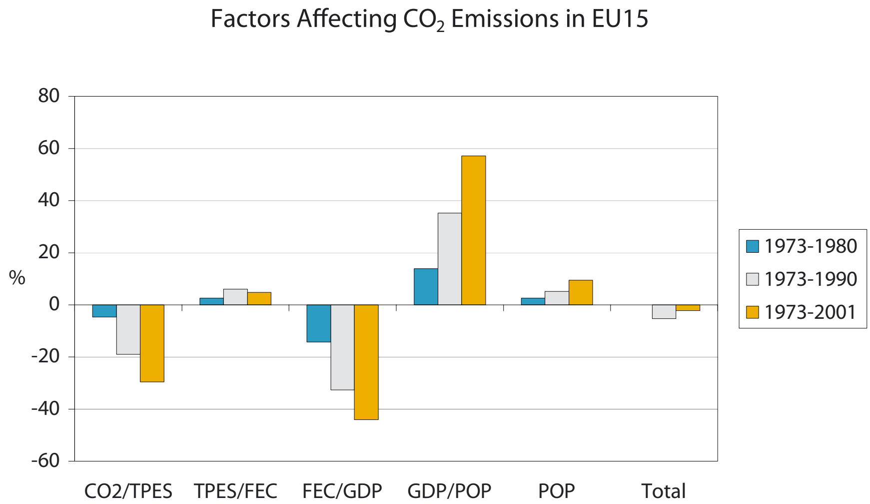

Figure 4.8. *A decomposition analysis for the factors affecting CO_2 emissions in the EU15 from 1973 to 2001.*

The decomposition analysis in Figure 4.8 for the EU15 shows that the fuel shift has been more significant than in the US contributing to a 30 % decrease in emissions. The structural shift in the EU has not been as significant as in the US. The population growth effect and the efficiency loss in the energy transformation system have been smaller leading to a minor decrease in total emissions from 1973 to 2001.

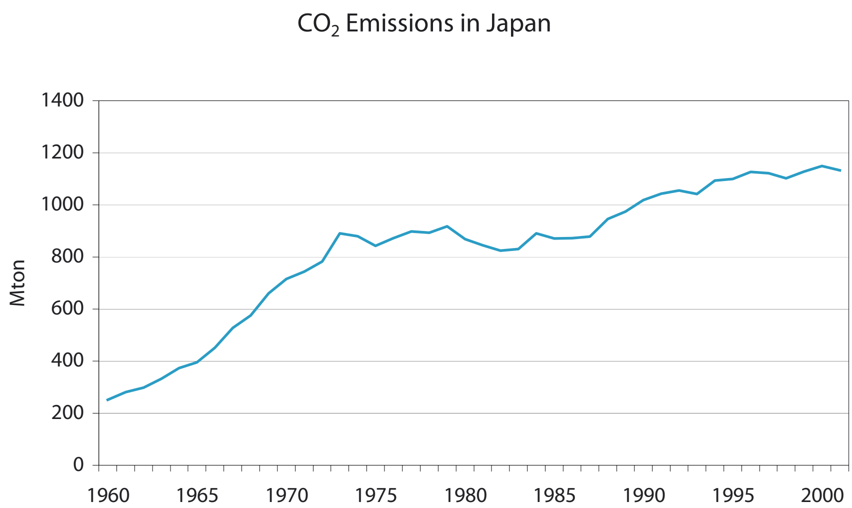

Figure 4.9a. *CO_2 emissions in Japan from 1960-2001 (Source IEA 2003a, b).*

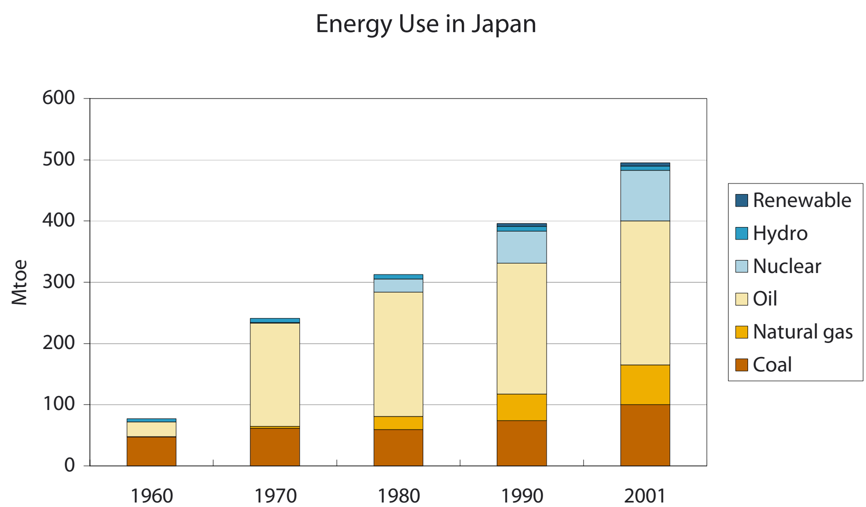

Figure 4.9b. *Primary energy use in Japan from 1960-2001 (Source IEA 2003a, b).*

In Japan CO_2 emissions stabilized after 1973 but started to increase again in the late 80's. The increased use of oil and coal seems to be the main reason for the emission increase, which was partly triggered by a fast increase in energy demand.

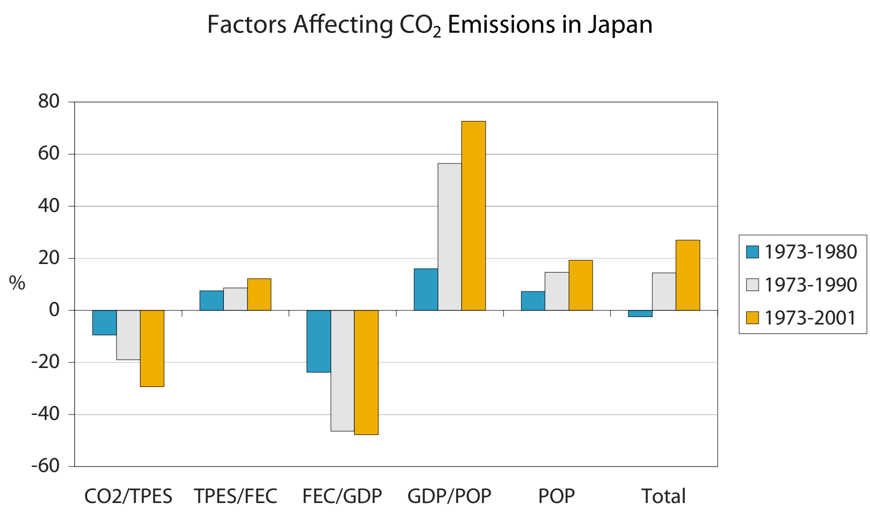

Figure 4.10. A decomposition analysis for the factors affecting CO_2 emissions in Japan from 1973 to 2001.

The decomposition analysis in Figure 4.10 for Japan shows that the fuel shift has been quite significant, as has its per capita production growth. The structural shift effect has not decreased emissions after 1990 and that has partly contributed to the total growth of emissions by 25 % from 1973 to 2001.

The other G7 countries

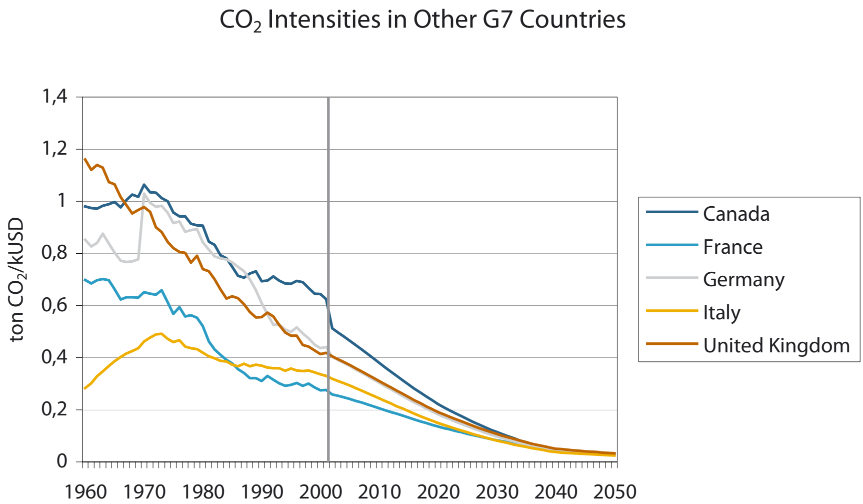

Figure 4.11a. Changes in the CO_2 intensity of the economies of the other G7 countries from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 to reach the C&C target.

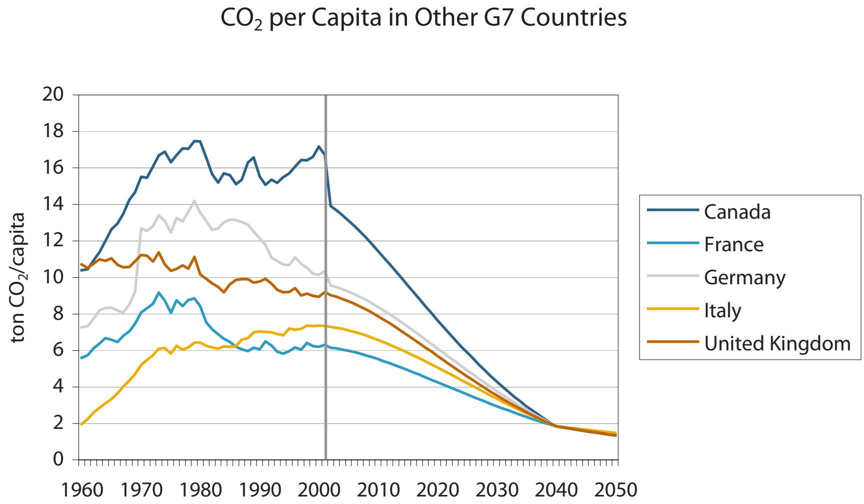

Figure 4.11b. Changes in the CO_2 emissions per capita of the economies of the other G7 countries from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 to reach the C&C target.

The development with regard to the CO_2 emission intensity changes in the G7 countries of Canada, France, Germany, Italy and the United Kingdom has generally been quite positive.

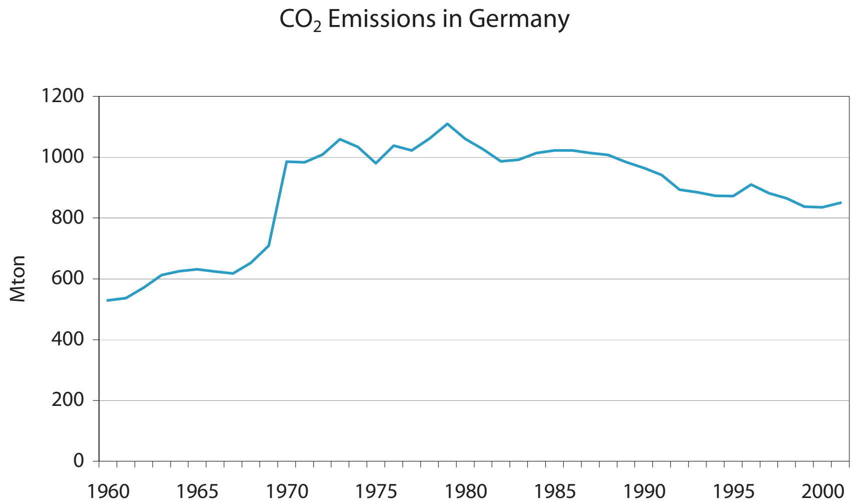

Figure 4.12a. CO_2 emissions in Germany from 1960-2001 (Source IEA 2003a, b).

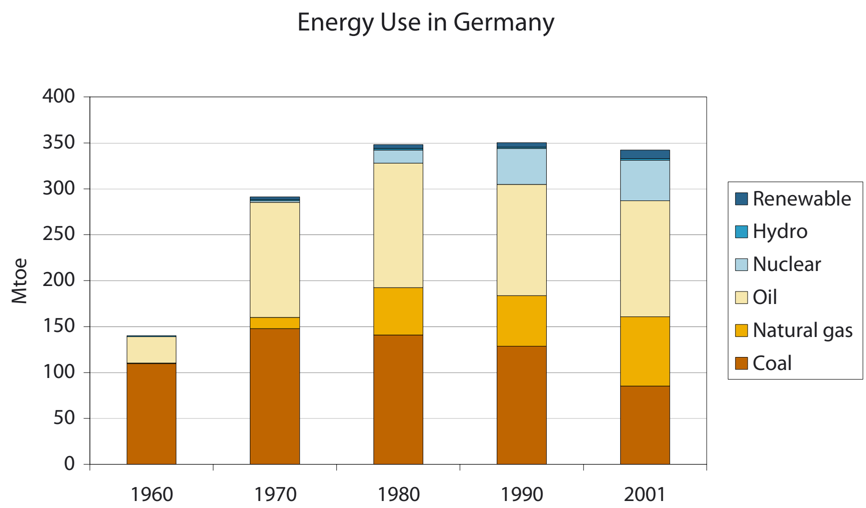

Figure 4.12b. Primary energy use in Germany from 1960-2001 (Source IEA 2003a, b). Note the change caused by the inclusion of former DDR data in 1971 into Germany's data in the IEA database.

In Germany the shift from coal to gas, an increasing use of nuclear energy and the stabilisation of oil use have been the main reasons, together with the stabilisation of total energy demand, for a decrease in CO_2 emissions.

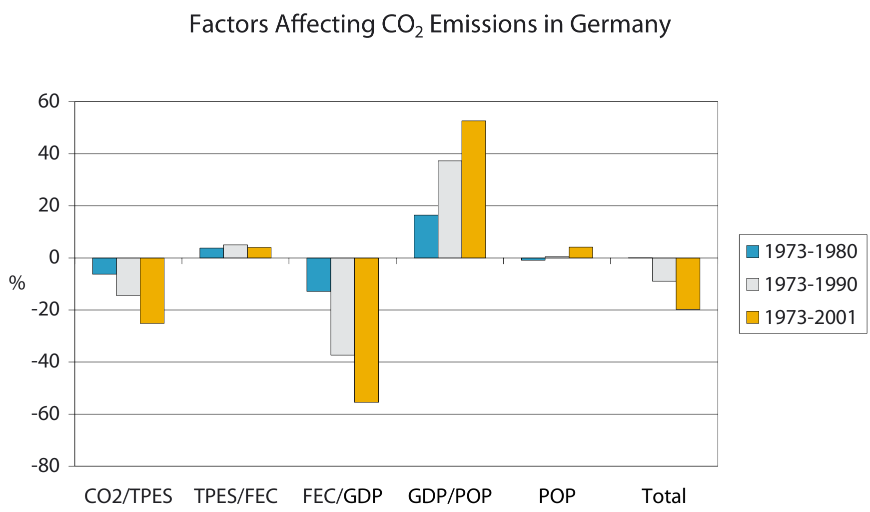

Figure 4.13. A decomposition analysis for the factors affecting CO_2 emissions in Germany from 1973 to 2001.

The decomposition analysis indicates that the fuel shift and the structural change in production in Germany have been the main drivers towards lower emissions. The efficiency increase with regard to production (see FEC/GDP) has partly been due to the modernization of the former East German facilities and structures. The economic growth of Germany has been slightly smaller than that experienced by the USA or Japan.

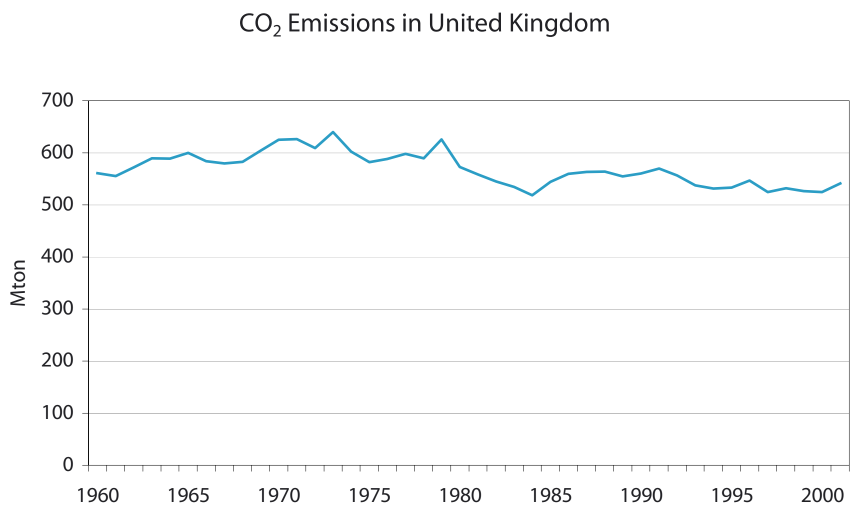

Figure 4.14a. CO_2 emissions in the United Kingdom from 1960-2001 (Source IEA 2003a, b).

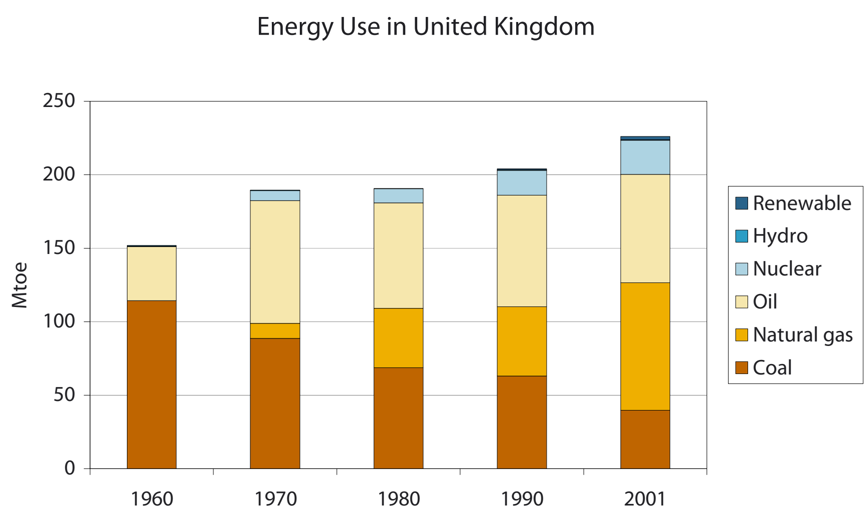

Figure 4.14b. Primary energy use in the United Kingdom from1960-2001 (Source IEA 2003a, b).

In the United Kingdom the decrease of CO_2 emissions has been mainly achieved with the shift from coal to gas and an increase in nuclear energy use. The moderate growth of energy demand has been one reason for the positive development of the emissions.

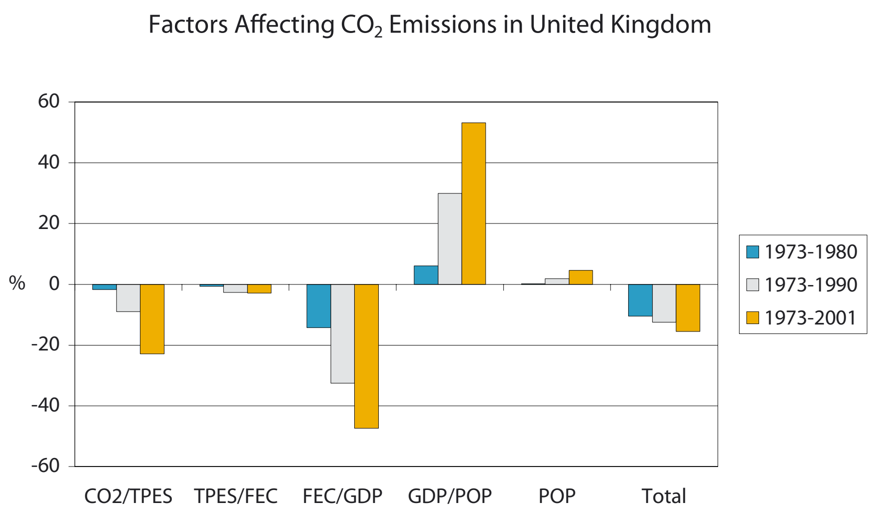

Figure 4.15. A decomposition analysis for the factors affecting CO_2 emissions in the United Kingdom from 1973 to 2001.

The decomposition analysis indicates that the structural change in the UK has almost compensated for the per capita growth in the economy. In this case the fuel shift, indicated by CO_2/TPES, has resulted in an absolute decrease of CO_2 emissions.

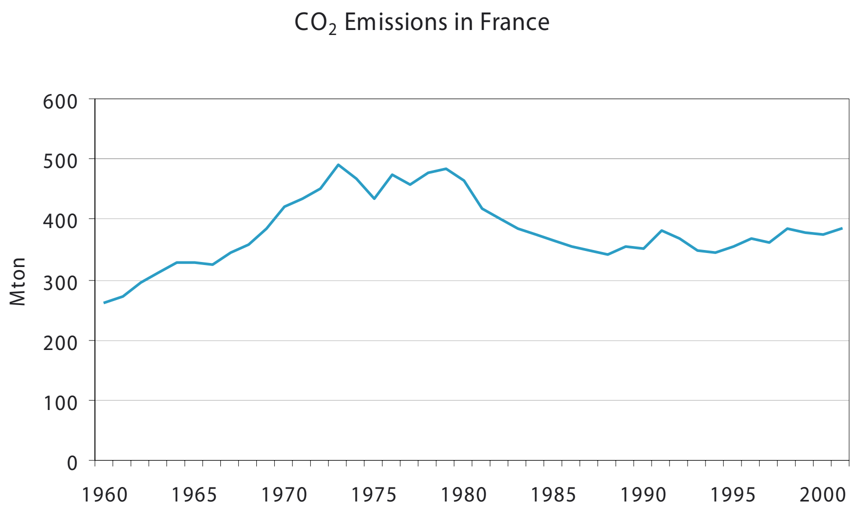

Figure 4.16a. CO_2 emissions in France from 1960-2001 (Source IEA 2003a, b).

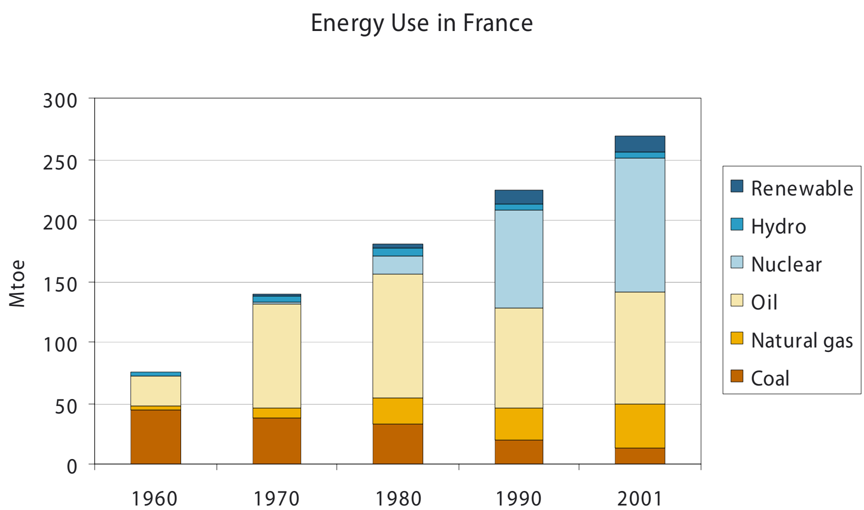

Figure 4.16b. Primary energy use in France from 1960-2001 (Source IEA 2003a, b).

In France CO_2 emissions have decreased considerably in the 1970's and 1980's partly due to the shift from coal to gas but mainly because of a considerable increase in nuclear energy production. The fast growth in energy demand has, however, caused a stabilisation of emissions in the 1990's and the increase in France's nuclear capacity has not been able to further decrease them. The energy intensity of the production structure has not decreased from the 1960's as a consequence of a build up in heavy industry that utilises the increase in nuclear energy.

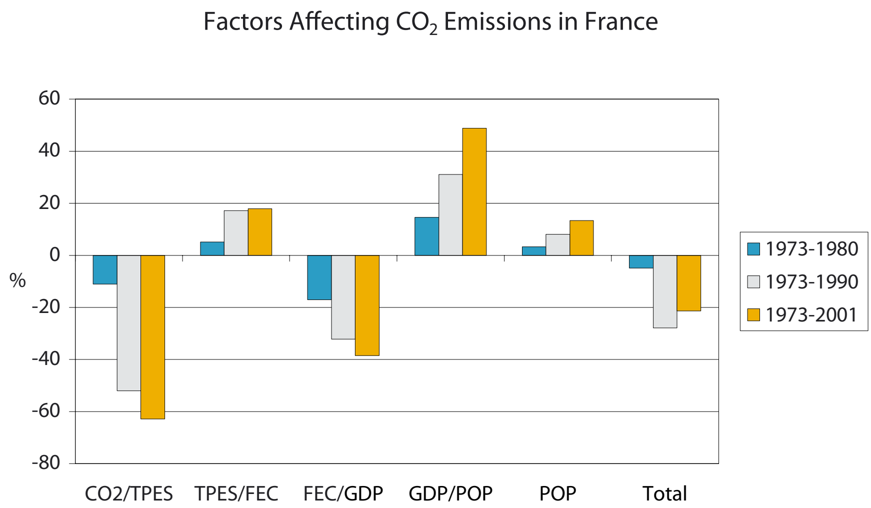

Figure 4.17. A decomposition analysis for the factors affecting CO_2 emissions in France from 1973 to 2001.

The decomposition analysis shows the large shift in fuel use that has taken place - mainly in the 1980's. The increased reliance on nuclear power has decreased the efficiency of the energy transformation chain and led to an increase in emissions by 20 %. The structural change in the French economy has not been as significant as e.g. in Germany or the UK as it decreased emissions only by less than 40 %. This was partly due to the reliance on domestic heavy industry, which was possible because of France's large nuclear production.

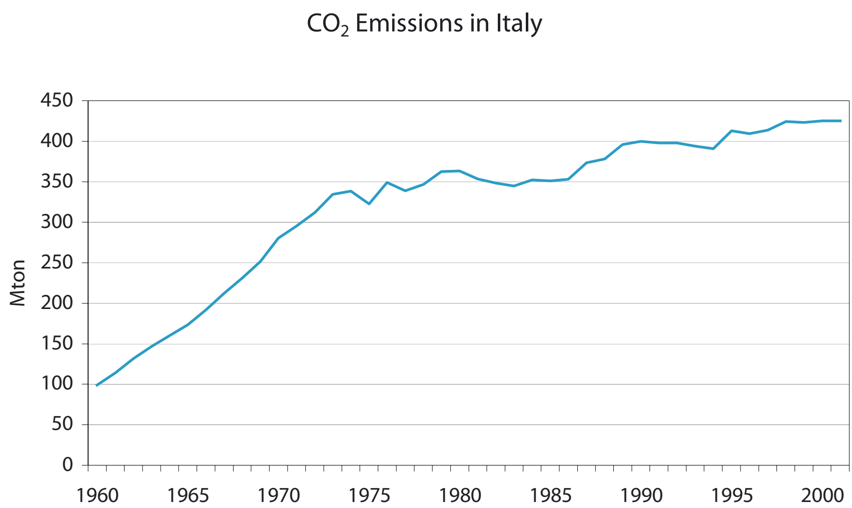

Figure 4.18a. CO_2 emissions in Italy from 1960-2001 (Source IEA 2003a, b).

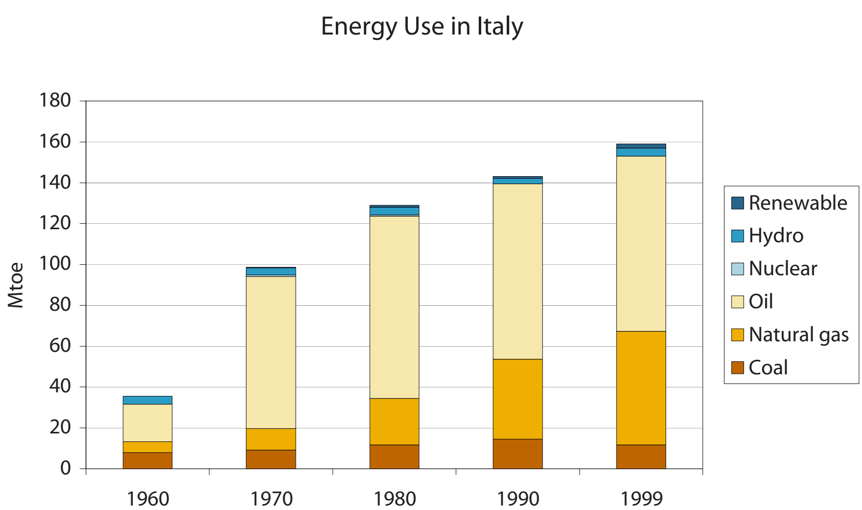

Figure 4.18b. Primary energy use in Italy from 1960-2001 (Source IEA 2003a, b).

In Italy the fast growth of emissions in the 1960's and early 1970's was mainly caused by rapid industrialization and the related growth in oil use. Since the first oil crisis the growth in emissions has been quite slow and the increase has been mainly in gas consumption, which has replaced some oil and coal consumption.

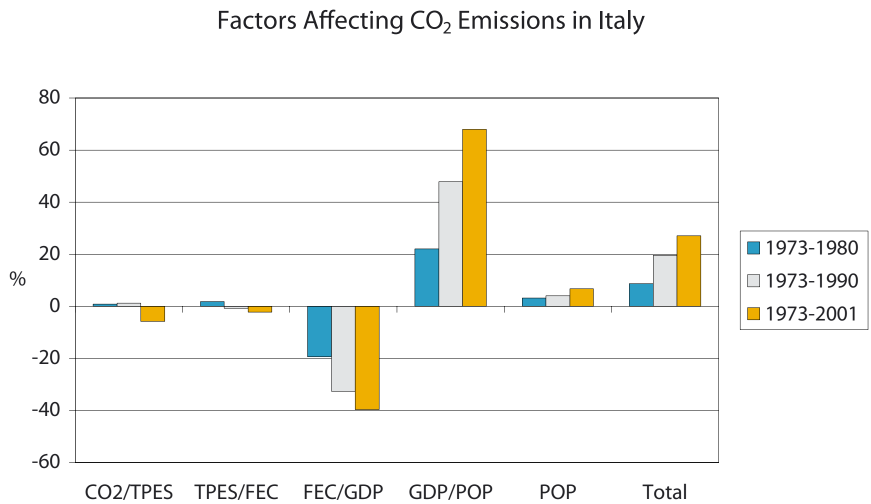

Figure 4.19. A decomposition analysis for the factors affecting CO_2 emissions in Italy from 1973 to 2001.

The decomposition analysis shows that there has been almost no fuel shift or efficiency change in the Italian energy sector. The structural shift of the economy has been modest in Italy and significant economic growth has resulted in an increase in emissions.

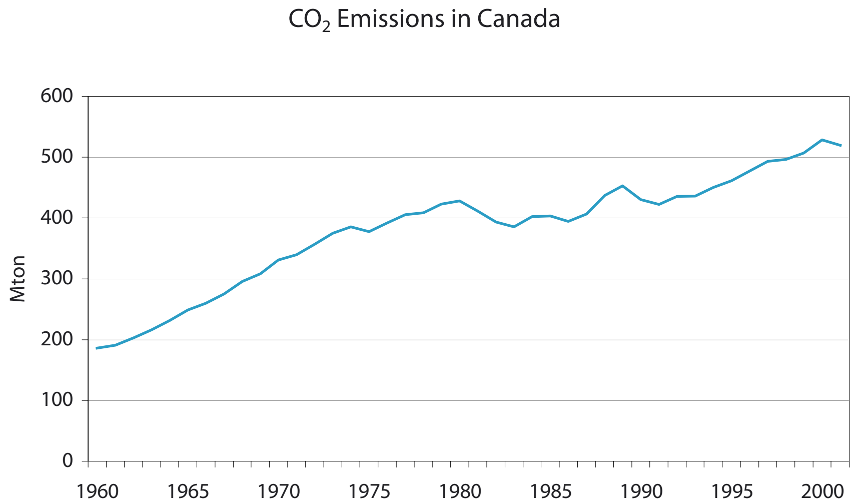

Figure 4.20a. CO_2 emissions in Canada from 1960-2001 (Source IEA 2003a, b).

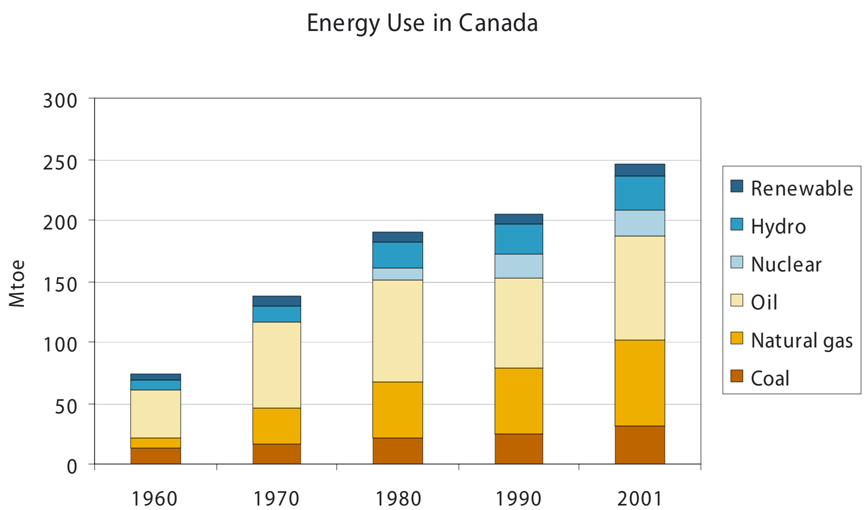

Figure 4.20b. Primary energy use in Canada from 1960-2001 (Source IEA 2003a, b).

In Canada the growth of CO_2 emissions has not been very fast since the first oil crisis. The increased production of hydro and nuclear power together with increased gas use has been able to reduce the growth of oil demand in spite of the general growth in energy demand.

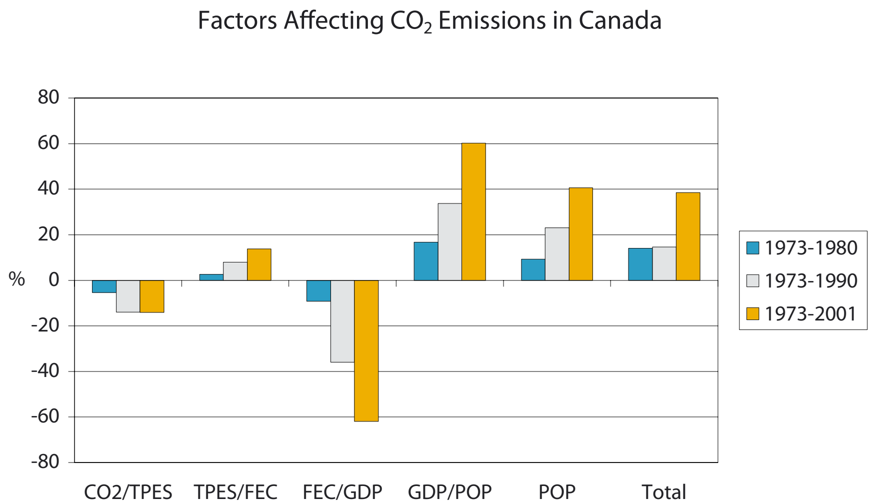

Figure 4.21. A decomposition analysis for the factors affecting CO_2 emissions in Canada from 1973 to 2001.

The decomposition analysis indicates that some fuel shifting has taken place in Canada, but at the same time the efficiency of the energy transformation has decreased. The structural shift in the economy has been remarkable and approximately compensated for the effect of the per capita economic growth. The high increase in Canada's population has contributed to the overall emission increase.

China and India

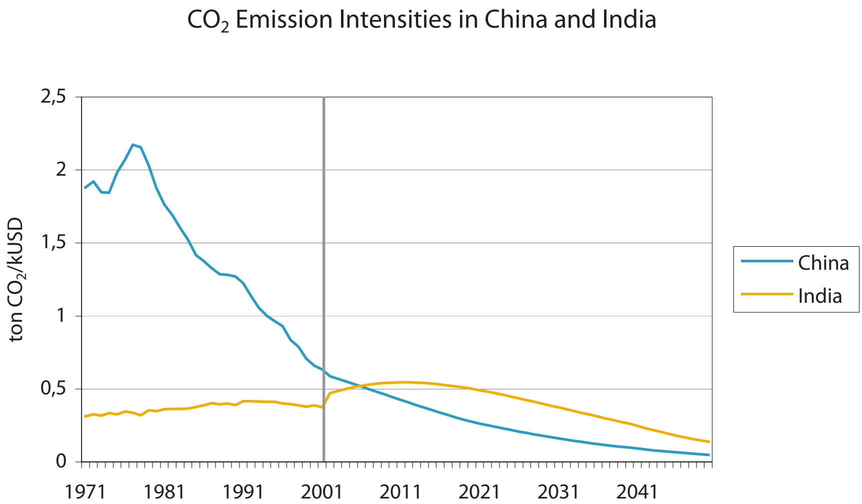

Figure 4.22a. Changes in the CO_2 intensity of the economies of China and India from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 to reach the C&C target.

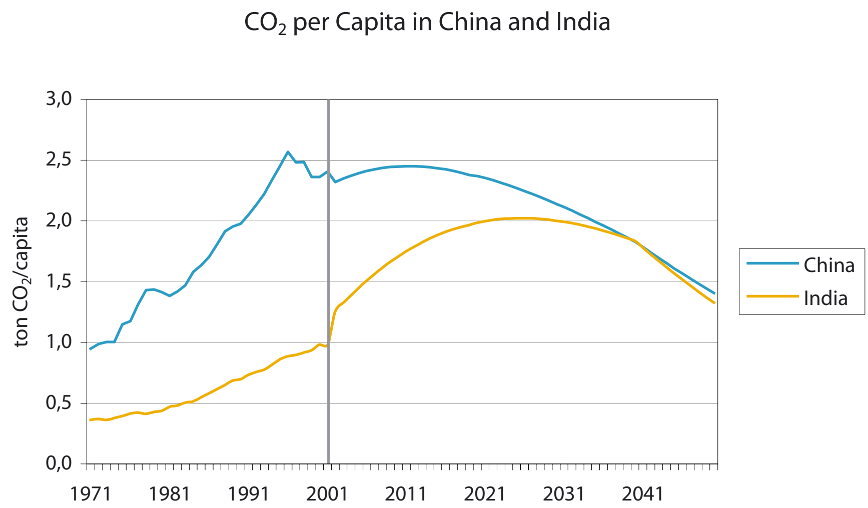

Figure 4.22b. Changes in the CO_2 emissions per capita of the economies of China and India from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 to reach the C&C target.

In China and India previous changes in the CO_2 intensities of the economies have been quite different from the main industrialized countries. Also the required changes in the future in order to reach the C&C target by 2040 look different. In China emission intensity was considerably high in the 1970's but it rapidly decreased to the US's level by 2001. The fast decrease was mainly caused by fast economic growth. To achieve the C&C target China can considerably reduce its speed of CO_2 intensity reduction. In India the CO_2 intensity level was very low in the beginning of the 1970's and slowly increased up to the mid 1990's after which there has been slow reduction. In order to reach the C&C target India could in fact increase its CO_2 intensity in the near future. This is mainly due to its very low level of CO_2 emissions per capita (about one ton).

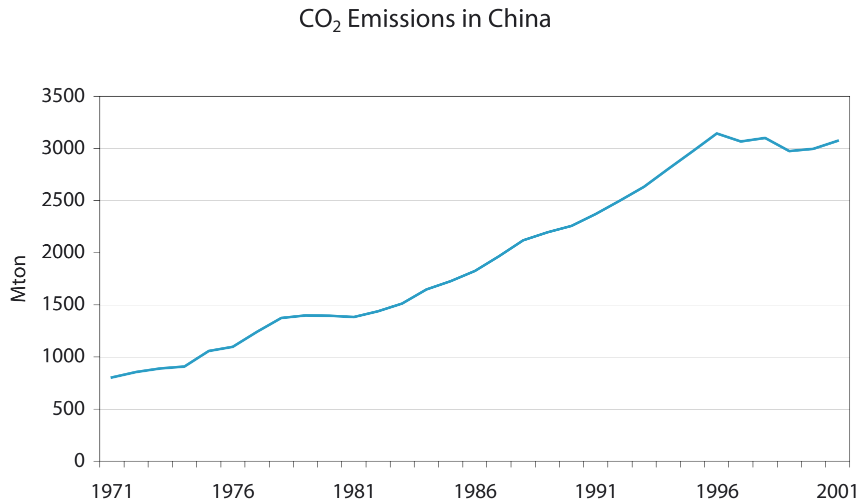

Figure 4.23a. CO_2 emissions in China from 1971-2001 (Source IEA 2003a, c).

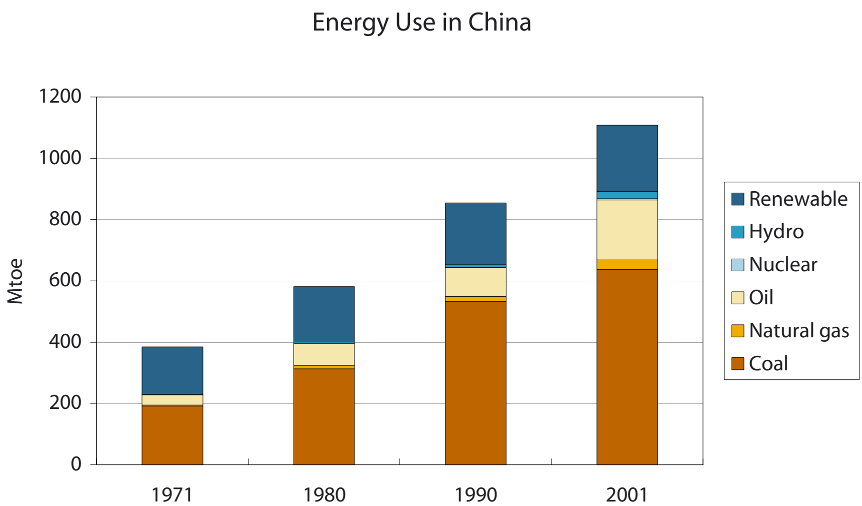

Figure 4.23b. Primary energy use in China from 1971-2001 (Source IEA 2003a, c).

In China emissions grew steadily up to 1996 after which they have levelled off. The fast increase in energy consumption has been met by an increased use of coal and oil. The total use of renewable energy sources has increased by over 50 % from 1973 to 2001, but the share of renewables has diminished due to the very fast overall increase in energy consumption.

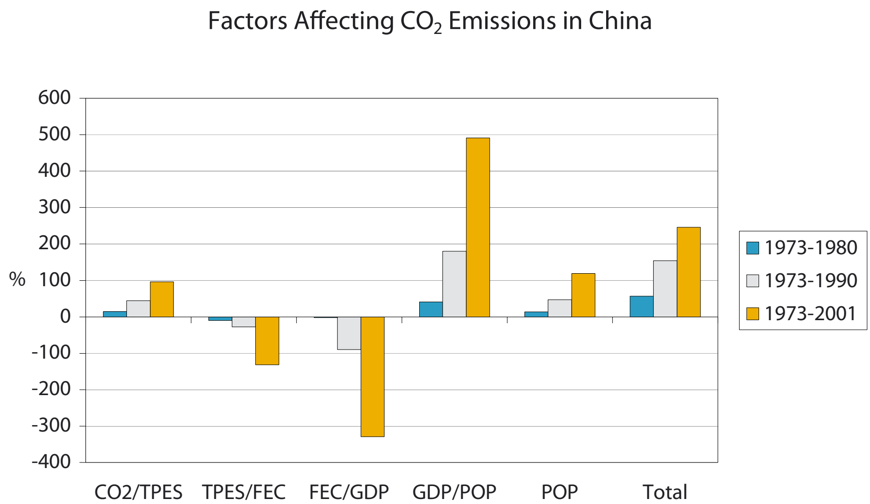

Figure 4.24. A decomposition analysis for the factors affecting CO_2 emissions in China from 1973 to 2001.

The decomposition analysis (note the scale) shows a large shift towards fossil fuels. The efficiency increase in the Chinese energy system has been considerable, especially in the 90's. The rapid structural change that lowered the energy intensity of the economy has contributed significantly to emission reduction. However, the per capita economic growth has contributed to an almost 500 % increase in CO_2 emissions compared to the 1973 level and the contribution of the population growth is over 100 %. The total increase in emissions was over 200 % between 1973 and 2001.

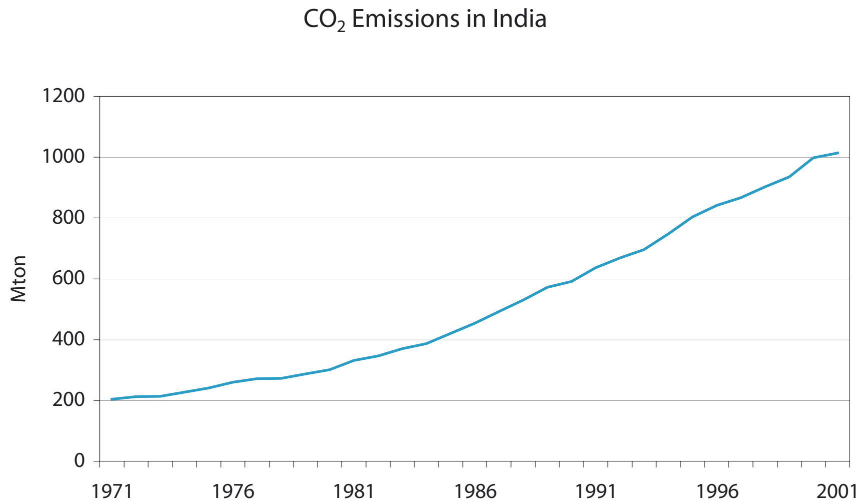

Figure 4.25a. CO_2 emissions in India from 1971-2001 (Source IEA 2003a, c).

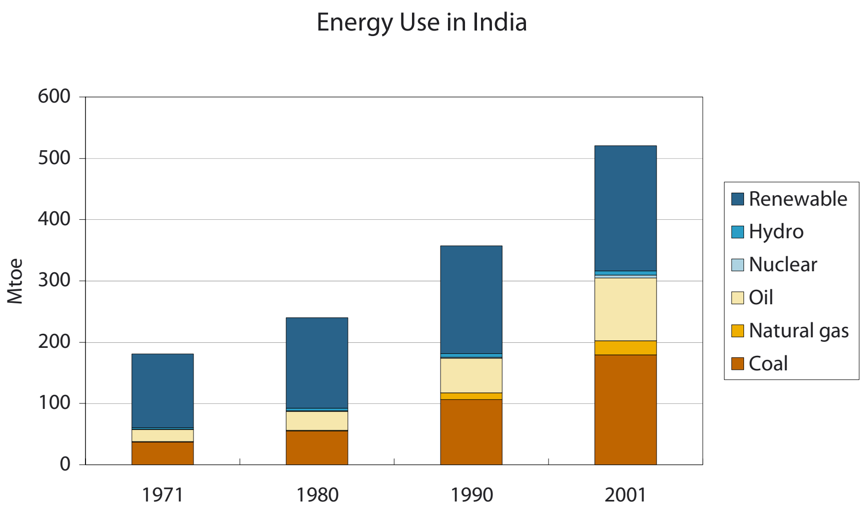

Figure 4.25b. Primary energy use in India from 1971-2001 (Source IEA 2003a, c).

In India the increase in CO_2 emissions was mainly due to the large increase in coal consumption and oil consumption. The use of renewables has increased by over 70 % from 1973 to 2001, but this has not been able to change the trend of emission increase.

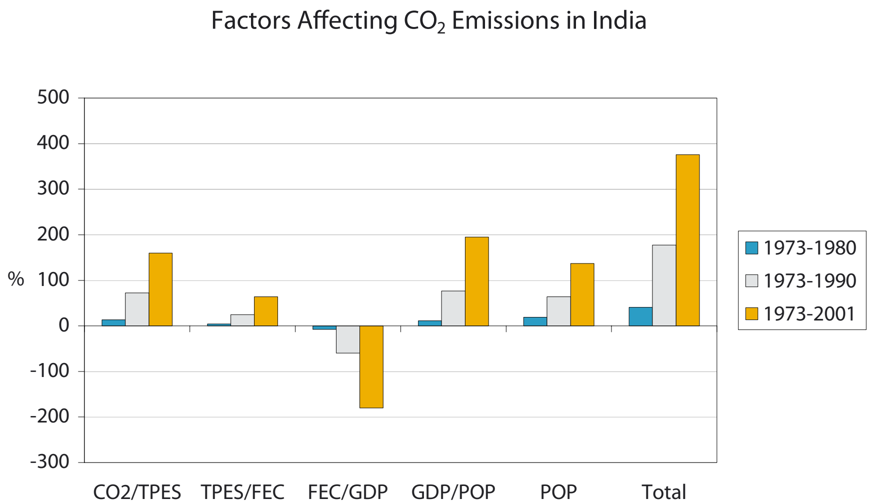

Figure 4.26. A decomposition analysis for the factors affecting CO_2 emissions in India from 1973 to 2001.

The decomposition analysis clearly shows a vast shift to a fossil dominated energy system in India. The per capita economic growth has been rapid, but the structural change in the economy has also been remarkable and almost compensates for the growth effect. The population growth in India has been rapid (about a 75 % increase from 1973 to 2001) contributing considerably to the total growth of emissions.

The Mediterranean EU countries

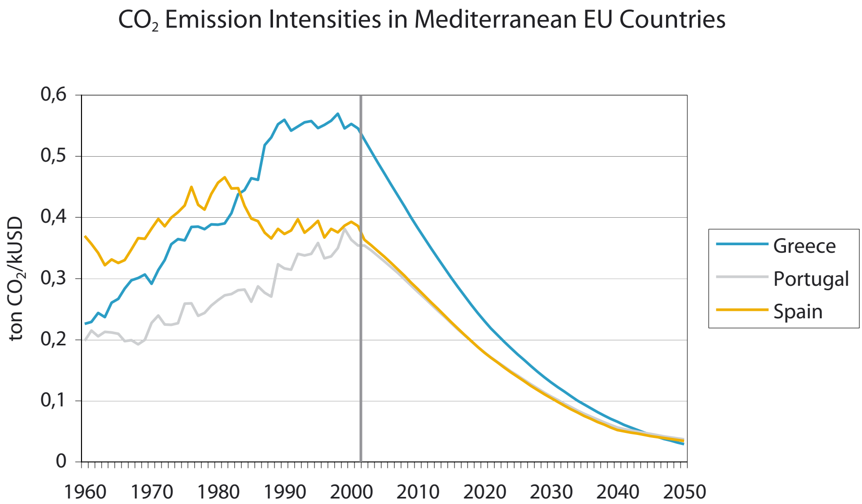

Figure 4.27a. Changes in the CO_2 intensity of the selected economies of the Mediterranean EU countries; Greece, Portugal and Spain from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

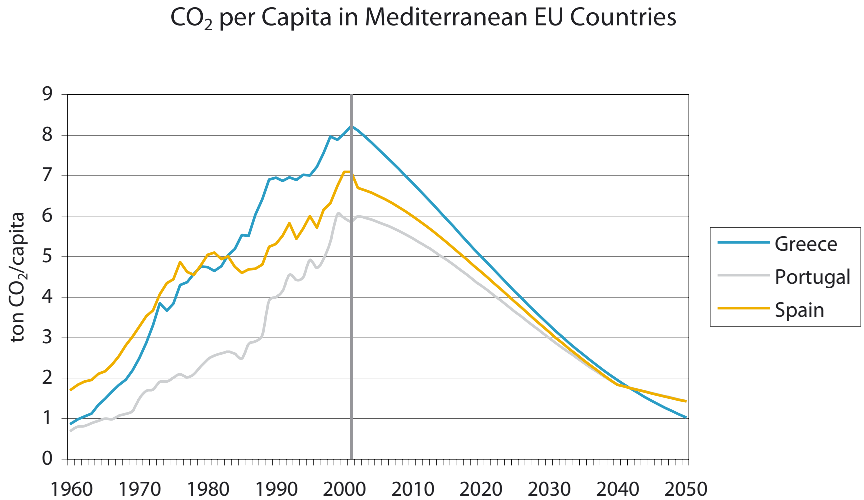

Figure 4.27b. Changes in the CO_2 emissions per capita of the selected economies of the Mediterranean EU countries; Greece, Portugal and Spain from 1960-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

In the Mediterranean EU countries, Greece, Portugal and Spain, CO_2 intensity has grown considerably due to the process of industrialization. To achieve the C&C target the countries must undergo a major change in the direction of their future development.

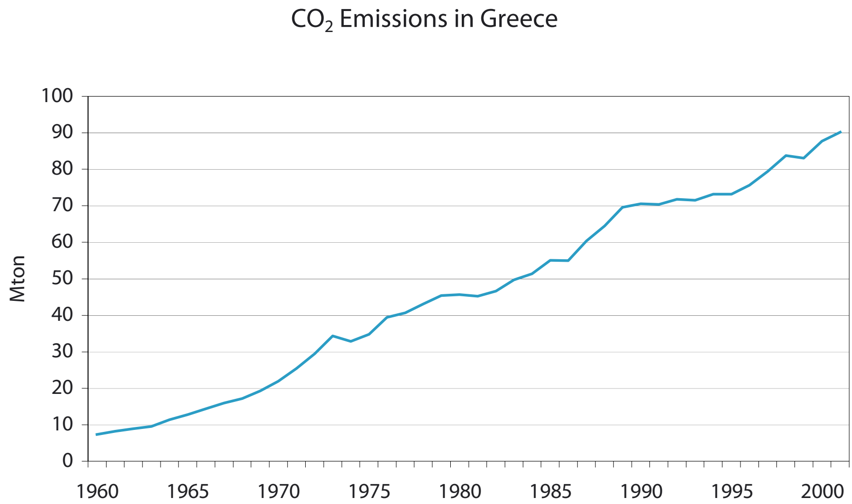

Figure 4.28a. CO_2 emissions in Greece from 1960-2001 (Source IEA 2003a, b).

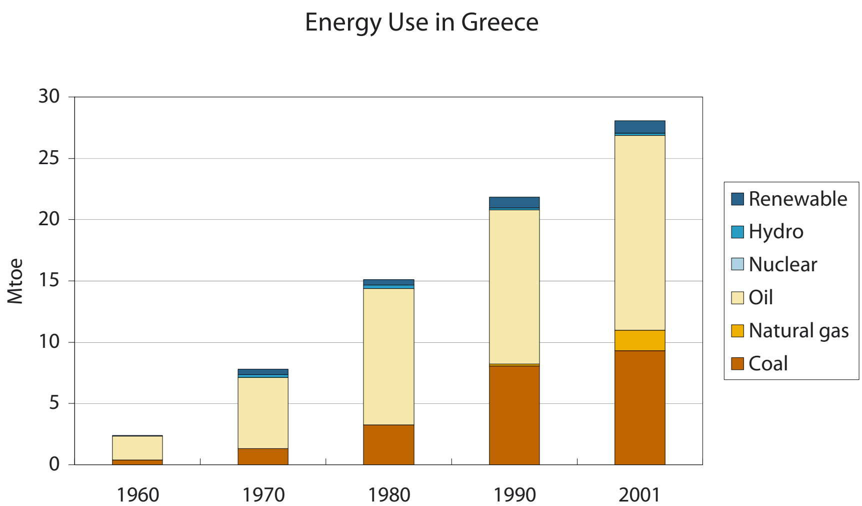

Figure 4.28b. Primary energy use in Greece from 1960-2001 (Source IEA 2003a, b).

In Greece the growth of CO_2 emissions is due to a fast growth in fossil fuel consumption, mainly coal and oil, consumption. This is quite typical for an industrializing economy.

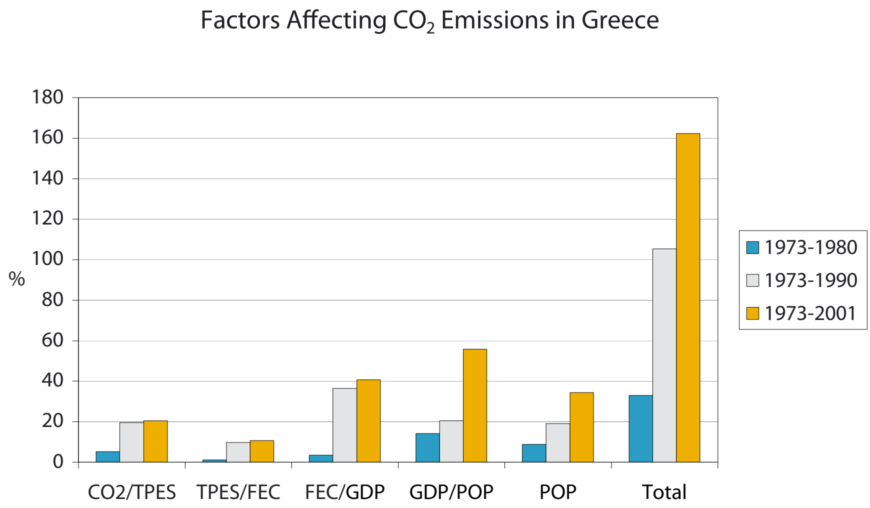

Figure 4.29. A decomposition analysis for the factors affecting CO_2 emissions in Greece from 1973 to 2001.

The decomposition analysis shows that all the five factors under study have contributed to an increase in emissions. The fuel shift (CO_2/TPES) has moved Greece towards more carbon intensive fuels and the efficiency of the energy transformation (TPES/FEC) has decreased. Even the energy intensity of the economy (FEC/GDP) has grown considerably contrary to the "old" industrialized economies. The growth of per capita production (GDP/POP) and population growth (POP) have both significantly contributed to the increase in emissions.

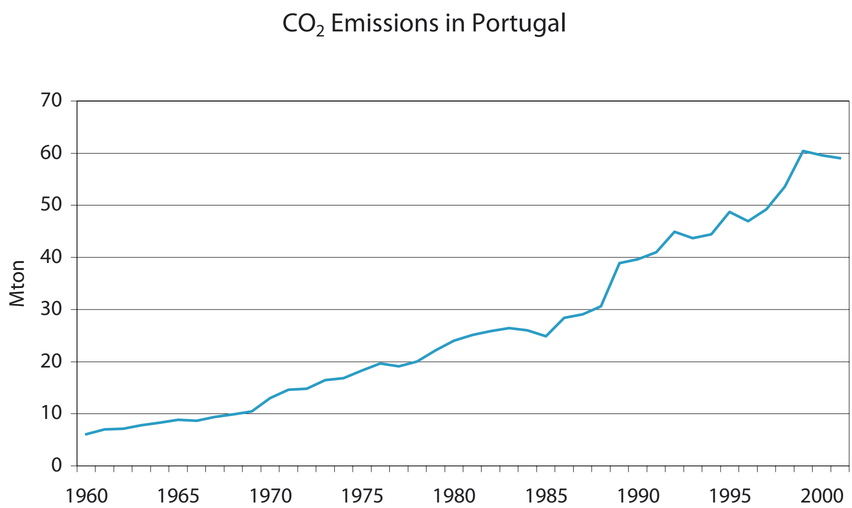

Figure 4.30a. CO_2 emissions in Portugal from 1960-2001 (Source IEA 2003a, b).

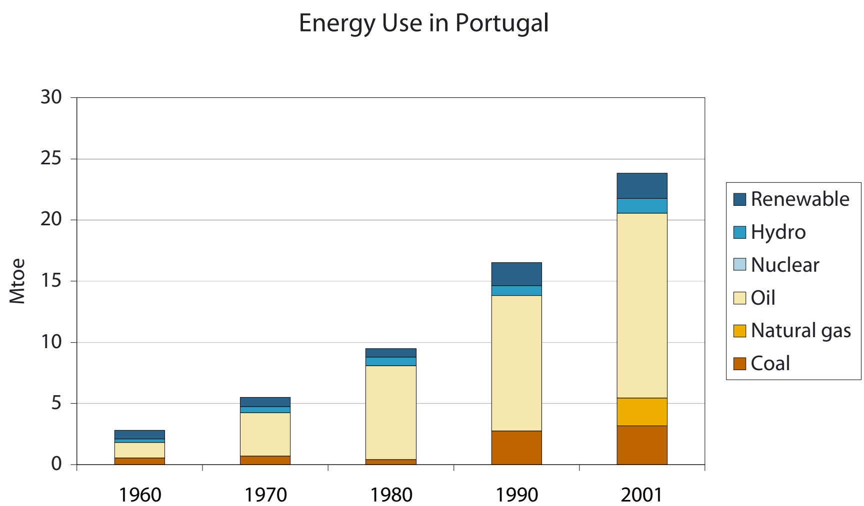

Figure 4.30b. Primary energy use in Portugal from 1960-2001 (Source IEA 2003a, b).

In Portugal the development has been quite similar to that of Greece, an exception is that the share of coal in the primary energy mix is smaller.

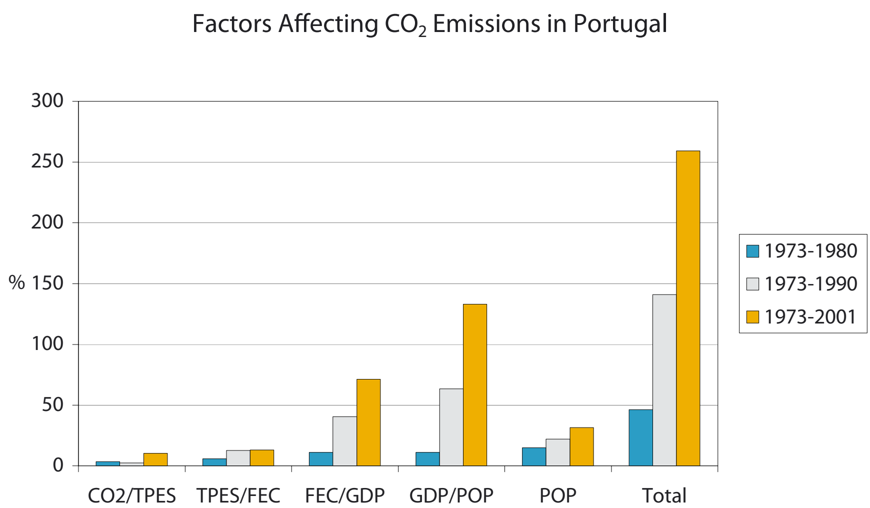

Figure 4.31. A decomposition analysis for the factors affecting CO_2 emissions in Portugal from 1973 to 2001.

The shift towards a more energy intensive production structure is even more evident in Portugal and also Portugal's per capita economic growth is higher than in Greece. The total growth of CO_2 emissions was over 250 % in Portugal between 1973 and 2001.

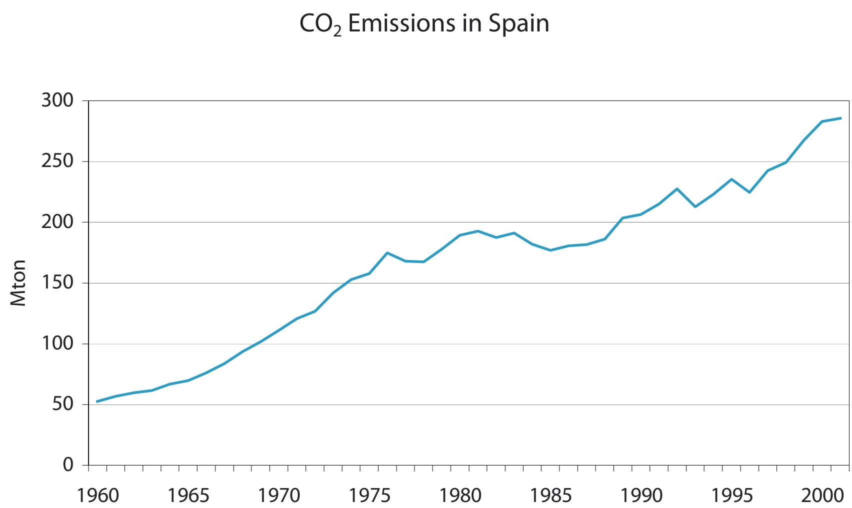

Figure 4.32a. CO_2 emissions in Spain from 1960-2001 (Source IEA 2003a, b).

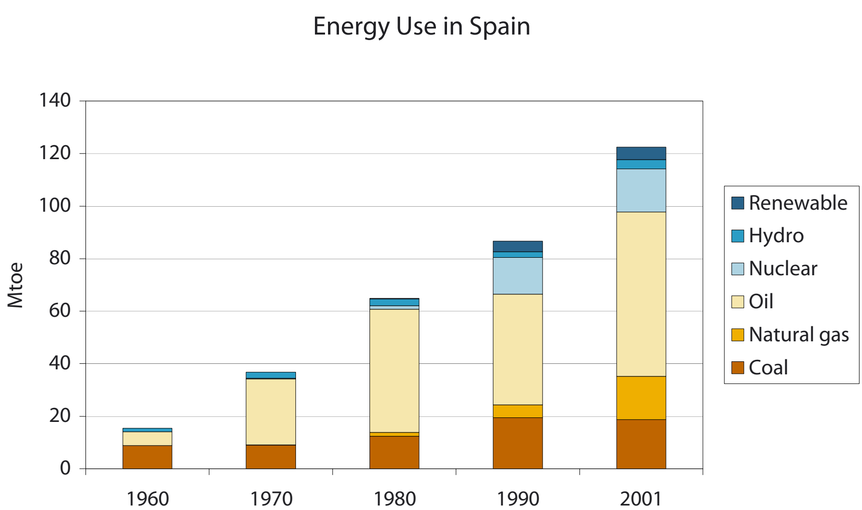

Figure 4.32b. Primary energy use in Spain from 1960-2001 (Source IEA 2003a, b).

In Spain the general trend of emission increase has also been considerable. The introduction of nuclear energy and natural gas has lowered the emission growth rate to some extent.

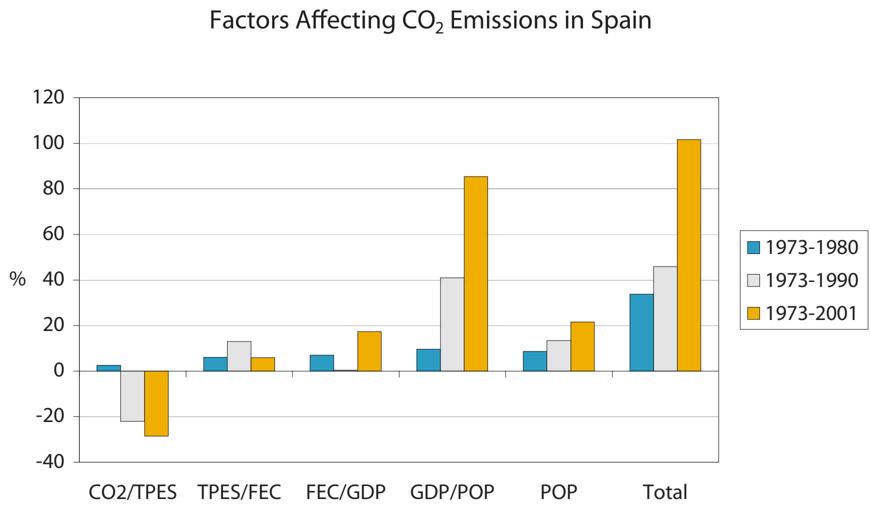

Figure 4.33. A decomposition analysis for the factors affecting CO_2 emissions in Spain from 1973 to 2001.

The fuel mix in Spain has shifted towards lower carbon content with the increased use of renewables and nuclear power. The production structure has shifted slightly in the direction of a more energy intensive production. The fast per capita economic growth has also been the main contributor to emission increases in Spain.

The Nordic countries

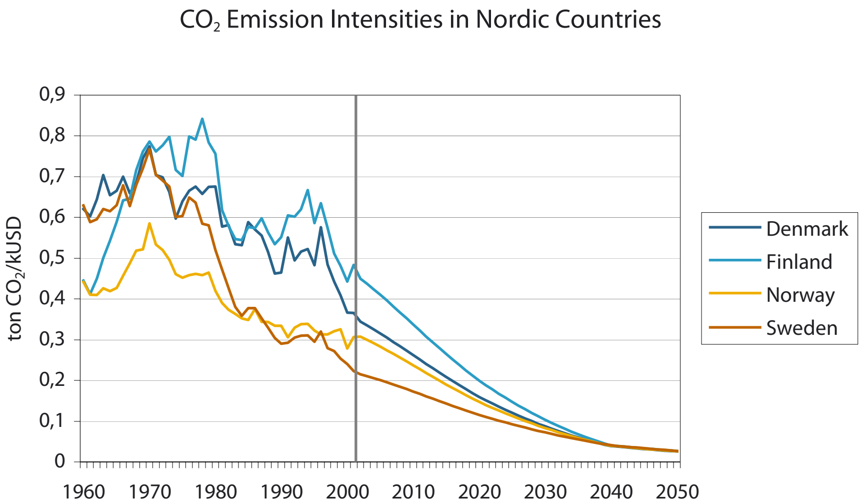

Figure 4.34a. Changes in the CO_2 intensity of the economies of the Nordic countries from 1960-2001 (Source: IEA 2003a) and their required development from 2002-2050 in order to reach the C&C target.

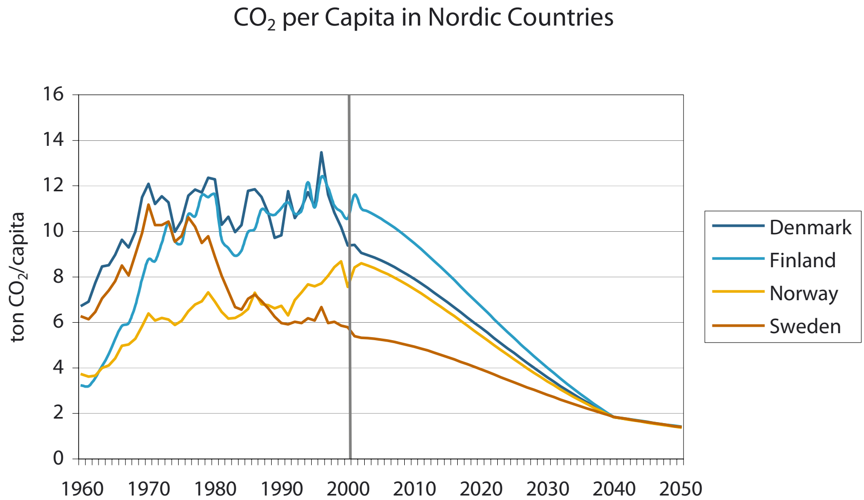

Figure 4.34b. Changes in the CO_2 emissions per capita of the economies of the Nordic countries from 1960-2001 (Source: IEA 2003a) and their required development from 2002-2050 in order to reach the C&C target.

The development in the Nordic countries of Denmark, Finland, Norway and Sweden has been quite different from the Mediterranean countries. The CO_2 intensity of the Nordic countries fell considerably in the 1970's and 1980's. However, development in the 90's stagnated, especially in Finland. Amongst the Nordic countries Finland would have to achieve the largest change in the direction of its CO_2 emission intensity trend in order to reach the C&C target.

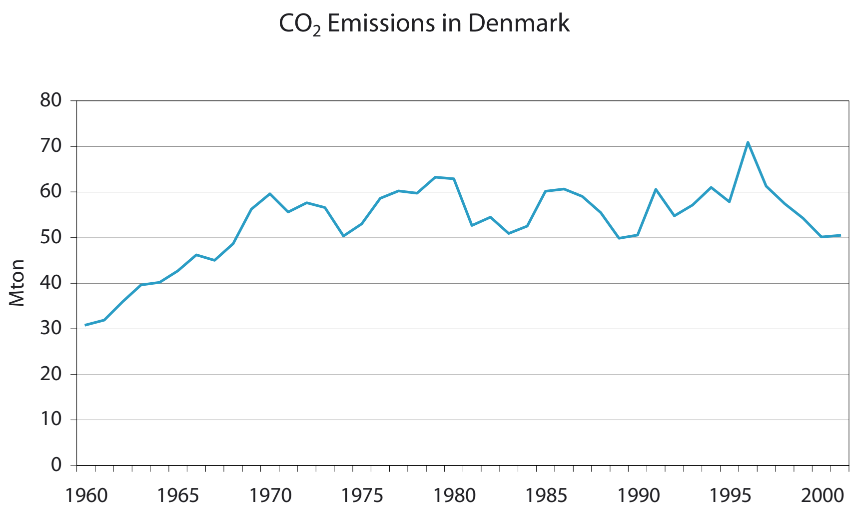

Figure 4.35a. CO_2 emissions in Denmark from 1960-2001 (Source IEA 2003a, b).

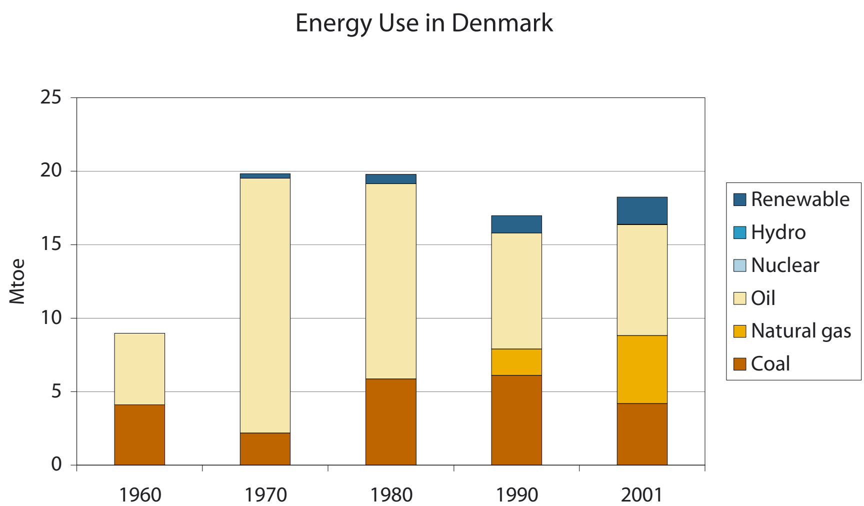

Figure 4.35b. Primary energy use in Denmark from 1960-2001 (Source IEA 2003a, b).

In Denmark the growth of CO_2 emissions slowed after the first oil crisis. The fluctuations in the amount of emissions were mainly caused by changes in hydro power production, caused by changes in precipitation, in the common Nordic electricity market and the related need for domestic coal power production in the absence of cheap hydro based electricity from Norway and Sweden. The fluctuations in the emissions of Finland are mainly of the same cause.

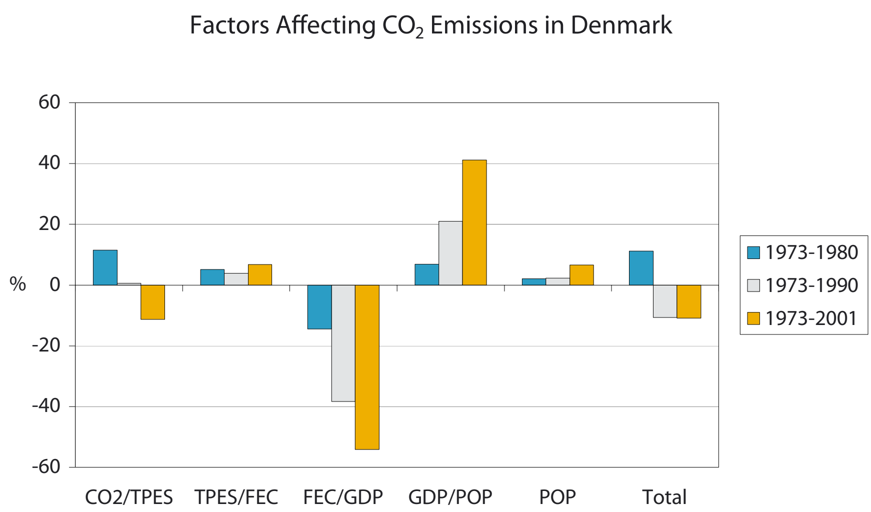

Figure 4.36. A decomposition analysis for the factors affecting CO_2 emissions in Denmark from 1973 to 2001.

The shift from oil and coal to natural gas and renewables, especially wind power, has been a significant trend in Denmark especially in the 1990's and is also indicated by the decomposition analysis. The considerable shift in the production structure towards a less energy intensive economy has been able to cut emissions more than the moderate increase in per capita economic growth.

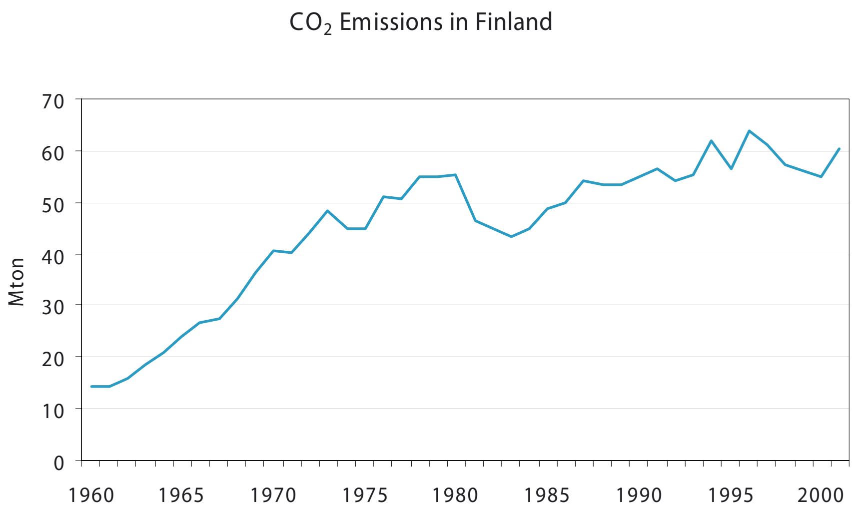

Figure 4.37a. CO_2 emissions in Finland from 1960-2001 (Source IEA 2003a, b).

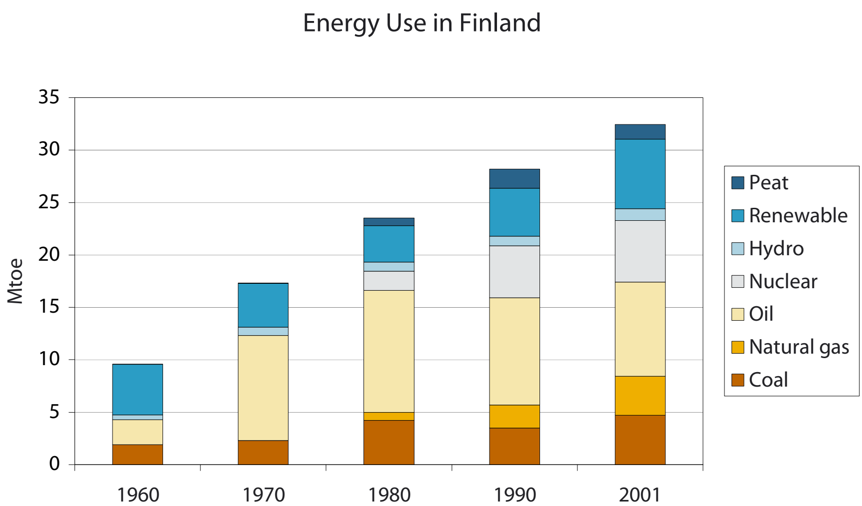

Figure 4.37b. Primary energy use in Finland from 1960-2001 (Source IEA 2003a, b).

In Finland the use of many different primary energy sources is worth noticing. The shift towards fossil based production was the trend especially in the 1960's. The share of renewable energy sources in Finland, especially forest based biomass, is remarkably high, but the rapid increase in energy consumption has led to an increased use of fossil fuels and a related increase in CO_2 emissions. The increase of nuclear production in the 1980's reduced emissions temporarily.

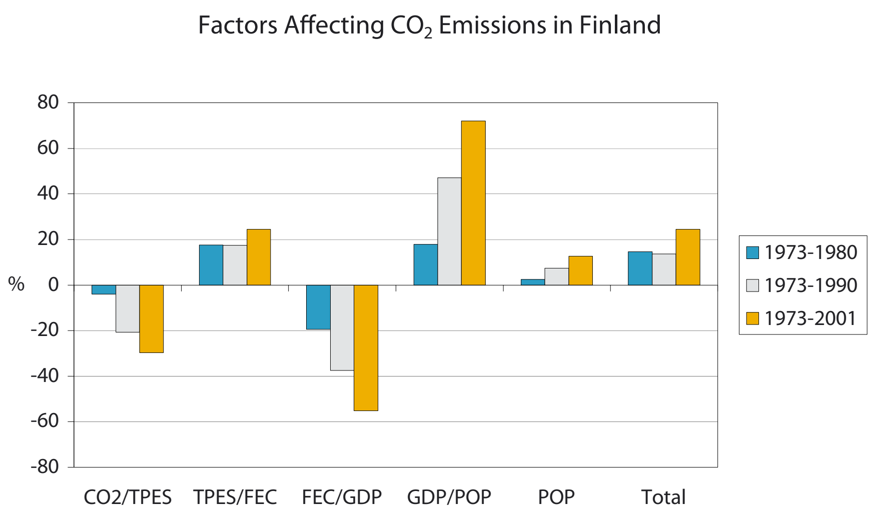

Figure 4.38. A decomposition analysis of the factors affecting CO_2 emissions in Finland from 1973 to 2001.

The decomposition analysis shows the fuel shift decreased emissions by 30 % from 1973 to 2001. The shift to a larger share of electricity in final energy consumption however, decreased the transformation's efficiency leading to an increase in emissions. The production structure in Finland has traditionally been quite energy intensive - relying mainly on pulp and paper and basic metal industries, but there seems to be a considerable shift towards the lighter industry and service structures. Finland's fast per capita economic growth has been the main component in increasing emissions.

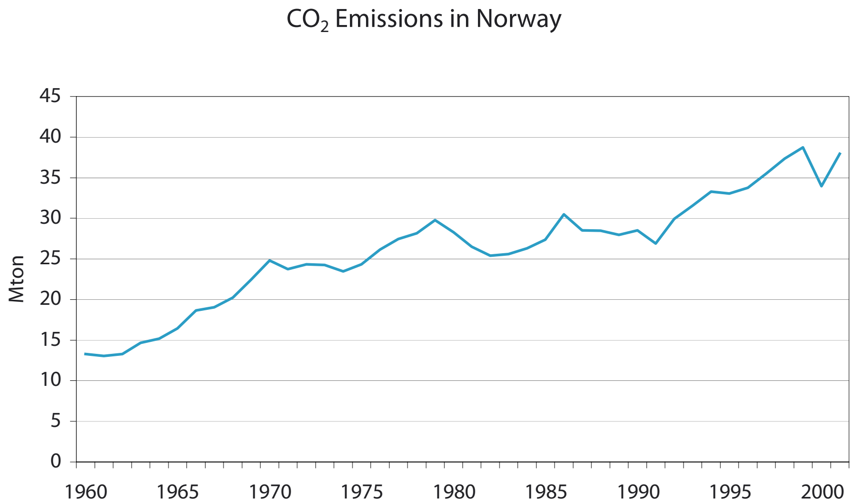

Figure 4.39a. CO_2 emissions n Norway from 1960-2001 (Source IEA 2003a, b).

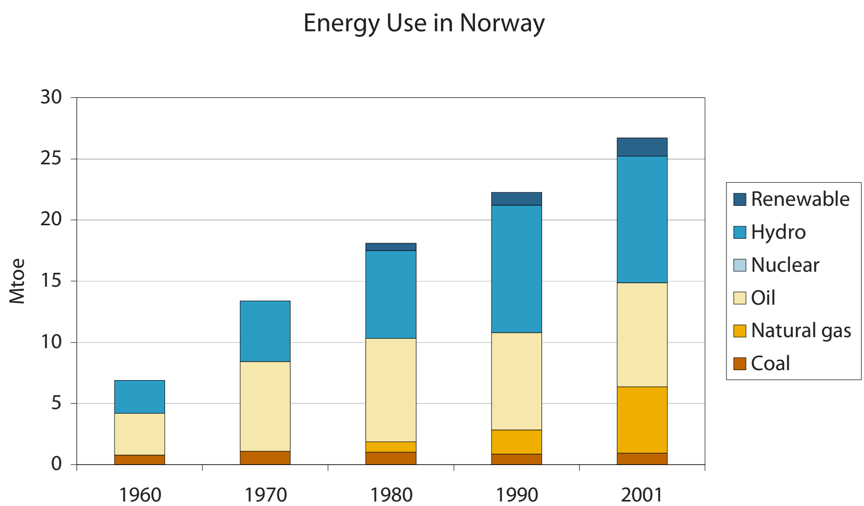

Figure 4.39b. Primary energy use in Norway from 1960-2001 (Source IEA 2003a, b).

Electricity production in Norway is based on hydro production keeping per capita emissions low, but future prospects for increasing the hydro capacity do not exist. With an increasing domestic consumption of electricity Norway will shift either from electricity exporter to importer or will have to build gas based production. The rapid increase of emissions in the 1990's was mainly caused by the increased use of natural gas in gas and oil production and to some extent in industry.

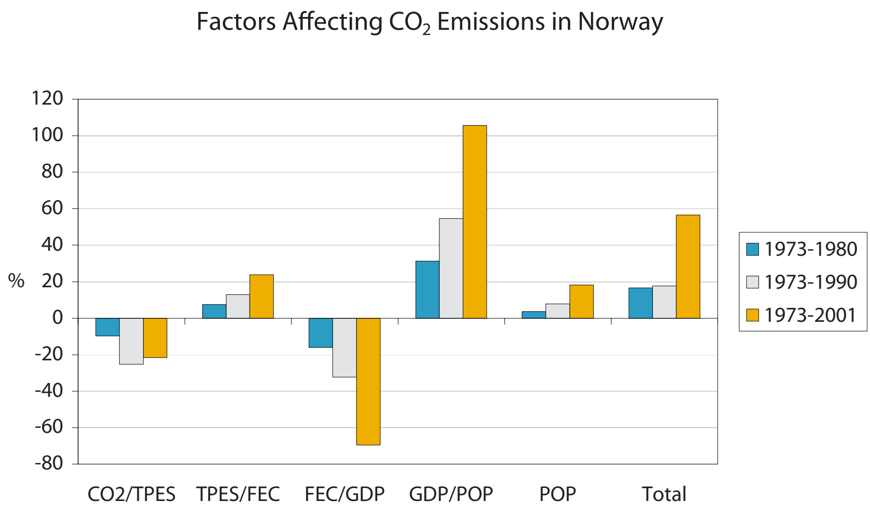

Figure 4.40. A decomposition analysis for the factors affecting CO_2 emissions in Norway from 1973 to 2001.

The decomposition analysis shows a small shift towards less carbon intensive primary energy (due to increased hydro-power) and lowered efficiency of the transformation. Structural change in the economy has been quite rapid but very fast economic growth especially in the 1990's has more than counterbalanced the positive changes.

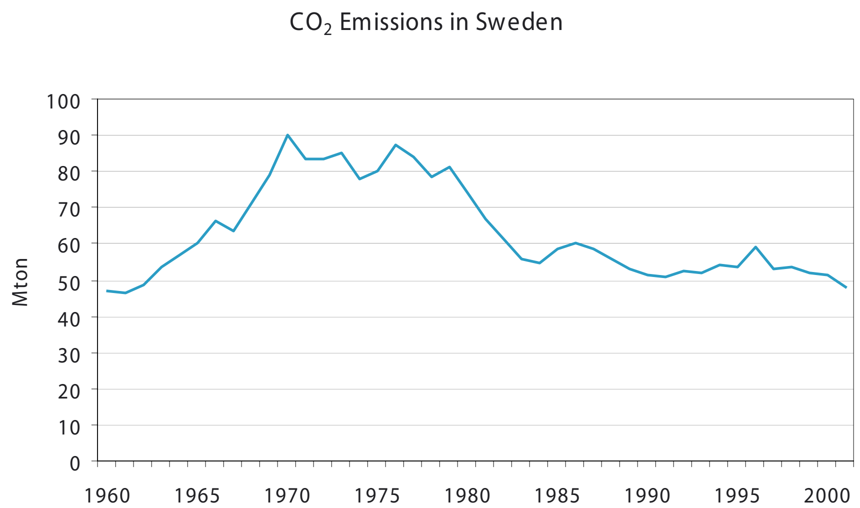

Figure 4.41a. CO_2 emissions in Sweden from 1960-2001 (Source IEA 2003a, b).

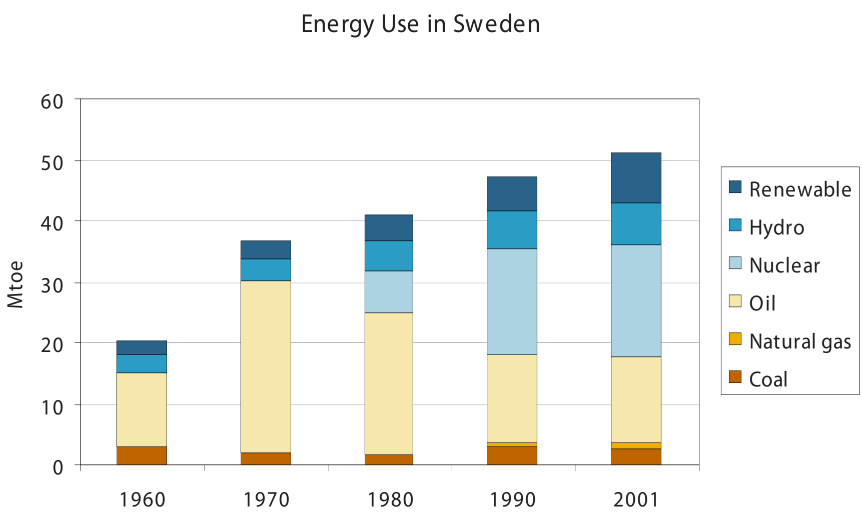

Figure 4.41b. Primary energy use in Sweden from 1960-2001 (Source IEA 2003a, b).

In Sweden the large share of nuclear power (50 % of electricity) and hydro power (also 50 % of electricity) is characteristic of the energy system together with considerable use of renewables (mainly wood based). The rapid increase in nuclear production in the 1970's and 1980's and the related decrease in oil use decreased the total amount of CO_2 emissions significantly.

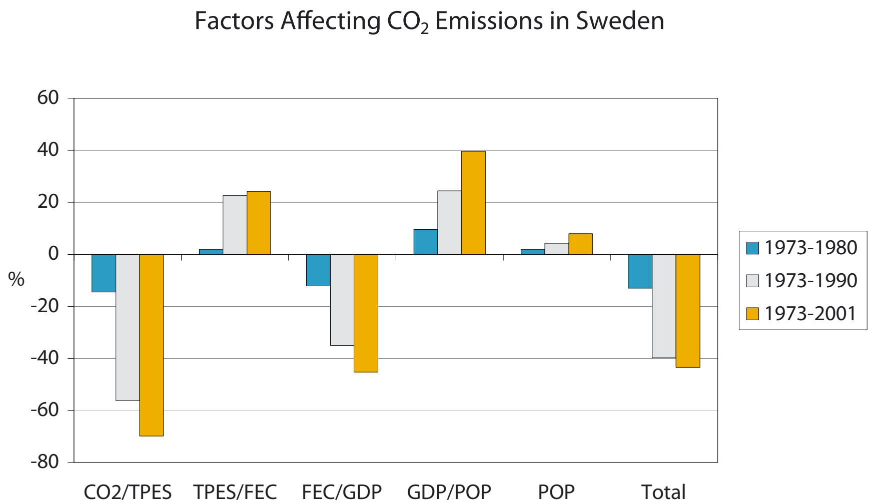

Figure 4.42. A decomposition analysis for the factors affecting CO_2 emissions in Sweden from 1973 to 2001.

The decomposition analysis clearly shows the large effect of fuel shifting. At the same time a decreased efficiency of transformation has increased emissions. The structural shift towards a less energy intensive economy has not been very significant, but moderate per capita economic growth has kept the emissions low though.

Latin America

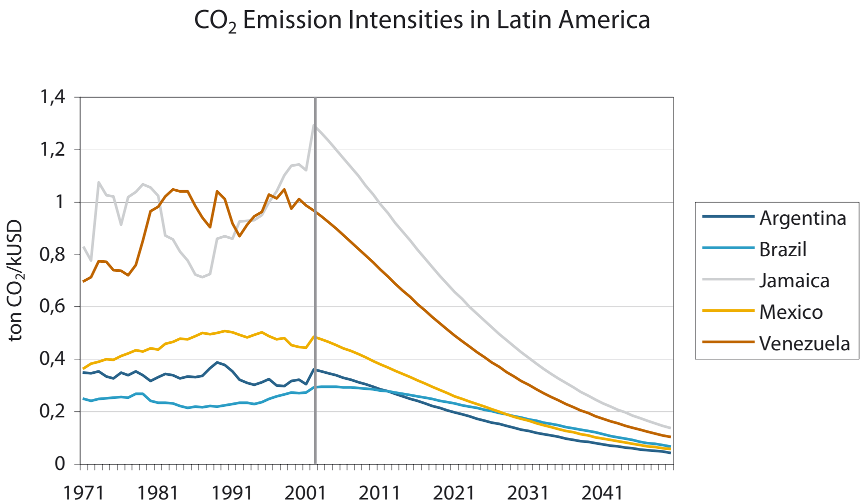

Figure 4.43a. Changes in the CO_2 intensity of selected economies in Latin America from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

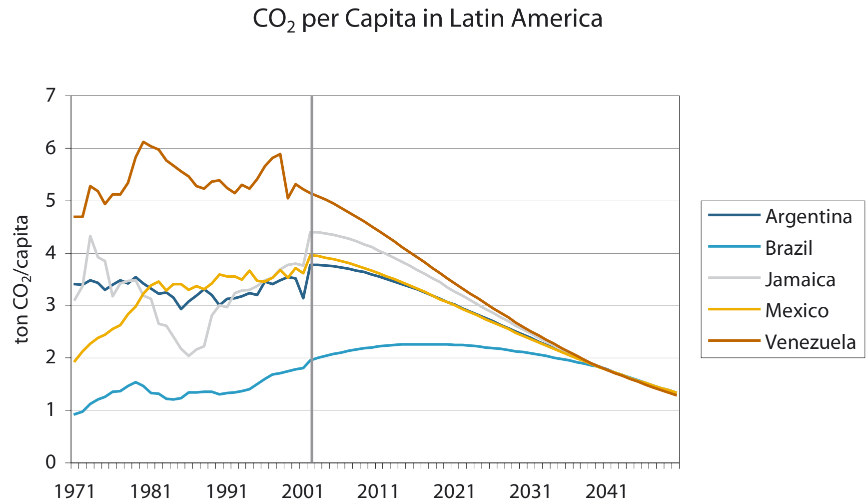

Figure 4.43b. Changes in the CO_2 emissions per capita of selected economies in Latin America from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

The general trend of CO_2 intensity increase is most evident in Venezuela and Jamaica of the selected Latin American countries. In order to reach the C&C target these countries need a major change in their development. The development trend in Brazil and Mexico has been quite favourable for reaching the target, but Argentina should slightly redirect its course.

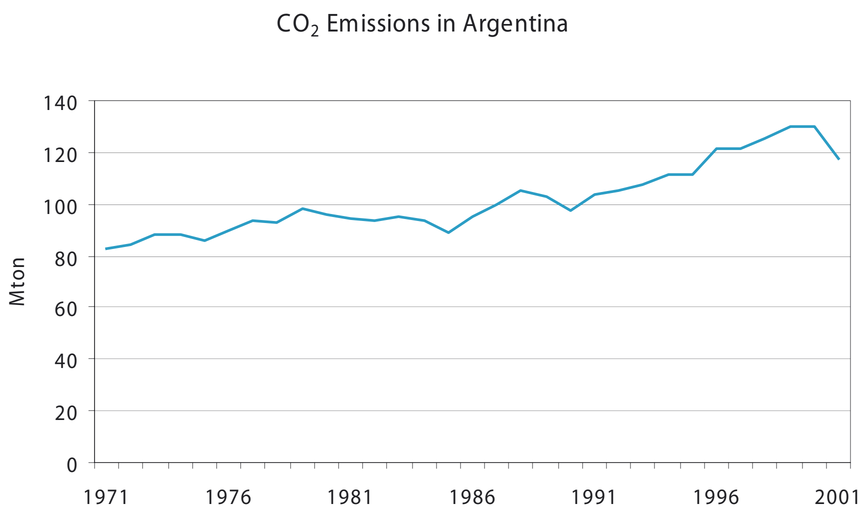

Figure 4.44a. CO_2 emissions in Argentina from 1971-2001 (Source IEA 2003a, c).

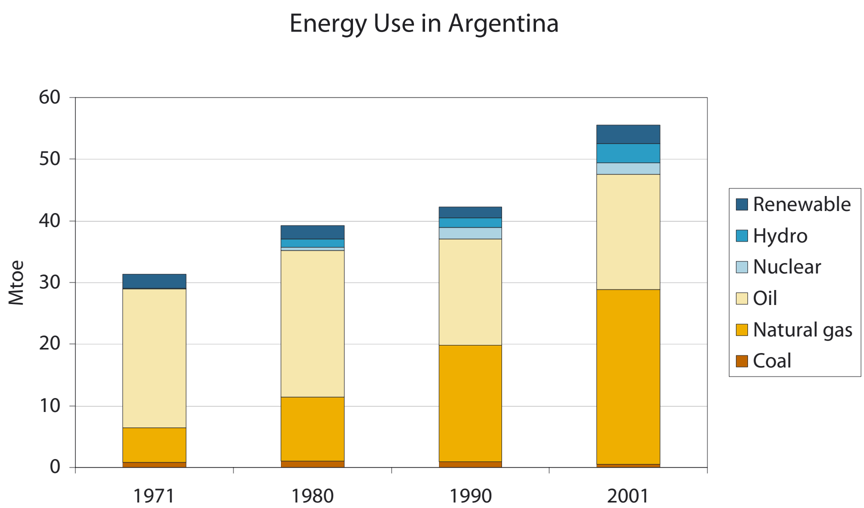

Figure 4.44b. Primary energy use in Argentina from 1971-2001 (Source IEA 2003a, c).

The slow growth of emissions in Argentina has been mainly due to moderate energy demand growth and an increased use of gas and renewables, which has replaced some oil use. The very fast economic growth of Argentina in the 1990's led to energy use growth in industry and in road transport, but the overall energy emission intensity decreased. The country has large potential for the development of renewable energy, but it has not been utilised so far to any large extent. Hydropower has been used to quite a large extent in electricity production, but the increase in thermal power production exceeded it in the late 1990's.

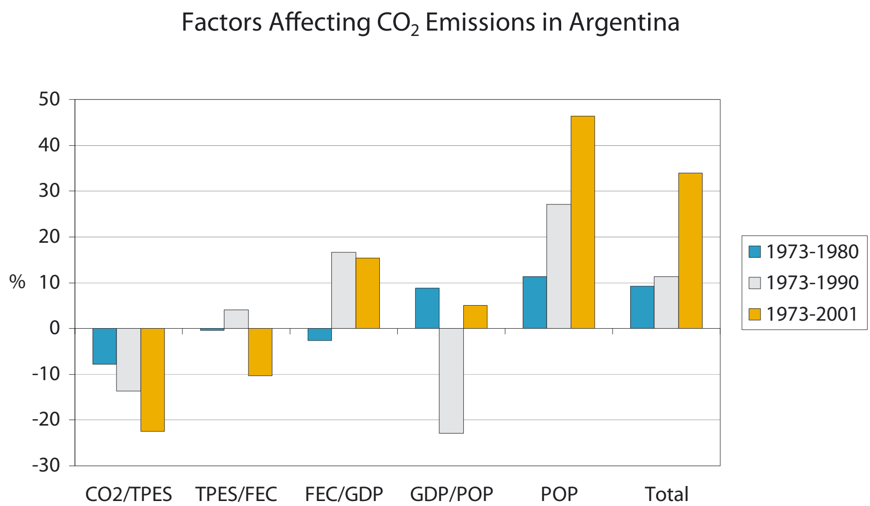

Figure 4.45. A decomposition analysis for the factors affecting CO_2 emissions in Argentina from 1973 to 2001.

The decomposition analysis shows the shift to less carbon intensive fuel use. The efficiency increase gained by energy transformation has decreased emissions, but at the same time the energy intensity of the economy increased resulting in increased emissions. Population growth is the single most important factor in the increase of emissions in Argentina.

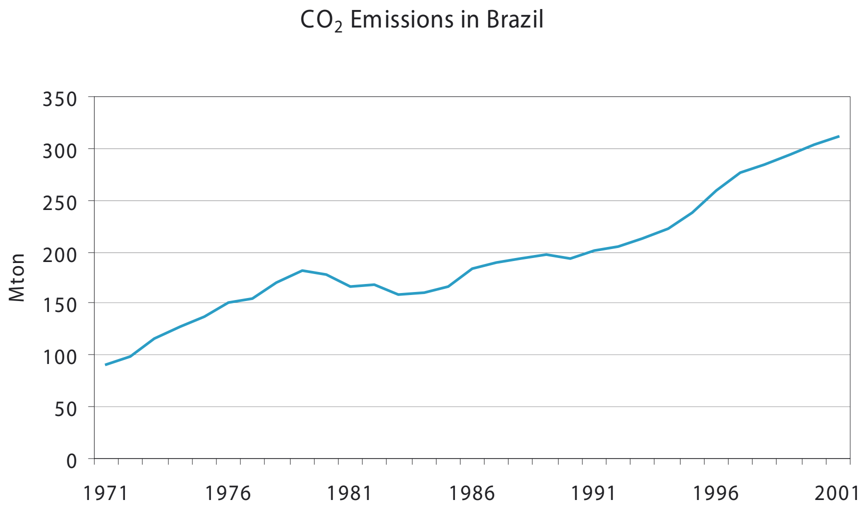

Figure 4.46a. CO_2 emissions in Brazil from 1971-2001 (Source IEA 2003a, c).

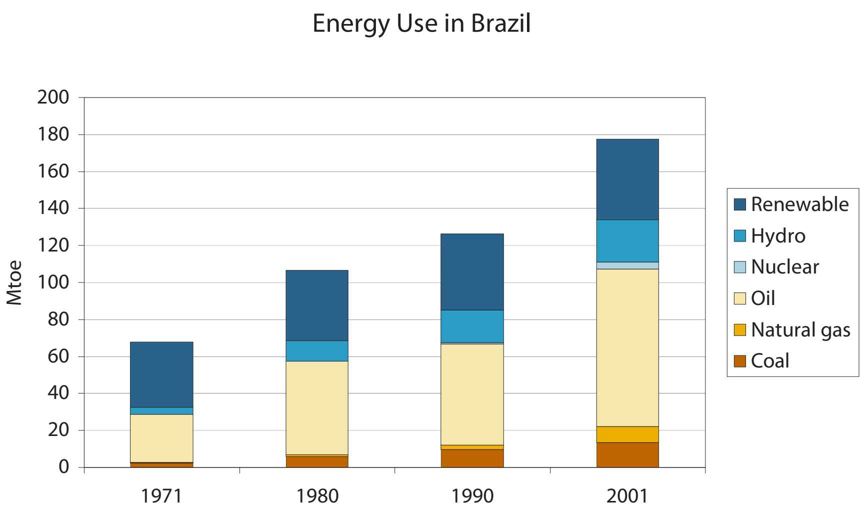

Figure 4.46b. Primary energy use in Brazil from 1971-2001 (Source IEA 2003a, c).

CO_2 emissions grew considerably in Brazil in the 1990's due to the increased use of oil and coal. The 70 % increase in renewables from 1971 to 2001 was not able to lower emissions though. Brazil's energy crisis resulted from a severe drought – important in a country that generates 93 % of its energy from hydroelectric sources - and consistent under-investment in the energy sector throughout the 1990s. Today the country's emissions are still growing due to its increasing industrial sector and road transport volume.

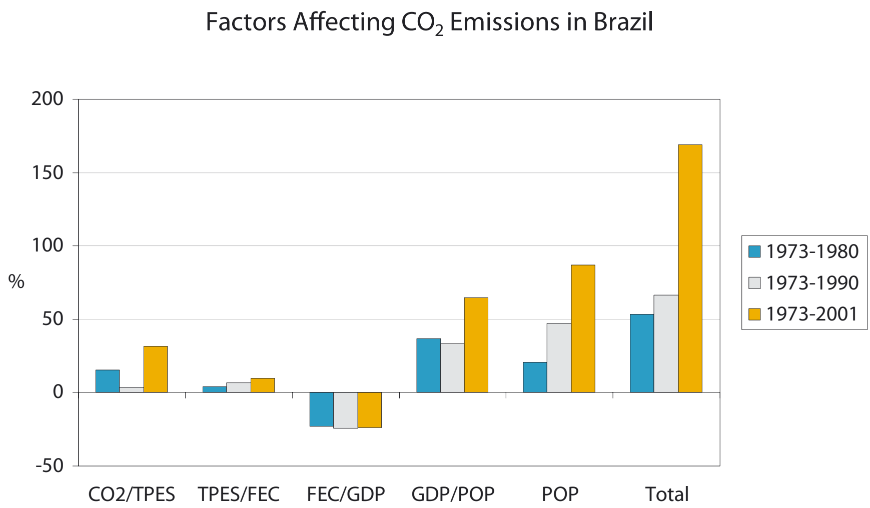

Figure 4.47. A decomposition analysis for the factors affecting CO_2 emissions in Brazil from 1973 to 2001.

The decomposition analysis indicates a shift towards more carbon intensive fuel use especially in the 1990's. The structural change in the economy did not affect emissions after 1980, but the considerable per capita economic growth and population growth resulted in a large increase of emissions between 1991 and 2001.

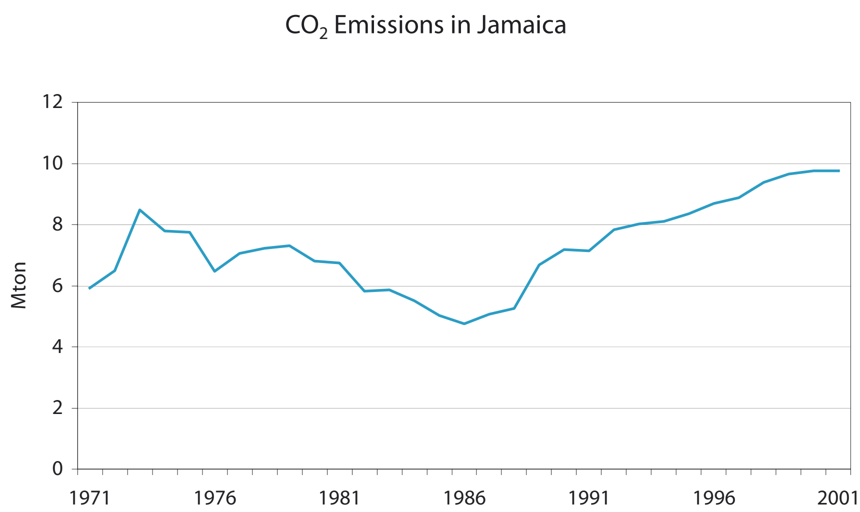

Figure 4.48a. CO_2 emissions in Jamaica from 1971-2001 (Source IEA 2003a, c).

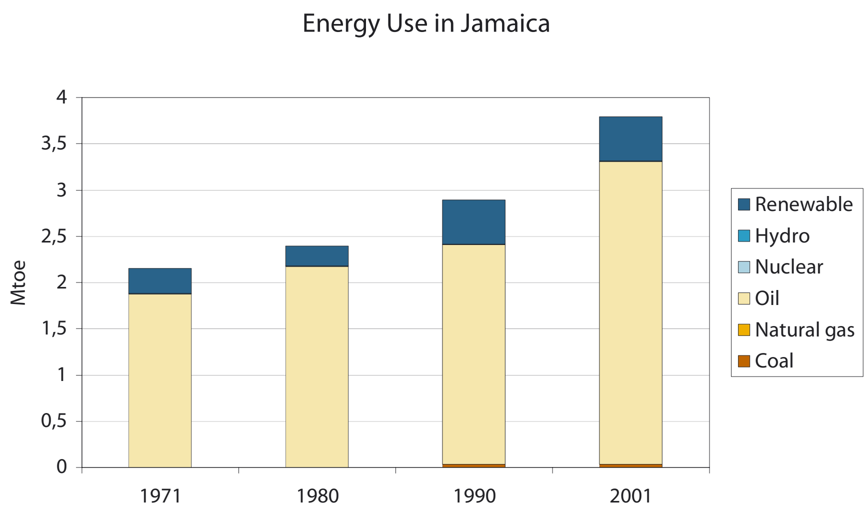

Figure 4.48b. Primary energy use in Jamaica from 1971-2001 (Source IEA 2003a, c).

The Jamaican energy system is almost entirely dominated by oil use and the emissions closely follow the changes in oil consumption. The growth of renewables, mainly biomass, was considerable in the 1990's according to the IEA's statistics.

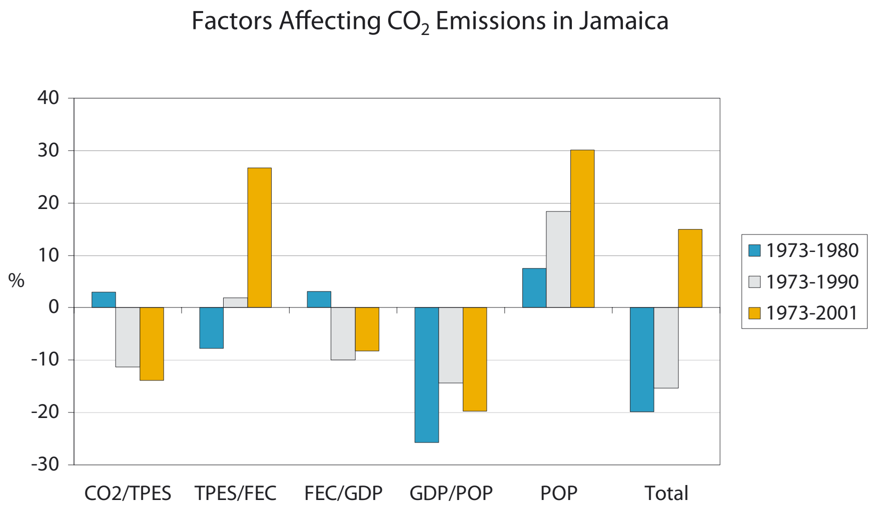

Figure 4.49. A decomposition analysis for the factors affecting CO_2 emissions in Jamaica from 1973 to 2001.

The decomposition analysis clearly indicates the growth of renewables, which have lowered the carbon intensity of the primary energy supply. The production structure has become less energy intensive and the decline of per capita economic output has kept emissions low. Population growth has been the main factor in increasing emissions in Jamaica.

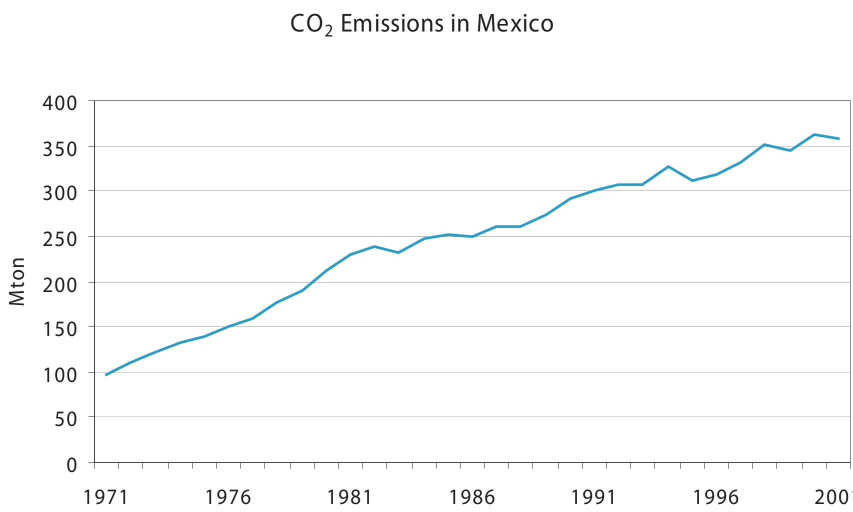

Figure 4.50a. CO_2 emissions in Mexico from 1971-2001 (Source IEA 2003a, b).

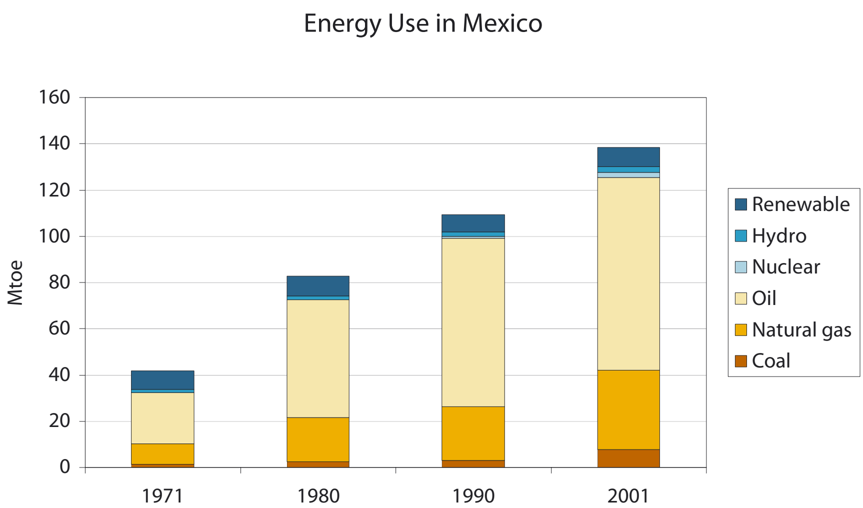

Figure 4.50b. Primary energy use in Mexico from 1971-2001 (Source IEA 2003a, b).

CO_2 emissions have steadily increased in Mexico due to the increased use of oil and gas. In the 1990's the main increases in emissions came from the electricity production sector and to some extent from the transport sector whereas emissions from industrial sectors decreased in the 1990's. The utilisation of abundant domestic resources may easily lead to inefficiencies and effective policy planning is needed in order to also take into account the environmental aspects of energy sector development.

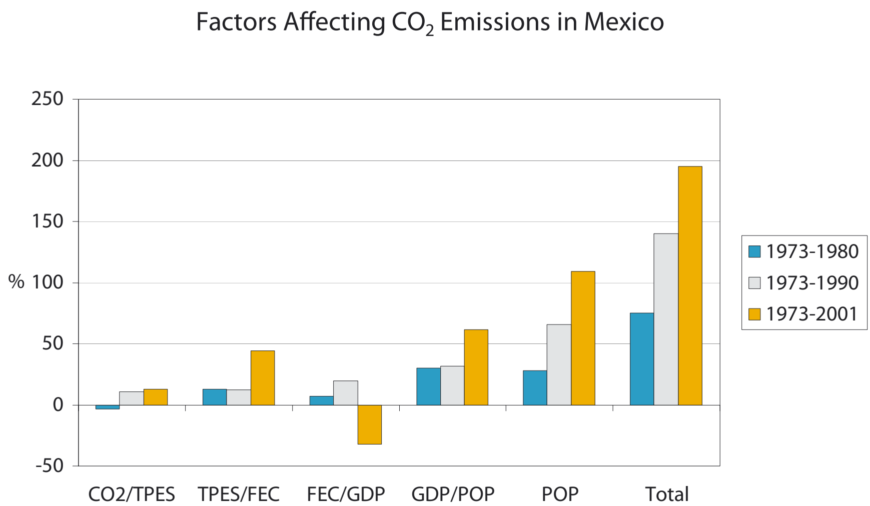

Figure 4.51. A decomposition analysis for the factors affecting CO_2 emissions in Mexico from 1973 to 2001.

The decomposition analysis shows a shift to increased fossil fuel domination in primary energy use and a decrease in the efficiency of energy transformation. A decrease in the energy intensity of the economy took place in the 1990's. Per capita economic growth and population growth have been the main drivers in increasing emissions.

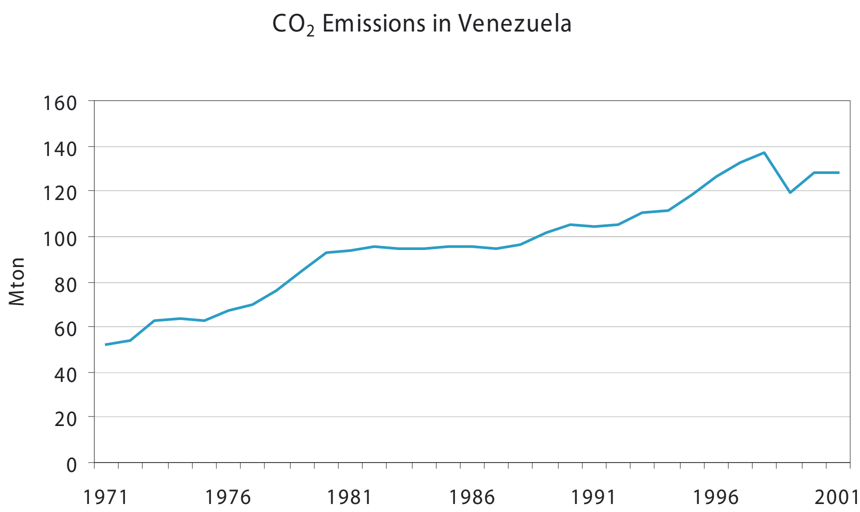

Figure 4.52a. CO_2 emissions in Venezuela from 1971-2001 (Source IEA 2003a, c).

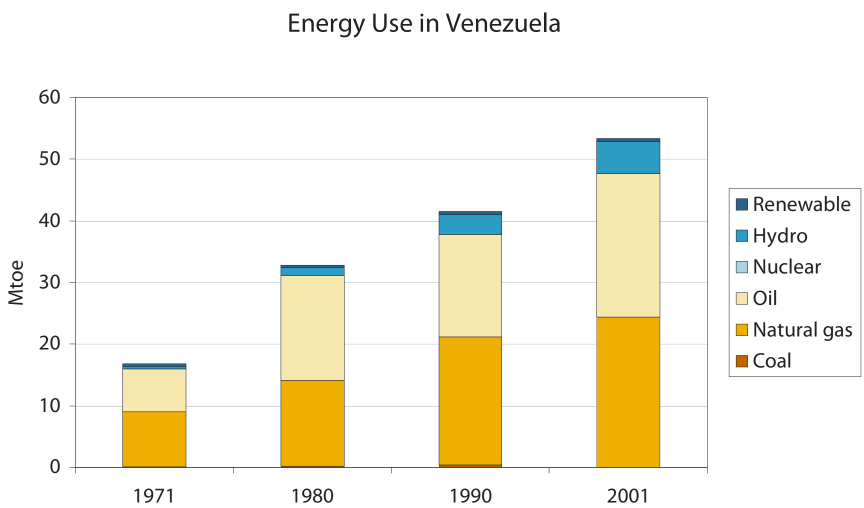

Figure 4.52b. Primary energy use in Venezuela from 1971-2001 (Source IEA 2003a, c).

Venezuela's energy sector is dominated by its upstream petroleum industry. About three-quarters of Venezuela's annual total energy production is oil, which accounts for about 80 % of Venezuela's export revenues and about one-third of its GDP. Venezuelans are the highest per capita users of electricity in Latin America. About 75 % of the country's electricity generation comes from hydropower. This is the country's largest use of renewable sources. Further hydropower plant constructions are anticipated in the next few years.

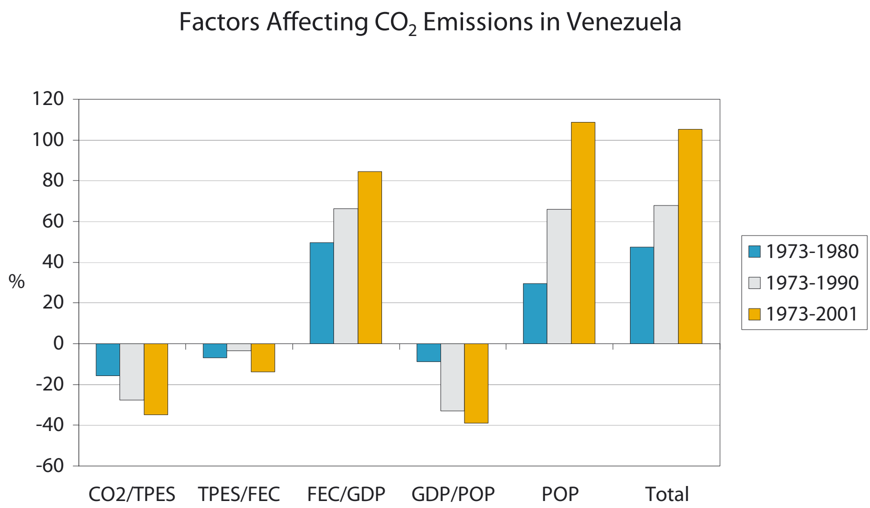

Figure 4.53. A decomposition analysis for the factors affecting CO_2 emissions in Venezuela from 1973 to 2001.

The decomposition analysis shows the decarbonisation of primary energy use in Venezuela. The large increase in the energy intensity of the economy indicates Venezuela's increased reliance on heavy petroleum based industries. Its declining economy has decreased the emissions, and meant a fast population growth has been the main contributor to an increase in emissions.

Since the C&C model requires not only contraction, but also the convergence of per capita emissions between countries, Venezuela, with its relatively high per capita emissions, cannot raise its emission intensity anymore but must decrease it rapidly. The figures indicate that industrialisation based on heavy industry, a fast increase in the use of fossil fuels, fast economic growth, as well as a fast increase in motorized private transport cannot work in the C&C model.

The transition countries

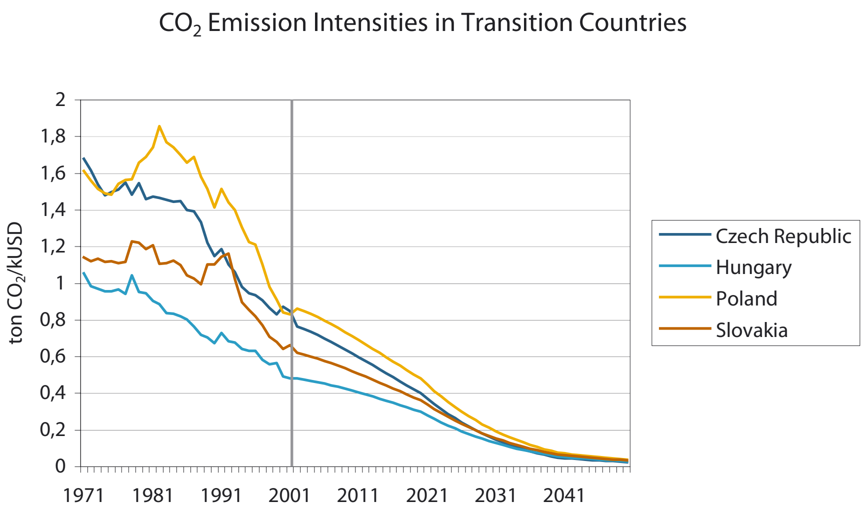

Figure 4.54a. Changes in CO_2 intensity in selected transition economies from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

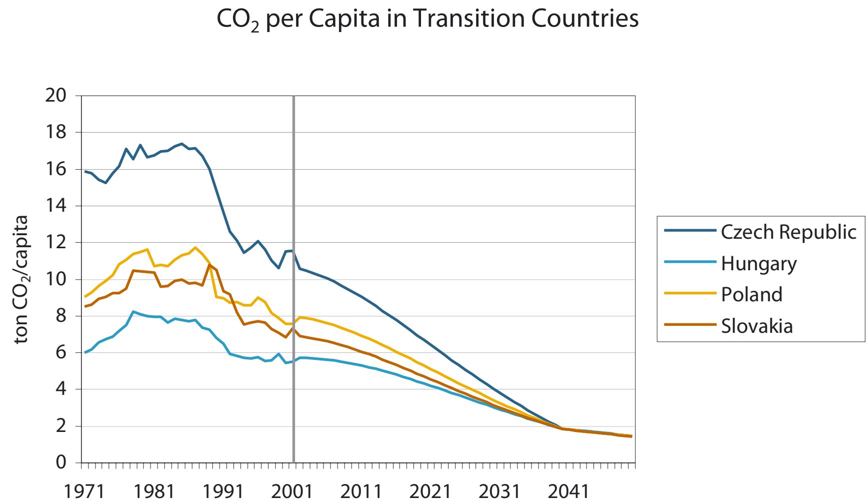

Figure 4.54b. Changes in CO_2 emissions per capita in selected transition economies from 1971-2001 (Source: IEA 2003a) and the required development from 2002-2050 in order to reach the C&C target.

The CO_2 intensities in the transition countries analysed have rapidly decreased in the 1990's due to the economic reformations taking place. The inefficient production systems of the Soviet era have been, to some extent, modernised and improved the efficiency of the systems.

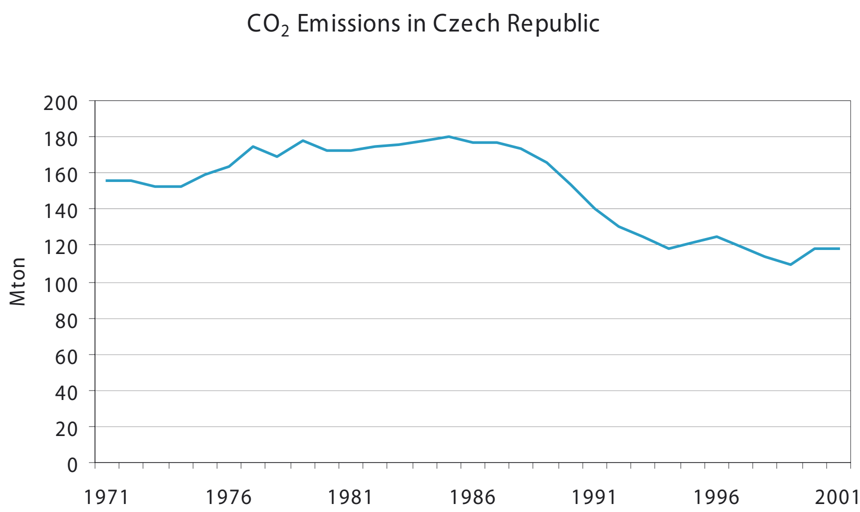

Figure 4.55a. CO_2 emissions in the Czech Republic from 1971-2001 (Source IEA 2003a, b).

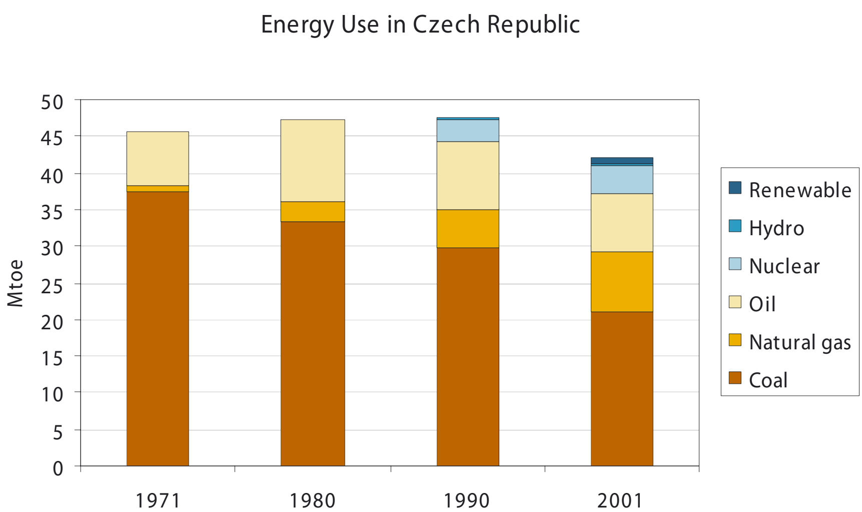

Figure 4.55b. Primary energy use in the Czech Republic from 1971-2001 (Source IEA 2003a, b).

Energy production in the Czech Republic used to be completely coal and oil dominated in the 1970's and 1980's. Nowadays, improved production efficiency has made it possible to decrease energy use and the simultaneous increase of nuclear production and a shift from coal to gas has decreased CO_2 emissions considerably.

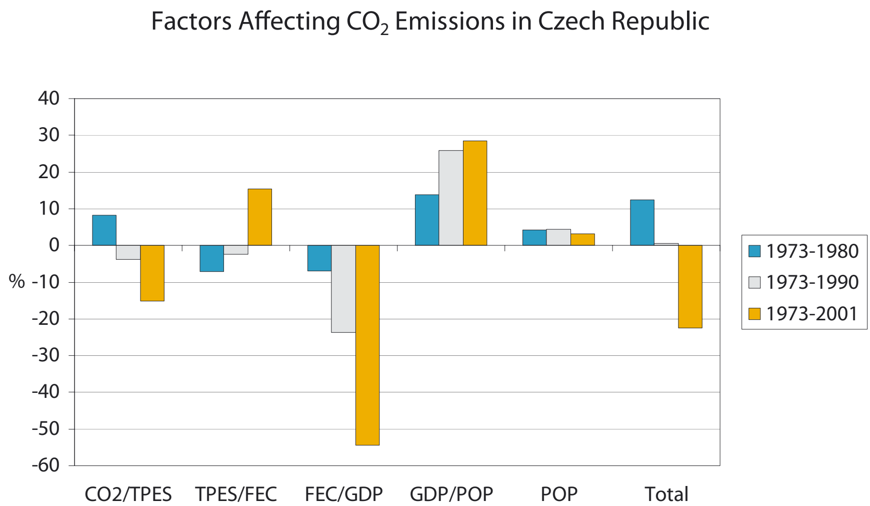

Figure 4.56. A decomposition analysis for the factors affecting CO_2 emissions in Czech Republic from 1973 to 2001.

The decomposition analysis indicates a fuel shift, which has, however, been counterbalanced by a decrease of efficiency in the transformation systems caused mainly by an increased share of electricity in final consumption. The significant structural shift to a less energy intensive production system in the 1990's has been the main reason for a decrease in emissions. Moderate per capita economic growth has helped keep emissions low.

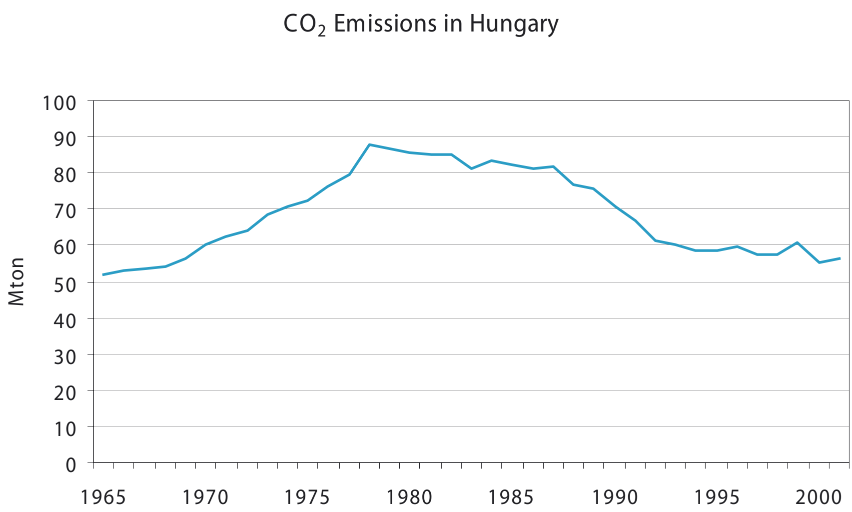

Figure 4.57a. CO_2 emissions in Hungary from 1965-2001 (Source IEA 2003a, b).

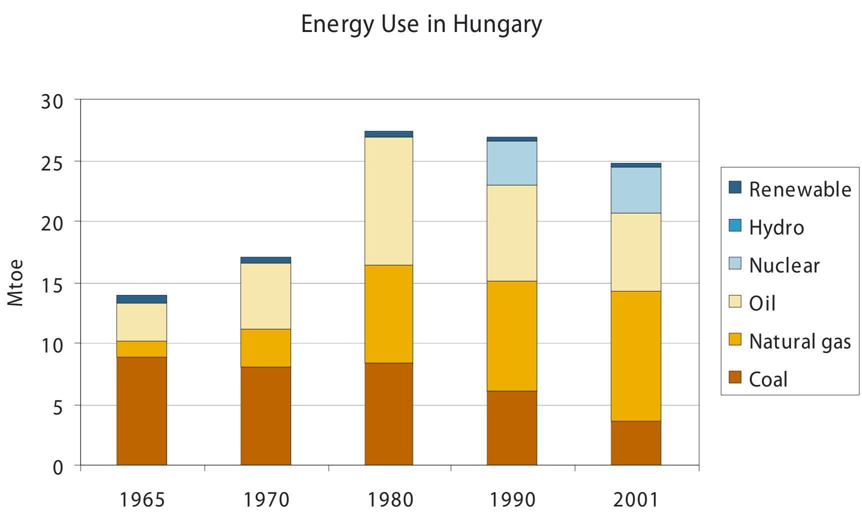

Figure 4.57b. Primary energy use in Hungary from 1965-2001 (Source IEA 2003a, b).

In Hungary a similar type of development has taken place to that of the Czech Republic. Increased production efficiency has made it possible to decrease energy consumption since 1980. At the same time the increased share of nuclear and natural gas and a decreased use of coal have been main drivers in lowering emissions.

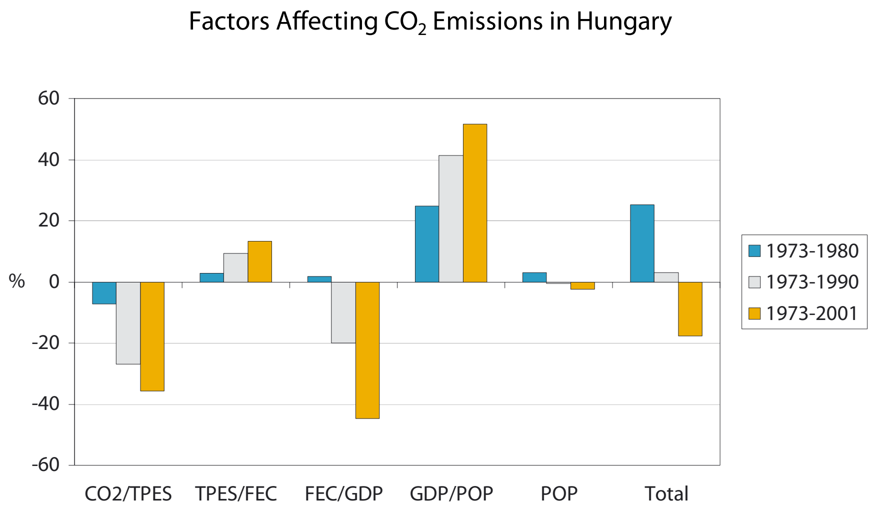

Figure 4.58. A decomposition analysis for the factors affecting CO_2 emissions in Hungary from 1973 to 2001.

The decomposition analysis shows the main reasons behind Hungary's decreasing emissions to be a fuel shift and a structural change in the economy.

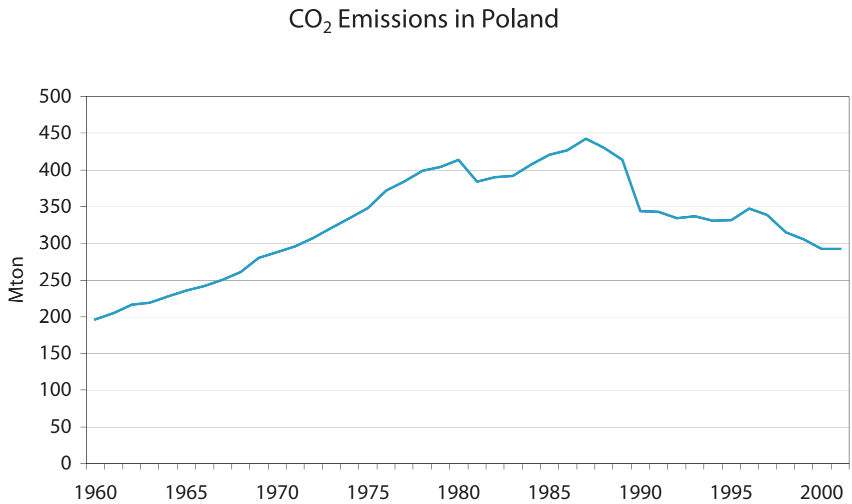

Figure 4.59a. CO_2 emissions in Poland from 1960-2001 (Source IEA 2003a, b).

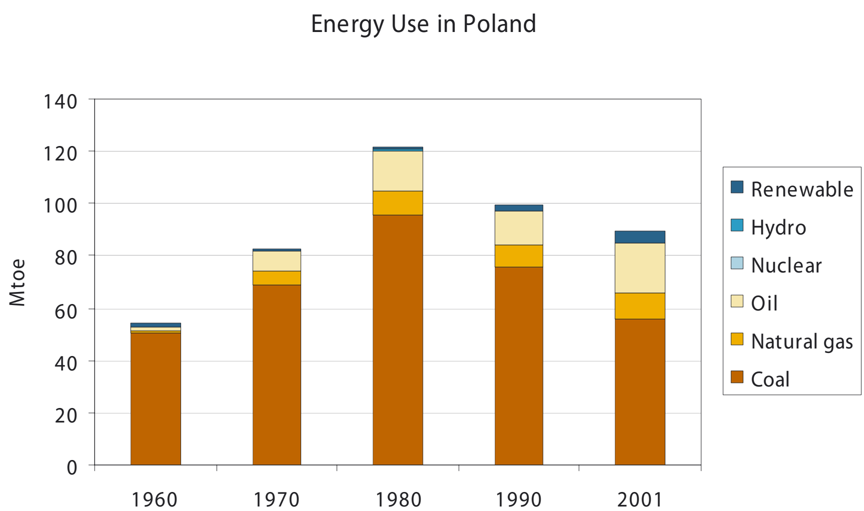

Figure 4.59b. Primary energy use in Poland from 1960-2001 (Source IEA 2003a, b).

Poland has been a coal production dominated country due to its large domestic resources. Its rapidly decreasing use of coal and an increasing share of gas and renewables have been the factors behind Poland's decreased emissions.

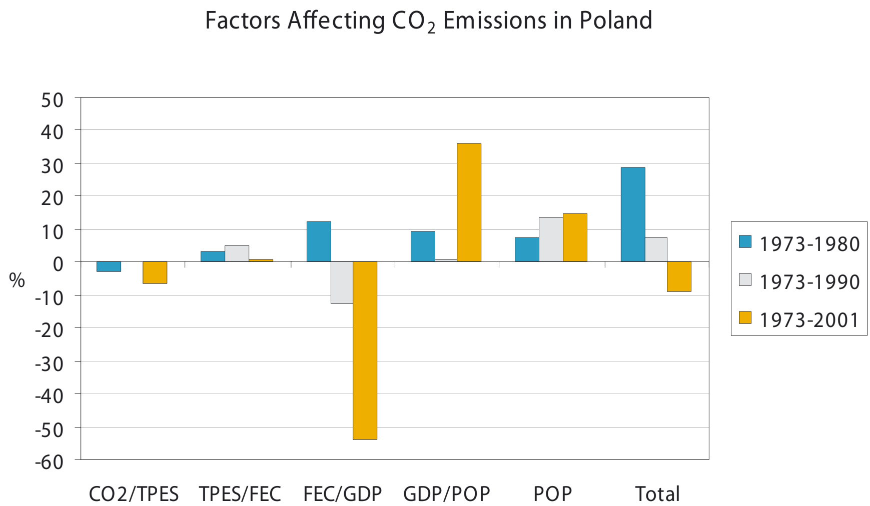

Figure 4.60. A decomposition analysis for the factors affecting CO_2 emissions in Poland from 1973 to 2001.

The decomposition analysis reveals the structural change in Poland's economy in the 1990's to be the main driver of change in its emissions.

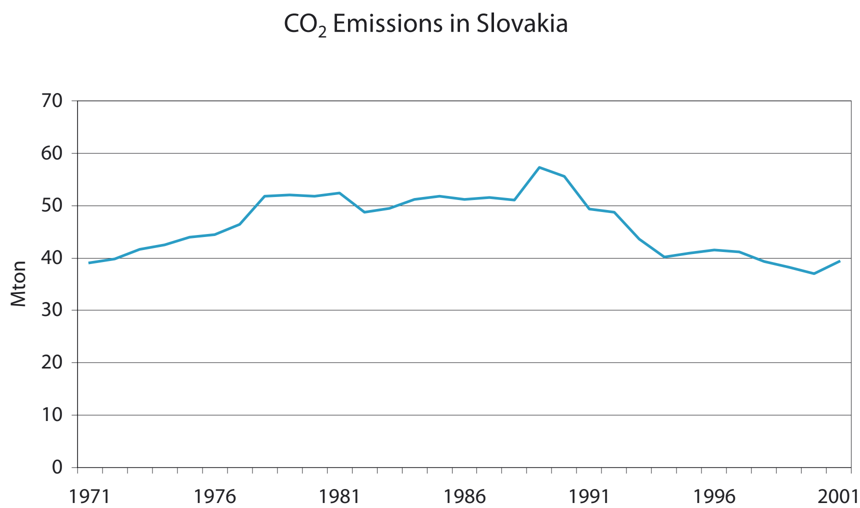

Figure 4.61a. CO_2 emissions in Slovakia from 1971-2001 (Source IEA 2003a, b).

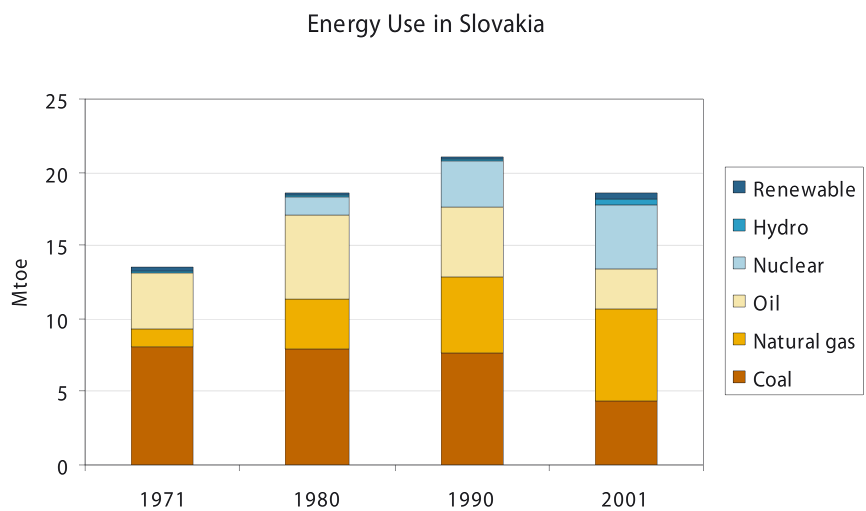

Figure 4.61b. Primary energy use in Slovakia from 1971-2001 (Source IEA 2003a, b).

Slovakia's decreasing emissions in the 1990's seem to be the result of a lowering of energy demand and a fuel shift. The reduced shares of coal and oil and an increased use of gas and nuclear power for power generation were the main reasons for the decrease.

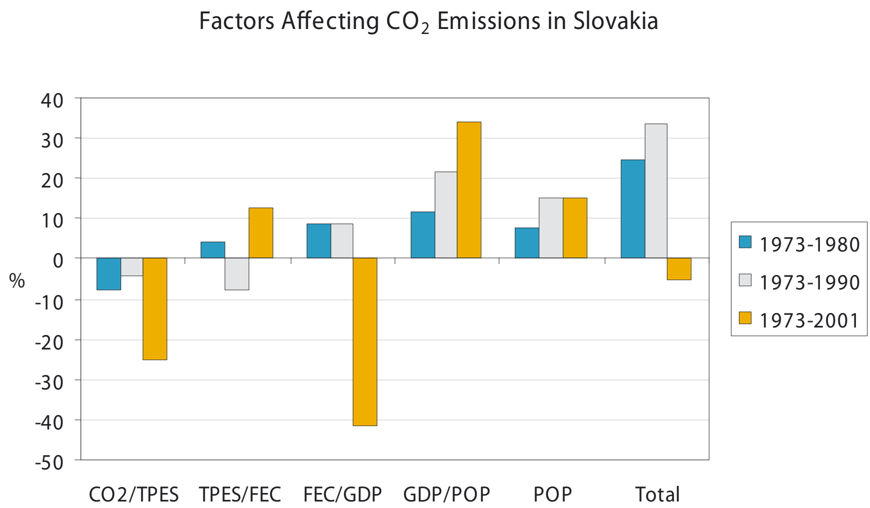

Figure 4.62. A decomposition analysis for the factors affecting CO_2 emissions in Slovakia from 1973 to 2001.

The decomposition analysis indicates the fuel shifting and changes in the economic structure to be the main forces driving decreases in the emissions of the Slovak Republic.

South and South-East Asia

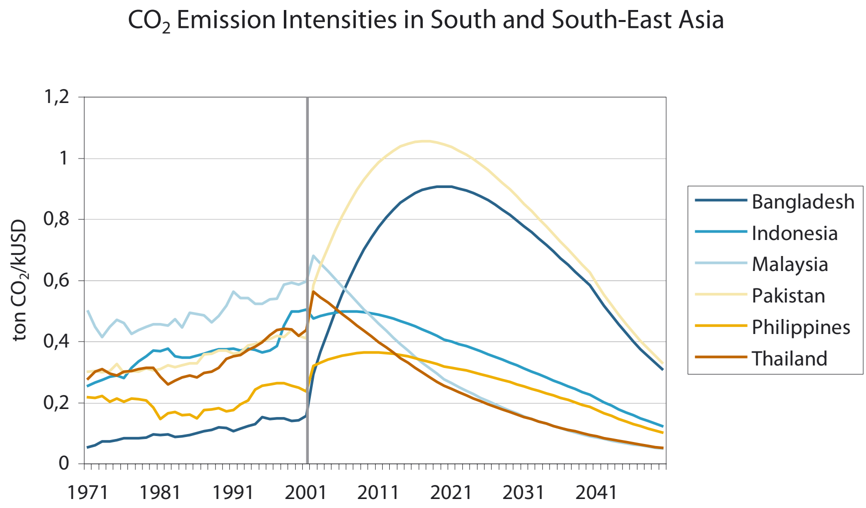

Figure 4.63a. Changes in the CO_2 intensity of the economies of selected South and South-Eastern Asian countries from 1971 to 2001 (Source: IEA 2003a) and their required development from 2002 to 2050 in order to reach the C&C target.

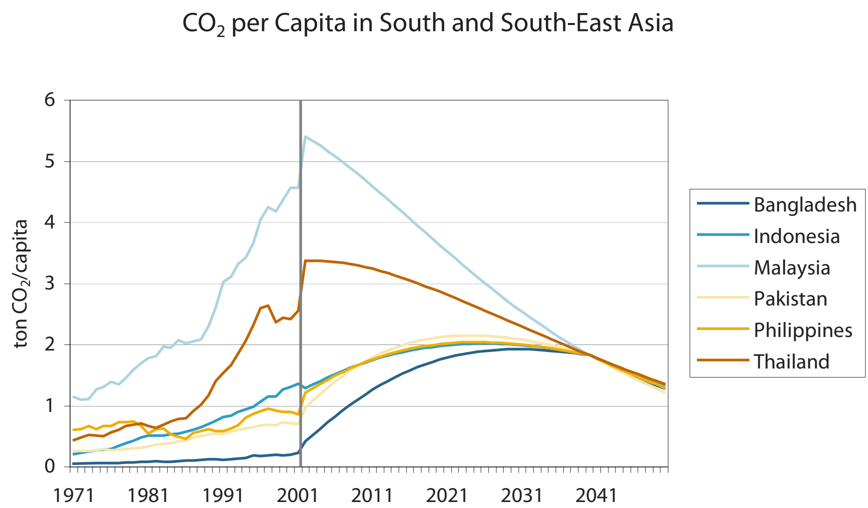

Figure 4.63b. Changes in the CO_2 emissions per capita of the economies of selected South and South-Eastern Asian countries from 1971 to 2001 (Source: IEA 2003a) and their required development from 2002 to 2050 in order to reach the C&C target.

The selected countries of South and South-East Asia have experienced large differences in their development regarding energy use and CO_2 emission intensities. On the one hand rapidly industrializing countries like Malaysia and Thailand have increased their emissions and emission intensity considerably and should reverse their development path in order to achieve the C&C target. On the other hand, countries with a very low level of CO_2 emissions per capita, like Bangladesh and Pakistan, could increase their emission intensity in the short run and still reach the C&C target. Lastly, Indonesia and the Philippines could even continue on their current path of slowly increasing emission intensity.

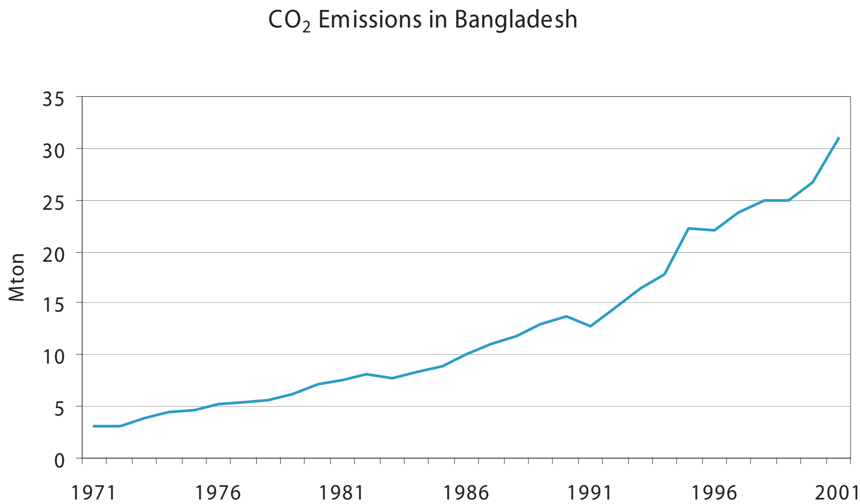

Figure 4.64a. CO_2 emissions in Bangladesh from 1971-2001 (Source IEA 2003a, c).

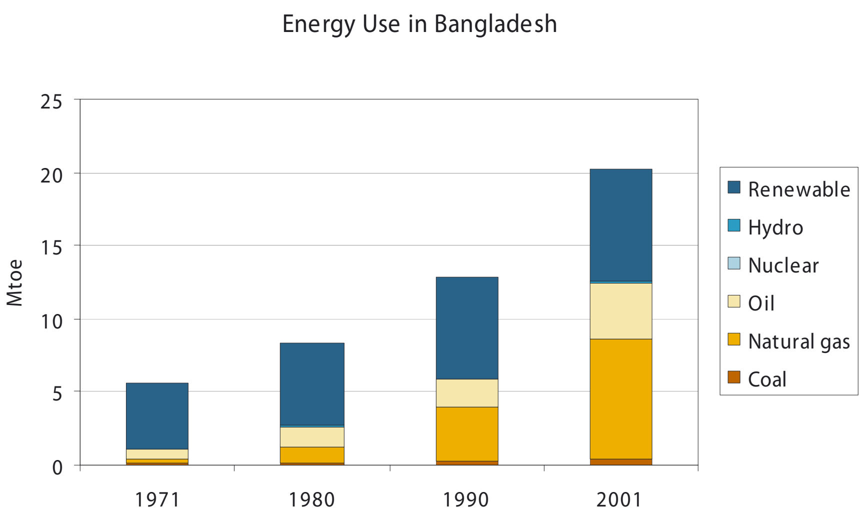

Figure 4.64b. Primary energy use in Bangladesh from 1971-2001 (Source IEA 2003a, c).

CO_2 emissions have been grown fast in Bangladesh, but still the level of emissions per capita is extremely low, only about 0.2 tons of CO_2 per year. The growth in emissions is due to an increased use of natural gas and oil although the use of renewables has been growing at the same time and their share remains at almost 40 % of the total supply.

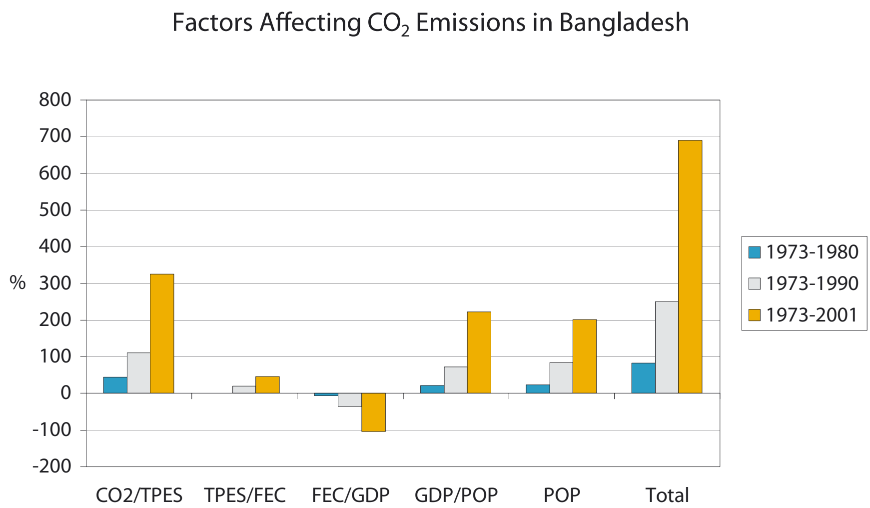

Figure 4.65. A decomposition analysis for the factors affecting CO_2 emissions in Bangladesh from 1973 to 2001.

The decomposition analysis indicates that the shift towards fossil fuels has been significant, from a starting point of almost zero in 1973. The economic structure of Bangladesh has changed considerably and shifted towards a less energy intensive system but its fast per capita economic growth and a rapid increase in population have increased emissions.

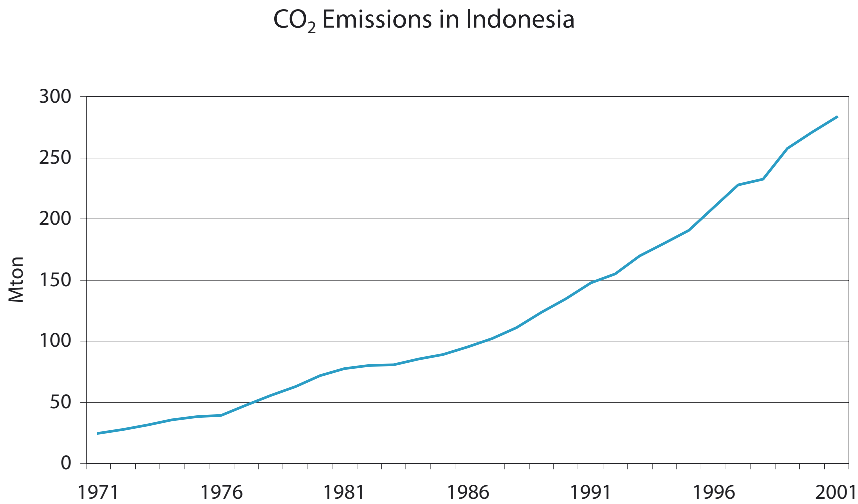

Figure 4.66a. CO_2 emissions in Indonesia from 1971-2001 (Source IEA 2003a, c).

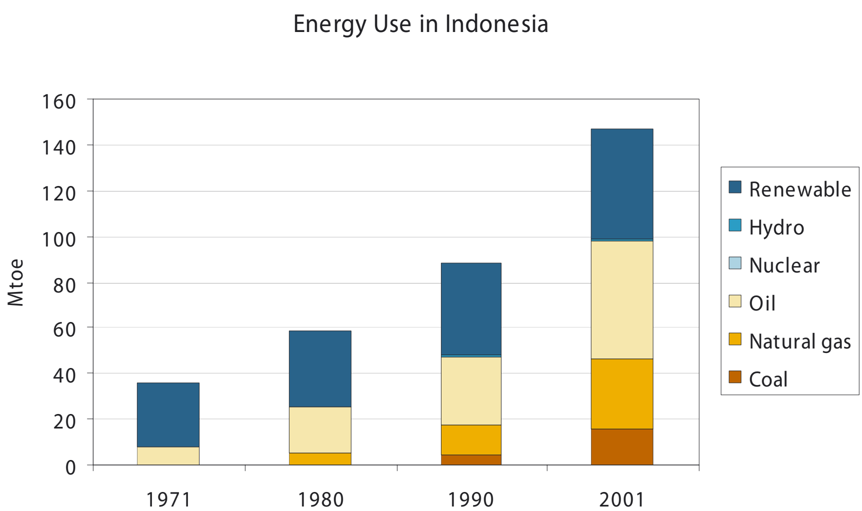

Figure 4.66b. Primary energy use in Indonesia from 1971-2001 (Source IEA 2003a, c).

CO_2 emissions in Indonesia have grown fast but the per capita level is still very low, it is currently only 1.2 tons. The increase in gas and oil consumption and the introduction of coal, mainly in the 1990's, have affected the amount of emissions released into the atmosphere. The use of renewables has grown steadily, but their share has diminished to one third of the total supply.

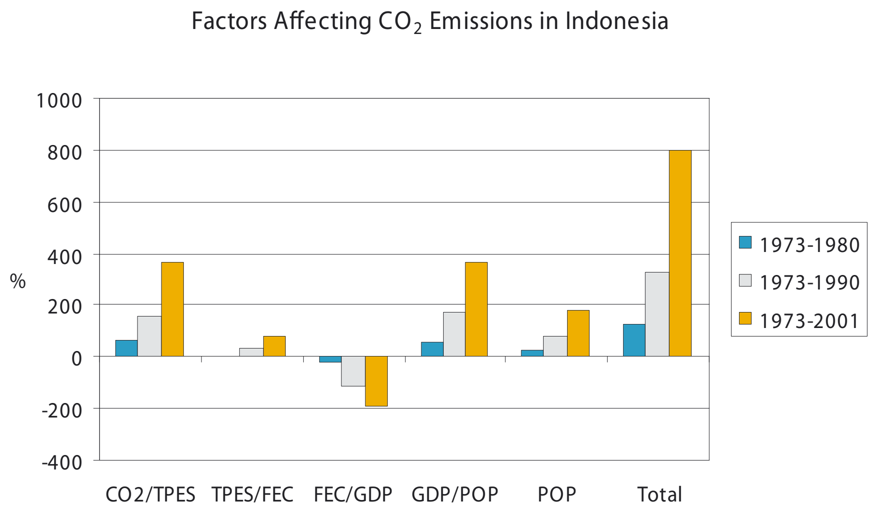

Figure 4.67. A decomposition analysis for the factors affecting CO_2 emissions in Indonesia from 1973 to 2001.

The decomposition analysis shows the role of fuel shifting and per capita economic growth to be the most significant factors affecting the increase in emissions, followed by population growth. Hence, the structural change in the economy has not been strong enough to counterbalance those factors.

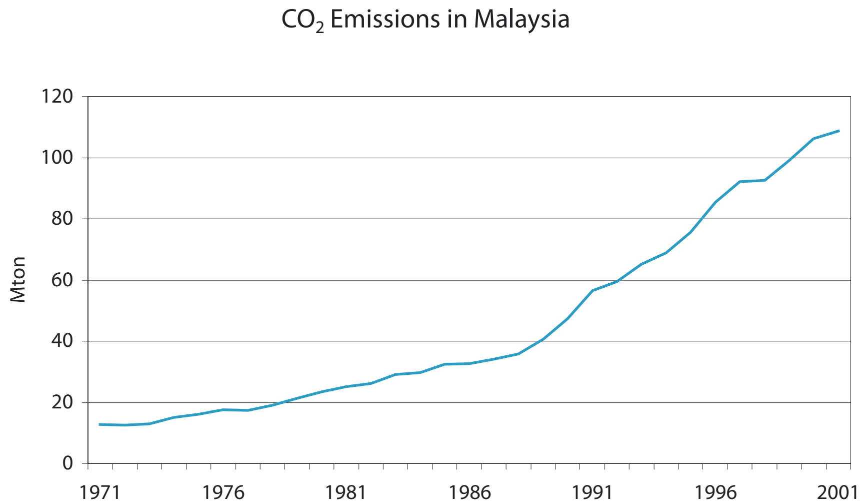

Figure 4.68a. CO_2 emissions in Malaysia from 1971-2001 (Source IEA 2003a, c).

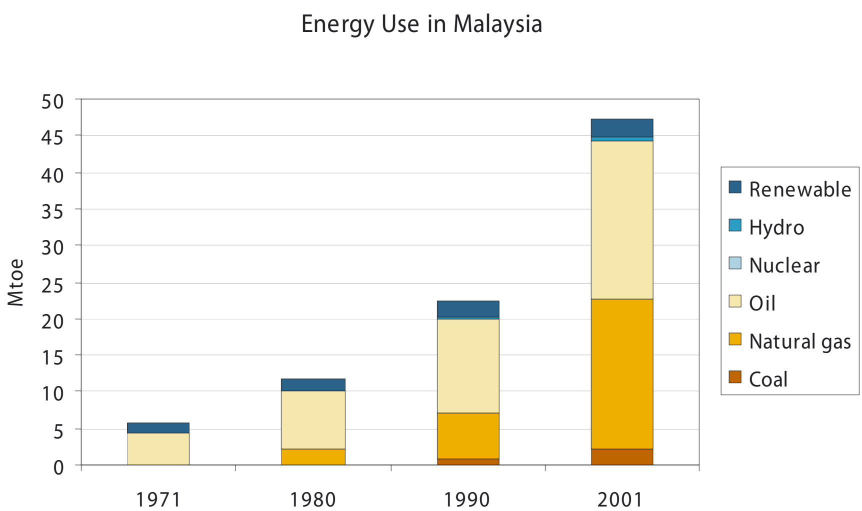

Figure 4.68b. Primary energy use in Malaysia from 1971-2001 (Source IEA 2003a, c).

In Malaysia fast economic growth and the use of fossil fuels has increased annual emissions per capita to a level of over 5 tons. The heavy reliance on fossil energy sources, over 90 % of the supply, can be seen from the Figure 4.68b.

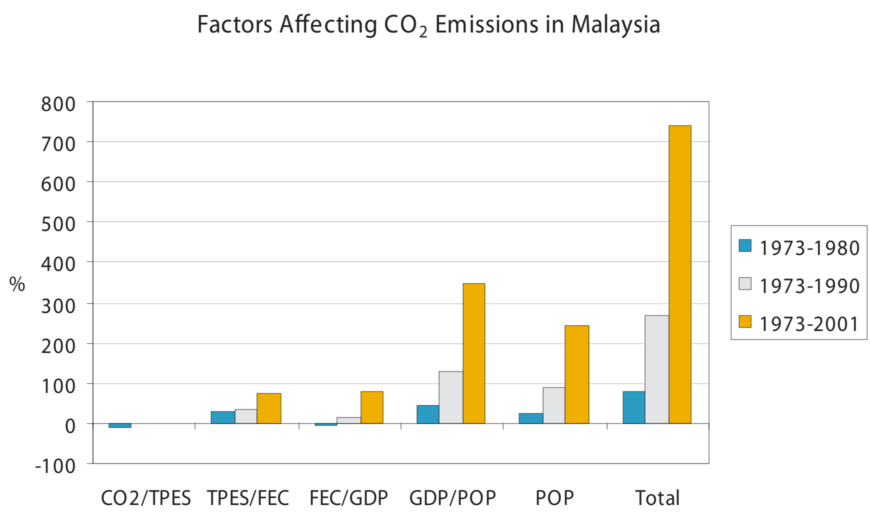

Figure 4.69. A decomposition analysis for the factors affecting CO_2 emissions in Malaysia from 1973 to 2001.

The decomposition analysis shows that all the five factors in the study have had the effect of increasing emissions. Even the economic structure has changed to become more energy intensive, which is contrary to almost all other countries except the Mediterranean countries of Portugal, Greece and Spain and the Latin American countries of Venezuela and Argentina. A fast per capita economic growth, plus rapid population growth have been the main drivers in the increase of emissions in Malaysia.

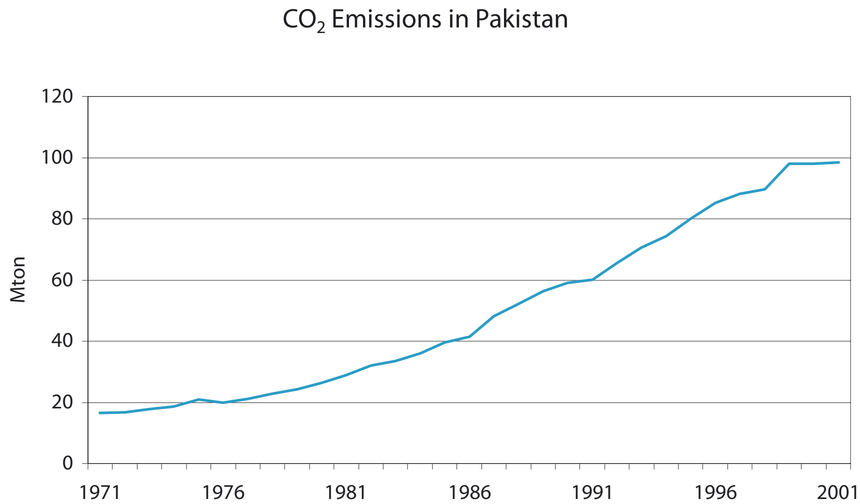

Figure 4.70a. CO_2 emissions in Pakistan from 1971-2001 (Source IEA 2003a, c).

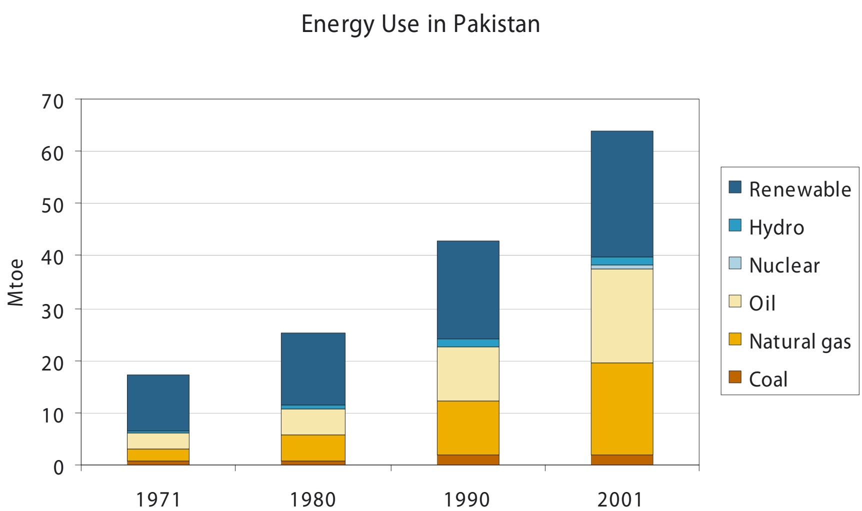

Figure 4.70b. Primary energy use in Pakistan from 1971-2001 (Source IEA 2003a, c).

In Pakistan the share of renewable energy sources has remained at over 40 %, but emissions have continued to grow due to an increased use of oil and gas.

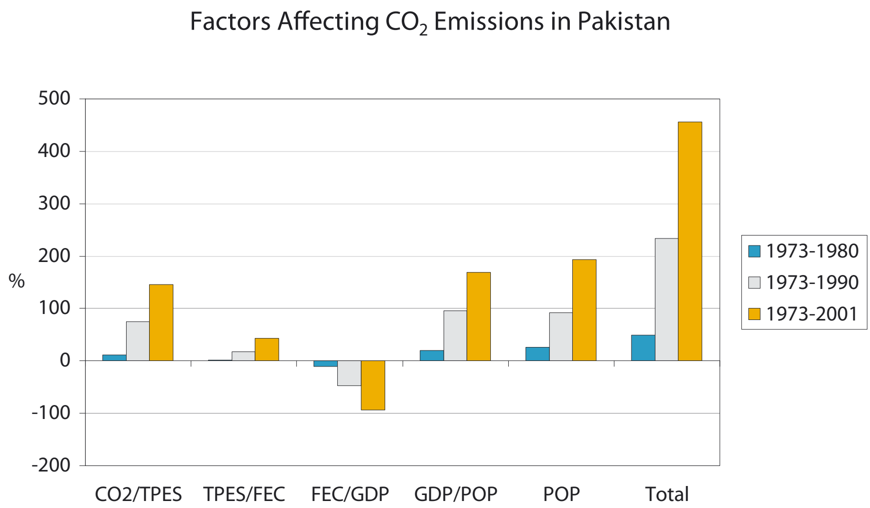

Figure 4.71. A decomposition analysis for the factors affecting CO_2 emissions in Pakistan from 1973 to 2001.

The decomposition results show that the population growth has been the most significant contributor to the increase of emissions in Pakistan. The fuel shift towards fossil fuels and a rise in per capita economic growth have also been significant factors. In Pakistan the structural shift in the economy towards a less energy intensive structure has been an important factor in lowering the growth of emissions.

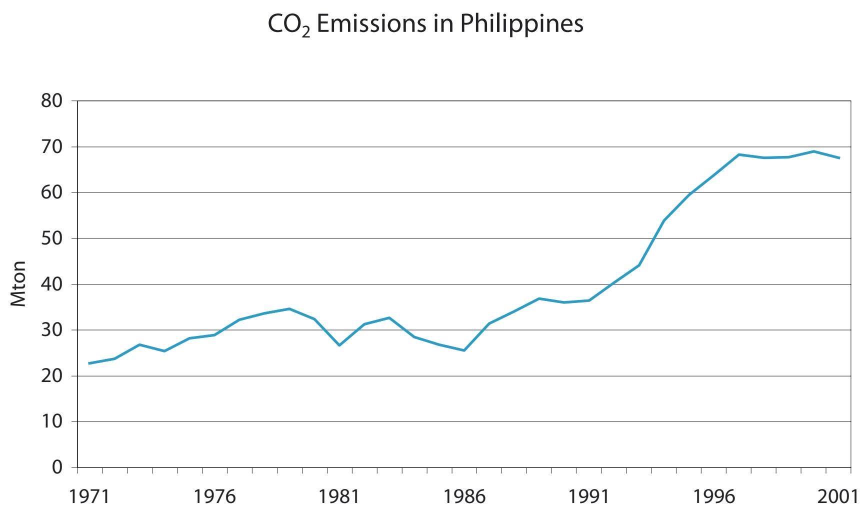

Figure 4.72a. CO_2 emissions in the Philippines from 1971-2001 (Source IEA 2003a, c).

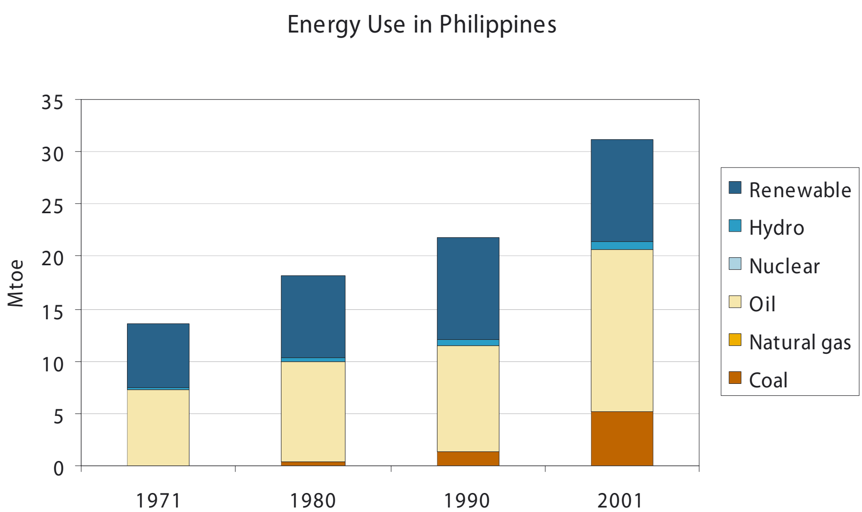

Figure 4.72b. Primary energy use in the Philippines from 1971-2001 (Source IEA 2003a, c).

In the Philippines the growth in CO_2 emissions started quite late in the 1990's. The share of renewables was over 45 % in 1990, but an increase in fossil fuel use reduced the share to one third in 2001.

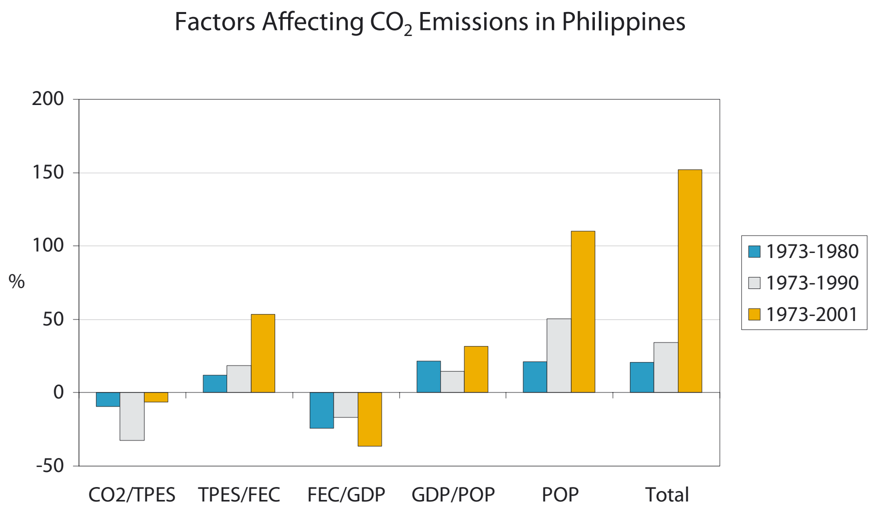

Figure 4.73. A decomposition analysis for the factors affecting CO_2 emissions in Philippines from 1973 to 2001.

The decomposition analysis shows that the fuel shift to a less carbon intensive energy use has not been very meaningful, as an efficiency loss in the transformation has increased emissions considerably. The structural change to a less energy intensive economy has been approximately counterbalanced by the slow per capita growth of the Philippines economy. The main factor in increasing emissions has been fast population growth.

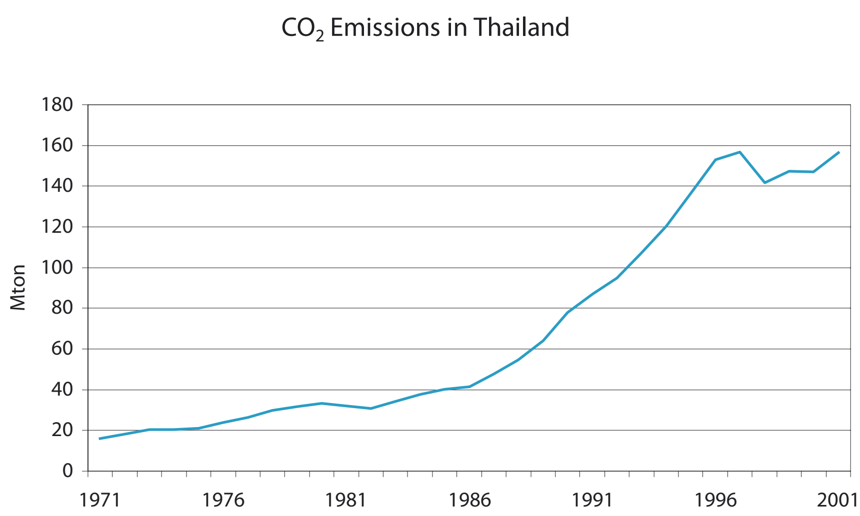

Figure 4.74a. CO_2 emissions in Thailand from 1971-2001 (Source IEA 2003a, c).

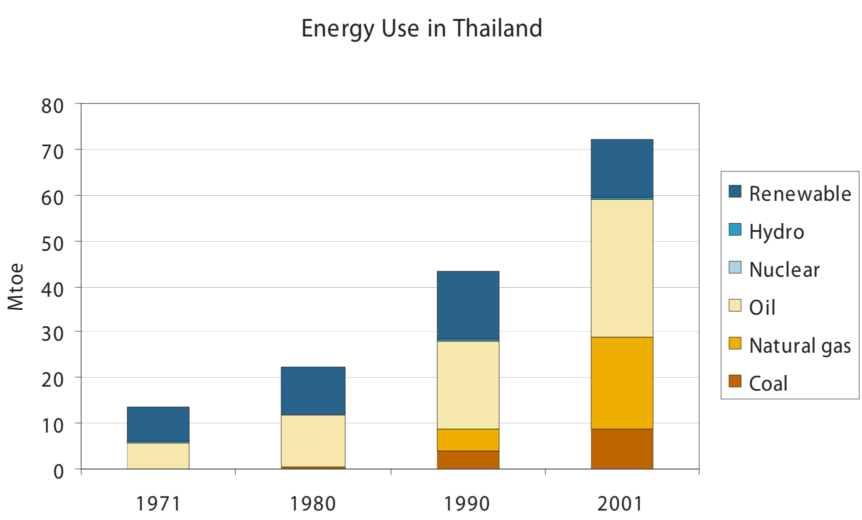

Figure 4.74b. Primary energy use in Thailand from 1971-2001 (Source IEA 2003a, c).

A fast CO_2 emission growth began in Thailand in the 1980's but the Asian economic crisis of the late 1990's cut the increase. The fast growth of emissions was caused by a rapid increase in gas, oil and coal use especially in the early 1990's. An increasing trend in the use of renewables was also reversed in the 1990's.

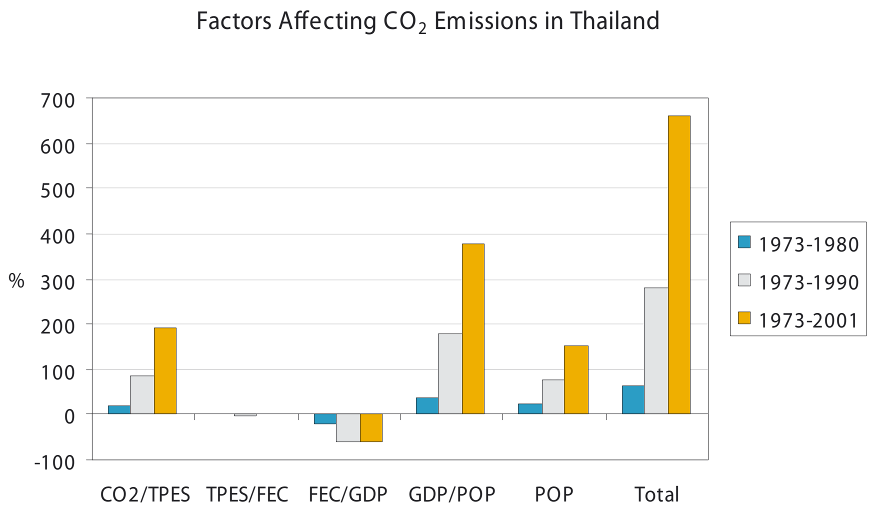

Figure 4.75. A decomposition analysis for the factors affecting CO_2 emissions in Thailand from 1973 to 2001.

The decomposition analysis reveals the important effect of fossil fuel use in the increase of emissions produced by Thailand. The shift to a less energy intensive economy has been quite modest, and has meant that per capita economic growth has been the main factor in the increase of emissions. Population growth has also been a significant factor.

A sensitivity analysis

For the sensitivity analysis of the results we have calculated the future development of GDP by using the high growth rates of the WEC scenarios. The growth rates for the EU15 countries is given in Table 4.1. The calculated required future CO_2 intensities are shown in Figure 4.76.

Table 4.1. Economic growth rates from 2002 to 2050, in percentages per year, for the EU15 countries. The scenarios are for high growth, medium growth and low growth.

Scenario	**Growth rates**					
	2002-2020			**2020-2050**		
EU-15	2.2	1.9	1.7	1.7	1.3	1.1

Source: Nakicenovic et al. 1998.

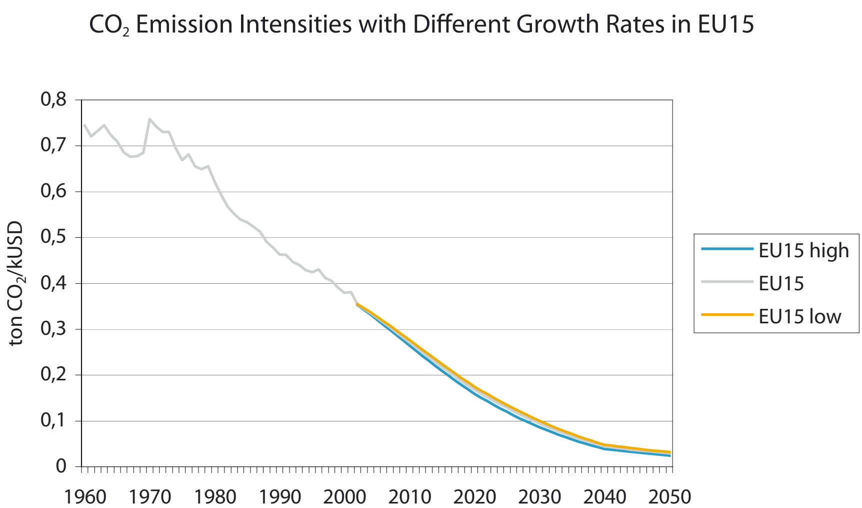

Figure 4.76. The required future development of CO_2 intensities for the EU15 countries in different growth scenarios.

The role of the transport sector

CO_2 emissions have grown in many countries due to the fast growth of transport sector emissions. The share of energy use in the transport sector has grown as can be seen in Figure 4.77. The fast growth of passenger car fuel use can be a major factor in many developing countries for future emission growth. Thailand is a good example of this. Fast economic growth in the 1990's has enabled a larger share of the population to buy a private car, and a transport policy based on private car use, has increased emissions significantly.

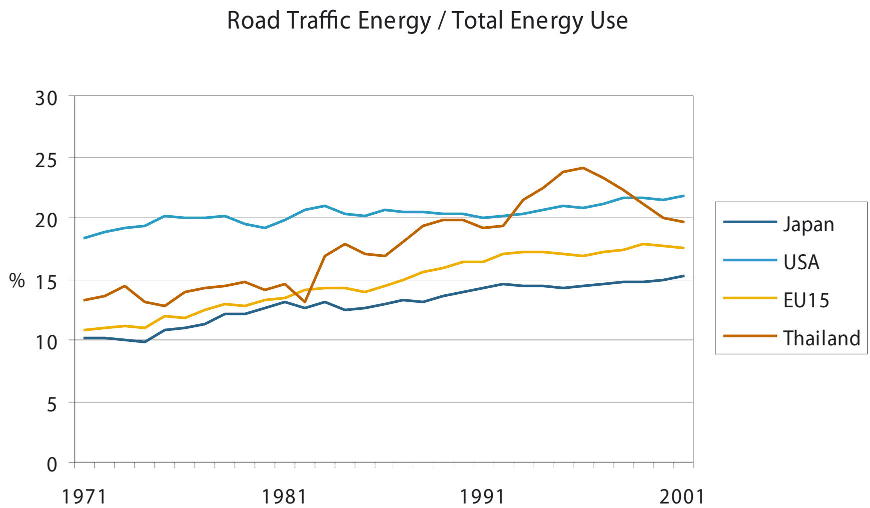

Figure 4.77a. The share of road traffic energy as percentage of the total amount of energy use, in selected countries. (Source IEA 2003b).

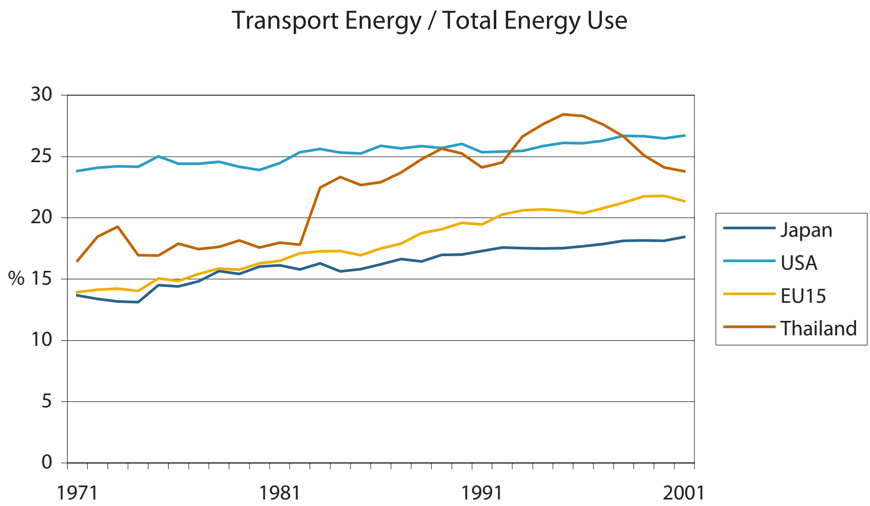

Figure 4.77b. The share of total transport energy as percentage of the total amount of energy use, in selected countries. (Source IEA 2003b).

5. CONCLUSIONS

It is a formidable challenge to decide what will happen in the post-Kyoto period after 2012. A new agreement needs to avoid causing economic hardship and allow developing countries to rise out of poverty, while promising sharp, long-term reductions in the GHGs that are a ubiquitous by-product of industrialised societies.

Though the Kyoto Protocol entered into force on the 16th of February 2005, it is clear that even if these targets are met, global emissions will not reach a sustainable level. Therefore, the focus on the longer-term objectives of the UNFCCC cannot be postponed for too long.

The Contraction and Convergence model requires in the future a decline of emissions in all countries which are above the sustainability limit of 1.8 tons of CO_2 per capita. The required changes in emission intensities, which are decisive from the techno-economic point of view, are, however, different. Generally industrialised countries have to follow their current downward trend, which can be achieved by improved energy efficiency, a shift to renewable energy sources and, mainly, by continuous structural changes in the production system. Economic growth has to a large extent come from light sectors of the economy such as services and ICT.

In a world that aims at Contraction & Convergence, the industrialised countries' emissions entitlement per their GDP can basically follow the current trend line in many countries. From this point of view the C&C model target, which requires vast emission reductions for industrialised countries, seems not to be too difficult because the structural changes in their economies will lead to a much lighter production structure reducing the need for increased energy use. The structural change of the production system seems to be more effective in intensity reduction than energy technology improvements. Part of the structural change includes the shift of heavy and polluting industry to developing countries, which cannot be seen as a healthy way of development from the sustainability point of view. The globalising economy makes it difficult to allocate emission entitlements equitably on a national basis.

For the developing countries the situation is different. Many developing economies are in the industrialising phase as indicated by their increasing emission intensities. According to the C&C model the emission intensities in some developing countries cannot grow anymore but need to decline rapidly beyond 2001, if economic growth is to continue. The results indicate that industrialisation based on a fast increase in the use of fossil fuels and fast economic growth cannot work in the C&C model. But in countries like India and Indonesia, the emission intensities can increase up to 2015. This is due to their present low levels of CO_2 per capita emissions – convergence for them means that they can increase emissions from the present very low level. The entitlements of India and Indonesia can grow until 2030 although their emission intensity has to start to decline in 2015.

Since this model requires not only contraction, but also the convergence of per capita emissions between countries, nations such as Venezuela and Thailand, with their relatively high per capita emissions, are required to start to reduce their emission intensities immediately. A western type of industrialisation based on heavy industry, fossil fuel use and a fast increase in motorised private transport cannot work in the contraction and convergence model. In this sense the model does not fulfil the criteria of equity, because it will not allow similar development paths for developing countries that many industrialised countries took.

Done well, the Contraction and Convergence model could provide a framework for a genuine long-term solution to climate change, which reduces political risks and provides businesses and investors with the sort of predictable framework they prefer. The target provided by the model seems not to be too hard for industrialised countries due to the possibilities offered by structural change and most developing countries can adjust their development policies to fit into the framework.

We have studied the changes in CO_2 intensity in the past and compared them to the required future intensity changes. We analysed (see Figure 5.1) the intensity trends in the periods 1973-1990 (A) and 1990-2001 (B) to gain an overview of what has happened after the first oil crisis and during the 90's. To reach the C&C target requires different intensity trends (C) from different countries and we have compared their historical and their required future trends in order to indicate the required direction of development. Figure 5.2 compares different countries indicating the differences between the decreases of A and C and between the decreases of B and C.

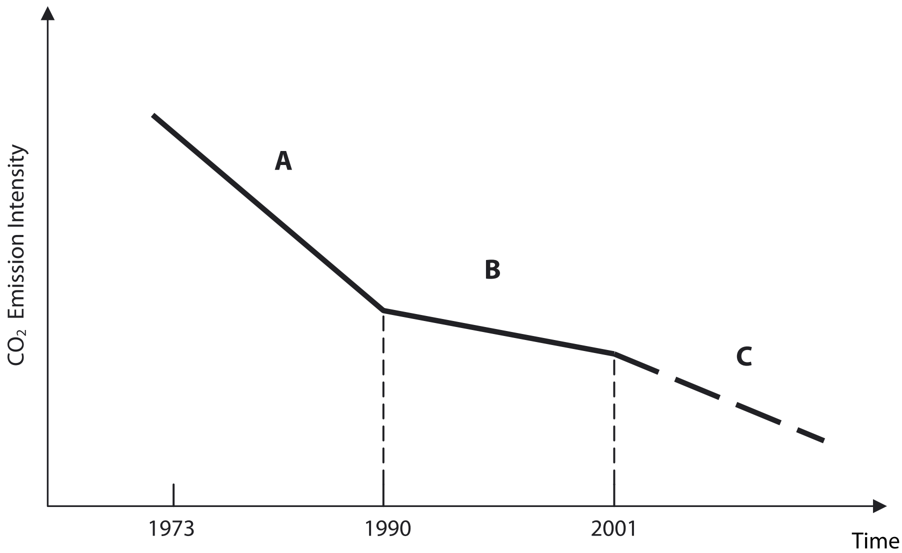

Figure 5.1. A comparison of the historical trends of CO_2 emission intensity and the required future trend needed to reach the C&C target.

In Figure 5.2 the horizontal axis describes the gross domestic product per capita (GDP/POP). The vertical axis on the scale from '+++' to '---' shows the change of the proportions between the historical trends and the future trend that is required to reach the C&C target. The dots indicate the historical CO_2 intensity that is proportioned to the change needed. The starting point dot represents CO_2 intensity change between the years 1973-1990 (A) and the dot with the arrow represents CO_2 intensity change in the years 1990-2001 (B). The division of the scale into plus and minus is based on calculations of the historical CO_2 intensity slope which is proportionate to the future CO_2 intensity slope (C) that is required to reach the C&C target of equal emissions per capita.

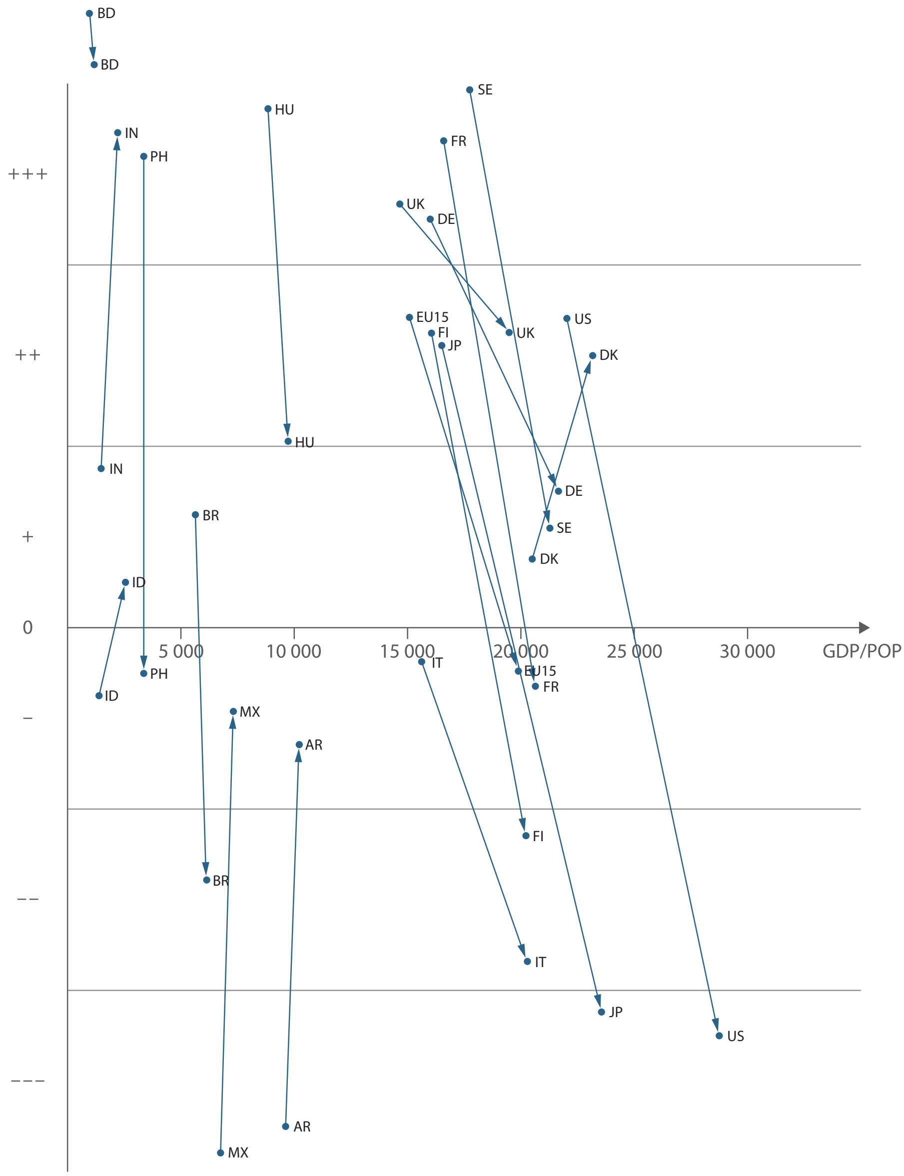

Figure 5.2. *The changes in CO_2 emission intensity trends. The direction of the historical trends of CO_2 intensities from the time periods 1973-1990 and 1990-2001 are compared to the direction of the future trend*

that is required to reach the C&C target. The required change is indexed/ranked according to a scale from '+++' to '---'. In the scale '+++' the CO_2 *intensity trend is adequate for reaching the C&C target. AR=Argentina, BD=Bangladesh, BR=Brazil, DE=Germany, DK=Denmark, FI=Finland, FR=France, UK=United Kingdom, HU=Hungary, ID=Indonesia, IN=India, IT=Italy, JP=Japan, MX=Mexico, PH=Philippines, SE=Sweden, US=United States, EU15=European Union 15.*

In the plus area (+, ++, +++) the CO_2 intensity of the countries is decreasing fast enough or, as in some developing countries with very low levels of per capita emissions, the CO_2 intensity is increasing slowly enough for them to achieve the C&C target. As long as the countries are in the plus area they are able to comply with the C&C target and are in a position to sell extra emission allowances. Correspondingly in the minus area (-,--,---) the CO_2 intensity is increasing too fast or decreasing too slow to keep track with the required change and the countries will have to buy emission allowances. Close to the zero level means the country is on track to achieve the C&C target. See Appendix 2 for the results of analysed countries.

The figure shows that CO_2 intensity development in most countries was favourable in the years 1973-1990, but that the decrease in emission intensity slowed down in the 1990's. Though the CO_2 intensity trend has been a decreasing one in several countries, it has slowed down during the last decade and is not progressing fast enough to reach the C&C target.

Obviously after the oil crisis an increase in prices and strong energy policy measures were able to change the production system and lead to a strong decrease in CO_2 intensity. Lower oil prices and a lesser interest in energy policy, in the 1990's, resulted in a slower decrease in CO_2 intensity. In several countries the decrease in CO_2 intensity has slowed down and without efficient energy policy measures the trend which leads towards the C&C target will be unattainable for most industrialised countries.

Policy recommendations

The results of the analysis show that a structural change in an economy is the most important element for reducing CO_2 emissions. In the industrialised countries, change in the economic system towards a lighter production structure has been the most decisive factor in the reduction of emissions. The shift usually takes place as the service sector increases its share and importance in an economy. With regard to industrial production a shift from traditional heavy industries such as basic metal or pulp and paper production towards information and communication technologies has enabled a decrease in the energy intensity of production. In addition, energy efficiency and the use of domestic energy resources instead of imported oil were actively promoted after the oil shocks in the 1970s by different policy instruments such as direct regulations on public and residential energy use, economic incentives for the use of other fuels than oil, and information campaigns on energy efficiency.

The dematerialization of national economies, which means producing larger economic output with less material input, is another element that has reduced CO_2 emissions. The immaterialization of consumption, which means that people consume more services and immaterial "goods" like information instead of material things, is another side of the transformation to lower greenhouse gas emissions. However, increasing economic activity together with an increasing population has overridden the positive effects of structural change and dematerialization.

The strategy for sustainable development should decouple economic development from environmental degradation and resource consumption. The results of the Terra2000 research project carried out by the Finland Futures Research

Centre indicate that the major global regions of the world economy have all realized some dematerialization of production since the first oil crisis in 1973. They produce more from less in material terms, which means that the same GDP volume of the early 1970s was produced in the year 2000 with about 40 % less natural resource intake or harmful discharges into the environment (Malaska et al, 2003).

To achieve efficiency improvements in material and energy use, new innovations in the areas of ICT and industrial ecology are called for. Teleservices, logistics, recycling, nano technology as well as biomaterials will all be key factors if we are to create an ecologically, socially, economically and culturally sustainable information society. From a scientific point of view, there is a pressing need to develop concrete ways of explaining and understanding dematerialization and immaterialization strategies at macro and micro levels. They must, however, be carefully analysed as to what kind of rebound effects they might produce as they may be related to the new ways of consumption and production. Those rebound effects can then easily counterbalance the gains of dematerialization and immaterialization (Vehmas et al, 2003).

Recycling is a structural solution to the techno-system's environmental problems, which has a direct effect on sustainability. Recycling immediately and positively affects the dematerialization of production and the immaterialization of consumption. Thus, recycling is one of the primary policy instruments of sustainability. As such it deserves continuous attention even though it has become since the 1970s a common and accepted principle of the techno-system. The vast potential for adding to recycling methods and applying them more widely in economic production and consumption is yet to be explored.

Economic incentives are crucial in directing economic systems to reduce the CO_2 emissions of all countries. Emission trading, which is a part of the Kyoto Protocol and the Contraction and Convergence model, provides an economic incentive because CO_2 emissions will obtain a price for the first time in human history. This will inevitably affect the operation of the energy market and improve the situation of CO_2 free or CO_2 neutral energy sources.

To reach sustainability in the climate policy area, the need for a comprehensive multi-level and multi-sectoral approach is needed. The governance system has to take into account and co-ordinate activities at; international, regional, national and local level, as well as across different sectors of the economy. Thus, each individual energy policy, industrial policy, economic policy, social policy, transport policy, housing policy, etc. has to be co-ordinated with all other policies in order to attain synergies and to avoid conflicting activities.

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APPENDIX 1

The Advanced Sustainability Analysis (ASA) applies decomposition analysis to the change in environmental stress in order to explain the underlying causes of change. The decomposition technique has been developed mainly in the field of energy studies for modelling the changing pattern of energy consumption and changes in energy intensity. The objective of decomposition analysis is to divide the observed change in environmental stress into the contributions of different factors of interest.

Different methods of carrying out the decomposition analysis can be grouped into those based on the Divisia index and those based on the Laspeyres index. The method applied in ASA is called complete decomposition, which has been developed from the Laspeyres index (cf. Sun, 1996; 1998). Complete decomposition means that there is no residual term from the decomposition which makes it different to many other methods. In ASA decomposition, the allocation of the residual term, i.e. the joint effect of identified factors into their separate effects, is the main focus.

In ASA, the causes of change between two time moments (typically years) are decomposed into two or more effects (Xeff, Yeff etc. in the following) which are identified in specific variants of the so-called IPAT equation (cf. Malaska, 1971; Commoner et al, 1971; Ehrlich & Holdren, 1971; see also Chertow, 2001). In the simplest form of the analysis, an effect of variable X (Xeff in the following) and an effect of variable Y (Yeff in the following) can be identified. The total change in the analyzed change, which in ASA refers to an indicator of change in environmental stress (ES) or social welfare (WF), is presented as a sum of these two effects between time moments 0 and t:

1. $$\Delta V = X_{eff} + Y_{eff}$$

In the simplest variant akin to the IPAT equation, the total value of V is defined by two variables X and Y as follows:

2. $$V = XY$$

The change in the variable V between time moments 0 and t can be presented as a difference:

3. $$\Delta V = V_t - V_0 = Y_0 \Delta X + X_0 \Delta Y + \Delta X \Delta Y$$

The first term on right hand side of the equation (3) denotes the contribution of variable X to the change and the second one the contribution of variable Y to the change in variable V. The third denotes the joint effect where both variables X and Y explain the change, and the term can be attributed to either variable X or Y, or both. In a general case where the share allocated to Y (Yeff) is marked as λ (0≤λ≤1) and correspondingly the share left to X (Xeff) is marked as (1-λ), the contributions of the factors X and Y are:

4a. $$Y_{eff} = X_0 \Delta Y + \lambda \Delta X \Delta Y = (X_0 + \lambda \Delta X) \Delta Y$$

4b. $$X_{eff} = Y_0 \Delta X + (1 - \lambda) \Delta X \Delta Y = (Y_0 + (1 - \lambda) \Delta Y) \Delta X$$

The coefficient λ can be set as a constant value, or it can be estimated on the basis of relative changes in the explaining variables X and Y. When λ=0 or λ=1, the joint effect will be totally allocated to Yeff or Xeff, respectively. When λ=0.5, the joint effect will be allocated equally to Xeff and Yeff. A simple method of providing a relative allocation is to define the coefficient λ in the following way:

5. $$\lambda = \frac{\left|\frac{\Delta X}{X_0}\right|}{\left|\frac{\Delta X}{X_0}\right| + \left|\frac{\Delta Y}{Y_0}\right|}$$

The decomposition methodology described above can be repeated for each one of the decomposed effects, i.e. to Xeff or to Yeff in equations 4a and 4b. This enables an increase the number of explanatory variables. For example, dividing Xeff further into two factors can be made by adding a new variable Z into the IPAT-variant equation in a way that

6a. $$X = UZ \Leftrightarrow U = \frac{X}{Z}$$

6b. $$X_{eff} = U_{eff} + Z_{eff}$$

The effects of the variables U and Z (Ueff and Zeff) to the original Xeff can be calculated as follows. ΔX in equation (4b) can be divided into the factors of U and Z:

7a. $$U_{eff} = (Y_0 + \lambda \Delta Y)(Z_0 + \gamma \Delta Z)\Delta U$$

7b. $$Z_{eff} = (Y_0 + \lambda \Delta Y)(U_0 + (1 - \gamma)\Delta U)\Delta Z$$

In equations (7a) and (7b), coefficient γ refers to the share of the joint effect ΔUΔZ allocated to variable U and coefficient (1-γ) refers to the share allocated to variable Z.

Similarly, the original Yeff can be divided into two factors by adding a new variable A into the IPAT-variant equation in a way that

8a. $$B = \frac{V}{A}$$

8b. $$C = \frac{A}{X}$$

8c. $$Y_{eff} = B_{eff} + C_{eff}$$

The effects of the variables B and C (Beff and Ceff) to the original Yeff can be calculated similarly as in the case of dividing the original Xeff. ΔY in equation (4a) can be divided into the factors of B and C:

9a. $$B_{eff} = \left(X_0 + (1-\lambda)\Delta X\right)\left(C_0 + \varphi\Delta C\right)\Delta B$$

9b. $$C_{eff} = \left(X_0 + (1-\lambda)\Delta X\right)\left(B_0 + (1-\varphi)\Delta B\right)\Delta C$$

In equations (9a) and (9b), coefficient f refers to the share of the joint effect ΔBΔC allocated to variable B and coefficient (1-φ) refers to the share allocated to variable C.

In addition, more effects can be identified by repeating the decomposition analysis for any new effect. All coefficients (λ, γ and φ) can be estimated on the basis of equation (5) by using the corresponding variables (U and Z for γ and B and C for f), or set at a constant value (0 ≤ λ, γ, φ ≤ 1).

APPENDIX 2

The change of CO_2 intensity required in the future in comparison with its historical trends. For this table '+' means that the historical trend is currently adequate to reach the C&C target.

Country	**1973-1990**	**1990-2001**
Argentina	–––	–
Australia	–––	–––
Austria	++	––
Bangladesh	+++	+++
Belgium	+++	–
Brazil	+	––
Bulgaria	+++	+++
Canada	++	0
China	+++	+++
Colombia	++	++
Cyprus	+	–
Czech Republic	+	+++
Denmark	++	++
Egypt	++	0
Estonia		+++
Finland	++	––
France	+++	0
Germany	+++	+
Greece	–––	–––
Hungary	+++	++
Iceland	+++	–
India	+	+++
Indonesia	0	0
Ireland	–	+++

Country	**1973-1990**	**1990-2001**
Italy	0	––
Jamaica	–––	–––
Japan	++	–––
Latvia		+++
Lithuania		+++
Luxembourg	+++	+++
Malaysia	–––	–––
Malta	–––	–––
Mexico	–––	–
Morocco	+++	+
Netherlands	+	+
New Zealand	–––	–––
Nigeria	+++	+++
Norway	+	–
Pakistan	+++	+++
Philippines	+++	0
Poland	–––	+++
Portugal	–––	–––
Republic of Korea	–––	–––
Romania	+++	+++
Russia		–––
Singapore	+++	+++
Slovakia	+++	+++
Slovenia		++
South Africa	–––	–––
Spain	–	–––
Sweden	+++	+
Switzerland	0	–
Tanzania	+++	+++
Thailand	–––	–––
Turkey	–––	–––
Ukraine	–––	–––
United Kingdom	+++	++

Country	**1973-1990**	**1990-2001**
United States	––	–––
Uzbekistan	+++	+++
Venezuela	–––	–––
Vietnam	+++	+++
Yemen	+++	+++
EU15	++	0
EU25		0

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CONVERGING CO_2 EMISSIONS TO EQUAL PER CAPITA LEVELS

Mission Possible?

Contraction and Convergence is one approach that has been proposed to allocate commitments regarding future greenhouse gas emission mitigation. In this study the historical rates of CO_2 emission intensity for different countries have been analysed and compared with the future intensity rates that are required to achieve the Contraction and Convergence target of 1.8 tons of CO_2 per capita. Additionally, the amount of CO_2 emissions per country was decomposed into different explanatory effects, which are also analysed in this paper. For that it was assumed that the CO_2 intensity of a country depends on energy and production technology, the fuel shares of the primary energy supply and the economic production structure.

The results show that trends in most industrialised countries, after the oil crises, could lead to the Contraction and Convergence target. However, the trends in the 1990's have usually not been sufficient due to weaker energy policy measures. Contrary to common assumptions, the results indicate that the per capita target could be a Mission Possible.

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