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BURDEN DIFFERENTIATION: GHG EMISSIONS, UNDERCURRENTS AND MITIGATION COSTS

The joint CICERO-ECN project on sharing the burden of greenhouse gas reduction among countries

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Acknowledgement

This report is the third Working Paper of the Burden Sharing study project that aims *to identify the most promising rules applicable for differentiation of greenhouse gas emission reduction burden among countries*. The project is carried out jointly by CICERO (Oslo, Norway) and ECN (Petten, The Netherlands) under ECN project number 7.7170. The project has started in October 1998 and will be completed by mid-2000. ISSN number: 0804-452X.

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Abstract

This Working Paper addresses the following issues:

- data on greenhouse gas emissions,
- factors bringing about greenhouse gas emissions,
- costs of emission reduction.

CONTENTS

SUMMARY

The primary aim of the present report is *to collect, and to perform a preliminary analysis of, information on indicators that are likely to have relevance for the design of burden sharing rules*. The indicators considered relate to emission figures per country, per gas, per source, data on energy efficiency, allowance factors for differences in emission levels, and information on the cost to reduce emissions of greenhouse gases.

This study takes into account the six greenhouse gases mentioned in Annex A of the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrous-oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur-hexafluoride (SF_6). At present total CO_2 emissions are by far the most important in terms of global warming potential (GWP), while the shares of CH_4 and N_2O in global GHG emissions are also non-negligible. The IPCC estimates that in 1995 emissions of CO_2 account for 84% and the other gases for 16 % of total GWP, among which CH_4 for 11% and N_2O for 4%. As data on emissions for the latter two gases are available for many countries, these will be included in further project activities to the extent possible. A disadvantage of their inclusion is the low level of reliability of the corresponding emission data as compared to CO_2 emission data. This disadvantage holds a fortiori for the remaining three 'Kyoto' gases. As the latter also contribute a very small share to total Global Warming Potential, inclusion of these emissions will be given low priority in subsequent research.

From an historical point of view, the industrialised countries are the largest contributors to the global emissions. Particularly, Western Europe showed the highest emissions in the 19th century, while North America played a prominent role during the 20th century. Present-day developing countries are poised to become the main contributors in the 21st century.

The increase of the world population is an important driving factor of GHG emissions. Moreover, since the First World War, CO_2 emissions per capita increased from less than 2 tonnes CO_2 eq. per capita to over 4 tonnes CO_2 eq. per capita. This increase is mainly the result of an increasing per capita demand for fossil fuels. In contrast, methane emissions seem to be closely related to agricultural and waste emissions and have shown a relatively steady level of emissions per capita over the past 150 years.

Differences between countries in the structure of their respective economy and energy supply do importantly contribute to the explanation of the variance of emissions per capita over countries of comparable per capita income levels. Moreover, in contrast to the decreasing energy intensities of most OECD countries, many non-industrialised countries are still associated with high and sometimes even rising energy intensities. On the other hand, economies in transition are presently showing rapidly decreasing energy intensities. These phenomena can also attributed for a large part to structural developments of the economies of these respective groups of countries. Therefore, the structure of national or regional (viz. the EU) economies should be an important consideration in designing burden sharing rules.

Certain factors are of crucial importance to the direct incremental cost bill of a country, notably:

- Prevailing levels of energy efficiency throughout the country's energy system. If, generally, the gap with international 'best practices' benchmarks is small (wide), the scope for improving energy-efficiency levels is correspondingly small (large) and expensive (cheap).
- The carbon intensity of energy supply. If a country's energy supply is relatively carbon-extensive (carbon-intensive), the scope for shifts to carbon-extensive primary energy carriers, including notably renewable sources of energy, will be correspondingly small (large) and expensive (cheap).

- The country's relative endowments of renewable sources of energy and natural gas will also determine the transition costs towards a carbon-extensive economy.

Due allowance should be given to transboundary indirect effects. It should even be considered that countries that are extremely dependent on carbon-intensive exports, notably countries heavily dependent on fossil fuel exports, will get appropriate, time-phased forms of assistance from the international community in bringing about a sound restructuring of their respective economy.

Evidently the cost of emission limitation commitments are a very important consideration for climate change negotiators. Consideration should therefore be given to major determinants of these commitments, e.g.:
- For countries that have already implemented many measures in the past (such as "greening" the tax system), further reduction will become increasingly costly.
- The risk of 'carbon leakage' (shifting of carbon-intensive activities to countries with more lenient emission policies) can be perceived to be serious.
- For countries with a fossil-fuel-intensive transport and energy-supply infrastructure a shift to a less fossil-fuel-intensive infrastructure might be quite costly.
- The same may hold for countries with a low renewable energy potential, and/or for countries for which 'going (more) nuclear' is not politically feasible.

The aforementioned considerations, especially country-specific allowance factors, should be duly allowed for in the design of burden-sharing rules. On the other hand, much attention should be given to the streamlining of complicated burden-sharing rules so that they will end up in being relatively transparent and simple.

1. INTRODUCTION

1.1 Introduction to the report

The primary aim of the present report is *to collect, and to perform a preliminary analysis of, information on indicators that are likely to have relevance for the design of burden sharing rules*. The indicators considered relate to emission figures per country, per gas, per source, data on energy efficiency, allowance factors for differences in emission levels, and information on the cost to reduce emissions of greenhouse gases. The kinds of questions that will be addressed in this report are:

- What are the most important greenhouse gases? (Chapter 2).
- Which greenhouse gases have large uncertainty ranges in emission figures? (Chapter 2).
- What are the primary driving forces of emissions of greenhouse gases? (Chapter 3).
- What kind of information sources with regard to emission figures is available? Which information sources are preferable to be used? (Chapter 3).
- At what level of detail should emission figures be explained? (Chapter 3).
- What is the value of aggregate emission indicators such as emissions per capita and emissions per GDP? (Chapter 3).
- For which indicators are emission data available? (Chapter 3).
- Can greenhouse gas abatement cost indicators be considered in burden sharing rules? (Chapter 4).
- Can the potential to abate emissions be included in burden sharing rules? (Chapter 5).
- What are key aspects of promising burden sharing rules? (Chapter 5).

1.2 Report outline

Chapter 2 gives an overview of greenhouse gas (GHG) emissions. This chapter includes emission data on a large group of countries and emission trends per region. Moreover, issues related to data sources for emission figures and the uncertainties in emission figures are addressed in this chapter. In Chapter 3, emission figures are related to selected explanatory factors, including aggregated indicators such as GDP, population and sectoral driving forces. Chapter 4 focuses on the costs of emission mitigation and on indicators that explain the differences in cost of meeting commitments. Finally, Chapter 5 presents preliminary inferences for the design of promising burden sharing rules.

2. OVERVIEW OF GREENHOUSE GAS EMISSIONS

2.1 Introduction

This chapter provides an overview of greenhouse gas (GHG) emissions. It presents global GHG emission figures, historic emission patterns, and shares of countries/regions and distinct gases in global GHG emissions. This chapter also includes a discussion of data sources for emission figures and a discussion of the uncertainty ranges in emission figures.

The present report is part of a study that aims to identify prospective burden sharing rules that can be applied to a wide range of countries. The emission consequences of various burden sharing rules will be quantified in this project partially based on greenhouse gas emission data. A set of 50 countries has been selected for which the quantitative analysis will be performed. This includes most industrialised countries and a selection of developing countries. The group of developing countries includes the larger ones, such as China, India and Brazil, and various smaller countries with specific features. It is noted that this report does not yet present emission data for all 50 countries selected.

2.2 Defining the scope of GHG emissions

Different greenhouse gases and the global warming potential

To the extent possible, this study takes into account the contributions of the greenhouse gases included in the Kyoto protocol:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphurhexafluoride (SF_6).

Since the annual emissions and the radiative forcing characteristics in the atmosphere differ considerably per greenhouse gas, it is important to have a measure to assess the warming impact of each gas to compare the impact of the different greenhouse gases. The Global Warming Potential (GWP) is developed to compare emissions of different greenhouse gases. The GWP relates the impact of a certain GHG emission to that of CO_2. The GWP broadly reflects the time cumulated radiative forcing of a gas with allowance for the differences in atmospheric lifetimes of greenhouse gases. The radiative forcing is commonly calculated over a 100-year timeframe. This choice is somewhat arbitrary and it can easily be argued that some GHGs should involve a longer or shorter time period. However, the 100-year timeframe is used in this study to be consistent with what has been chosen by the UNFCCC for the Kyoto Protocol and most other studies (Gielen and Kram, 1998; UNEP, 1994; Beeldman et al., 1998). GWPs of non-CO_2 GHGs range from 21 for methane to 23900 for sulphur hexafluoride (for a 100-year timeframe). Since these figures involve average approximations, it does not really mean that the impact of a particular methane emission is exactly 21 times higher than that of CO_2. In this manner, all greenhouse gases can be expressed as CO_2 equivalents as each CO_2 equivalent is supposed to behave identically in the atmosphere (see Table 2.1).

Table 2.1 *GWP in CO_2 equivalents*

Substance	Chemical Formula	GWP (100 years)
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
HFCs	CHF compound	140-11700
PFCs	CF compound	6500 and 9200
Sulphurhexafloride	SF_6	23900

Source: IPCC (1995).

Although the impact of CO_2 is small in terms of GWP, CO_2 still contributes the most to the overall global warming due to its large emission quantities. Figure 2.1 shows the contributions of the GHG emissions to the total global warming.

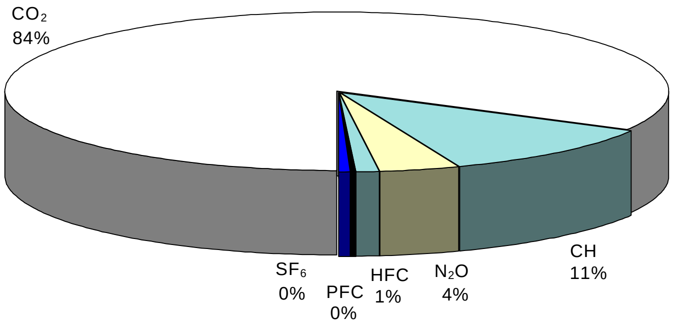


Figure 2.1 *Share of greenhouse gases in total greenhouse gas emissions, 1995, calculated by means of a GWP with a 100-year time horizon*

Consistent with the Kyoto Protocol, precursors of ozone such as NO_x and volatile organic compounds are not considered. In addition, CFCs and HCFCs are not taken into account as these gases are already regulated under the Montreal Protocol. The Kyoto protocol includes emissions by sources and removal by sinks resulting from direct human-induced land-use change and forestry activities. The latter is limited to afforestation, reforestation and deforestation since 1990.

Sources and sinks of greenhouse gas emissions

CO_2 emissions result from the burning of fossil fuels. Therefore, all sectors that use large amounts of fossil fuels, such as power generation, transport, industry and households, can be regarded as essential contributors to CO_2 emissions. CO_2 is stored in biomass like forests. On the other hand, deforestation results usually in CO_2 emissions. Besides, CO_2 emissions are also due to some industrial processes such as the production of cement and ammonia (IPCC, 1996).

Anthropogenic methane emissions are largely due to livestock (i.e. enteric fermentation), rice production, landfills and energy production (mining of coal and natural gas) (IPCC, 1996).

Nitrous oxide is emitted as a result of fertiliser use in agriculture and combustion processes and by the chemical industry (e.g. production of fertiliser) (IPCC, 1996).

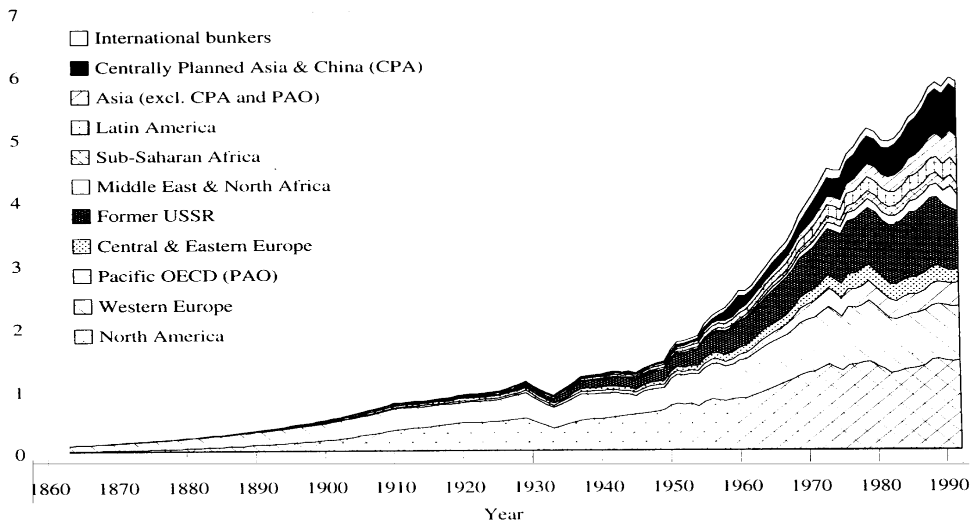
After the Montreal Treaty, HFCs are mainly emitted as CFC and HCFC alternatives causing no direct damage to the ozone layer. These compounds are used as insulation and packaging foams, solvent, cooling equipment, fire extinguishers, dry cleaning and as aerosols. HFC-23 is also emitted by the chemical industry. PFCs are mainly emitted in primary aluminium production, whilst additional emissions occur where PFCs are used as CFC alternatives. SF_6 emissions are mainly related to the use of high voltage equipment because of its insulating and arc extinguishing qualities (IPCC, 1996).

Specific sector and source categories mentioned in Annex A of the Kyoto-protocol are given in Table 2.2.

Table 2.2 *Sectors and source categories mentioned in annex A of the Kyoto protocol*

Energy/ fuel combustion	Energy/ Fugitive emissions from fuels	Industrial processes	Agriculture	Waste
• Energy industries • Manufacturing industries and construction • Transport • Other sectors • Others	• Solid fuels • Oil and natural gas • Others	• Mineral Products • Chemical industry • Metal Production • Other production • Production of halocarbons and sulphur hexafluoride • Other	• Enteric fermentation • Manure management • Rice cultivation • Agricultural soils • Burning of residues • Other	• Solid waste disposal on land • Wastewater handling • Waste incineration • Other

Source: Kyoto Protocol, Annex A.



Source: IPCC 1995.

Figure 2.2 *Global energy-related CO_2 emissions*

Energy-related CO_2 emissions have increased over the past decades as shown in Figure 2.2. Western Europe was the main contributor to CO_2 emissions before 1900. By that year, emissions in North America also started to grow strongly and caught up with Europe between world wars one and two. For the former USSR, the CO_2 emissions started to increase around 1920. In 1970, CO_2 emissions from the Western countries and formerly centrally planned countries comprised about 80% of the global emissions, decreasing to about 65% by 1990. This drop is mainly due to the strong increase of emissions in other world regions (notably in China, other Asia and Latin America). Between 1890 and 1990 the level of CO_2 emissions in these regions has increased by a factor 19. By comparison, in Europe and North America CO_2 emissions increased by a factor 7. Hence, starting out from a low base emissions in non-western regions are increasing particularly strongly. This process is expected to continue in the near future and will eventually result in present-day developing countries becoming the largest emitters.

2.3 Current emission levels

The IMAGE model estimates world emissions for 1990 at 26 Pg CO_2, 436.2 Tg CH_4 and 16.0 Tg N_2O. In CO_2 equivalents, these figures compare to 26 Pg CO_2, 9.2 Pg CO_2 eq. for methane and 5.0 Tg CO_2 eq. for Nitrous Oxide (Alcamo et al., 1998). Statistical differences in the sources considered give rise to differences among the various estimates of world emissions. These kinds of variations should be taken into account when interpreting the data below.

Tables 2.3 and 2.4 show greenhouse-gas emission data for eighteen selected industrialised countries for 1990 and 1995, respectively. The United States appears to be the largest contributor to all major GHG emissions. As a share of global emissions, the contributions of the US are as follows: CO_2 31%, CH_4 12% and N_2O 8%. Overall, the US contributes about 25% to the GHG emissions in terms of CO_2 equivalent. For most countries, CO_2 is the largest contributor to national emissions, except for New Zealand where methane is responsible for the largest contribution.

In case of CO_2 and CH_4, Germany, the United Kingdom, and the United States together contribute about 80% and 75% to the total emissions of the 18 countries considered in Table 2.3, respectively. The corresponding shares for PFCs and SF_6 of Canada, Germany, and the United States together are 71% and 84% respectively. Although the USA is the largest emitter of all countries that did report HFCs emissions, it is difficult to conclude which countries are the main contributors to the emissions due to lack of data. Finally, France, Germany, and the United States are together responsible for 64% of the N_2O emissions of the 18 reporting countries of Table 2.3.

Table 2.3 *Greenhouse gas emissions 1990 for a selection of 18 industrialised countries in [Tg CO_2-Eq]*[1]

	CO_2	CH_4	N_2O	HFC	PFC	SF6	Total
Austria	61.88	12.33	3.66				78
Belgium	116.09	13.31	9.55		0.07	0.48	139
Canada	464.00	67.20	26.66		5.94	2.87	567
Chech Republic	165.49	18.65	8.00		0.00		192
Finland	53.80	5.17	5.58				65
France	378.38	63.36	56.33	2.97	2.00	0.14	503
Germany	1014.16	119.32	70.06	0.26	2.69	3.90	1210
Iceland	2.15	0.29	0.12		0.31	0.01	3
Ireland	30.72	17.03	9.11				57
Monaco	0.07						0
Netherlands	167.55	23.18	15.87	4.91	2.46	1.39	215
New Zealand	25.48	35.83	14.73		0.60	0.55	77
Norway	35.54	9.07	4.65		2.55	2.20	54
Slovak Republic	60.03	8.59	3.88		0.50		73
Sweden	55.45	6.80	2.85		0.40	0.96	66
Switzerland	45.07	5.12	3.57				54
United Kingdom	583.75	93.74	37.20	1.37	2.09	0.62	719
United States	4965.51	623.91	132.12	44.04	18.35	25.69	5810
Total 18 countries	8225	1123	404	54	38	39	9882

[1] Non-totals are presented by two digits, whereas totals are rounded off to whole numbers. Blanks indicate no data available.

Source: UNFCCC 1997, SBI Seventh session.

Since similar data are also available for the year 1995, figures can be compared to determine the changes taken over the period 1990-1995. As both tables only involve 18 countries, the changes found should not be considered as a global trend but rather as a trend within the Western world. From 1990 to 1995, total GHG emissions of the 18 countries considered increased by 1.7%; of which CO_2 emissions by 1.4%, N_2O emissions by 1.4%, HFC emissions by 72%, PFC emissions by 12%, and SF_6 emissions by 24%. In contrast, CH_4 emissions showed a slight decrease (0.42%).

Table 2.4 *Greenhouse gas emissions 1995 in [Tg CO_2-Eq]*[1]

	CO_2	CH_4	N_2O	HFC	PFC	SF6	Total
Austria	62.02	12.18	3.97		0.01		78
Belgium	121.30	13.34	10.01	0.59	0.07	0.48	146
Canada	499.53	78.37	33.42	0.50	6.02	1.89	620
Chech Republic	128.82	15.39	6.70	0.00			151
Finland	56.05	5.06	5.58	0.08	0.00	0.10	67
France	385.35	59.72	53.79				499
Germany	894.50	101.83	67.89	2.88	1.67	6.00	175
Iceland	2.28	0.29	0.12	0.01	0.05	0.01	3
Ireland	33.93	17.05	8.06				59
Monaco	0.13						0
Netherlands	183.40	22.32	18.14	8.45	2.39	1.46	236
New Zealand	27.37	34.34	14.48	0.18	0.02	4.37	81
Norway	37.88	9.85	4.34	0.24	1.44	0.57	54
Slovak Republic	48.52	6.64	2.42		0.32		58
Sweden	58.11	6.22	2.85	0.20	0.39	1.24	69
Switzerland	44.17	4.94	3.66	0.26	0.07	0.72	54
United Kingdom	543.34	80.16	29.45	2.55	0.57	0.81	657
United States	5214.71	650.48	144.77	76.65	29.19	30.83	6147
Total 18 countries	8341	118	410	93	42	48	10053

[1] Non-totals are presented by two digits, whereas totals are rounded off to whole numbers. Blanks indicate no data available.

Source: UNFCCC 1997, SBI Seventh session.

In 1995, the United States is also the largest contributor to the GHG emissions of the 18 countries considered. In the United States, the emissions of the six gases covered by the Kyoto protocol increased by 5.8%. Even in relative terms, the contribution of the US to the GHG emissions increased during this period.

Figure 2.3 relates the last column of Tables 2.3 and 2.4 by showing the growth or reduction in CO_2 equivalent emissions in 1995 compared to 1990. Monaco, Canada, The Netherlands and the United States showed the highest emission growth rates amongst the 18 industrial countries considered with growth rates of 82%, 9.4%, 9.7% and 5.8%, respectively.

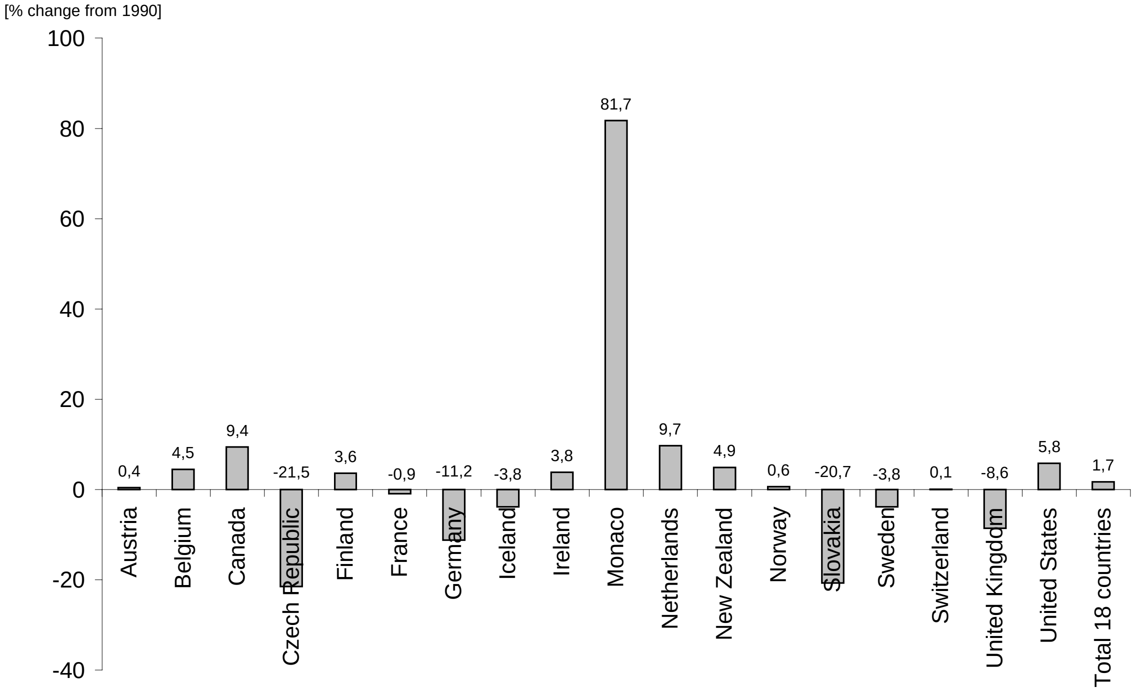


Figure 2.3 *Emissions in 1995 cf. 1990*

Source: UNFCCC 1997.

Figure 2.4 presents the reduction targets according to the Kyoto protocol and the agreements among EU member states. A comparison between Figure 2.3 and 2.4 shows that only in the Czech Republic, France, Germany, Iceland, Ireland, Norway and Slovakia emissions have been going down.

For the other countries considered, the rates of change of GHG emissions during the period 1990-1995 were higher by far than allowed by the Kyoto Agreement (c.f. Figures 2.3 and 2.4). Most probably, this is also the case in more recent years as most industrial countries saw their energy use increasing between 1995 and 1998 (IEA, 1998).

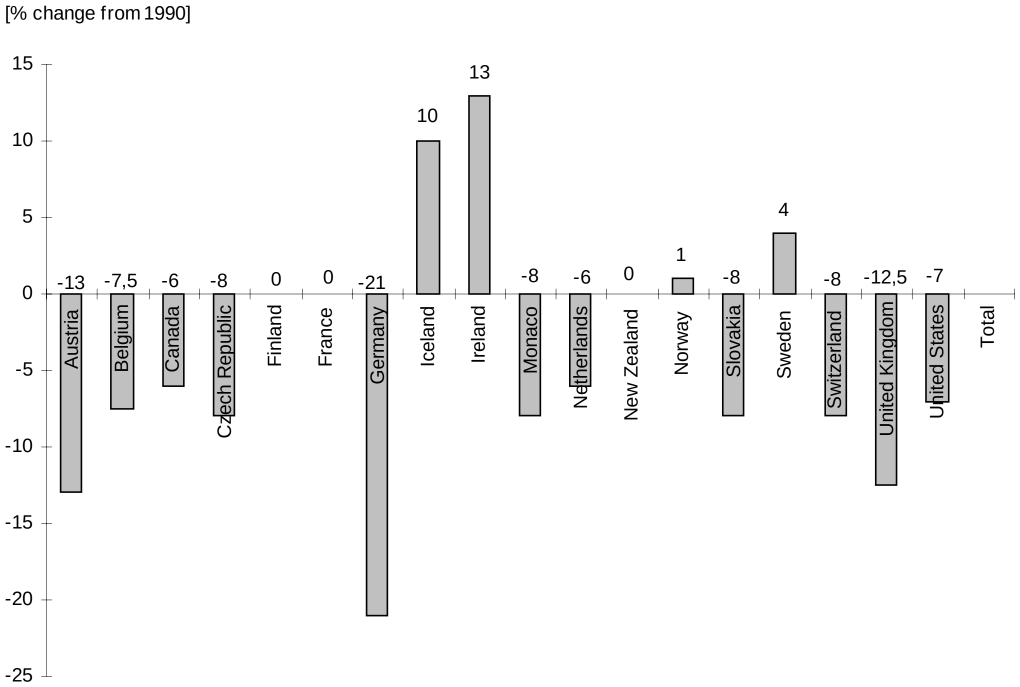


Figure 2.4 *Reduction agreements for 2010 according to the Kyoto protocol*

2.4 Quality and availability of emission data

2.4.1 Quality of data

The quality of the statistics with respect to GHG emission differs considerably per greenhouse gas and emission source. Several studies (Gielen and Kram, 1998, Second national communication Australia) have reported uncertainty ranges for the emission data for GHGs. Table 2.5 illustrates the uncertainty ranges of the differences per gas according to different references.

Table 2.5 *Uncertainties reported in Second National Communications*

[%]	CO_2	CH_4	N_2O	HFC	PFC	SF6	LUC
Australia		20-80	20-80				30-40
Denmark	2	100	100				
Canada	4	30	40				
Netherlands	2	25	50	50	100	50	

Source: Gielen and Kram 1998; Second national communication Australia.

Besides national communications, energy statistics can also be used to assess energy-related emissions. Few non-Annex 1 countries have submitted national communications but there are ongoing efforts in various countries to produce an emission inventory.

2.5 Data sources for sectoral emission data

For countries of which no national communication is published, historical emission data can be assessed in a fairly reliable way by using energy statistics. Every national communication is subject to an in-depth review of the reliability and transparency of the statistics and its consistency with respect to the guidelines for producing national communications. However, the study of Gielen and Kram (1998) has raised questions about the consistency of national emission figures for trace gases such as SF6 and PFC.

To be able to quantify burden-sharing rules, specific information about countries is needed. Clearly, it is preferred to use a country's emission inventory as reference. However, this is not available for all countries. Below, countries are listed of which national communications are available. First national communications generally present data from the year 1990, and second national communications for the year 1995. Most first national communications do not present data for the gases PFC, HFC and SF6. In the first and second national communications, all Parties provided statistics on anthropogenic emissions of CO_2, CH_4, N_2O. In the second national communications, data were added for emissions of HFCs, PFCs and SF_6. In addition, emission statistics related to land-use change are also reported. However, problems arise with the assessment of the emissions of HFCs, PFCs and SF_6 since data are lacking for a number of years in the 1990-1995 period.

First National Communication (when Second National Communication is not available)
Egypt, Italy, Kazakhstan, Korea (Rep.), Latvia, Lithuania, Luxembourg, Mexico, Russian Federation, Senegal, Uruguay, Zimbabwe.

Second National Communication
Australia, Austria, Belgium, Bulgaria, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Japan, The Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States of America.

No data yet
Bangladesh, Belarus, Bolivia, Brazil, China, India, Indonesia, Kuwait, Mongolia, Nigeria, Saudi Arabia, South Africa, South Korea, Taiwan, Turkey, Ukraine, Yemen. Some of these countries are working on emission inventories, which we hope will be available shortly. These are Bolivia, Kazakhstan and Yemen. Other countries working on emission inventory are Costa Rica, Ecuador, Ghana, and Suriname.

When no data are available from the country itself, an estimate will have to be made based on other sources. A first estimate of the energy-related GHG emission can be derived by using the IEA energy balances. Data about topics such as population in 1990, population growth estimates and climate have to come from other sources. Population data are readily available, for instance via the UN, the FAO, the US Census Bureau and other organisations. Climate data to assess temperature correction may be derived from Schipper at the IEA. For a number of countries, data may not be available (e.g. Kuwait, Mongolia and Turkey). In these cases, the methodology of the IPCC can best be used to assess these figures lacking.

2.6 Data requirements for estimating GHG emissions

The methods for estimating emissions of GHG gases are divided in 'Tiers' encompassing different levels of activity and technology detail. Tier 1 methods are generally rather simple and, therefore, they require less or less detailed data compared to Tier 3 which involves the most complicated methods.

The IPCC ‘Greenhouse gas inventory workbook’ is divided in 6 modules:

- Energy
- Industrial Processes
- Solvents and other product use (virtually non-existent)
- Agriculture
- Land-Use Change and Forestry
- Waste.

+ *Energy*

This module is divided in two main categories:

- *Fuel Combustion*
  Tier 1 methods
  - CO_2 emissions
    By reference approach
    By main source categories
  - Non CO_2 from fuel combustion by source categories

  Tier 2 methods
  - Emissions from aircraft

- *Fugitive*
  Methane emissions from coal mining and handling
  Methane emissions from oil and natural gas activities
  Ozone precursors and SO_2 from oil refining

- *Methane emissions from coal mining and handling*
  For CH_4 emissions from coal mining and handling, the amount of coal produced is the main determinant. Data can be derived from the IEA energy balances. Preferably, the data should distinguish surface mines from underground mines. However, this distinction is usually not applied by the IEA.

- *Methane emissions from oil and gas activities*
  To calculate CH_4 emissions from oil and gas activities, data are required about the number of wells drilled, the quantity of oil produced, the quantity of oil refined, the quantity of gas produced and the quantity of gas consumed. These data are available from the IEA and the UN statistical division. The number of wells drilled is probably the most problematic.

+ *Industrial Processes*

- *N_2O from nitric acid*
  - Needed: Production data of nitric acid
  - As some 90% of the nitric acid is used for synthetic fertiliser production, the statistics reported for ammonia nitrate are a good bases for nitric acid. Multiplying by a factor of 63/28 nitric acid production data can be obtained. For many countries, statistics on ammonia nitrate production are published by the FAO.

- *N_2O from adipic acid.*
  - Needed: Adipic acid production.
  - Roughly 120 Mton CO_2 equivalents per year is emitted world-wide, of which over 75% in the USA, Western Europe and Japan. For these countries, data are available, for other countries data might not be available.

- *CH_4 from silicon carbide.*
  - Needed: the amount of petrol coke consumed.
  - IEA statistics are a good source.

- *Solvents and other product use*
  Virtually non-existent.

- *Agriculture*
  - *CH_4 from enteric fermentation.*
    - Needed: Average annual population of each livestock type.
    - FAO production yearbook provides these data. The World Resource Institute provides CH_4 data from livestock aggregated.

  - *CH_4 from manure management.*
    - Needed: Average annual population of each livestock type.
    - FAO production yearbook provides these data. The World Resource Institute provides CH_4 data from livestock aggregated.

  - *N_2O from animal waste management systems.*
    - Needed: Average annual population of each livestock type.
    - FAO production yearbook provides these data. The World Resource Institute provides CH4 data from livestock aggregated.

  - *CH_4 from rice cultivation.*
    - Needed: Harvested area by water management type.
    - The World Resource Institute provides CH4 emissions figures from wet rice agriculture. The FAO is another possible source, together with the China Agricultural Yearbook, and the IRRI rice almanac.

  - *CO_2 from savanna burning.*
    - Needed: Annual area burned per savanna type.
    - FAO is an authoritative source of data, although the data might be less reliable.

  - *CH_4 from savanna burning.*
    - Needed: Annual area burned per savanna type.
    - FAO is an authoritative source of data, although the data might be less reliable.

  - *Methane from burning of agricultural residues.*
    - The FAO is a possible data source, but it is unclear as to whether this source can provide all the information needed.

  - *N_2O from agricultural soils.*
    - Needed: Total use of synthetic fertiliser.
      - average annual population of each livestock type,
      - dry pulses and soybeans produced,
      - dry production of other crops,
      - area of cultivated organic soils.
    - The FAO has all the information needed.

- *Land-Use Change and Forestry*
  Data have not yet been gathered for this topic.

+ *Waste*

- *CH_4 from solid waste disposal sites (SWDS).*
  - Needed: Amount of waste per category of SWDS.
    - fraction degradable organic carbon, amount which actually degrades,
    - fraction of CH_4 in Landfill gas.
  - Consultation with national experts is the methodology recommended. Unless countries have done this themselves and published their findings, the calculation can not be reproduced.

- *CH_4 from waste water handling.*
  - Needed: Total population
  - As said before, various organisations and institutes provide population data.

- *CH_4 from industrial waste and sludge streams.*
  - Needed: Total industrial output.
  - Waste water produced per unit.
  - Unless the country has published statistics on total industrial output, it will be difficult to reproduce the calculation.

- *N_2O from human sewage.*
  - Needed: Average annual per capita protein consumption.
  - Population.
  - Unless countries have published statistics on their average annual per capita protein consumption, it will be difficult to reproduce the calculation.

2.7 Summary

This study takes into account the six greenhouse gases mentioned in Annex A of the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrous-oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur-hexafluoride (SF_6). The relative impact of a certain emission of a GHG can be assessed by expressing the emission in terms of a CO_2 emission. At present total CO_2 emissions are by far the most important in GWP terms, while the shares of CH_4 and N_2O in global GHG emissions are also non-negligible.

From an historical point of view, the industrialised countries are the largest contributors to the global emissions. Particularly, Western Europe showed the highest emissions in the 19th century, while North America played a prominent role during the 20th century. Developing countries are poised to become the main contributors in the 21st century.

Although the Kyoto protocol sets targets for the reduction of GHG emissions, in the second national communication only a few countries report reductions in their total GHG emission between 1990 and 1995. By contrast, most countries report a rise in total GHG emissions with growth rates during the period 1990-1995 up to 10%.

The quality of available data is an essential aspect in selecting BSRs. However, both the quality and the availability of data vary substantially among countries and among the six Kyoto greenhouse gases. In general, CO_2 data are characterised by the lowest and PFC by the highest uncertainty range. Data is more readily available for industrialised countries than for developing countries.

The present project attempts to consider, in addition to CO_2, the other five GHGs covered by the Kyoto Protocol. Thereby, the emphasis will be put on inclusion of CH_4 and N_2O because of the importance of their respective contributions to global GHG emissions as well as the quality of the data concerned.

3. DRIVING FORCES OF GREENHOUSE GAS EMISSIONS

3.1 Introduction

Chapter 2 showed that large differences exist in the emission levels per country. Many factors contribute to these differences and these factors can considered to be the driving forces of changing GHG emission patterns.

A way commonly accepted of expressing environmental impact in general involves the so-called IPAT equation or Kaya identity (IPCC, 1996), which is based on concepts introduced by Ehrlich and Holdren (1971). The IPAT equation relates the increment of environmental stress to population change, changes in the wealth per capita, and technological change. In case of the energy-related GHG emissions, the IPAT formula could take the following form:

$$GHG = POP \times (GDP/POP) \times (ENERGY/GDP) \times (GHG/ENERGY) \qquad (3.1)$$

In equation (3.1), GHG refers to greenhouse gas emissions, POP to population, Energy to total energy use, and GDP to Gross Domestic Product. Although equation (3.1) is very trivial from a mathematical point of view, it relates energy-related GHG emissions to a number of driving forces at an aggregate level. It is possible to adjust this equation to study the GHG emissions at a more detailed level and to add non-energy-related GHG emissions.

Since the purpose of this study is to set burden differentiating rules and not to predict future GHG emissions, the indicators are used somewhat differently compared to equation (3.1) in order to make cross-country comparisons how countries perform with regard to the indicators involved. The first indicator shown in this chapter involves the GHG emission levels per capita while the second takes into account the energy use per unit of GDP. The latter is often referred to as the energy intensity. These two aggregate indicators have frequently been suggested in the climate negotiations to be part of burden sharing rules (see Project Working Paper No. 2). In this chapter, these two indicators are described in more detail.

3.2 Emissions and population size

Over the past 150 years, world population has increased strongly. An estimate of the population size for the year 1850 is 1.2 billion people. In 1994, the world population amounted to 5.6 billion people (US Census Bureau, 1999). This increase in population size has certainly affected GHG emissions. In addition, emission levels have been estimated for the two main gases (i.e. CO_2 and CH_4) over the past 150 years (CDIAC, 1999). Figure 3.1 shows the development of these GHG emissions together with that of population.

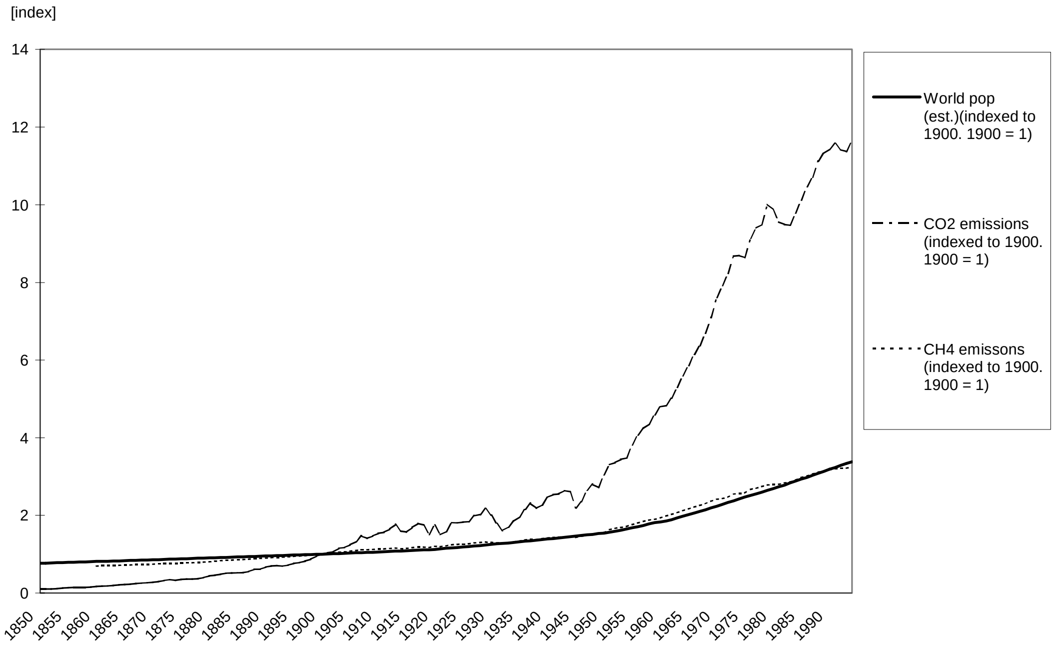


Figure 3.1 *Carbon dioxide emissions, methane emissions and world population*
Source: CDIAC 1999.

Population growth can be decomposed into two driving factors:

- the natural population growth rate,
- the net migration rate.

In the absence of human tragedies, positive natural rates of growth of the population can hardly be significantly reduced at short notice. Yet, it cannot be totally excluded that inclusion of the first driving factor will fail to meet broad-based support. First, in principle it can be reduced – at least at the longer term - through behavioural change. Second, reduction of the natural growth rate to a level close to long-term population stability would improve welfare prospects and prospects for sustainable development at both the individual and the national level. Third, countries experiencing negative natural rates of growth of the population will have to meet more stringent emission if fixed in per capita terms. For certain countries that, to date, can not be classified as ‘rich’ this might yield less ‘fair’ outcomes. Russia might be a case in point. Yet a medium-term allowance factor for a lopsided population distribution of women in the childbearing age cohorts is defendable anyhow for countries undergoing rapid demographic transition towards a ‘steady population state’.

Population growth that is attributable to in-migration has to be allowed in any burden sharing formula. Some countries are faced with strong immigration. These countries not only contribute to (often) relieving countries of origin somewhat of socio-economic distress but also accept additional ‘sources’ for GHG pollution from countries of origin.

In conclusion, the treatment of population growth in burden sharing rules is a potentially controversial issue. Possibly most climate change negotiators will accept the rate of change in population as an allowance factor. Some may, however, debate full inclusion of the component that is attributable to the natural population growth.

The effect of the oil crises in the late seventies and the early eighties are clearly indicated by the CO_2 emission levels. The same holds for the economic crisis in the thirties and for both World Wars. In addition, it can be seen that after the Second World War CO_2 emissions increased at a higher rate than population, which is mainly due to the increasing use of fossil fuels per capita.

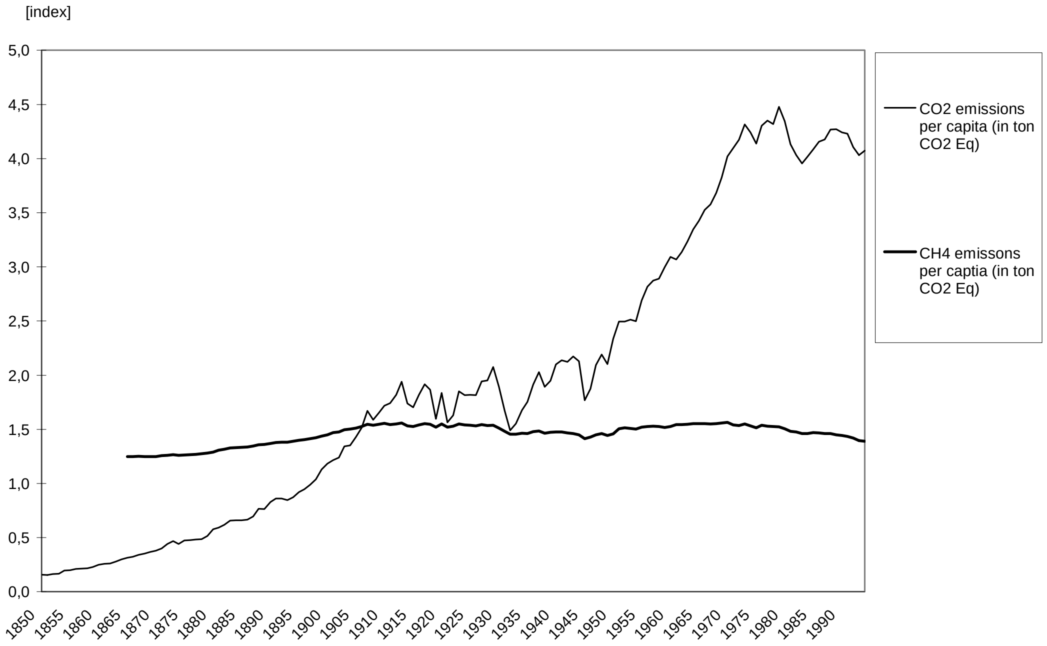


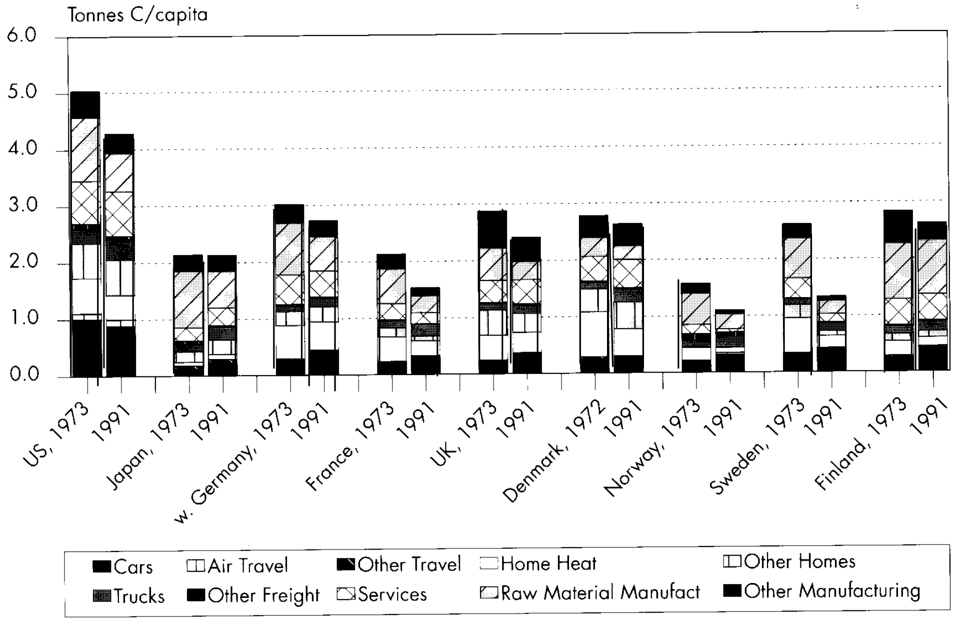
Figure 3.2 *CO_2 and CH_4 emissions per capita over time*
Source: CDIAC 1999.

Figure 3.2 shows average global CO_2 and CH_4 emissions per capita. It can be seen that the world average CH_4 emission per capita are much more stable over time than the average CO_2 emissions per capita. Yet over the last 30 years also CO_2 emissions per capita seem to stabilise by and large.

An explanation of the stabilising methane emissions per capita might be that these emissions are closely linked to agricultural activities. Obviously, agriculture activities mainly comprise food production. Since the demand for food per person does not vary much, the same may hold for related CH_4 emissions per capita. However, it should be noted that the CH_4 emissions are mainly associated with cattle-breeding and rice production. Changes in food patterns may, therefore, affect the CH_4 emissions patterns. Neglecting the latter, one may assume that methane emissions are linked with population size.

As mentioned before, the increasing CO_2 per capita levels are mainly due to an increasing fossil fuel use. This, in turn, is mainly due to activities such as heating, energy, transport and the growing individual demand for goods and services.

CO_2 emissions per capita at a sectoral level for nine industrial countries are depicted in Figure 3.3. This figure indicates that the (energy-related) CO_2 emissions per capita decreased slightly between 1973 and 1991 for some countries (Japan, Denmark, Finland) and decreased considerably in others (Sweden, France, Norway). The strong decrease in the latter countries is most probably the result of a shift in electricity supply (i.e. from a fossil-fuel-based electricity supply to a nuclear/hydro-based electricity supply).



Note: Calculated using the average coefficients for each energy source for final demand (or primary losses)
Source: National sources and IPCC coefficients, as analysed by LBNL

Figure 3.3 *CO_2 emissions per capita in 1973 and 1991 (IEA, 1997)*

According to the IEA, the average CO_2 emissions per capita are relatively stable despite a slight temporary setback between 1973 and 1985 which is mainly due to the oil crises. Although the national emissions per capita differ in absolute terms, the development paths of the energy-related CO_2 emissions show some similarities over time as the emissions per capita are associated with a setback around 1980 for most countries implying that they suffered from the oil crises.

When non-western countries are also taken into account, the developments may be less uniform. Figure 3.4 shows primary energy supply for a number of Western countries, Poland, Mexico, and South Korea. Although the developments in CO_2 emissions may not be totally similar to that of primary energy use, the latter is used here as an indicator for energy-related GHG emissions. The energy use in Poland and South Korea shows different patterns compared to the Western countries. The US shows the highest energy use. For South Korea, energy use per capita increased continuously and does not seem to be affected by the oil crises.

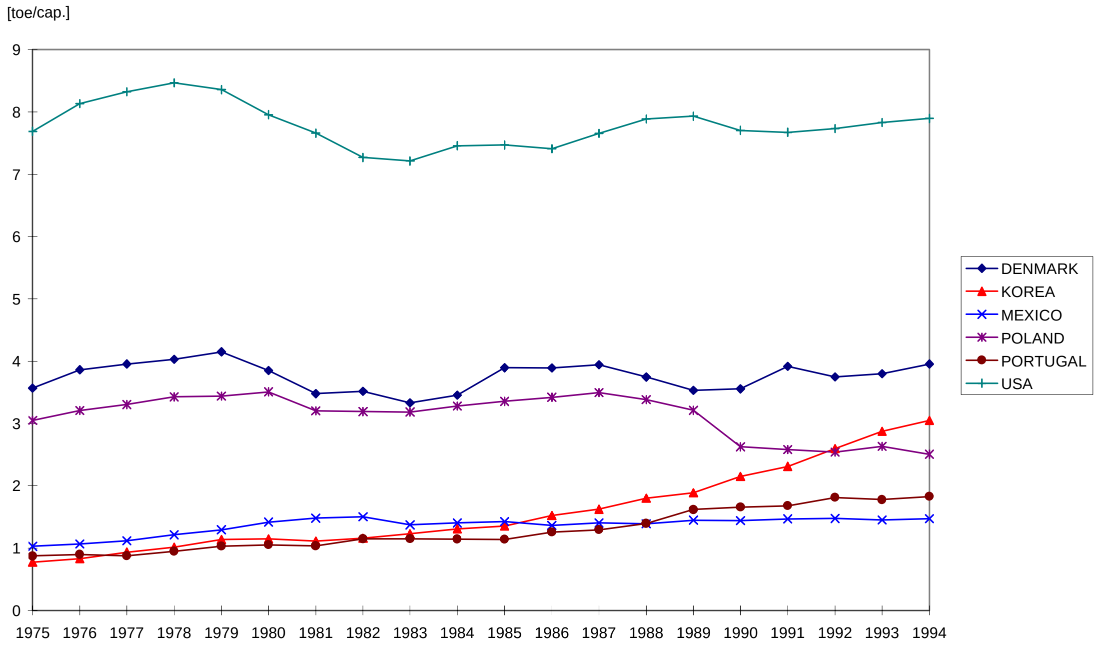
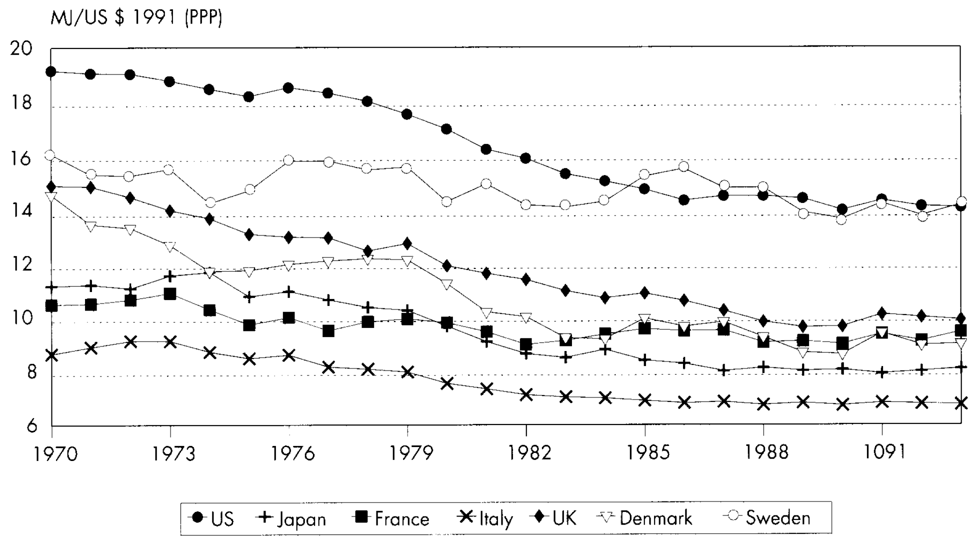


Figure 3.4 *Total primary energy supply (TPES) per capita*
Source data: IEA 1998.

3.3 Level of energy intensity

The level of aggregate energy intensity can also be regarded as an important undercurrent of GHG emissions. Through adoption of energy-efficient technology energy intensity can be importantly reduced, other factors such as the structure of the economy remaining the same. This section focuses on the developments regarding aggregate energy intensity as indicated by energy use per unit GDP (adjusted for price inflation). Figure 3.5 shows the latter indicator over the past 25 years.



Source: IEA Energy Balances of OECD Countries, OECD Economic Statistics

Figure 3.5 *Total primary energy supply per unit of GDP*

In the countries considered, energy use per unit GDP has decreased steadily. For Sweden, this decline is the least and less fluent, although in total the decline still is 12.5% between 1970 and 1992. The United States exhibited the highest energy intensity (i.e. energy use divided by GDP) in 1970 but this country also witnessed a sharp decline in the ensuing two decades.

A number of non-Western countries show much higher energy intensities, especially Poland. Although the reason for this is uncertain, there is a possibility that this may be attributed to the fact that Poland was until recently a centrally planned economy with regulated energy prices substantially below long-run marginal costs (cf. Figure 3.6).

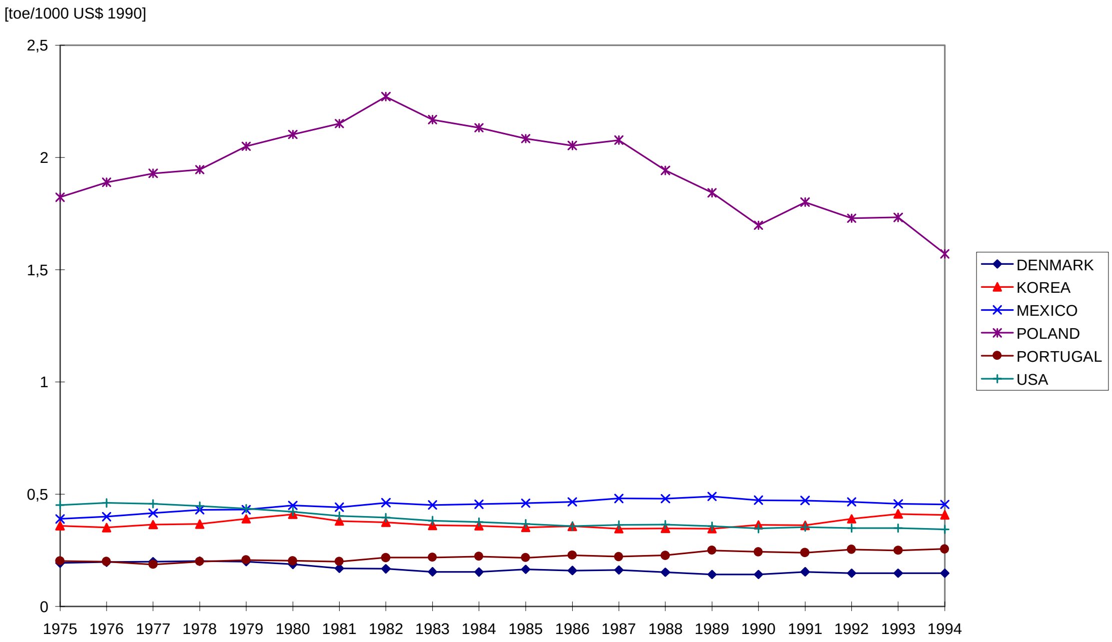


Figure 3.6 *Total primary energy supply per unit of GDP*
Source data: IEA 1998.

Removing Poland from Figure 3.6 presents a clearer view of the developments of Mexico and South Korea (cf. Figure 3.7). It can be observed from Figure 3.7 that the energy intensities of both countries show an increasing trend whereas they are decreasing for most Western countries. More or less, the same also holds for Portugal. This would suggest that countries that are have not yet reached the 'post-industrial services economy' phase tend to experience increasing aggregate energy intensity.

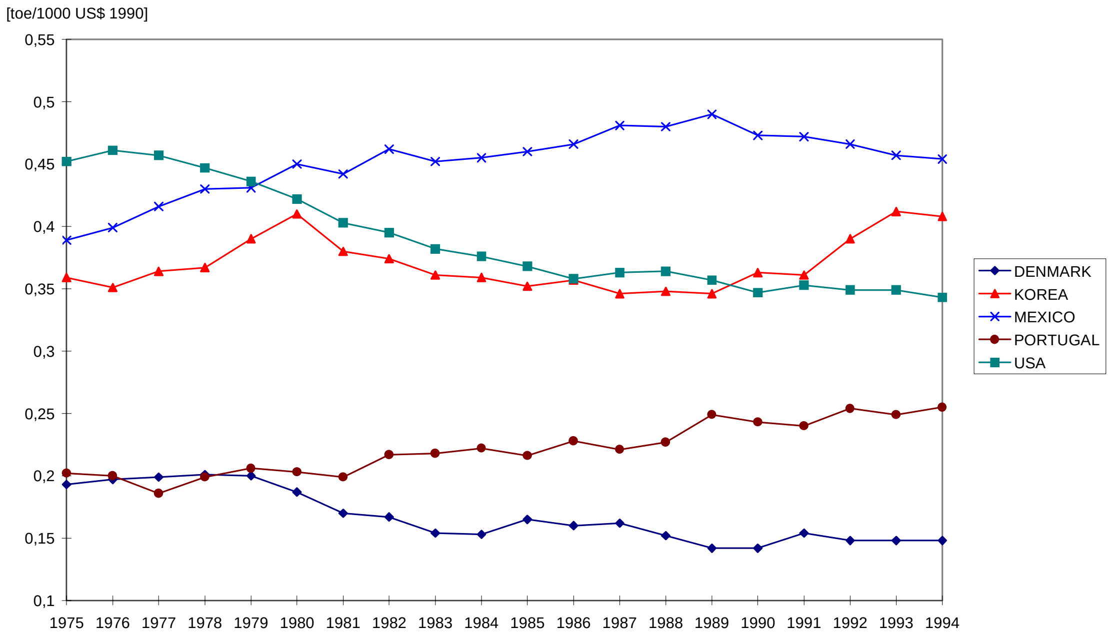


Figure 3.7 *Total primary energy supply (TPES) per unit of GDP*
Source data: IEA 1998.

3.4 Reflections on aggregated data

The previous sections showed trends in GHG emissions in a number of industrialised and industrialising countries. Obviously, the results shown can not present a complete understanding of changing GHG emission patterns but they give an indication of a number of the essential relationships.

It was hypothesised that total GHG emissions depend, among other things, on the structure of the economy concerned. At first sight, there also appear to be other national differences in the relationship between GHG emission levels and their apparent driving forces. For instance, the US shows relatively high GHG emissions levels, which might be related to the fact that the spatial infrastructure in the US started to develop relatively late compared to other western countries. Therefore it might be much more directed towards the use of the truck and car (IEA, 1997). The latter could explain why the ownership of cars is deeply ingrained in the American way of living. In addition, space is much less limited in the US compared to European countries, which might induce relatively large dwellings and, hence a higher per capita energy use for space heating or cooling. In addition, thin population densities as such account for higher per capita levels of transportation services. On the other hand, countries such as Sweden and Norway have relatively low emissions per capita as a result of the ample potentials for renewable energy sources and/or the large share of nuclear power.

In addition, energy intensities also develop differently per country as for instance, most Western countries exhibit decreasing energy intensities whereas energy intensities of South Korea and Mexico (still) show an increasing trend. Poland, to the extent that it can be considered a ‘non-western country’, forms an exception to this general rule as over the past decade energy intensities in this country show a decreasing trend. Evidently this relates to the transition of Poland’s economy from a less efficient, heavy-industry oriented, centrally planned one to a market-oriented economy with (more) inherent price and profit incentives towards efficient use of resources, including energy resources, and with a shift in economic structure towards less-energy-intensive light industry and services.

Although the national-level driving forces described above strongly affect GHG emissions, consideration of driving forces at sub-national aggregation levels provides a more complete picture of underlying factors. However, disaggregation is often complicated by the availability of data. Therefore, it is proposed to use an aggregation level similar to that of the IPCC standard for the national emission inventories since it can be expected that countries will not provide more information than necessary to national communications. Given data availability, an optimal level of detail should be found. In the next section a very preliminary exploration of the (data-constrained) possibilities is made that will be elaborated upon in the second phase of the present project.

3.5 Sectoral indicators

The challenge in choosing sectoral indicators is to strike a good balance between inclusion of proper indicators of all major driving factors of the level of national GHG emissions and dearth of reliable detailed information on such indicators, notably in non-OECD countries. Examples of relevant explanatory aspects are the primary energy mix, fuel conversion activities and associated efficiencies and the nature of the economic activities within main sectors, e.g. Industry and Agriculture.

The Triptych approach forms a good point of departure (Blok et al., 1997). Hitherto, with regard to the burden differentiation issue this approach is the only one that explicitly allows for differences in economic structure. Moreover, this approach was successfully employed for intra-EU sharing of the EU assignment laid down in the Kyoto Protocol. For each country concerned Triptych specifies reduction targets for three distinct broad sectors:

- the ‘domestic sector’ (households, services, light industry, agriculture and transportation) and its associated non-power energy use,
- the electricity sector with the associated power generation mix (energy input mix and CHP share),
- the most energy-intensive sectors producing internationally tradable commodities (refineries, iron & steel, chemical, aluminium, minerals and paper & pulp) and their associated non-power energy use.

Application of the Triptych approach requires the availability of reliable and comparable national data, among other indicators, on:

- energy consumption by sector (sectors as indicated above),
- population forecasts,
- indicative plans for the future deployment of nuclear power,
- heating degree days.

Early 1998, the initiators of the Triptych approach have prepared another paper with renewed Triptych calculations (Phylipsen et al, 1998). Apart from correction for some errors, the following points were raised:

- Light industry was included in households, but part of its output is for other sectors. Therefore, in alternative calculations light industry was included in heavy industry and not in households. The effect on the resulting emission reduction targets was slightly upward for some countries. From a practical point of view, data at aggregated industry level appear somewhat easier to obtain for non-EU countries.
- Shifting freight transportation to heavy industry yielded broadly similar reduction target results for the distinct EU countries.

Ybema has looked at broadening the Triptych approach to include non-EU OECD countries. He concluded that the differences between OECD countries (with also broadly similar per capita income levels) of resulting emission reduction targets are larger than between EU member states as result of larger differences in the various underlying energy and non-energy indicators (Ybema, 1997). As differences among countries with emerging and developing economies are even larger than among the OECD countries, the same conclusions would hold *a fortiori* for these countries. Hence, although the Triptych approach can, in principle, be quite instrumental in consensus building, in its present form the resulting proposed objectives would be too drastic for a number of countries to be acceptable.

In the Triptych approach, a relatively simple allowance method was applied for the countries with an economy in a relatively mature stage of development. Broader application of a Tryptich-like approach would warrant a further elaboration of (an) allowance factor(s) such as ‘developmental emission requirements’, ‘structural transition requirements for fossil fuel exporters’ and ‘infrastructural requirements for countries with low population densities’, with specific attention for exemption and graduation issues[1]. Should methane emissions be included, it might be considered to analyse emissions from agriculture (notably paddy growing and animal husbandry) separately.

Though it is difficult to make any hard statement on availability of data in non-OECD countries, based on the information presented in Chapter 2 and in an article by Judson (1999) the following conclusions seem justified:

- It will be possible to apply a Triptych-like approach from a data availability perspective for at least 90 non-OECD countries. For three important sectors (Industry and Construction, Transportation, Households and Others) these data appear to be available (Judson et al., 1999). However, at sectoral level the data required are less reliable than at aggregate level. Also there are substantial differences between data published by the UN and by the IEA, even though these publications are based on the same data sets.
- Two more aspects have to be considered in collecting data for a burden sharing study. One is that the data should be of such quality that it is not a potential source of criticism for any burden sharing rule outcome. With regard to presently less reliable data this might pose a serious problem. Another aspect is that for evaluating burden sharing rules the countries have to be chosen in such a way that different types of countries (such as economies in transition, OPEC, newly industrialised countries and developing countries) are well represented.

3.6 Summary

The increase of the world population is an important driving factor of GHG emissions. Methane emissions seem to be closely related to agricultural and waste emissions and have shown a relatively steady level of emissions per capita over the past 150 years. Since the First World War, CO_2 emissions per capita increased from less than 2 tonnes CO_2 eq. per capita to over 4 tonnes CO_2 eq. per capita. This increase is mainly the result of an increasing demand for fossil fuels.

Also, differences between countries in the structure of their respective economy and energy supply result in differences in emissions per capita. The United States shows the highest CO_2 emissions per capita of the world, which is probably due to its relatively low population density, the relatively large houses in this country and a transportation infrastructure based on cars. By contrast, some other wealthy countries with a low population density, e.g. Norway, have much more subdued emissions per capita on account of factors such as large-scale use of renewable energy.

In contrast to the decreasing energy intensities of most OECD countries, many non-industrialised countries are still associated with high and sometimes even rising energy intensities. On the other hand, economies in transition are presently showing rapidly decreasing energy intensities.

The Triptych approach has quite interesting features for stimulating the process of consensus building but needs to be adapted to account in a more pronounced way for country-specific allowance factors such as developmental emission needs.

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[1] Ybema (1997) made similar observations.

4. INDICATORS DETERMINING THE COST OF EMISSION ABATEMENT

4.1 Introduction

For many countries considering to commit themselves to a certain level of emission reduction, the expected cost consequences of commitments to limit emissions of GHGs are of paramount importance. In fact, cost projections for a country form overriding considerations for its policy makers and climate change negotiators to assess the burden of emission reduction commitments of the country concerned. Yet there is no straightforward and unique way neither to forecast the future cost of emission mitigation policy packages nor to establish their emission impact. Different cost perspectives can be considered and, in fact, a wide range of approaches is being used to project the cost of future emission reductions.

Some major issues will be reviewed in this chapter related to making ex ante cost projections, and ex post cost estimates, of emission reduction policy packages. The following issues will be addressed:
1. What kind of costs can be associated with dedicated emission reduction activities?
2. What factors play a role to the cost burden of a country of mitigation programmes (dedicated emission reduction activities)?
3. What methods to determine the cost of reduction commitments are being applied?
4. How can the cost figures be calculated?
5. Is it possible to derive cost figures from other directly measurable indicators?

It is noted that most of the literature focuses on energy related CO_2 emissions. International comparable information on the cost of emission reduction of other GHGs is scanty.

4.2 Cost of specific mitigation activities

In this section, cost concepts used for establishing mitigation costs of specific activities or programmes are outlined and reviewed[2]. This will set the stage for the discussion on assessing mitigation costs of reaching specific emission (reduction) targets in the next section.

At the outset, it should be stressed that only the cost of activities to mitigate (possible) anthropogenic climate change are considered by the present project, *not* the cost of adaptation or non-adaptation to climate change. Banuri et al (1996) argue that, in principle, the costs of impacts as well as the cost of risk bearing for such impacts should be covered in climate change negotiations. However, as these costs and their incidence over the globe are quite speculative, credible quantification of the cost of climate change impacts and associated risk bearing and, hence, their inclusion in climate change negotiations can hardly, if at all, be made operational.

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[2] This section draws partly on (UNEP, 1998).

Cost and benefits of distinct activities can be regarded from three major perspectives: the private perspective, the perspective of the national economy, and the perspective of society. Monetary costs and benefits accruing to individual persons or entities are called *financial costs and benefits*. Costs from the perspective of the national economy, including national external effects[3] (such as aerosols and acid rain affecting the national territory) are often referred to as *economic costs and benefits*[4]. When assessing the value of the effects of distinct activities from the broadest societal perspective, transborder external effects impacting on other countries are included. It is a matter of dispute whether or not to include income distribution concerns too in social costs and benefits and, if so, how[5]. Costs and benefits from the societal perspective are often referred to as *social costs and benefits*.

Cash flows of financial costs and benefits can readily be measured ex post. Often some form of periodical financial accounts is prepared by the entity concerned. Financial values are based on the prevailing market prices. For assessing economic or social costs the *opportunity costs* concept plays an important role. It should be established what is the value to the economy/society of the resources used for undertaking an activity in their best alternative application. Indirect taxes or subsidies (apart from externality allowances) should be removed from market prices, as the tax/subsidy components denote merely transfers (to or from the public sector) and do not relate to real resource value.

Discussions on the burden sharing issue can either relate to the net or incremental[6] economic costs or to the incremental social costs of mitigation programmes. UNEP (1998) proposes to focus on the net social costs from a global perspective. However, it will not come as a surprise if most climate change negotiators turn out to be most interested tacitly in the net economic costs (from a national perspective) of implementing the mitigation programme of their own country. Yet for some other countries, notably fossil fuel exporters, the transborder costs of mitigation measures taken by other countries can be quite significant. For these countries the social cost concept matters most from a negotiation point of view. This report will adhere to the social cost concept. Where useful from a negotiation point of view, the economic cost concept will also be considered.

Furthermore, for governments wanting to implement mitigation programmes also the *total* financial cost of programme implementation to be borne by the public sector is relevant information for government budget preparations.

Mitigation programmes can have important benefits. Consider e.g. the introduction of a more energy-efficient production technology that reduces the use of fossil fuels per unit of output. It may also reduce the use of (other) materials per unit of output. Therefore, the *total* costs of mitigation programmes is not an appropriate basis for mitigation cost assessment from the perspectives of the national economy or from society at large. Only the *incremental* costs relative to the ‘without programme’ situation should be considered.

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[3] External effects of specific projects are effects, positive and negative ones, that will not be captured by the future cash-flows accruing to the project sponsors, because these effects do not translate into costs or revenues for the project sponsors. These effects may translate into revenues (positive ones) or costs (negative ones) for other parties than the project sponsors elsewhere in the economy or be of such a nature that these cannot be (readily) expressed into monetary values, e.g. loss of biodiversity. In the economic analysis - concerned with assessment of the selection of projects from the perspective of their attractiveness to the economy at large - the analyst should endeavour to account for external effects in monetary terms to the maximum extent possible and provide qualitative information on aspects for which this is not possible.

[4] Economic pricing should allow for external costs affecting the country’s policy objectives: see e.g. (Squire and Van der Tak 1975, pp 21-23).

[5] Income distribution concerns are generally not integrated in economic prices (costs and benefits).

[6] Net or incremental: after having made due allowance for mitigation programme benefits.

Let us consider the incremental cost concept by reverting to the case of the energy-efficient production technology. If it can be assumed that there will be no product output changes as a result of the mitigation programme concerned (qualitatively and quantitatively), the costs of producing the output with the 'without programme' technology should be subtracted from the total costs of producing the same output in the 'with programme' case. This way, the incremental costs can be established.

In a number of cases the incremental costs can be negative. Implementation of these 'no regrets' cases can be justified on pure economic grounds. However, in cases of *projected negative incremental costs* one should consider carefully why the activities concerned have not been implemented already anyway. It might well be that the analysts projecting negative incremental costs have overlooked serious implementation barriers that can only be scaled at substantial additional costs (e.g. large awareness campaigns, the provision of extension services, use of foreign exchange to arrange loans from foreign financiers, etc.).

The most contentious issue in preparing projections of incremental costs or in estimating incremental costs ex post is the determination of the baseline scenario or 'without mitigation programme' scenario. The easiest assumption is to equate the baseline scenario with the situation existing just before implementing the mitigation programme. In practice, in many cases project/programme analysts apply this assumption. Yet without programme implementation the situation in the sectors involved in the mitigation programmes and in the economy as a whole will change too. It will always be a matter of speculation how the baseline situation will develop (or, ex post, would have been changed) over time. UNEP (1998) suggests to use multiple 'credible' baselines in order to provide insight into the sensitivity of cost projections (ex ante) or cost estimates (ex post) of mitigation activities and programmes. Yet in practice, this will be quite cumbersome. Moreover, the fundamental flaws in assessing incremental cost cannot be scientifically removed. In conclusion, policy makers should always be made aware of the inherent weak basis for assessing mitigation costs when presenting outcomes of mitigation cost assessments of specific projects and programmes.

4.3 The cost burden of reduction assignments for a country

In the previous section, the cost concepts used for establishing costs of specific mitigation activities have been outlined and reviewed. In this section, the mitigation cost issue will be expanded to the level of assessing the costs to a country of achieving agreed GHG emission mitigation targets. In this case, the *incremental* (economic or social) mitigation cost concept will form the point of departure. In order to effectuate agreed GHG reduction assignments, countries that have made commitments have to prepare *effective*[7] *countrywide mitigation programmes*. The main issue at stake is: what will be the net overall cost impact upon a country's economy of simultaneous implementation of effective country-wide implementation programmes? This type of assessment is often referred to as an example of a *macroeconomic cost assessment*, i.e. an economy-wide cost assessment.

The ensuing stocktaking of this issue in the remainder of this section will proceed along the following lines:

- Methods to translate an agreed emission assignment for a country into a credible country portfolio of GHG abatement activities,
- Identification of distinct types of incremental effects to a particular country of implementation of mitigation programmes by several countries,
- Methods to assess these distinct types of incremental effects,
- A concluding brief review of strengths and weaknesses of projecting mitigation cost burdens.

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[7] Effective in the sense of achieving the country's agreed mitigation assignment.

Methods to prepare a country mitigation programme for meeting its assignment

There are basically two types of methods to prepare country portfolios of GHG abatement activities, i.e. *simulation models* and *least-cost optimisation models for energy systems and related GHG emissions*. Both types of models require a baseline scenario of socio-economic development over the projection time horizon with assumptions concerning population growth and economic growth rates per sector. The projection model should then be applied to make projections of energy demands and of attendant GHG emissions. Having established projected baseline emission levels for a prospective 'budget period', projections of total emission reduction requirements can be made to meet the agreed assignment. The projection model should help to compose least-cost GHG abatement activities.

For the application of simulation models (e.g. LEAP) assumptions need to be made on the cost of energy conversion and end-use technologies, the penetration of these technologies per end-use, fuels used per energy technology and energy conversion efficiencies. With the help of scenario assumptions the model will generate projections of energy demand/supply, total energy system costs and GHG emissions. For the application of least-cost optimisation models (e.g. MARKAL, EFOM), in addition to assumptions on socio-economic development, information is needed on energy costs, investment and recurrent cost of energy technologies, lifetimes of energy-technology investments and the commercialisation potential of energy technologies. Imputing the required information the optimisation models will generate least-cost projections to energise the economy with attendant GHG emissions and total energy system costs.

Having projected national baseline emission levels, analysts using a *simulation model* will prepare a long-list of mitigation options in energy supply and use. Based on iterative simulations with applications of these options and accompanying assessments of costs and application scope at pre-feasibility level, a least-cost portfolio of mitigation options can be projected yielding in total the required emission reduction. In addition, the total energy supply system costs corresponding with the reduction scenario can be projected. In order to obtain the incremental mitigation costs, the total energy supply system costs in the baseline scenario have to be deducted from the total energy supply system costs in the reduction scenario. At times, in mitigation analyses incremental mitigation costs have been confused with total mitigation costs.

By virtue of their inherent cost-optimisation properties, *least-cost optimisation models* can readily handle GHG emission constraints, produce the projected least-cost combination of energy conversion and end-use technologies and projections of the incremental (i.e. additional) costs of the introduction of emission constraints. Least-cost models are also capable of making better allowance of inter-activity impacts because of their ability to perform integrated economy-wide analysis, while simulation models - performing partial analyses - are less capable of accounting for interactions between distinct activities and sectors. E.g., when at the same time effective energy-saving lamp marketing campaigns and an activity to improve conversion efficiencies in the power sector are underway, energy system optimisation models (as distinct from simulation models) can account well for the reduced electricity savings scope for each of these GHG reduction activities because of mutual interactions. On the other hand, data requirements for energy system optimisation models and scarce expert capabilities to run these models are prohibitive for many developing countries. All in all, it can be concluded that there is no single superior model that can most effectively be applied throughout the world.

Identification of effects on incremental country cost burdens

Several types of effects of implementing country mitigation programmes can be discerned on the total incremental costs to a country including:

- *Direct effects*

  The direct incremental costs of specific mitigation activities can be obtained through 'bottom-up' pre-feasibility analysis at project level. In the preceding section, an outline was presented of how to assess the incremental costs of specific mitigation activities without making allowance for the indirect effects that follow suit.

- *Within-country indirect effects*
  Implementing a mitigation programme can affect the national and international competitiveness of a wide range of economic activities with associated costs and benefits. Domestic economic activities, the competitiveness of which might be adversely affected, are carbon-intensive basic industry activities such as the production of steel, cement, fertilisers, basic chemicals such as fertilisers, etc. Because of stringent domestic carbon reduction policies, *carbon leakage* i.e. relocation of carbon-intensive economic activities to countries with less stringent carbon reduction policies may occur with welfare loss at the national level but also at global level (diversion of production to less efficient foreign producers). On the other hand, carbon-extensive economic activities will be stimulated, especially if these offer substitution opportunities for carbon-intensive activities. The net result of the within-country indirect effects on total welfare levels of a country depend highly on the pre-programme importance of carbon-intensive economic activities and the extent of international synchronisation of carbon reduction policies. The net result can be gauged in a crude way by *top-down economic model tools* such as input-output models and general equilibrium models.

- *Secondary effects*
  Because of substantial negative direct incremental costs to a country pursuing stringent carbon reduction policies, at the macroeconomic level effective demand may fall back. Top-down economic models may also capture these types of effects crudely. Negative secondary effects may even be transmitted to major trading partners.

- *Transboundary indirect effects of mitigation programmes in other countries*
  Negative indirect impacts can be experienced by exporting countries of inputs to carbon-intensive industries located in countries pursuing stringent carbon-reduction policies. The same goes for producers of carbon-intensive consumer goods. Exporters of fossil fuels will be hit most by stringent carbon-reduction policies in major demand areas for fossil fuels. Recipient countries of investments in carbon-intensive industries may fetch positive welfare effects. These types of effects can only be captured in a very rough manner by top-down global economic models.

4.4 Implications for burden-sharing rules: preliminary conclusions

Based on the findings in the previous sections some preliminary remarks can be made on the development of useful burden-sharing rules.

I Due allowance should be made for the direct incremental costs to a country of implementing the least-cost mitigation programmes that would meet the burden indicated by the proposed burden-sharing rule. Certain factors are of crucial importance to the direct incremental cost bill of a country, notably:
  - Prevailing levels of energy efficiency throughout the country’s energy system. If, generally, the gap with international ‘best practices’ benchmarks is small (wide), the scope for improving energy-efficiency levels is correspondingly small (large) and expensive (cheap).
  - The carbon intensity of energy supply. If a country’s energy supply is relatively carbon-extensive (carbon-intensive), the scope for shifts to carbon-extensive primary energy carriers, including notably renewable sources of energy, will be correspondingly small (large) and expensive (cheap).
  - The country’s relative endowments of renewable sources of energy and natural gas will also determine the transition costs towards a carbon-extensive economy.

II Due allowance should be given to the within-country indirect effects. The blow that might be given to specific carbon-intensive economic activities might be locally quite severe, even when these activities would be ‘best practices’ in their respective trade.

III It appears that less attention is due to secondary effects, provided the incidence of these effects is distributed equitably throughout the economy. If the country's policy makers have well designed and communicated the country's mitigation programme and created sufficient political clout to its defence, some loss of welfare seems acceptable.

IV Due allowance should be given to transboundary indirect effects. It should even be considered that countries that are extremely dependent on carbon-intensive exports, notably countries heavily dependent on fossil fuel exports, will get appropriate, time-phased forms of assistance from the international community in bringing about a sound restructuring of their respective economy.

V Evidently the cost of emission limitation commitments are a very important consideration for climate change negotiators. Consideration should therefore be given to major determinants of these commitments, e.g.:

- For countries that have already implemented many measures in the past, further reduction will become increasingly costly.
- The risk of 'carbon leakage' (shifting of carbon-intensive activities to countries with more lenient emission policies) can be perceived to be serious.
- For countries with a fossil-fuel-intensive transport and energy-supply infrastructure a shift to a less fossil-fuel-intensive infrastructure is supposed to be costly.
- The same may hold for countries that have already implemented a 'green' tax system, for countries with a low renewable energy potential, and/or for countries for which 'going (more) nuclear' is not politically feasible.

5. PRELIMINARY FINDINGS ON BSR DESIGN

5.1 Introduction

This concluding chapter contains some main findings of the first stage of the present research project on Burden Differentiation. Section 5.2 gives preliminary findings on data availability. Data availability aspects are being investigated more thoroughly in the next study stages. Section 5.3 presents guidelines for structuring activities on the design of widely acceptable burden sharing rules.

5.2 Data availability

The Kyoto Protocol covers five other greenhouse gases in addition to CO_2. The IPCC estimates that in 1995 emissions of CO_2 account for 84% and the other gases for 16 % of total global warming potential, among which CH_4 for 11% and N_2O for 4%. As data on emissions for the latter two gases are available for many countries, these will be included in further project activities to the extent possible. A disadvantage of their inclusion is the low level of reliability of the corresponding emission data as compared to CO_2 emission data. This disadvantage holds a fortiori for the remaining three ‘Kyoto’ gases. As the latter also contribute a very small share to total Global Warming Potential, inclusion of these emissions will be given low priority in subsequent research.

For OECD countries data availability on CO_2 emission reduction, at aggregated national and at broad sectoral level, is fairly good. For non-OECD countries the data situation is less favourable. The National Communications to the FCCC Secretariat is the most authoritative data source. It will be attempted to include the other GHGs in the project database, especially CH_4 and N_2O. The challenge for the present study is to identify a level of detail that makes convincingly proper allowance for country-specific circumstances on the one hand and for availability of reliable data on the other.

5.3 On designing burden sharing rules

For developing a burden sharing rule that is expected that for garnering broad-based support it is necessary to:

- Concentrate first on the inclusion of allowance factors for country-specific characteristics that contribute significantly to variations in emissions per capita.
- Establish which of these are expected to get broad-based support in the climate change negotiation arena. Preliminary analysis suggests that appropriate indicators for economic structure characteristics would appear to constitute a serious candidate allowance factor, implying a sectoral approach as exemplified by the Triptych approach.
- Develop a method to normalise unadjusted emission targets for the latter type of allowance factors and to apply burden sharing rules to adjusted emission rates.
- An important issue outstanding is trans-national cost-effectiveness in reaching emission targets. It remains to be seen whether to allow for cost-effectiveness in burden sharing rules themselves or, alternatively, in proposals for the mode of application of these rules.

- Country-specific *allowance factors* for burden differentiation among nations with comparable living standards tend to be proposed by negotiating countries that have a keen interest in including these for reducing their abatement burden. The EU-wide support for the Triptych approach in sharing the EU emission reduction assignment among its member states suggests that the country-specific economic structure is an allowance factor for emission differentiation, which may well meet broad-based support. This would require a relatively simple but intuitively appealing sectoral approach in developing burden-sharing rules, based on reliable and verifiable data.
- As for other possible allowance factors, the Triptych approach also includes a local climate-related allowance factor. Furthermore, it can be expected that exporters of fossil fuels will demand allowance for the negative impact on their national economies of global GHG emission reduction. The same is likely to hold for large countries with low population densities as the transport and energy infrastructure of these countries is expected to adversely affect levels of energy efficiency. Last but not least, implicit or explicit allowance should be made for ‘developmental emission requirements’.
- It is important to note that the outcomes of the Triptych approach, which makes allowance for driving factors to national emission levels *at sectoral level*, has served to specify a successful *initial* distribution of EU emission targets. However, ensuing further negotiation among EU member states were required for reaching a full agreement among the EU member states. Evidently, in the decisive negotiation phase researchers can never substitute official negotiators. In the best case, researchers can provide supportive clues to be used by negotiators totally at their own convenience in the quest to find a negotiated consensual solution for burden sharing.
- Inclusion of population growth as an allowance factor cannot completely be taken for granted. Possibly most climate change negotiators will accept the rate of change in population as an allowance factor. Some may, however, debate full inclusion of the component that is attributable to the natural population growth.
- Due allowance should be made for the direct incremental costs to a country of its least-cost mitigation programme that would meet the burden indicated by the proposed BSR. Certain factors are of crucial importance to the direct incremental cost bill of a country, notably:
  - Prevailing levels of energy efficiency throughout the country’s energy system. If, generally, the gap with international ‘best practices’ benchmarks is small (wide), the scope for improving energy-efficiency levels is correspondingly small (large) and expensive (cheap).
  - The carbon intensity of energy supply. If a country’s energy supply is relatively carbon-extensive (carbon-intensive), the scope for shifts to carbon-extensive primary energy carriers, including notably renewable sources of energy, will be correspondingly small (large) and expensive (cheap).
  - The country’s relative endowments of renewable sources of energy and natural gas will also determine the transition costs towards a carbon-extensive economy.
- Due allowance should be given to the within-country indirect effects. The blow that might be given to specific carbon-intensive economic activities might be locally quite severe.
- Due allowance should be given to transboundary indirect effects. It should even be considered to make countries that are extremely dependent on carbon-intensive exports, notably countries heavily dependent on fossil fuel exports, eligible for appropriate, time-phased forms of assistance from the international community in bringing about a sound restructuring of their respective economy.
- Last but not least, burden-sharing rules should be transparent and relatively simple. A good balance should be struck between these features on the one hand, and significant country-specific allowance factors on the other.

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