Climate Change

Climate Change 16/07

ISSN 1862-4359

Greenhouse gas burden sharing within the European Union

An Evaluation of the Triptych Approach

Umwelt Bundes Amt

Für Mensch und Umwelt

Climate Change

16

07

ISSN
1862-4359

Greenhouse gas burden sharing within the European Union

An Evaluation of the Triptych Approach

by

Alexandra Börner

Humboldt University Berlin

UMWELTBUNDESAMT

This Publication is only available as Download under
http://www.umweltbundesamt.de/klimaschutz-e

This study was carried out under supervision of
Martin Weiß, German Federal Environment Agency and
Jens Barthel, Humboldt University Berlin

The contents of this publication do not necessarily
reflect the official opinions.

Publisher: Federal Environmental Agency (Umweltbundesamt)
P.O.B. 14 06
06813 Dessau-Roßlau
Tel.: +49-340-2103-0
Telefax: +49-340-2103 2285
Internet: http://www.umweltbundesamt.de

Edited by: Section I 4.1, Benno Hain
Section I 1.3, Gabriele Coan

Dessau-Roßlau, November 2007

Abstract

In 1997, at the United Nations conference on climate change hosted in Kyoto, Japan, the European Union committed to reduce greenhouse gas emissions by 8 per cent in the period from 2008 to 2012, with 1990 as baseline. The EU members agreed to reduce their emissions jointly under consideration of their different national circumstances in a burden sharing agreement. The basis for this agreement is a sectoral bottom-up model, the so-called 'Triptych' approach. The goal of this thesis is to analyse the deviations of the EU countries' emission paths from their Kyoto targets. Therefore, interpolated emission allowances are compared to actual emissions in 2005. In order to find reasons for those different developments, sectoral emission trends, energy indicators and socio-economic data have been analysed for Germany, the United Kingdom and Spain. As a result, different drivers are detected for the different developments of emission paths. The main finding is that the economic growth rates assumed for Cohesion Fund countries were too low. Convergence in living standards within the EU-15 developed at faster pace than assumed in the model. In particular transport is an emerging driver of emissions. The results confirm that the integration of civil aviation into the European emissions trading system (ETS) will be necessary in order to limit further increasing emissions. The assumptions made on fuel mix were not met in all countries. The results of the case studies suggest that domestic fuel resources are preferentially treated in national energy policy. In particular in Germany, great discrepancies between climate policy targets and investment decisions of the energy industry and the automotive industry are detected. The outlook of this thesis deals with European emissions trading and discusses the options of future burden sharing agreements. This can be reduced to the emissions' trading sector and the non-trading sectors. Therefore, an ambitious cap for emissions' trading and technology standards within a harmonised institutional framework will be necessary. The challenge for the future agreement will be the integration of the twelve new member states of EU-27.

Contents

1 Introduction 11
2 Theory of burden sharing 14
2.1 Burden sharing approaches 14
2.1.1 Criteria 14
2.1.1.1 Economic efficiency 14
2.1.1.2 Equity 15
2.1.1.3 Political acceptability 16
2.1.1.4 Environmental effectiveness 16
2.1.2 Options 16
2.1.2.1 Grandfathering 17
2.1.2.2 Per capita convergence 17
2.1.2.3 Carbon intensity 18
2.1.2.3 Multi-criteria convergence 18
2.1.2.4 Equal mitigation costs 18
2.1.2.5 Bottom-up models 19
2.2 The Triptych approach 19
2.2.1 Model explanation 19
2.2.2 The power producing sector 21
2.2.3 The heavy industry 22
2.2.4 The domestic sectors 23
2.2.5 Model results 24
3 Case studies 26
3.1 The EU-15 26
3.1.1 Economy 26
3.1.2 Emissions situation 27
3.1.3 EU climate policy 32
3.2 Germany 33
3.2.1 National circumstances 33
3.2.1.1 Economy 33
3.2.1.2 Energy 33
3.2.1.3 Emissions 35
3.2.1.4 Climate policy 36
3.2.2 The power producing sector 37
3.2.2.1 Model results and analysis 37
3.2.2.2 Model simulations for the year 2020 43
3.2.3 Heavy industry 45
3.2.3.1 Model results and analysis 45

3.2.3.2 Model simulations for 2020 48
3.2.4 Domestic sectors 49
3.2.4.1 Model results and analysis 49
3.2.4.2 Model simulations for 2020 53
3.2.5 Summary for Germany 54
3.3 The United Kingdom 55
3.3.1 National circumstances 55
3.3.1.1 Economy 55
3.3.1.2 Energy 56
3.3.1.3 Emissions 56
3.3.1.4 Climate policy 57
3.3.2 The power producing sector 58
3.3.2.1 Model results and analysis 58
3.3.2.2 Simulations for 2020 62
3.3.3 Heavy industry 63
3.3.3.1 Model results and analysis 63
3.3.3.2 Simulation for 2020 65
3.3.4 Domestic sectors 66
3.3.4.1 Model results and analysis 66
3.3.4.2 Simulation for 2020 68
3.3.5 Summary for the UK 69
3.4 Spain 70
3.4.1 National circumstances 70
3.4.1.1 Economy 70
3.4.1.2 Energy 70
3.4.1.3 Emissions 71
3.4.1.4 Climate policy 72
3.4.2 The power producing sector 72
3.4.2.1 Model results and analysis 72
3.4.2.2 Simulations for 2020 76
3.4.3 Heavy industry 77
3.4.3.1 Model results and analysis 77
3.4.3.2 Simulation for 2020 79
3.4.4 Domestic sectors 79
3.4.4.1 Model results and analysis 79
3.4.4.2 Simulation for 2020 82
3.4.5 Summary for Spain 83
4 Model evaluation 84
4.1 The power producing sector 84
4.2 The heavy industries 86

4.3 Domestic sectors ... 89
4.4 Revised Triptych assumptions ... 91
5 Future burden sharing agreement ... 93
5.1 The European emissions trading system ... 93
5.1.1 Grandfathering ... 93
5.1.2 Auctioning ... 94
5.2 Options for a future EU burden sharing agreement ... 94
6 Summary and Conclusions ... 96
7 Literature ... 99
8 Annex ... 105
8.1 The United Nations Framework Convention on Climate Change and the Kyoto Protocol ... 105
8.1.1 Annex-I countries to the United Nations Framework Convention on Climate Change ... 105
8.1.2 Kyoto targets of Annex-I countries ... 106
8.2 The power producing sector ... 106
8.2.1 Model equations ... 106
8.2.2 Fuel input data for model simulations of the power producing sector 109
8.2.2 Electricity production by nuclear power ... 109
8.2.3 Generation efficiencies and emission factors ... 110
8.3 The heavy industry ... 110
8.4 The domestic sector ... 111
8.5 Energy-related CO_2-emissions reported to the UNFCCC ... 112

List of Figures

Figure 1 Projected relative changes of greenhouse gas emissions in EU-15 by 2010, and Kyoto targets in per cent... 13
Figure 2 Sketch of convergence of CO_2 per capita in the domestic sectors... 24
Figure 3 Simulated Triptych allowances compared to Kyoto targets of EU-15 in per cent.. 25
Figure 4 GDP per capita in EU-15.. 27
Figure 5 Greenhouse gas emission paths of EU-15 countries from 1990 to 2005 28
Figure 6 Total greenhouse gas emissions in EU-15 countries in 1990, Kyoto targets and projections for 2010... 28
Figure 7 Greenhouse gas emissions per capita in EU-15 30
Figure 8 Greenhouse gas emissions per unit of GDP in EU-15 31
Figure 9 Germany: Gross inland energy consumption by fuel........................ 34
Figure 10 Germany: Energy-related CO_2-emissions by sector......................... 35
Figure 11 Germany: Energy-related CO_2-emissions in the power producing sector vs. model results 40
Figure 12 Germany: Energy-related CO_2-emissions in the heavy industry vs. model results.. 46
Figure 13 Germany: Energy-related CO_2-emissions in the domestic sectors vs. simulated allowances 50
Figure 14 Germany: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005 51
Figure 15 Germany: Index of emissions from transport by transport means.... 53
Figure 16 United Kingdom: Energy-related CO_2-emissions by sector............. 57
Figure 17 UK: Energy-related CO_2-emissions of the power producing sector vs. model results.. 60
Figure 18 UK: Energy-related CO_2-emissions of the heavy industry vs. model results 64
Figure 19 UK: Energy-related CO_2-emissions in the domestic sectors vs. model results 67
Figure 20 UK: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005 67
Figure 21 UK: Index for emissions from transport by transport meaning 68
Figure 22 Spain: Energy-related CO_2-emissions by sector 71
Figure 23 Spain: Energy-related CO_2-emissions in the power producing sector vs. model results... 74
Figure 24 Spain: Energy-related CO_2-emissions in the heavy industry vs. model results 78
Figure 25 Spain: Energy-related CO_2-emissions in the domestic sectors vs. model results.. 80
Figure 26 Spain: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005 81
Figure 27 Spain: Index of emissions from transport by transport means 82
Figure 28 Comparison of predicted emission allowances to actual emissions in the power producing sectors of Germany, the UK and Spain 85
Figure 29 Comparison of results for the heavy industries in Germany, the UK and Spain 87
Figure 30 Energy intensity in Germany, the UK and Spain 88

Figure 31 CO_2-Emissions per capita in the domestic sectors in Germany, the UK and Spain 89
Figure 32 Comparison of results for the domestic sectors in Germany, the UK and Spain 91

List of Tables

Table 1 Options for greenhouse gas burden sharing agreements 19
Table 2 The Triptych model.. 20
Table 3 Germany: Electricity production by fuel, 2005: model results vs. real data 39
Table 4 Germany: Comparison of model assumptions and actual fuel mix of the power producing sector 40
Table 5 Germany: Comparison of the assumptions made for 2020 and simulation results.. 44
Table 6 Germany: Model assumptions on heavy industry vs. real data........ 47
Table 7 Germany: 2020 simulations for the heavy industry 49
Table 8 Germany: Model assumptions and predicted allowances for the domestic sectors.. 54
Table 9 UK: Electricity production by fuel in 2005: model results vs. real data59
Table 10 UK: Comparison of model assumptions to real results.................... 61
Table 11 UK: Comparison of the assumptions made for 2020 and simulation results 63
Table 12 UK: Model assumptions on heavy industry vs. real data................. 64
Table 13 UK: Model assumptions and predicted allowances in the domestic sectors 69
Table 14 Spain: Electricity production by fuel: model results vs. real data...... 73
Table 15 Spain: Comparison of model assumptions and real results in the power producing sector.. 76
Table 16 Spain: Comparison of the assumptions for 2020 and simulation results in the power producing sector 77
Table 17 Spain: Model assumptions on the heavy industry vs. real data........ 79
Table 18 Spain: Model assumptions and predicted allowances in the domestic sectors 83
Table 19 Emission reduction targets of Annex-I countries mentioned in Annex B of the Kyoto Protocol 106
Table 20 Summary of the model assumptions made on fuel shares............ 108
Table 21 Gross electricity production by fuel in PJ provided by the 'IEA Electricity information 2006' (IEA, 2006)... 109
Table 22 Electricity production by nuclear power plants in Conventional Wisdom Scenario 109
Table 23 Assumptions on generation efficiencies and emission factors by fuel and by country.. 110
Table 24 Energy related CO_2-emissions in Mt: Input data for the heavy industry provided in the CRF-tables of the UNFCCC................................. 110
Table 25 Energy-related CO_2-emissions in Mt: Input data for the domestic sectors provided in the CRF-tables of the UNFCCC.................................. 111
Table 26 Energy-related CO_2-emissions in Germany provided in the CRF tables of the UNFCCC 112
Table 27 Energy-related CO_2-emissions in the United Kingdom provided in the CRF tables of the UNFCCC.. 113
Table 28 Energy-related CO_2-emissions in Spain provided in the CRF tables of the UNFCCC 113

1 Introduction

In 1992, at the global Earth Summit in Rio de Janeiro, national representatives from more than 150 countries signed the United Nations Framework Convention on Climate Change' recognising global climate change as a 'common concern of humankind' (UNFCCC, 2005). The ultimate objective of the treaty is to stabilise 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (Article 2, UNFCCC). The Convention was enforced on 21 March, 1994. Today, it enjoys almost universal membership with 191 ratifications. It commits national governments to gather and share information on greenhouse gas emissions launch and co-operate national strategies for climate change mitigation and adaptation including the provision of financial and technological support to developing countries. [1] As follow-up of the UNFCCC, the signatories agreed to meet annually at the 'Conference of the Parties' (COP).

In 1997, the third COP was hosted in Kyoto, Japan, where the Parties adopted the 'Kyoto Protocol.' It commits industrialised countries to reduce their combined greenhouse gas emissions by at least 5 per cent within the period from 2008 to 2012 based on their levels in 1990. On 16 February, 2005, with the ratification of Russia the Protocol was implemented.[2] Today, it has been ratified by 175 countries (UNFCCC, 2007). Australia and the United States of America, which together are the greatest emitters of greenhouse gases per capita in the world, have signed the Kyoto Protocol, but have not ratified it yet.[3]

The article 4.2(b) of the Kyoto Protocol states that the parties may return 'individually or jointly' to their greenhouse gas emission levels from 1990. Therefore, the European Union decided to reduce emissions jointly in the so called 'European bubble.' It allows EU-members

---

[1] Greenhouse gases are: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). They are noted in CO_2-equivalents (CO_2-eq).

[2] The Kyoto Protocol should enter into force 90 days after it has been ratified by at least 55 Parties to the UNFCCC accounting for at least 55 per cent of total CO_2-emissions of industrialised countries in 1990.

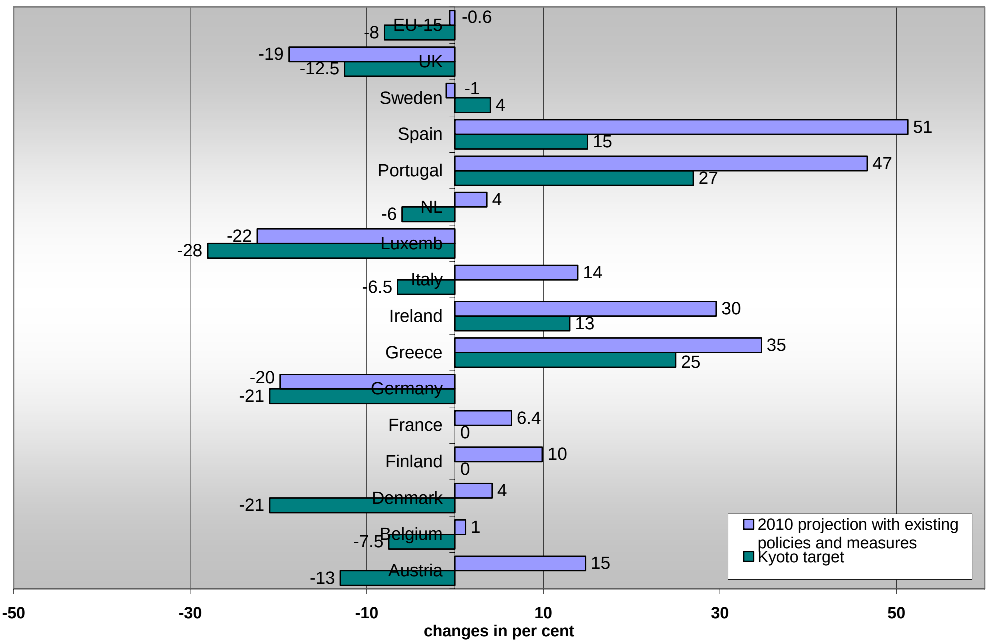
[3] In 2002, CO_2 emissions per capita were 20.2 t p.a. in the US and 17.3 t p.a. in Australia (compared to 10.6 t CO_2 in Germany and the global average of 4 t CO_2, BMU, 2006).

to redistribute the overall reduction target of 8 per cent among its members according to their capability to reduce emissions. Thereby, the issue was how to distribute these different national targets in an economically efficient way which is also perceived as fair among the EU members. This raised the issue of greenhouse gas burden sharing within the European Union. In 1997, EU members agreed to use the 'Triptych approach,' as framework for their burden sharing agreement. It is a sectoral bottom-up model calculating emission allowances for each member state, while considering particular national circumstances, such as, emission reduction potentials, fuel mix, economic power and population growth. Figure 1 compares the resulting emission reduction targets of the EU-15 members in per cent to their currently projected changes of greenhouse gas emissions by 2010 (EEA, 2006). Luxembourg, Denmark and Germany have committed to the most ambitious emission targets, whereas the Cohesion Fund countries, Portugal, Greece, Spain and Ireland were allowed to increase their emissions by 2012, in order to allow enhanced economic growth.[4] The blue bars in Figure 1 show the projected emission changes for 2010 with existing policies and measures. Referring to current projections under existing policies and measures, the results are poor: the United Kingdom and Sweden will be the only countries reaching their reduction targets, while all other members will fail to achieve their targets. The greatest deviations can be observed for Spain, Austria, Denmark, Italy, Portugal and Ireland (see chapter 3). The current projection for the whole EU-15 is only -0.6 per cent. Hence, the EU-15 is far from reaching its total greenhouse gas reduction target of -8 per cent with existing policies and measures. However, the EU is projected to reach the Kyoto target with the use of additional policies and measures and the flexible mechanisms of the Kyoto Protocol (see Figure 6). [5]

[4] The European Cohesion Fund was established in 1994 in order to support economic less developed member states with a GNP of less than 90 per cent of the European average (Dinan, 1998)

[5] In order to reduce these emissions cost-effectively, the Protocol allows flexible mechanisms like emissions trading, 'Joint Implementation' (JI) or the 'Clean Development Mechanism' (CDM) defined in the Articles 6, 12 and 17 of the Kyoto Protocol. These mechanisms allow Annex-I Parties to implement emissions reduction projects in countries with lower abatement costs. Hence, the amount of emissions reductions established in foreign countries should be taken into account for the own emissions reduction target.

Figure 1 Projected relative changes of greenhouse gas emissions in EU-15 by 2010, and Kyoto targets in per cent



Source: EEA (2006)

The objective of this thesis is to find reasons for the deviations of the current projected emission paths from the national Kyoto targets in 2010. Therefore, based on the logic of the Triptych model, allowances for 2005 are simulated by linear interpolation of the assumptions made in Triptych. The aim is to evaluate the Triptych approach, which is the current framework of the burden sharing agreement, and give recommendations on future options. Emission trends, energy indicators and socio-economic data for Germany, the United Kingdom and Spain, are analysed in three case studies. This work is structured as following: Chapter 2 provides general theory on the options of burden sharing and the underlying criteria for an evaluation. There upon, the Triptych model is introduced. Chapter 3 presents the three country studies comparing interpolated emission allowances to the real data in 2005, by sector. Simulations of feasible emission targets for 2020 are provided, as well. In chapter 6, the results are concluded in order to evaluate the Triptych model, and approved assumptions are suggested. Chapter 5 summarises general recommendations of the future burden sharing agreement in the post-2012 commitment period, and chapter 6 concludes.

2 Theory of burden sharing

2.1 Burden sharing approaches

Greenhouse gas burden sharing can be described as an approach to tackle the issue of a fair and efficient distribution of the 'burden' of greenhouse gas reduction among a group of countries. Article 4 of the United Nations Framework Convention on Climate Change takes into account the 'common but differentiated responsibilities' and 'specific national and regional development priorities, objectives and circumstances' of the signatories (UNFCCC, 2007). 'Circumstances' refers in particular to different paths of economic development and emissions reduction potentials. Important determinants are the country's population, economy, technology, fuel mix, infrastructure and climate conditions. Reflecting on these specific national circumstances and different potentials, several political and economic criteria must be developed in order to establish a fair burden sharing agreement.

2.1.1 Criteria

Sijm et al. (2007) describe the relevant criteria of a burden sharing agreement as environmental effectiveness, economic efficiency, i.e. cost-effectiveness, equity, political acceptability and the ease of implementation.

2.1.1.1 Economic efficiency

The most efficient way of internalising external costs arising from climate change damages is the implementation of a carbon market. Economically, the efficient amount of emissions is the quantity of emissions, where marginal benefits from emissions' mitigation are equal to marginal abatement cost. If the firm's marginal abatement costs exceed the permit price, firms can buy emission permits on the carbon market. Hence, emissions trading enables the market participants to abate emissions at lowest cost. In contrast to an emissions tax or command and control mechanisms, the carbon market creates no welfare losses. Hence, the market is the most efficient instrument for emissions mitigation. In order to achieve efficient results, the economy has to meet the general conditions of perfect competition, which can hardly be obtained in reality. Market power of firms, scale effects and imperfect information create imperfect competition that inhibits efficient results on a market. This is mostly the case in monopoly or oligopoly structured markets. In general, large firms, generating profit, are better off at the introduction of a carbon market since they are able to compensate carbon costs with firm-intern subsidies. Moreover, regarding the high transaction costs in the domestic sectors, emissions trading cannot be applied to all sectors of the economy. This is the main reason for supplementing the emissions trading system by additional instruments, such as a Pigou-tax, technology subsidies, command and control mechanisms, or voluntary agreements. Unfortunately, these instruments are less efficient than an emissions trading system and create welfare losses from market distortions (Perman et al., 2003). Moreover, asymmetric information, lobbying and other rent-seeking activities of firms lead to inefficient results of command and control instruments.

2.1.1.2 Equity

Equity is a widely discussed issue where normative criteria are necessary for evaluation. Sijm et al. (2007) differentiate between equal rights, acquired rights, the polluter-pays principle and the ability-to-pay principle. In particular, in international climate policy, the equal rights principle becomes increasingly important.[6] It claims that every human being has the same right to use the atmosphere. In contrast to it, the 'acquired rights' criterion (or 'sovereignty principle') allocates emission rights according to the 'status quo' of emissions at a certain point in time. The 'polluter-pays' principle states that the producers of emissions are themselves responsible for emissions mitigation. Hence, the more a country pollutes, the more it has to contribute to pollution abatement. Finally, the ability-to-pay principle takes into account the economic potential of a country. Accordingly, the wealthiest nations should contribute most. An important aspect of equity consideration is the time frame, because the amount of greenhouse gas emissions in the atmosphere is a stock variable with a very low rate of decay (Perman et al., 2003).

[6] Please note the current debate on equal rights and emissions per capita initiated by the German chancellor Merkel on her visits in China and Japan (September 2007)

2.1.1.3 Political acceptability

An economically efficient solution is useless if it is not politically acceptable. National governments claim their sovereignty and again, the agreement should be considered as “fair”. In order for the agreement to be accepted it must meet the preferences of the majority of the participating countries. In terms of political economy, this condition would be fulfilled when the proposal meets the preferences of the ‘median voter,’ unless unanimity is necessary (e.g. Blankart, 2002). Moreover, national governments are generally not willing to give up their decision sovereignty in favour of European community policy.

2.1.1.4 Environmental effectiveness

According to environmental effectiveness, the environmental quality target, i.e. the ‘cap’, should be consistent with a long-term target. The overall long-term climate target should be stated clearly in order to avoid unfavourable technology lock-in and grant investment security. The European Union attempts to increase the global mean temperature by 2°C in order to prevent the consequences of dangerous climate change.

2.1.2 Options

Phylipsen et al. (1998) discuss different burden sharing approaches that have been developed so far. The majority of them apply ‘top-down’ criteria in order to determine national emission reduction targets. ‘Top-down’ criteria regard the economy ‘from the top,’ applying aggregate indicators as, for instance, total emissions, total economic output (GDP), population, energy intensity or carbon intensity. They formulate general targets but do not consider how these aggregate data are composed in detail. In contrast to that, ‘bottom-up’ models regard the economy ‘from the bottom’ taking into account its composition, potentials and sectoral developments. The conflict of ‘top-down’ versus ‘bottom-up’ describes in general the different positions of climate policy makers in international climate negotiations.[7]

[7] This means in particular that the USA is rather in favour of bottom-up approaches vs. European climate policy prefers top-down targets. The United States prefer to consider emissions reduction potentials in order to avoid

2.1.2.1 Grandfathering

The simplest allocation rule is the grandfathering approach. It distributes emission rights at a uniform ('flat') rate, according to the countries' present emission levels (e.g. Grubler and Nakicenovic, 1994; Ridgley and Rijsberman, 1994). This method protects acquired rights as it is based on the 'sovereignty principle.' It cannot be perceived as 'fair,' as it neither considers equity principles, like 'equal rights' or 'polluter pays,' nor historical responsibility. Moreover, it does not account countries' different economic growth or emission reduction potentials. The result of a flat rate reduction is therefore less efficient and politically hard to accept. Despite its disadvantages, this approach can be easily implemented.

2.1.2.2 Per capita convergence

Another application would be a convergence approach of emissions per capita (e.g. Grubb, 1989; Grübler and Fuji, 1991; Ecofys, 2007). This approach assumes a common convergence level of emissions per capita to be reached in a certain convergence year. Corresponding to their convergence level, countries are either allowed to increase or reduce their emissions. This approach seems to be acceptable from an egalitarian point of view, reflecting each person's equal right to use the atmosphere, but it neither considers technological nor economic potential. Furthermore, the approach is hardly acceptable for a number of countries due to its strong distributive impacts.[8] From a macro-economic point of view, such a strong redistribution could exert a shock to the economy pushing it out of equilibrium. The consequence could be an economic recession in the developed countries that would affect developing countries, too. Figure 7 shows greenhouse gas emissions per capita in EU-15 countries in 1990. According to equal emissions per capita, countries like Luxembourg, Ireland and Germany would have to reduce emissions, whereas countries like Portugal and Spain were allowed to increase emissions.

---

welfare losses for the industry. European climate policy rather insists on binding overall reduction targets (UBA, 2007).

[8]On a global scale, this would mean convergence to emissions of 2 t CO_2-eq per capita, in order to avoid a temperature increase by more than 2°. (which assumes not more than 450 ppmv CO_2-eq in the atmosphere; Ecofys, 2007). Germany currently emits 12 t CO_2-eq per capita (see Figure 7).

2.1.2.3 Carbon intensity

In contrast to the per capita approach, burden differentiation could also be agreed on the convergence in carbon intensity levels of the countries' economies (Ridgeley and Rijsberman, 1994; ABARE, 1995). Carbon intensity relates CO_2-emissions to the gross domestic product (GDP) of an economy. Hence, the more CO_2 per unit of GDP an economy emits the more it should reduce. This GDP-based approach could be considered 'fair' as it generates equal welfare losses. However, it would not be acceptable to countries with low GDP as it is maintaining the 'status quo' of welfare distribution: 'high GDP-countries were allowed higher emissions' (Phylipsen et al., 1998). Figure 8 shows the greenhouse gas intensities of EU-15 countries in 1990. Following this approach, countries like Greece, Ireland and Luxembourg would have to reduce their emissions whereas countries like Sweden, Austria and France were allowed to increase their emissions.

2.1.2.3 Multi-criteria convergence

After discussing emissions per capita and carbon intensity, the conclusion of the two approaches is to combine those criteria in a multi-criteria approach (Ringius and Torvanger, 1997). Top-down indicators such as emissions per capita, emissions per unit of GDP, or GDP per capita could consider national circumstances, such as population, GDP, carbon intensity, temperature and land area (Phylipsen et al., 1998). By applying this model, the choice of the weighting factors is critical as they can heavily influence the final results. Hence, the acceptability of such model strongly depends on its results.

2.1.2.4 Equal mitigation costs

Models referring to 'equal abatement costs' or 'equal welfare losses' distribute the economic burden of emission reduction equally over all countries relative to their GDP. Hence, the share of abatement costs as percentage of GDP would be the same for each country. They would be preferred in economic theory, but their application requires a large amount of data. Their compliance and monitoring would be difficult to maintain, and historic responsibility would not be considered.

2.1.2.5 Bottom-up models

In contrast to the aggregated top-down modelling approaches, bottom-up models take into account specific national reduction potentials and particular national circumstances (Grubb, 1996; Blok et al. 1997; Phylipsen et al., 1998). A well-known sectoral bottom-up model is the Triptych approach, which became the framework for greenhouse gas burden sharing in the 'EU bubble' under the Kyoto protocol (see section 2.2). Table 1 lists some of these burden sharing options evaluated by the introduced criteria.

Table 1 Options for greenhouse gas burden sharing agreements

Criteria	Environmental effectiveness	Economic efficiency	Political acceptability	Equity	Simplicity of implement.
Grandfathering	0	-	0	-	++
Per capita convergence	0	-	0	+	++
Multi-criteria convergence	0	-	+	++	+
Equal mitigation costs	0	+	0	+	-
Triptych	0	0	+	++	-

++ very good, + good, 0 intermediate, - poor
Source: Sijm et al. (2007)

2.2 The Triptych approach

2.2.1 Model explanation

The Triptych approach is a sectoral bottom-up model, developed by Blok, Phylipsen and Bode at Utrecht University in 1997 (Blok et al., 1997; Phylipsen et al., 1998). It was developed under the Dutch presidency of the European Union in order to calculate the burden sharing targets for the EU members under the Kyoto Protocol. The model originally proposed an overall emission reduction target of 13 per cent for the EU-15. However, this target was reduced in the negotiations to 8 a per cent emission reduction for the whole European Union. The Triptych model distinguishes three economic sectors: the power producing sector, the internationally oriented heavy industry, and the domestic sectors. For each sector, specific exogenous assumptions are made in order to calculate the sectoral allowances with a sectoral objective function. These sectoral allowances add up to the total allowance in the overall objective function of the model:

$$A_{total} = A_{power} + A_{heavy\ industry} + A_{domestic} \quad (1)$$

The total allowance is the national emissions target for the EU member state within the burden sharing agreement. This approach was the basis for the Kyoto negotiations. In the original Triptych version, only energy-related CO_2-emissions were considered.[9]

Table 2 The Triptych model

Triptych model: 3 sectors		
Power Producing Sector	**Heavy Industry**	**Domestic sectors**
Electricity production	Iron and steel, building materials, non-ferrous metals, non-metallic minerals, chemical industry, pulp and paper, energy transformation, coal mining, oil and gas extraction, coke ovens, petroleum refining	Light industry, services, agriculture, households, transportation
Sectoral allowance	Sectoral allowance	Sectoral allowance
National allowance		

Source: Phylipsen et al. (1998)

Table 2 shows the three sectors of the Triptych model adding up to the national allowance. Provided the different exogenous assumptions, the model is designed to consider national circumstances, such as fuel mix, competitiveness considerations, the ability-to-pay principle, and costs considerations (Phylipsen et al.). The assumptions underlying each sector and the derived model equations will be discussed in the following section.

[9] Groenenberg et al. (2001, 2002), Höhne et al. (2003) and Phylipsen et al. (2004) developed ‚Global Triptych,' ‚Global Convergence Triptych,' ‚Extended Global Triptych' and 'Triptych 6.0'as extended versions of the Triptych model. Furthermore, the Triptych methodology is applied in the Fair 2.0 emission allocation model (RIVM, 2003).

2.2.2 The power producing sector

In the power producing sector, the partial emission allowances for each fuel add up to the sectoral allowance for this sector:

$$A_{power} = A_{solid} + A_{liquid} + A_{gas} + A_{CHP} \quad (2)$$

In order to calculate partial allowances, two steps must be taken. First, the modelled amount of electricity production by fuel is divided by its corresponding generation efficiency. Second, the resulting primary energy use is multiplied with the corresponding emission factor in order to obtain CO_2-emissions. The applied formula and the assumptions made on emission factors and generation efficiency are explained in Annex 8.2. The power producing sector consists merely of electricity production. Neither heat production nor other greenhouse gases than CO_2 are included. The particular reason for modelling the electricity sector is to model the countries' fuel mix. In the Triptych model, specific assumptions are made on each country's electricity production and fuel mix in 2010:

1.) According to the level of economic development, total electricity production is assumed to grow by an annual rate of 1.9 per cent in the Cohesion Fund countries, and by 0.9 per cent p.a. in other countries. Hence, the Cohesion Fund countries are expected to show higher economic growth rates than other EU members.
2.) The share of solid fossil fuel is expected to decline to 50 per cent of 1990 levels in Germany, 65 per cent in the UK and Denmark, and 70 per cent in other EU countries.
3.) Liquid fossil fuels are assumed to decline to 70 per cent of 1990 levels in all countries.
4.) The share of renewable energy is supposed to increase to 8 per cent of electricity production in 1990 over the capacity of renewable energy already in place in 1990.
5.) 15 per cent of total electricity production in 2010 will be generated with combined heat and power (CHP).
6.) The use of nuclear power is assumed according to the data reported in the 'Conventional Wisdom Scenario' of the European Commission (Blok et al., 1997; see Annex 8.2).
7.) The remainder of electricity production is filled by natural gas.

The base year for the calculations is 1990. For the simulations, electricity input data by fuel was taken from the ‘Electricity Information 2006’ (IEA, 2006).

2.2.3 The heavy industry

The heavy industry sector includes the internationally oriented heavy industry, i.e. iron and steel production, building materials, non-ferrous metals, non-metallic minerals, chemical industry, pulp and paper, energy transformation, coal mining, oil and gas extraction, coke ovens and petroleum refining. In order to calculate the sectoral target, only energy-related, not process-related, CO_2-emissions are considered. The model assumes production growth rates of 2.1 per cent p.a. for Cohesion fund countries and 1.1 per cent p.a. for other EU countries taking into account the different potentials of economic growth. Furthermore, the model assumes an annual efficiency improvement of 0.7 per cent p.a. until 1995 and 1.5 per cent p.a. between 1996 and 2010 for each country. In addition, an annual decarbonisation rate of 0.17 per cent is assumed for fuels for all countries. The emission allowance A_{Ind} for this sector is the product of the initial emissions E_{Ind} in 1990, the growth factor (1+g), the efficiency factors (1-e_x, x = 1, 2), and the decarbonisation factor (1-d) to the power of the corresponding number of years:

$$A_{Ind,t} \quad = \quad E_{Ind,1990}(1+g)^{t-1990}(1-e_1)^{1995-1990}(1-e_2)^{t-1995}(1-d)^{t-1990} \quad (3)$$

t (t > 1990) is the projection year, and e_1 and e_2 indicate the different levels of efficiency improvement. The base year for the calculation is 1994 for Germany and 1990 for the other EU members.[10]

The input data was taken from the ‘National Inventory Reports’ to the UNFCCC (2007). Energy related CO_2-emissions of the categories listed in Table 24 are added (see Annex 8.3).

[10] 1994 was chosen as base year for Germany in order to consider the shut-down and renovation of industrial facilities resulting from the German reunification.

The light industry was excluded from category I.A.2f 'other non-specified,' applying the industry shares reported by Phylipsen et al. (1998).[11]

2.2.4 The domestic sectors

The third sector covers the domestic sectors, i.e. transport, households, commercial, agriculture and the light industry. For this sector, the model assumes linearly converging emissions per capita among EU members by 2030. The convergence level for this sector is 3 t CO_2 per capita in 2030, which is 30 per cent below the EU average in 1990. Figure 2 illustrates the idea of per capita convergence to a common convergence level in 2030. Each graph sketches a country's path of emissions per capita moving from the base level in 1990 to the common convergence level in the year 2030. For the 2005 simulation, emissions per capita are calculated by linear interpolation.

$$CO_{2\,pc,t} = CO_{2\,pc,1990} - \frac{t-1990}{2030-1990}(CO_{2\,pc,1990} - CO_{2\,pc,2030}) \quad (4)$$

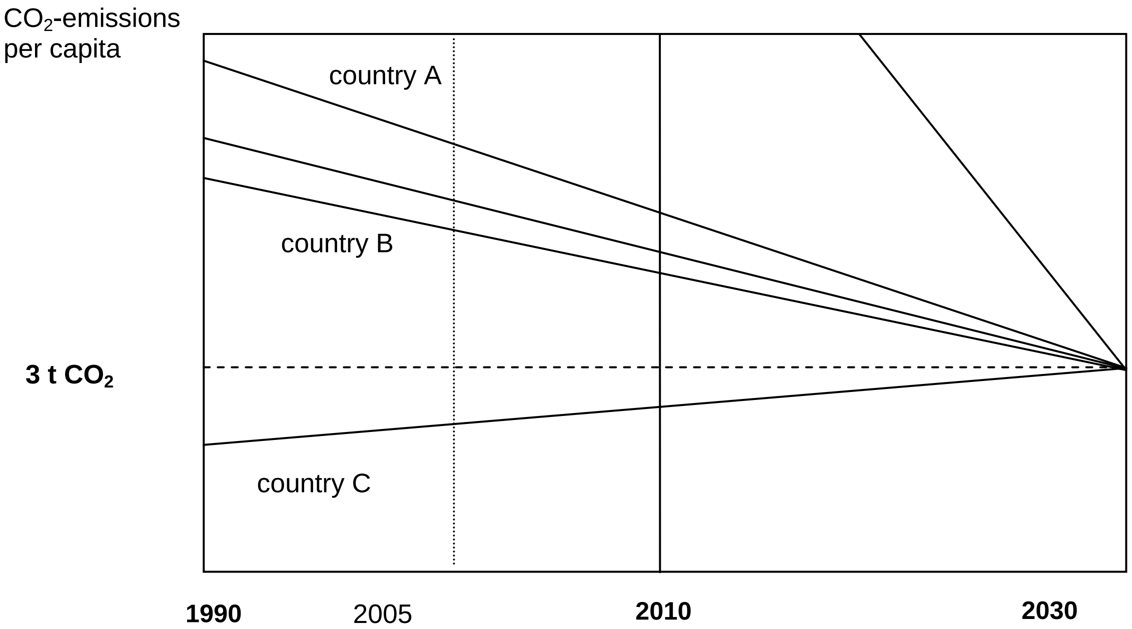
The sectoral allowance in year t (t > 1990) is calculated by multiplying the per capita allowance with current population projection figures.

$$A_{dom,t} = CO_{2\,pc,t}\ POP_t \quad (5)$$

A climate correction could be applied by multiplying the country's per capita allowance with its ratio of degree days to the EU average. However, only heating days were available. Hence, in this study, heating days and cooling days are assumed to balance each other. Input data for 1990 was taken from the UNFCCC (2007; see Table 25 in Annex 8.4), and population data was taken from Eurostat (2007).

[11] In the original Triptych version, Phylipsen et al. (1998) used data from the European Communication to the UNFCCC in 1996. In order to separate the heavy from the light industry, they applied industry shares of 1992 reported by Capros et al. (1995).

Figure 2 Sketch of convergence of CO_2 per capita in the domestic sectors

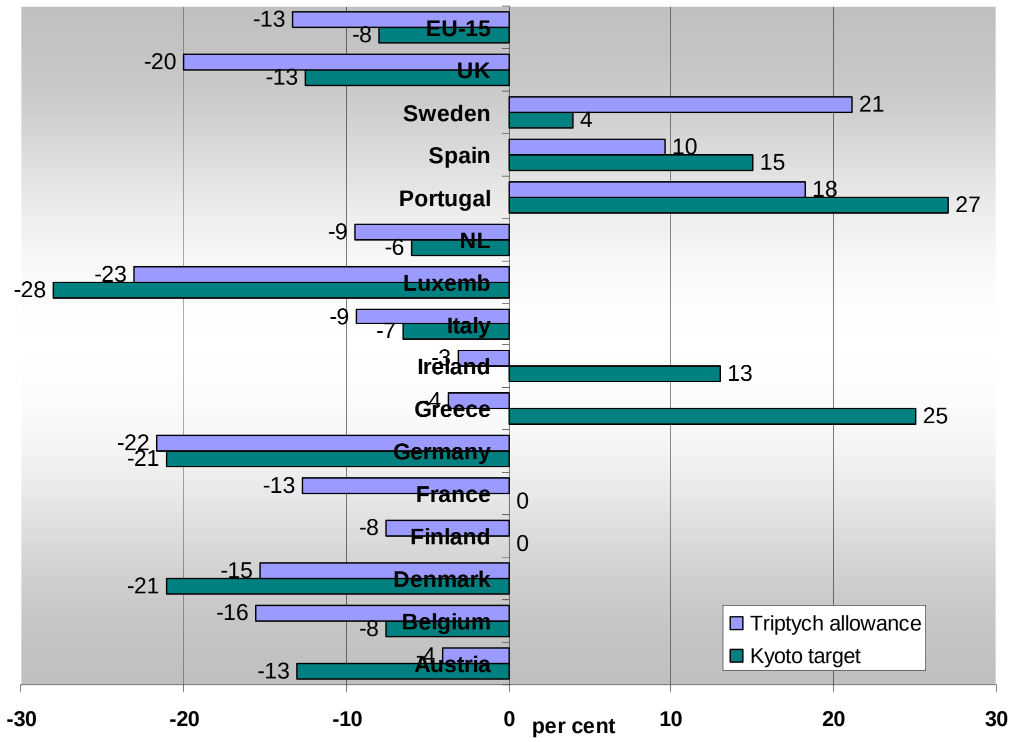


Source: Phylipsen et al. (1998)

2.2.5 Model results

The burden sharing results calculated in the original Triptych version from 1997 assumed a European reduction target of 13 per cent. Figure 3 compares the absolute reduction targets of energy-related CO_2-emissions calculated by Triptych in 1997 to the finally negotiated Kyoto targets of greenhouse gas reduction. During the Kyoto negotiations, the overall EU target had been negotiated to 8 per cent greenhouse gas emission reduction by 2010. The comparison of the national Kyoto targets to the emission allowances calculated by Triptych shows that the finally negotiated allowances differ from the original proposal. Actually, the UK, Spain, Portugal, the Netherlands, Italy, Ireland, Greece, Germany, France, Finland and Belgium negotiated less stringent emission reduction targets, whereas Sweden, Luxembourg, Denmark and Austria committed to more ambitious reduction targets than proposed by Triptych. The goal of the following chapters is to analyse the validity of the Triptych model. Hence, only the Triptych allowances based on energy-related CO_2-emissions are considered, not the negotiated Kyoto targets.

Figure 3 Simulated Triptych allowances compared to Kyoto targets of EU-15 in per cent



Source: EEA (2006), Phylipsen et al. (1998)

3 Case studies

In this chapter, three country case studies are presented in order to compare the actual emission paths of those countries to the developments assumed in the Triptych approach. Therefore, real data are compared to interpolated model results for 2005. The aim is to find reasons for the different developments of emission paths within the European Union, and to evaluate the validity of the Triptych model assumptions. Moreover, simulation results for 2020 are calculated within the Triptych framework but under improved assumptions. Germany, almost meeting its target, the United Kingdom, exceeding its emission target, and Spain, failing its target, were chosen for the three case studies. First, this chapter gives an overview of the EU-15 countries, second, the case studies are presented, and finally, the results are concluded.

3.1 The EU-15

3.1.1 Economy

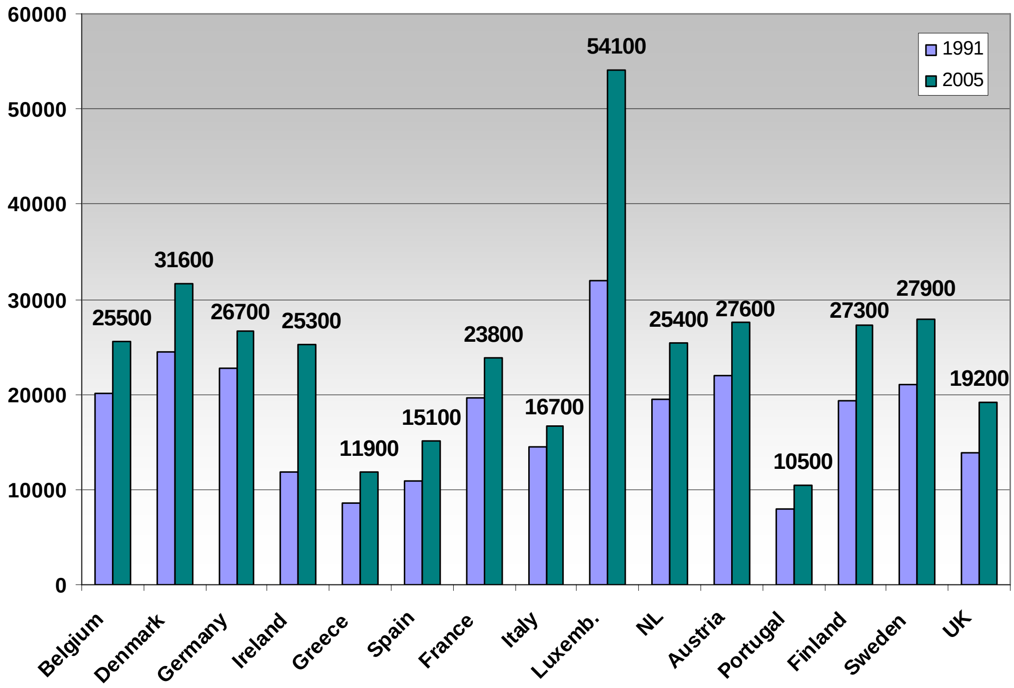
In 2005, the total population of the EU-15 countries was 388 million people. The most populated country is Germany with 82 million people, followed by France, the United Kingdom, and Italy with around 60 million inhabitants each (Eurostat, 2007). In 2005, the gross domestic product (GDP) produced in EU-15 was 8,359 €$_{1995}$.[12] The major economy is Germany, producing more than one quarter of the GDP of EU-15. It is followed, by France (18 per cent), the United Kingdom (14 per cent), and Italy (12 per cent). In terms of GDP per capita, Luxembourg is the wealthiest country in Europe. The lowest living standards are found in Portugal, Greece and Spain, as former Cohesion Fund countries, and Italy (Eurostat, 2007). Figure 4 illustrates the development of living standards, expressed in GDP per capita, in EU-15 member states between 1991 and 2005.[13] Ireland and Luxembourg showed the highest growth rates of GDP per capita by 5 per cent p.a. The average annual growth rate of GDP per capita in

[12] €$_{1995}$ are (real) Euros measured in prices and exchange rates of 1995.

[13] Data of 1991 were used for comparison since no data was reported on GDP per capita for Germany, Portugal and Spain in 1990.

EU-15 countries was 2 per cent per year. In 1990, the largest economic sector in all states was the tertiary sector, accounting for approximately two thirds of value added.

Figure 4 GDP per capita in EU-15

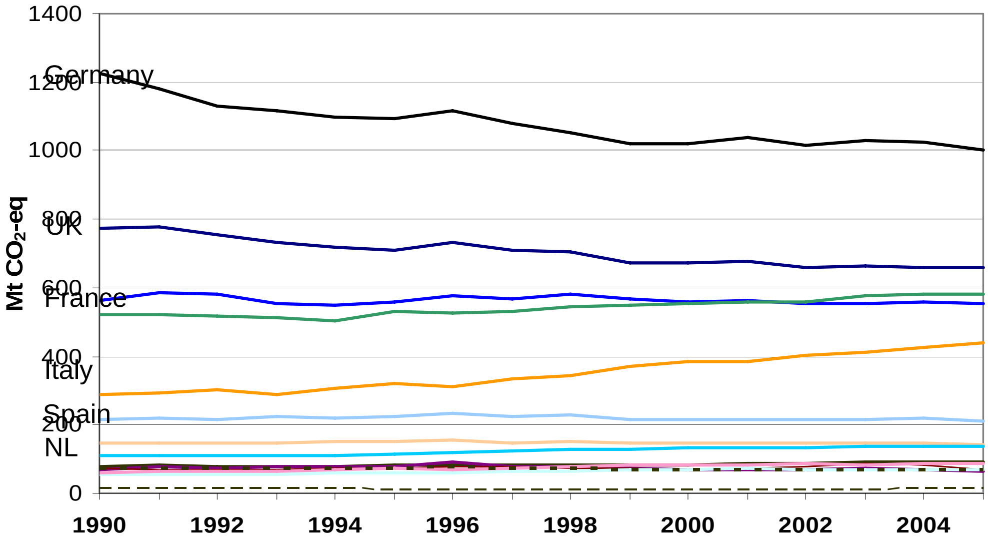


Source: Eurostat (2007)

3.1.2 Emissions situation

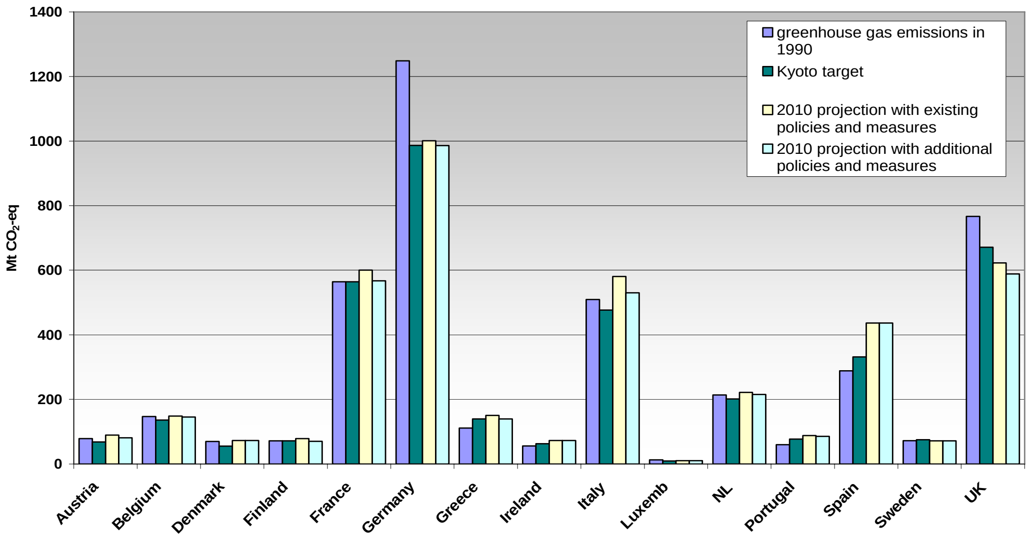
Figure 5 draws the total greenhouse gas emissions of EU-15 members between 1990 and 2005. Germany is by far the greatest emitter in Europe, followed by the United Kingdom, France and Italy. Spain is an emerging emitter in the EU.

Figure 5 Greenhouse gas emission paths of EU-15 countries from 1990 to 2005



Source: EEA (2007)

Figure 6 Total greenhouse gas emissions in EU-15 countries in 1990, Kyoto targets and projections for 2010[14]



Source: EEA (2006)

[14] 'With additional policies and measures' includes the use of additional measures, the flexible mechanisms of the Kyoto Protocol and carbon sinks. For France, Germany, Greece, Luxembourg, Sweden and the United Kingdom the use of flexible mechanisms was not reported. Germany, for instance, wants to renounce on the use of flexible mechanisms during the first commitment period (2008-2012).

Figure 1 and Figure 6 compare the total greenhouse gas emissions of EU-15 countries in 1990 to their Kyoto targets in 2010. Luxembourg (-28 per cent), Denmark and Germany (-21 both) have committed to the most ambitious emission reduction targets, followed by the United Kingdom (-13), Austria (-13), Belgium (-8), Italy (-7) and the Netherlands (-6). The Cohesion fund countries, Portugal (+27), Greece (+25), Spain (+15) and Ireland (+13) were allowed to increase their emissions by 2012, allowing for increased economic growth. Sweden (+4), France and Finland (0 both) negotiated less stringent emission reduction targets for 2012. Referring to current projections, the United Kingdom and Sweden will be the only countries surpassing their targets. Germany will almost reach its target, while all other members will not reach their targets.

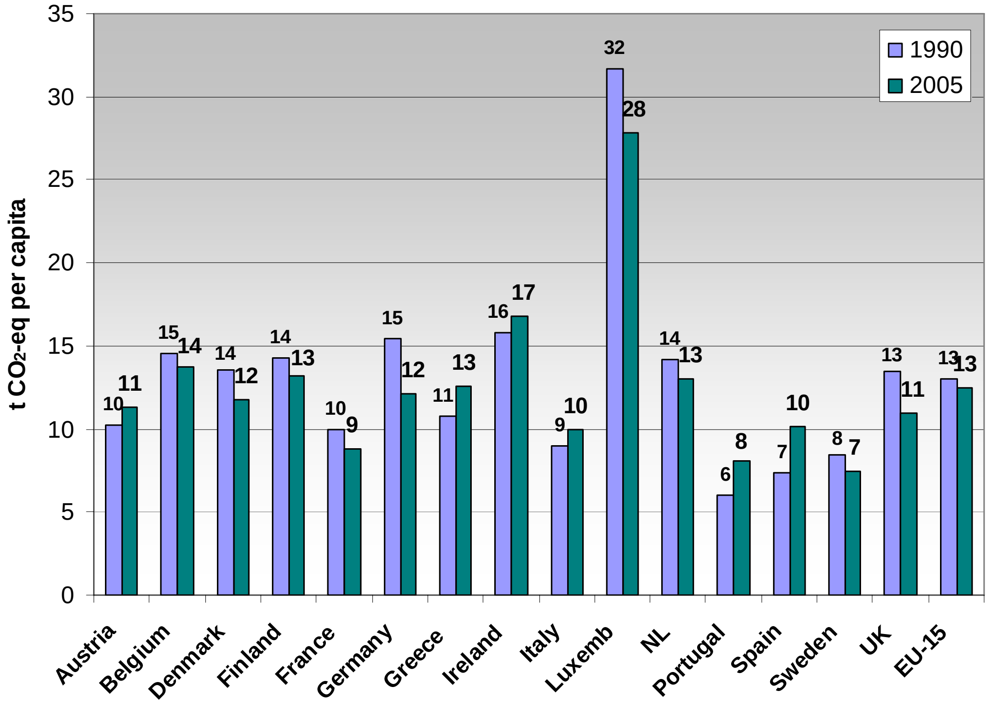
The greatest deviations from the Kyoto targets in percent can be observed for Spain (+36), Austria (+28), Denmark (+25), Italy (+21), Portugal (+19) and Ireland (+17). Also Finland (+10) and France (+6) would exceed their zero emission reduction targets. The EU-15 is far from reaching its total reduction target of -8 per cent under existing policies and measures, referring to the current projection of only -0.6 per cent.[15]

These numbers can be put into perspective by relating them to the countries' population or gross domestic product (GDP). Figure 7 and Figure 8 relate greenhouse gas emissions to population size and economic output (GDP). In 1990, Luxembourg, Germany and Ireland were the greatest emitters per capita. They emitted more than 15 t of CO_2-eq per inhabitant.[16] By 2005, one observes convergence in emissions per capita in EU-15. On the one side, wealthier countries with relatively high emissions per capita, like Luxembourg, Germany, Belgium and the Netherlands, tended to decrease their emissions per capita. On the other side, less developed countries with rather low per capita emissions in 1990, as Greece, Portugal and Spain increased emissions per capita, by 2005.

[15] The picture changes when looking at the 2010 projections with additional policies and measures and the use of the Kyoto Protocol's flexible mechanisms: Luxembourg, the United Kingdom, the Netherlands, Finland and Sweden would exceed their targets, while Germany is expected to reach its reduction target. The EU-15 would meet its overall reduction target of -8 per cent with the use of additional policies and measures and the flexible mechanisms of the Kyoto Protocol.

[16] In particular Luxembourg emitted an extraordinary sum of 32t CO_2-eq per capita in 1990 (28t in 2005). This can be explained by its small population size of less than half a million inhabitants or correspondingly, its high GDP per capita

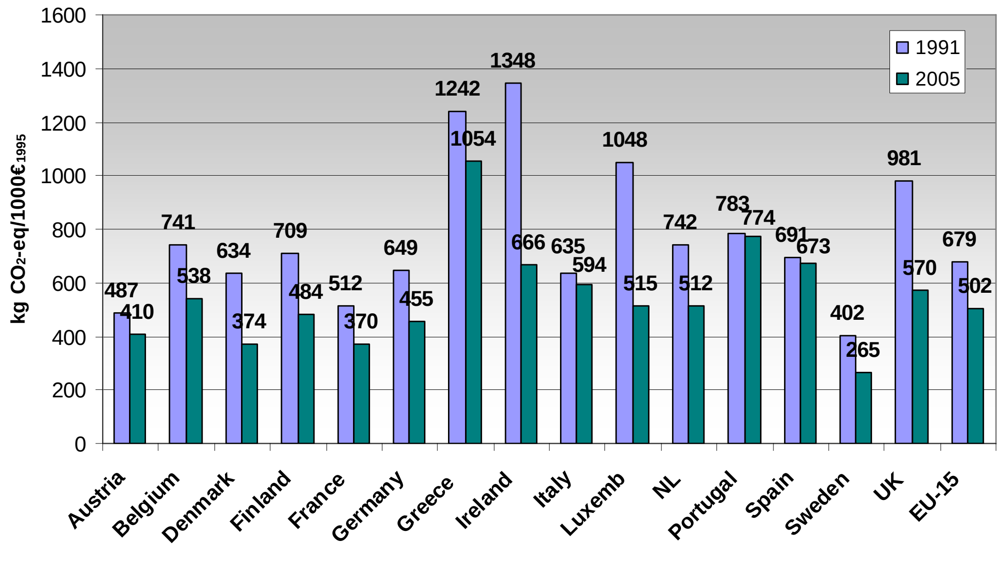
Figure 7 Greenhouse gas emissions per capita in EU-15



Source: EEA (2007), Eurostat (2007)

In 1990, the greatest emitters per unit of GDP were Ireland, Greece and Luxembourg with more than 1 t CO_2-eq per 1000 $€_{1995}$. By 2005, all EU members have decreased their greenhouse gas intensities, i.e. the ratio of emissions per unit of GDP. Ireland, Luxemburg and the United Kingdom made the greatest efforts by reducing up to 50 per cent of their greenhouse gas intensities.

Figure 8 Greenhouse gas emissions per unit of GDP in EU-15



Source: EEA (2007), Eurostat (2007)

The primary reason for decreasing energy intensity in some countries is their fuel mix. High shares of nuclear power, as for instance, in France (41 per cent of gross energy consumption in 2005), or renewable energy, as in Sweden (35 per cent nuclear power and 30 per cent renewable energy of gross energy consumption in 2005; EC, 2006), determine significantly the greenhouse gas intensity of a country. Furthermore, economic productivity and energy efficiency are important indicators for these different emission paths (Figure 5). However, other factors like energy and climate policy, the sectoral economic development or the environmental attitude of the population may play a significant role, too. The three case studies, presented in the main part of this work, aim to explain these different developments. For this purpose, three countries with different emissions and economic situation were chosen. On the one side, Germany and the UK, starting from a relatively high level of economic development and greenhouse gas emissions, on the other side, Spain, starting from a relatively low level of economic development with low per capita emissions in 1990, are considered. The United Kingdom and Germany exhibit decreasing emissions, while showing moderate economic growth. Spain exhibits increasing emissions and relatively high rates of economic growth.

3.1.3 EU climate policy

The European Commission has set ambitious climate policy goals with an overall greenhouse gas reduction target of at least 20 per cent by 2020 compared to 1990 emission levels.[17] Given significant reduction efforts of other countries, the EU is considering a total emissions reduction of 30 per cent by 2020 (BMU, 2007). Furthermore, the European Commission attempts to increase its share of renewable energy in gross inland energy production to 20 per cent by 2020.[18] Moreover, the EU wants to increase its energy efficiency by 20 per cent by 2020 compared to 1995 levels. In order to achieve these ambitious climate policy targets a new burden sharing agreement for the 27 EU members will be necessary as climate and energy policies are not harmonised between EU member states, yet. As climate change is a global public good, one must be aware of the potential prisoners' dilemma. The member states have an incentive to deviate from their commitments and to benefit from other countries' efforts. Therefore, co-operation and control are needed in order to avoid free riding. Based on the Triptych approach, the EU member states negotiated carefully highly differentiated emission reduction targets for the Kyoto Protocol. However, co-operation can be useless if there is no global enforcement mechanism. In light of this fact, the reasons for the strong deviations of some countries from their original emissions reduction targets are of interest in the three case studies described in the following section.

[17] The European Commission is the executive branch of the European Union. It consists of 27 Commissioners, one for each member state, and is currently led by José Manual Barroso, the Commission President. The work of the Commission is divided into departments, the Directorates-General (DG).

[18] Additionally, a target of 10 per cent biofuels and 18 per cent combined heat and power generation (CHP) shall be met by 2020 (The European Council on 9 March, 2007; BMU, 2007).

3.2 Germany

3.2.1 National circumstances

3.2.1.1 Economy

The Federal Republic of Germany (BRD) is the largest economy in the European Union with a real GDP of 2,200 billion $€_{1995}$ in 2005 (1,819 billion $€_{1995}$ in 1991). Germany's average economic growth was 1.4 per cent p.a. between 1991 and 2005 with negative growth rates in 1993 (-0.8 per cent) and 2003 (-0.2 per cent). Germany has the largest population in Europe with 82.4 million inhabitants in 2005. Germany's population has been decreasing since 2003 and is forecasted to shrink to around 70 million people by 2050 (Destatis, 2006). The German living standard, expressed in GDP per capita, rose by 22 per cent, from 21,900 $€_{1995}$ in 1990 to 26,700 $€_{1995}$ in 2005 (Eurostat, 2007). The German economy is a service economy with a growing service sector generating 69 per cent of value added in 2000. In contrast to that, value added in the German industry remained constant in absolute terms. The primary sector produced only 1.3 per cent of value added in 2000 (EC, 2006).

3.2.1.2 Energy

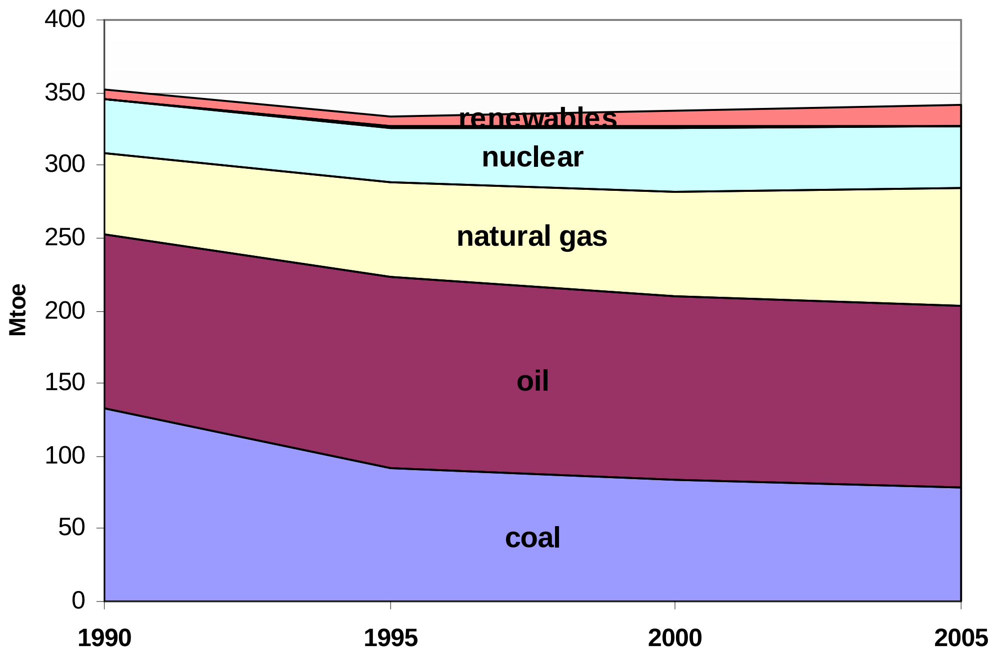
Germany's total primary energy supply (TPES) was 345 million tonnes of oil equivalents (Mtoe) in 2005. Total primary energy supply peaked in 1979 and was slightly decreasing until 2005.[19] Although Germany produces 70 per cent of its coal supply domestically, the overall import dependency of fuels is 62 per cent (IEA, 2007).[20] Figure 9 illustrates the fuel mix of gross inland energy consumption based on figures used for the PRIMES model in the European Commission's 'Energy and Transport – Trends to 2030.' The figure shows a significant decline in the use of solid fossil fuels between 1990 and 1995. By 2005, the use of natural gas and

[19] In 2005, 36 per cent of TPES was covered by oil, 24 per cent by coal, 23 per cent by natural gas, 12 per cent by nuclear power, and 5 per cent by renewable energy.

[20] The greatest share of imported fuels is oil accounting for 54 per cent of total net imports (124 Mtoe) in 2005 (EC, 2006).

renewable energy increased significantly. Hence, coal and oil were mainly substituted by natural gas and renewable energy.

Figure 9 Germany: Gross inland energy consumption by fuel



Source: EC (2006)

The decline in gross energy consumption until 1995 can be explained by Germany's reunification leading to the restructuring and modernisation of industrial facilities, particularly in the former German Democratic Republic (IEA, 2007). Thereafter, energy consumption remained almost stable. Sectoral analyses show that energy intensity in the industrial and tertiary sectors fell significantly to 81 per cent and 63 per cent of 1990 levels in 2005 (EC, 2006).[21] In contrast to it, energy intensity in the residential and transport sectors remained almost stable with only 97 per cent of 1990 levels each in 2005.[22] Gross energy consumption per unit of GDP decreased by 20 per cent between 1990 and 2005.

---

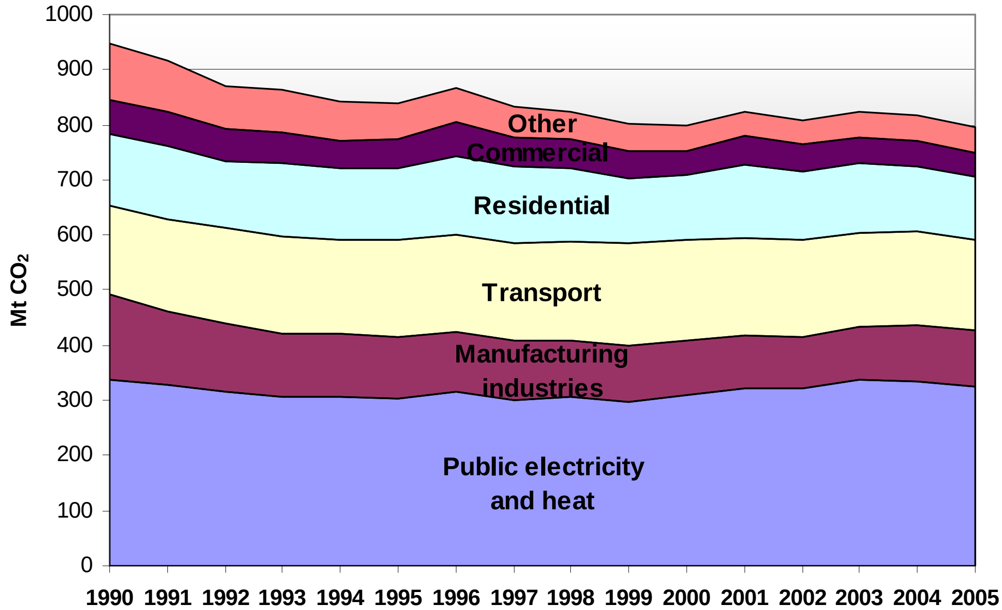
[21] Energy intensities were calculated in the following: industry and tertiary = energy on value added, residential = energy on private income, transport = energy on GDP (EC, 2006).

[22] Actually, absolute final energy demand decreased in the industry (-16 per cent) and tertiary sector (-13 per cent), whereas it increased in the residential (16 per cent) and the transport sector (17 per cent) from 1990 to 2005.

3.2.1.3 Emissions

Figure 10 illustrates the paths of energy-related CO_2-emissions by sector in Germany. The total energy-related CO_2-emissions dropped by 15 per cent from 1,032 Mt CO_2 in 1990 to 873 Mt CO_2 in 2005.

Figure 10 Germany: Energy-related CO_2-emissions by sector



Source: UNFCCC (2007)

In each sector, except transport, CO_2-emissions were reduced between 1990 and 2005. The emissions of the manufacturing industry were reduced by one third, emissions in the commercial sector dropped by 30 per cent, and the residential sector emitted 12 per cent less in 2005 than in 1990. In contrast to that, the transport sector shows slightly increasing emissions by 2005 with a peak in 1999 (UNFCCC, 2007; see Annex for details). Germany's CO_2-emissions per capita decreased from 12 t CO_2 per capita in 1990 to 10 t in 2005. However, the German standard of living, expressed in GDP per capita increased by almost 22 per cent between 1990 and 2005.

3.2.1.4 Climate policy

Germany's climate policy is implemented by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU. The Federal Environment Agency (UBA) has a consulting function in order to supply the Ministry and the public with background information. Other institutions influencing climate policy in Germany are non-governmental organisations (NGOs) like Greenpeace, WWF, Germanwatch and BUND. However, there is the strong group of power producers and manufacturing industry lobbying for less stringent climate policy measures.

Referring to a study investigated by the German Federal Environment Agency (UBA) in 2006, the German public shows a rather positive attitude towards the environment. Thereafter, 50 per cent of the respondents rank environmental protection as important issue, 67 per cent want Germany to be a leader in international climate policy, 87 per cent would prefer a consequent switch to renewable energy and almost all of them want more energy saving products. Environmental protection is on the second place of the most important problems behind unemployment (BMU, 2006).

This strong environmental attitude gives support to the German climate policy, which claims a leading position in international climate policy (UBA, 2007). The core of German climate policy is the 'National Climate Protection Programme' of 2000, which has been revised in 2005 and in 2007. Germany's current climate policy goal is an emissions reduction of 40 per cent by the year 2020 with 1990 as base year. Furthermore, the German government attempts to increase the share of renewable energy in electricity production to 12.5 per cent in 2010 and at least 20 per cent in 2020. The share of renewable energy in total primary energy supply should be 10 per cent in 2020. 6.75 per cent of total fuel consumption share should be met by biofuels in 2010 (IEA, 2007). Moreover, the National Climate Protection programme aims at doubling energy productivity by 2020 compared to 1990 levels. This would require an annual efficiency increase of 3 per cent. In order to achieve these ambitious goals, the government implemented the 'CO_2 Building Rehabilitation Programme', the 'Cogeneration Act' and the '2007 Energy Efficiency Action Plan.' Moreover, the 'Ecological tax reform' of 1999, the 'Renewable Energy Law' of 2000 and the 'Market Incentives Programme' are major policies already in place. Financial incentives for energy savings are provided by the ‘Eco tax.’ The ‘Feed-in tariff’ promotes the extensive deployment of renewable energy (see section 3.2.2).

3.2.2 The power producing sector

Referring to the IEA (2007), good energy policy consists of energy security, economic efficiency and environmental sustainability. Germany attempts to meet these claims with its key energy policies combining security of supply, affordable energy prices, effective environment protection and climate change mitigation. The central principle of German energy policy is to give market participants their individual responsibility and to create conditions in which market forces can lead to economic favourable results. Nevertheless, the liberalisation of the German electricity market has not been successfully completed, yet. The German electricity market consists of four major players, E.ON, RWE, EnBW and Vattenfall, producing 75 per cent of electricity. They own 70 per cent of electricity generating capacity and the whole electricity transmission system (IEA, 2007). This oligopoly structure of the German electricity market generates market imperfections inducing players to set prices over the level of perfect competition.

In this section, the simulated model results for Germany’s electricity sector are compared to data for the year 2005, currently reported by the IEA. The results are analysed in the discussion part. Finally, the results of a simulation for the year 2020 are presented and compared to recent simulations of Ökoinstitut et al. (2007).

3.2.2.1 Model results and analysis

In order to simulate model results for 2010, the same assumptions as those of the original Triptych model are made (see section 2.2.2). Linear interpolation was applied for simulating the emission allowance for 2005. The interpolated assumptions are summarised in the middle column of Table 4. Electricity input data for 1990 was taken from the ‘Electricity Information

2006' of the International Energy Agency (IEA, 2006; see left hand column of Table 3). In 1990, emissions from electricity generation were 322 Mt CO_2.[23]

Table 3 compares the simulated results of electricity production by fuel to the actual numbers of 1990 and 2005, reported by the IEA (2006). In comparison to 1990, the use of coal decreased by 5 per cent of 1990 levels, liquid fuels remained constant, and nuclear power increased by 7 per cent by 2005. Electricity production from natural gas increased by 60 per cent, and the use of renewable energy tripled between 1990 and 2005. Linear interpolation of the assumptions made in 2.2.2 yields the model results listed in the right hand column of Table 3.[24] Comparing these numbers, the actually produced amount of total electricity in 2005 was slightly lower than the electricity amount projected by the model (-1.6 per cent). The actual use of coal in Germany exceeds the model result by 52 per cent and oil combustion by 14 per cent. Although the use of natural gas has considerably increased since 1990, it reached hardly half of the predicted value. Electricity from combined heat and power (CHP) was slightly over the simulated amount for 2005. Finally, the use of renewable energy exceeds the model predictions by 30 per cent.

[23] This figure is lower than the 374 Mt reported by Phylipsen et al. (1998). However, applying the same procedure, CO_2-emissions from electricity generation in 2005 yield 293 Mt CO_2. This is exactly the same number that is reported by the German Federal Environment Agency (UBA). Hence, deviations to the numbers reported by Phylipsen et al. (1998) must be due to differences in accounting methodology between the IEA and the EC. Besides, because of the German reunification, it is generally difficult to get reliable data for 1990. The more current data is reported the more reliable it is.

[24] Linear interpolation assumes a linear development with constant derivatives. Exponential growth with decreasing or increasing derivatives is also possible in theory but is not assumed in this study.

Table 3 Germany: Electricity production by fuel, 2005: model results vs. real data

	Gross electricity production in 1990 (input data; IEA, 2006)		Gross electricity production in 2005 (IEA, 2006)		*Model results for 2005 (output data)*	
	PJ	%	PJ	%	*PJ*	*%*
Solid fossil fuels (coal)	1,159	59	1,101	49	*724*	*32*
Liquid fossil fuels (oil)	37	1.9	37	1.7	*33*	*1.5*
Natural gas	146	7.4	233	10	*524*	*23*
Renewables and waste	89	4.5	271	12	*208*	*9.2*
Nuclear power	549	28	587	26	*513*	*23*
Share of CHP[25]	-	-	*261*	*11.7*	*255*	*11.3*
Total electricity	1,980		2,228		*2,265*	

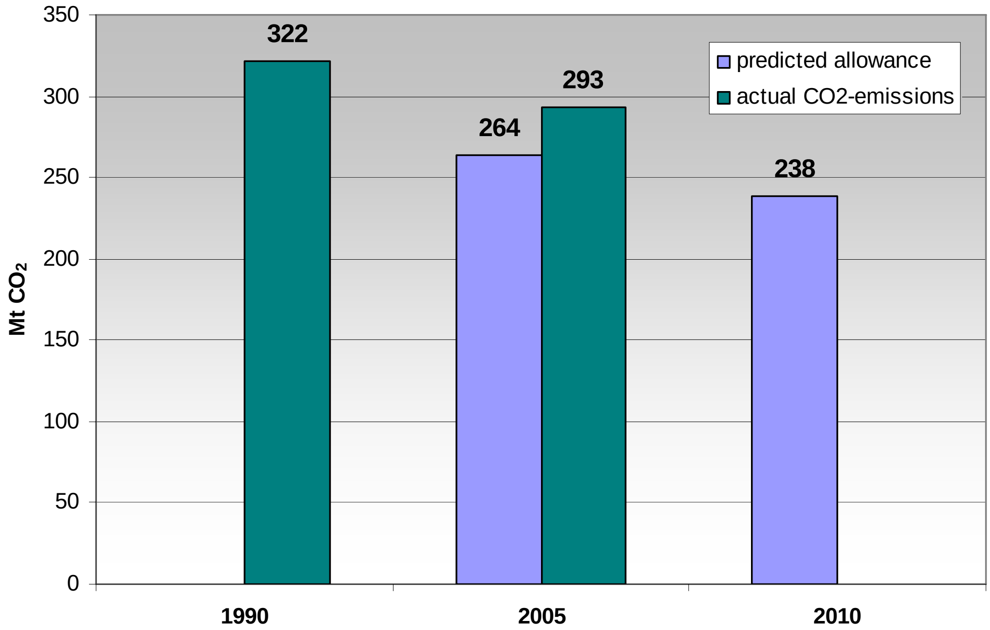
Source: IEA (2006), EC (2006), Phylipsen et al. (1998), *own calculations*

The application of the input data to the formulas noted in Annex 8.2 yields the sectoral emissions allowance of 264 Mt CO_2 for 2005. This is less than the actual CO_2-emissions of 293 Mt CO_2 from electricity production in the year 2005. Hence, the German power producing sector exceeded its predicted emissions for the year 2005 by 11 per cent. Figure 11 compares the emissions allowances predicted by the model to the actual emissions in 2005. The predicted allowance for the year 2010 is 238 Mt CO_2.

Table 4 compares the model assumptions made in 2.2.2 to the actual fuel shares reported by the IEA. The left hand column summarises the assumptions made in Triptych, the middle column shows the interpolated assumptions for 2005, and the right hand column presents the actual shares for 2005, based on IEA data (2006).

[25] The CHP indicator as percent of electricity from CHP was taken from EC (2006). In the model, the amount of electricity produced from CHP is included in total electricity production. In the actual figures, electricity produced from CHP is not included total electricity. CHP is reported as share of total electricity production.

Figure 11 Germany: Energy-related CO_2-emissions in the power producing sector vs. model results



Source: IEA (2006), own calculations

Table 4 Germany: Comparison of model assumptions and actual fuel mix of the power producing sector

Assumptions (shares in per cent)	Original Triptych assumptions for 2010	*interpolated assumptions for 2005*	2005 results reported by IEA (2006)
Annual growth in electricity production	0.9	*0.9*	0.8
Share of solid fuels based on 1990 levels	50	*62.5*	95
Share of liquid fuels based on 1990 levels	70	*77.5*	100
(Additional) share of renewable energy[26]	4.5+8%-points	*4.5+6%-points*	4.5+7.5%-points
	= 12.5	*= 10.5*	= 12
Share of CHP	15	*11.3*	11.7

Source: Phylipsen et al. (1998), IEA (2006), EC (2006), *own calculations*

[26] The result is the share of electricity produced from renewable energy in 2005, based on total electricity production in 1990.

Comparing the actual fuel mix in 2005 to the assumptions made in the model gives these results:

1.) The model assumptions on total electricity production in Germany fit very well. Total electricity production grew by 0.8 per cent annually. Thereby, two effects should be considered: On the one side, the rise in living standards since the German reunification in the eastern part of Germany, and the generally increased use of technical appliances may have led to an increase in electricity consumption. On the other side, the shutdown and renovation of industrial facilities in the former German Democratic Republic led to a decline of electricity consumption in Germany. In general, it is critical to use 1990 as base year for Germany. This is due to different accounting methods and the sustained change in economy and society. The economic structure, personal habits, preferences and the standard of living changed substantially after 1990, at least in East Germany. Hence, 1990 is no representative year for forecasting energy consumption in Germany in the 1990s.[27] However, although total electricity production increased less than assumed, the resulting CO_2-emissions exceed the predicted emissions allowance. The difference in fuel mix explains the emissions overshoot in Germany's power producing sector.

2.) In 2005, the expected decrease in the use of solid fossil fuels to 62.5 per cent of 1990 levels was not met at all. Instead, the use of coal combustion decreased by only 5 per cent, by 2005. The assumed bisection of solid fossil fuels by 2010 is far from reality in Germany. This result illustrates the discrepancy between Germany's ambitious climate policy goals on the one hand, and the intention of Germany's successful lobbying energy industry on the other. Chapter 5 shows that the allocation method of the First National Allocation Plan (NAP I) can be compared to a subsidy of fossil fuel combustion, favouring the 'status quo' of Germany's fuel mix. Another reason for this allocation could be energy security as Germany disposes of ample reserves of hard coal and lignite (IEA, 2007).

[27] Moreover, data from 1990 can be unreliable as there were different statistic and accounting methods used in the two former states. This results in inconsistent data and is the reason why statistics on 1990 were often reversed or readjusted later on (UBA, 2007). This should at least explain why the data for Germany reported by Phylipsen et al. (1998) differ from the data provided by the IEA (2006) and the UNFCCC (2007).

3.) Instead of the expected decrease to 77.5 per cent of 1990 levels, the use of liquid fuels in electricity production remained constant. This deviation is negligible, as electricity generation from oil combustion covers less than two per cent of Germany's fuel mix.

4.) The switch to gas assumed in the Triptych model did not take place in Germany. As gas combustion has lower emission factors and higher conversion efficiency than other fossil fuels, it was expected to substitute electricity generated from coal combustion and nuclear power. Although the use of natural gas increased by 60 per cent, it still holds a relatively low share in Germany's fuel mix accounting for 10 per cent only.

5.) The expected increase in the use of renewable energy by 6 per cent points of 1990 levels was exceeded by 1.5 per cent points in 2005. The success in the development and deployment of Germany's renewable energy technology is mainly due to Germany's 'Renewable Energy Law' (EEG) enacted in 2000 and amended in 2004. According to this law, the operator of renewable energy technology is rewarded by the government with a differentiated feed-in-tariff, which is guaranteed for 20 years (IEA, 2007).[28] This policy guarantees investor security and led thus to the strong increase in the use of renewable energy. Consequently, the share of renewable energy in gross electricity production grew from 3.4 per cent in 1990 to 10.4 per cent in 2005.[29] Neij et al. (2003) examined the learning process that takes place with the increased deployment of renewable energy technology. They found learning rates by 10 per cent for the German wind industry with. Continuing this development could make electricity generation from renewable energy technology competitive to conventional electricity production.

6.) The expected share of electricity from combined heat and power (CHP) of 11.25 per cent was well met with 11.7 per cent in the year 2005. However, there is no comparable measure promoting the use of CHP like the 'Renewable energy law.' More efforts could be made in order to exploit potentials for the use of CHP on a large scale.

[28] The tariff ranges from 3.8 €-cents per kWh for hydro power to 56.8€-cents per kWh for solar power. The exact amount depends on the duration of operation and the applied digression rates. Power producers are obliged to feed electricity generated by renewable energies into the electricity grid (IEA, 2007).

[29] This is 4.7 per cent of primary energy use in 2005 (BMU, 2007).

3.2.2.2 Model simulations for the year 2020

In the following, two possible scenarios are developed for the year 2020. The different scenario results are compared to the projections reported by Öko-Institut et al. (2007) in the 'Policy scenarios for climate protection IV.' On the one hand, a rather pessimistic but probably more realistic scenario based on recent information on the future German fuel mix, is developed. This is the 'Energy industry' scenario. On the other hand, an ideal 'Climate policy scenario,' based on current climate policy objectives, is developed, too.

On the Conference of Ministers in Meseberg on 23 August, 2007, the German government adopted the 'Integrated Energy and Climate Programme.' It contains a long agenda of policies and measures aiming to reach the current national climate policy goal of a greenhouse gas reduction of 40 per cent by 2020 based on 1990 levels. Two of the objectives mentioned in the programme are a share of 25 per cent of renewable energy and 25 per cent CHP of total electricity production by the year 2020 (BMU, 2007).

Considering these goals, the assumptions, listed in the left hand column of Table 5, are made in the 'Climate policy scenario' for 2020.[30] The base year for the calculations is 2005. These rather ambitious assumptions yield 231 Mt CO_2 emissions for 2020. This would be 21 per cent less than the currently produced CO_2-emissions in 2005 (293 Mt).

[30] Referring to the policies proposed in Triptych, the use of coal combustion is supposed to shrink to 70 per cent of 1990 levels. The use of oil is supposed to shrink by 20 per cent of 1990 levels, because it is expected to decrease further (UBA, 2007). Higher generation efficiencies of fuels are expected for 2020. Generation efficiencies of 43 per cent for solid and liquid fuels and 55 per cent for gaseous fuels are assumed. The emission factors of fuels remain constant.

Table 5 Germany: Comparison of the assumptions made for 2020 and simulation results

Assumptions	*'Climate policy' scenario*	*'Energy industry' scenario*	Öko-Institut et al. 'with measures'[31]
Annual growth in electricity production (%)	*- 0.1*	*+ 0.5*	0
Share of solid fuels based on 1990 levels (%)	*70*	*110*	94
Share on liquid fuels based on 1990 levels (%)	*20*	*20*	-
Share of renewable energy in 2020 (%)	*25*	*22*	22
Share of CHP in 2020 (%)	*25*	*9.8*	9.8
Simulated CO_2-emissions in 2020 (Mt CO_2)	*231*	*318*	318

Source: Öko-Institut et al. (2007), *own calculations*

In contrast to Germany's current climate policy goals, recent information suggests that at least 25 new coal fired power plants are currently planned in Germany (UBA, 2007; BUND, 2007).[32] They would emit around 140 Mt CO_2 per year (BUND, 2007). Consequently, internal estimations of the German Federal Environment Agency suggest a net[33] increase of electricity generated by coal fired power plants to 117 per cent of 1990 levels by 2020 (UBA, 2007).[34] Provided this information, the 'Energy Industry' scenario assumes increasing coal combustion to 110 per cent of the 1990 level. Moreover, 0.5 per cent annual growth of electricity production is assumed, with 2005 as baseline. For renewable energy and combined heat and power (CHP), the same assumptions as reported in the 'Policy Scenarios IV' are made (see middle column of Table 5). These rather realistic assumptions yield 318 Mt CO_2-emissions in

[31] The ,with measures'-scenario of Öko-Institut et al. assumes almost stable electricity consumption in 1990 (550 TWh), 2000 (557 TWh) and 2020 (558 TWh). There is a peak in 2010 (570 TWh). The use of oil is not reported explicitly.

[32] However, the exact number of currently planned power plants is unknown as there is no central authority regulating the amount of operating power plants in Germany (except for nuclear power because of the nuclear phase-out law). For building a new power plant, the operator only needs admission from the corresponding local authority, i.e. the municipality.

[33] 'net' considers the currently known decommissioning of coal fired power plants

[34] This scenario assumes that all power plants being currently planned were admitted.

2020. Öko-Institut et al. (2007) report the same amount of emissions for 2020 in their 'with measures'-scenario of 'Policy Scenarios IV' though assuming a different fuel mix.[35]

3.2.3 Heavy industry

In this section, the assumptions made in the Triptych model are used in order to simulate the emissions allowance for the heavy industry in 2005. This simulated result is compared to current data reported by the UNFCCC (2007). Furthermore, a simulation for the year 2020 that was calculated under adjusted assumptions is presented at the end of this section.

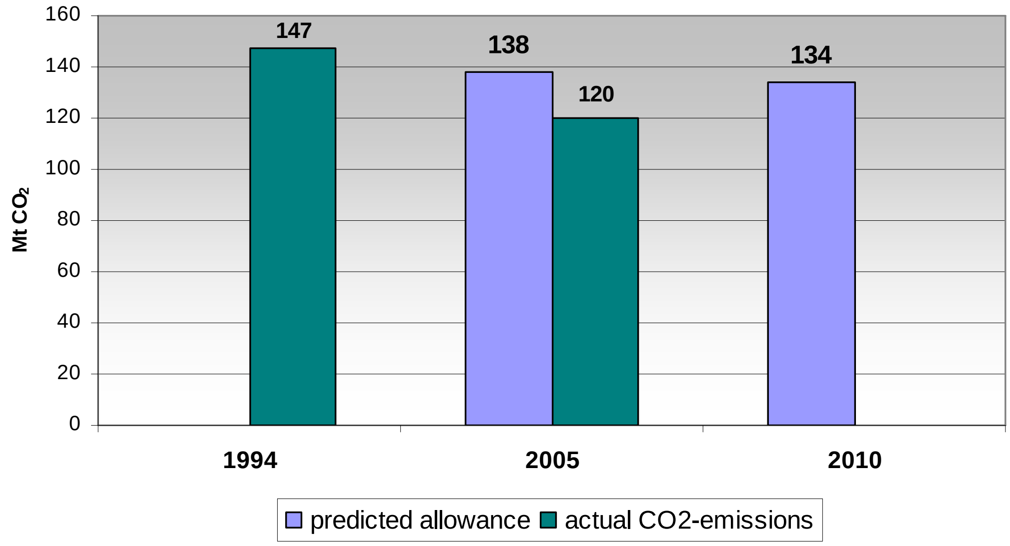
3.2.3.1 Model results and analysis

For calculating the partial allowances for 2005 and 2010, the assumed productivity growth rate, the efficiency improvement rate, and the decarbonisation rate are applied to the objective function (3) in section 2.2.3 (see Table 6 for assumptions). The emissions input data of the heavy industry is taken from the German National Inventory, reported to the UNFCCC (2007, see Annex 8.3). The sum of these emissions yields 147 Mt CO_2 in 1994.[36] 1994 was selected as particular base year for Germany in order to take into account the large efficiency gains resulting from the German reunification. Actually, energy-related emissions of the heavy industry decreased by 26 per cent between 1990 and 1994.

[35] The 'Energy industry scenario' predicts an increase in electricity production to 668 TWh, whereas Öko-Insitut predicts only 558 TWh in 2020. Actually, Germany's electricity consumption was 613 TWh in 2005 which is more than 11 per cent over the 1990 level (IEA, 2007). This difference would make Germany a net electricity exporter mainly exporting electricity from coal combustion.

[36] This is 20 Mt less than Phylipsen et al. (1998) reported in their paper. Yet, it is likely that the data available to Phylipsen et al. (1998) in 1997 was different to the data reported in 2007.

Figure 12 Germany: Energy-related CO_2-emissions in the heavy industry vs. model results



Source: UNFCCC (2007), own calculations

Figure 12 compares the predicted emission allowances for the heavy industry to the CO_2-emissions reported to the UNFCCC (2007). The model predicts an allowance of 138 Mt CO_2 for 2005. The real values are already below this number with 120 Mt CO_2 reported for 2005. The predicted allowance for 2010 is 134 Mt CO_2.

Germany's heavy industry emitted 15 per cent energy-related CO_2-emissions less than predicted by the model. Table 6 compares the assumptions made in the Triptych model to the current economic development reported by Eurostat (2007) and the European Commission (EC, 2006). Value added in the industrial sector grew at an annual rate of 1.54 per cent between 1994 and 2005.[37] Moreover, energy efficiency in the industrial sector increased by 1.1 per cent between the years 1995 and 2005 (EC, 2006).[38] According to the European Commission, carbon intensity in the industrial sector was reduced by 6.25 per cent between 1995 and 2005, and by almost 17 per cent since 1990. This corresponds to an annual decrease of 0.64 per cent of carbon intensity between 1995 and 2005.

---

[37] The light industry is included in this number, construction is excluded. The resulting difference in value added from food and ceramics production is assumed to be negligible.

[38] In order to estimate the 'decarbonisation rate' assumed by Phylipsen et al. (1998), the 'carbon intensity indicator' of the 'PRIMES' model (EC, 2006) was used as an instrument.

Table 6 Germany: Model assumptions on heavy industry vs. real data

Per cent annually	Original Triptych model	Real data
Physical production growth rate (1991-1994)	-	-2.4
Physical production growth rate (1995-2005)	1.1	1.54
efficiency improvement rate of 1995[39]	1.5	1.1
decarbonisation rate[40]	0.17	0.64

Source: Phylipsen et al. (1998), Eurostat (2007), EC (2006)

In accordance with energy efficiency improvements from German reunification already incorporated in the model, its heavy industry performed considerably well. The actual emissions in 2005 were only 87 per cent of the emission allowance predicted by the model. Moreover, energy intensity in the whole economy has decreased by more than 10 per cent since 1994 (see Figure 30).[41] Nevertheless, the assumptions made in the model were not met. Although the annual production growth rate assumed in Triptych was exceeded, and the assumed efficiency improvement rate was not reached, the heavy industry sector emitted less CO_2 than predicted by the model. The gap in economic growth and efficiency improvement was probably compensated by decline in carbon intensity (EC, 2006). However, from an econometric point of view, it is possible that other important variables influencing the results were not considered in the model. This would induce an 'omitted variable bias.' Otherwise, different methodologies of data segregation, i.e. different definitions for 'industry' could have influenced the results, too.

Energy savings in the industrial sector are mainly based on voluntary agreements between the industry and the government. According to the German Federation of Industries, the German industry agreed to reduce specific CO_2-emissions by 28 per cent by 2005, based on 1990 levels

[39] Energy intensity indicators between 1995 and 2005 are taken from EC (2006).

[40] As proxy for the 'decarbonisation rate' applied by Phylipsen et al. (1998), the carbon intensity indicator of the PRIMES model, reported by the European Commission (EC, 2006), was applied.

[41] Eurostat (2007) reports energy intensity of 157 kg oil equivalents per 1000€$_{1995}$ in 2005 (vs. 177 kg oe in 1994). Considering the decreasing emissions despite of increasing production growth, decoupling of economic growth from emissions is observed.

(BDI, 2004). This should correspond to a reduction of 35 per cent of total greenhouse gases by 2012. According to Triptych, this target was not met as CO_2-emissions decreased only by 13 per cent in the heavy industry. However, considering CO_2-emissions of the whole manufacturing industry, as reported in category I.A.2 of the National Inventory, this target was exceeded with a reduction of 33 per cent.

Germany's heavy industry performed considerably well, decreasing emissions to 87 per cent of the allowance predicted by the Triptych model. Total emissions decreased although economic growth was higher and efficiency improvements were lower than assumed. An important explanatory variable in Germany was carbon intensity. Probably, this sector could be modelled more in detail using additional variables. In order to explore the drivers of decarbonisation and efficiency improvements a disaggregated analysis of the industrial branches would be useful.

3.2.3.2 Model simulations for 2020

Two scenarios are assumed for the development of Germany's heavy industry by 2020. The 'baseline' scenario is an extrapolation of the past trends assuming an efficiency improvement rate of 1 per cent per year and an annual productivity growth rate of 1.5 per cent. The second scenario attempts to incorporate the current energy policy goal to double energy efficiency by 2020 (BMU, 2007). This implies an efficiency improvement rate of 3 per cent per year. Both scenarios assume the annual activity growth rate of 1.5 per cent as it was experienced in the past. The decarbonisation rate in both cases refers to the development of the carbon intensity indicator used in the 'PRIMES' model (EC, 2006). The base year is 2005. Table 7 compares the assumptions and the results of the 'baseline' and the 'energy efficiency' scenario. By applying an extrapolation of the development between 1994 and 2005, the model predicts constant emissions of 120 Mt CO_2 for 2020. In contrast to it, successfully implementing Germany's current policy goal of an annual energy efficiency improvement of 3 per cent would yield only 88.6 Mt CO_2-emissions in 2020. This is a difference of 31.4 Mt CO_2 in the heavy industry sector between both scenarios. In comparison to these two scenarios, the extrapolation of the Triptych assumptions with 2005 as base year would yield an allowance of 110 Mt CO_2 for 2020. That is 10 Mt CO_2 less than actual emissions from the heavy industry in 2005.

Table 7 Germany: 2020 simulations for the heavy industry

	Original Triptych	*'baseline' scenario*	*'energy efficiency' scenario*
Physical production growth rate (%)	1.1	*1.5*	*1.5*
efficiency improvement rate (%)	1.5	*1*	*3*
decarbonisation rate (%)	0.17	*0.46*	*0.46*
Emissions in 2020 (Mt CO_2)	**110**	***120.3***	***88.6***

Source: Phylipsen et al. (1998), *own assumptions*

3.2.4 Domestic sectors

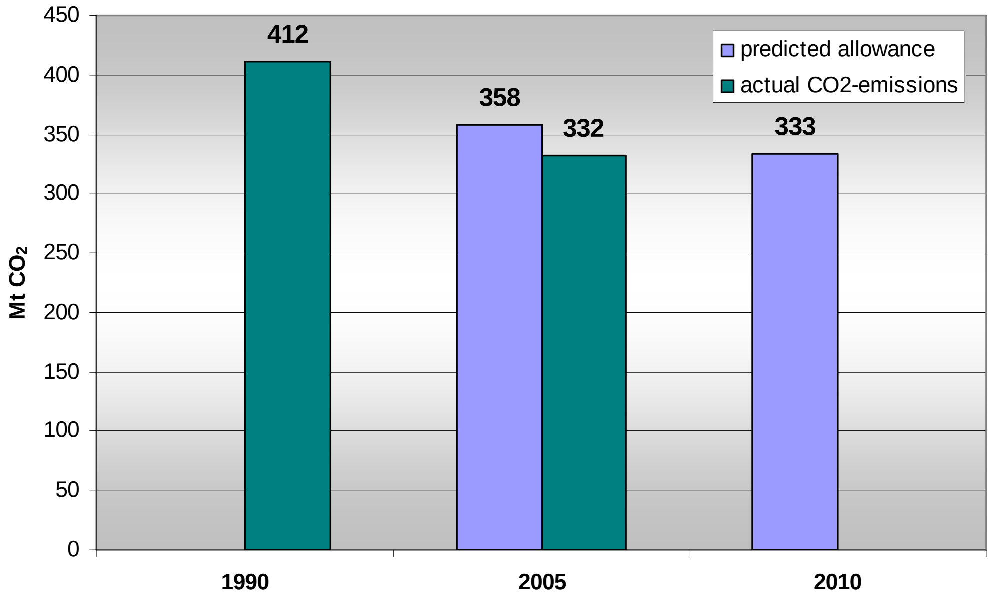
In this chapter, the current developments of emissions in Germany's domestic sectors are compared to the predicted model allowance. Furthermore, a simulation for the year 2020 is presented.

3.2.4.1 Model results and analysis

For the domestic sectors, the Triptych model assumes convergence of emissions per capita among EU member states by 2030 (see section 2.2.4). According to the emissions data of the UNFCCC, energy-related CO_2-emissions were 411.5 Mt CO_2 in Germany's domestic sectors in 1990 (see Table 25 in Annex 8.4).[42] Based on a population of 79.4 million people, emissions per capita were 5.2t CO_2 in 1990. Linear interpolation of the convergence level in 2030 yields 4.3 t CO_2-emissions per capita in 2005. This number multiplied with 82.4 million people (Destatis, 2006) gives an allowance of 358.4 Mt CO_2 for the domestic sectors in 2005 (see Figure 13).

[42] This number is a bit lower than the 423 Mt CO_2 reported by Phylipsen et al. (1998). However, this difference is negligible due to the fact that Germany's total emissions for the year 1990 reported by Phylipsen et al. (1998) exceed the currently reported data by 36 Mt CO_2.

Figure 13 Germany: Energy-related CO_2-emissions in the domestic sectors vs. simulated allowances

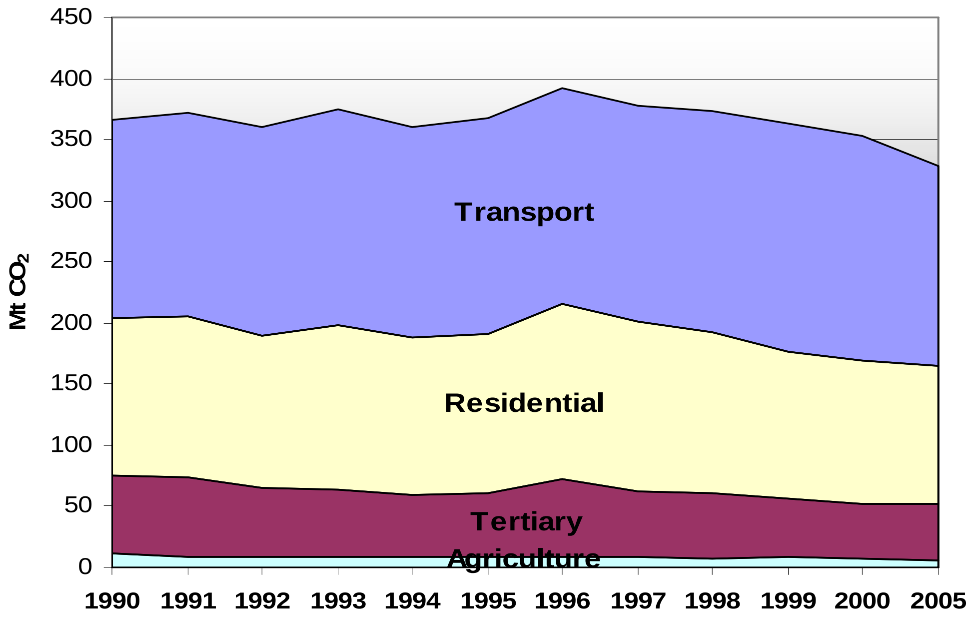


Source: UNFCCC (2007), own calculations

The actual amount of emissions reported to the UNFCCC was 331.5 Mt CO_2, which is 27 Mt less than the predicted allowance for 2005.[43] For 2010, linear interpolation yields 4.1 t CO_2-emissions per capita in the domestic sectors. Recent population projections suggest a population of 81.8 million people living in Germany in 2010. This yields an emission allowance of 333 Mt CO_2 for 2010, which is almost the same amount as the actual emissions in 2005. Figure 14 shows the CO_2-emission paths of the tertiary, the residential, the agricultural and the transport sector as reported to the UNFCCC (2007). In 2005, half of the emissions were produced by transport, one third in the residential sector, followed by the tertiary sector and agriculture. The greatest emission reductions by 2005 were made in the agricultural sector with less than two thirds of its 1990 emissions. Emissions of the tertiary sector were reduced by 30 per cent of 1990 levels, and by more than ten per cent in the residential sector. Only in transport, emissions slightly increased by one per cent of 1990 levels. In 1999, emissions from transport peaked at 15 per cent over the level of 1990 (see Annex).

[43] However, population data in Germany could be unreliable as the last population headcount took place in 1987. Therefore, it is likely, that population figures in Germany overestimate the actual number of people. Hence, the projected allowances could be too high, as well.

Figure 14 Germany: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005



Source: UNFCCC (2007)

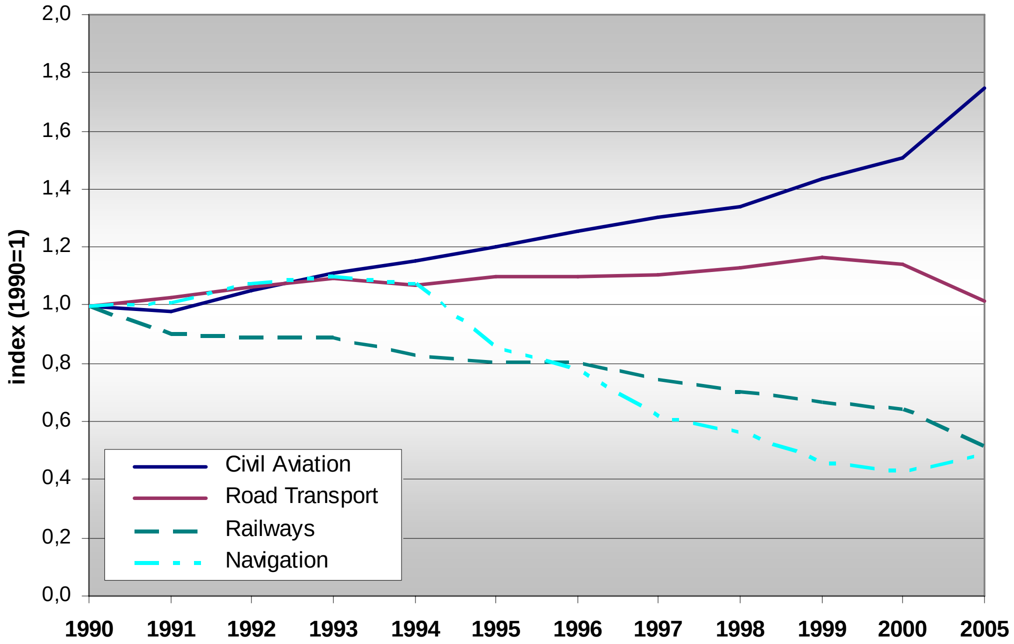
Although total emissions from transport slightly decreased by 2005, the total amount of kilometres travelled per person increased by 6.4 per cent (EC, 2006). Correspondingly, energy demand for transport increased by 17 per cent between 1990 and 2005. In Germany, the land use for urban area and infrastructure is increasing continuously. This creates more transport and hence, more emissions. Efficiency in passenger transport increased only by one per cent, whereas it even decreased in freight transport by 3 per cent. Private cars and motorcycles hold a share of 79 per cent of total passenger transport, whereas only 8.5 per cent of the total distance is travelled by train and 4.6 per cent by plane. The German car industry committed to reduce average emissions of cars to 140 g CO_2/km by 2008, with 185 g CO_2/km (1998) as baseline (ACEA, 1998). However, in 2007, German car manufacturers are far from that goal with 163 g CO_2/km on average. Moreover, current marketing campaigns, promoting sport utility vehicles with high fuel consumption drive companies like Volkswagen in the opposite direction (Germanwatch, 2007).[44] However, the greatest increase in passenger transport was made by aviation. The kilometres travelled by plane more than doubled between 1990 and

[44] Therefore, the non-governmental organisation Germanwatch currently blames Volkswagen to violate the OECD guidelines for multinational enterprises on sustainable development (Germanwatch, 2007).

2005. Figure 15 illustrates the development of emissions in the transport sector by transport means. With the implementation of the ecological tax reform in 1999, emissions from road transport and railways started to decrease (by 13 and 22 per cent,) whereas emissions from civial aviation increased by 22 per cent. Inland aviation is preferentially treated in Germany since kerosene for inland flights is not taxed (Bundestag, 2004). The integration of aviation into the European emissions trading system could considerably restrain the development of emission paths in the domestic sectors. Another important issue is the development in the residential sector. The German government attempts to promote energy efficiency for domestic appliances and in buildings. Therefore, a 'top-runner' approach defining the most efficient appliances as benchmark should be introduced (Das Parlament, 2005). Furthermore, the 'Building Rehabilitation Programme' was launched in order to improve the energy efficiency of buildings in Germany. Cooling becomes an increasingly important issue. Provided that domestic air conditioning becomes affordable to private households, emissions in the residential sector would increase substantially.[45] Moreover, the number of households in Germany is increasing, from 33.8 million in 1990 to 36.7 million in 2000. This implies increased electricity demand in the residential sector. Probably, both effects, a top-runner approach increasing technological energy efficiency, and increased electricity demand for cooling would balance each other. The future energy demand of households will strongly depend on the technological development of those appliances. In the short run, an increase in energy demand is likely, but in the long run, efficiency gains could lower energy consumption.

[45] Domestic cooling is indeed the reason, why no degree-day correction was applied to the model. Electricity demand for increased air conditioning in southern countries (Spain) would probably outweigh increased energy demand for heating in northern countries (Germany, UK).

Figure 15 Germany: Index of emissions from transport by transport means



Source: UNFCCC (2007)

3.2.4.2 Model simulations for 2020

Since the assumptions made in the Triptych approach fit very well with the actual development of Germany's domestic sectors, they will be applied for the simulation of the emissions allowance for the year 2020. Linear interpolation of the convergence level in 2030 yields emissions of 3.4 t per capita for 2020. High life expectancy in Germany but rather low net immigration to Germany would result in a population of 80.5 million people by 2020 (Destatis, 2006).[46] Under these assumptions, an emission allowance of 283 Mt CO_2 is predicted by the model. Alternatively, the same population size in 2020 would produce 330.5 Mt CO_2 under the assumption that 2005 per capita emissions are applied. Depending on the future development of emissions per capita, total emissions could differ by 55.3 Mt CO_2 in the domestic sectors. Table 8 lists the assumptions made on population size, emissions per capita and the resulting

[46] The ‚Variant 2 – W1' scenario of the German Federal Statistical Office assumes a high life expectancy of 85.4 years for male and 89.8 years for female persons. Net immigration of 100,000 persons per year and a constant birth rate of 1.4 births per woman are assumed.

emissions allowances for the domestic sector in Germany. The assumptions on population size are taken from the scenarios calculated by the German Federal Statistical Office (Destatis, 2006). Current projections are lower than the numbers assumed in 1997, when the original Triptych model was calculated. As expected, the adjusted model simulations fit better to the current emissions situation than the assumptions made in 1997.

Table 8 Germany: Model assumptions and predicted allowances for the domestic sectors

	1990	2005	2010	2020
Population (Mio)	79.4	82.4	81.8	80.5
t CO_2 per capita	5.2	4.3	4.1	3.5
Predicted CO_2-emissions (Mt)[47]	(411.5)	358.4 (332)	333	283

Source: Destatis (2006), own calculations

3.2.5 Summary for Germany

Germany is projected to almost meet its Kyoto target of 21 per cent greenhouse gas reduction by 2012. The current projected emissions reduction with additional policies and measures is 19.8 per cent by 2010 (EEA, 2006). However, Germany is the greatest emitter of greenhouse gases in the EU-15. In 2005, CO_2-emissions in Germany were 46 per cent over the emissions amount produced in the UK, the second largest emitter in the EU-15 (UNFCCC, 2007). In 2005, 45 per cent of the CO_2-emissions considered in Triptych were produced by the domestic sector, almost 40 per cent by the power producing sector, and 16 per cent by the heavy industry. In Germany, emissions were reduced in all three sectors that were distinguished by the Triptych model. The greatest amount of emissions was reduced in the domestic sector (19.4 per cent) and the heavy industry (18.4 per cent), followed by the power producing sector (9 per cent). In comparison to the simulated emission allowance for 2005, actual emissions went below the partial allowances for the heavy industry and the domestic sectors. In particular the heavy industry succeeded in reducing emissions, based on voluntary agreements. In the domestic sectors, emissions per capita could be reduced substantially. However, road transport

[47] The real data are written in brackets (UNFCCC, 2007).

was significantly increasing until the introduction of the eco tax in 1999. Emissions from civil aviation increased substantially, too. This gives rise to the issue of taxation of kerosene for inland flights and the integration of air transport into the European emissions trading system. The emissions allowance for the power producing sector was exceeded in 2005. The reason for this failure of the power producing sector is Germany's fuel mix that does not meet the model assumptions. Although Germany's 'Renewable energy law' boosts the development and deployment of renewable energy, the use of solid fossil fuels remained almost stable. The switch to gas assumed by the model did not take place. Actually, there is a discrepancy between the investment decisions of power producers and climate policy objectives in Germany. Actually, the extended use of coal is the reason why Germany will not reach its Kyoto target.

3.3 The United Kingdom

3.3.1 National circumstances

3.3.1.1 Economy

The United Kingdom of Great Britain and Northern Ireland (UK) had a population of 59.8 million people in 2004, which is expected to grow to 60.3 million by 2010 and 65.7 million by 2031 (Eurostat, 2007; Defra, 2006). The UK's real gross domestic product was 1,147 billion $€_{1995}$ in 2005 which is approximately half of the German GDP. By 2005, the country experienced 14 years of consecutive economic growth, which has been the longest period of stable and sustainable economic growth in Britain for 50 years (Defra, 2006). Britain's real GDP per capita grew by almost 40 per cent between 1990 and 2005 (Eurostat, 2007). The United Kingdom is the second largest exporter of services in the world. In 2003, 32 per cent of gross value added was produced in the financial and business sectors, 16 per cent in the wholesale and retailing sector, and 15 per cent in the manufacturing industry (Defra. 2006). Agriculture generated only 1.6 per cent of value added (EC, 2006).

3.3.1.2 Energy

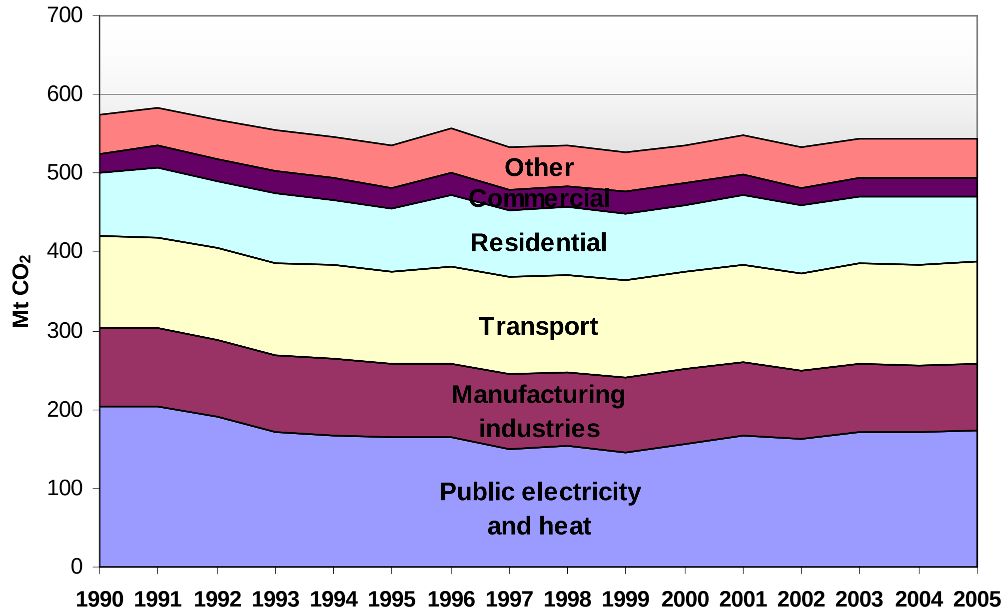
In 2004, total primary energy supply (TPES) was 234 million tonnes of oil equivalents (Mtoe) in the United Kingdom.[48] Thereof, 37.4 per cent were covered by natural gas, 35.8 by oil, 16 per cent by coal, 9 per cent by nuclear power, and 1.6 per cent by renewable energy (IEA, 2007). Between 1994 and 2004, TPES grew at an annual average rate of 0.5 per cent, which is less than the average growth rate of the OECD countries (1.3 per cent). However, energy intensity of the British economy was decreasing by more than 20 per cent in the same period (Eurostat, 2007).

3.3.1.3 Emissions

Figure 16 shows the energy-related CO_2-emissions in the UK by sector, as they were reported to the UNFCCC (2007). Total emissions slightly decreased 544 Mt CO_2 in 2005. Almost one third of CO_2-emissions was produced by public electricity and heat production, 24 per cent were emitted in the transport sector, and 16 per cent were emitted in the residential sector and the manufacturing industries. In comparison to 1990, emissions slightly decreased in each sector, but in transport and the residential sector (see Annex 8.5).

[48] This is about one tenth of TPES in the United States (2,326 Mtoe), and less than half of TPES in Japan (533 Mtoe; IEA, 2007).

Figure 16 United Kingdom: Energy-related CO_2-emissions by sector



Source: UNFCCC (2007)

3.3.1.4 Climate policy

In the United Kingdom, the Department for Environment, Food and Rural Affairs (DEFRA) is responsible for implementing and coordinating climate policy. Furthermore, the British Department for Trade and Industry (DTI), the Department for Transport (DfT), and her Majesty's Treasury (HMT) are involved in climate policy making. The British government funds the 'Carbon Trust', an independent company, which helps the UK to move towards a low carbon economy (Defra, 2006). The UK has set ambitious climate policy goals that it attempts to reach under the use of a variety of policies and measures. The UK is well on track to meet its Kyoto target of 12.5 per cent greenhouse gas emission reduction below 1990 levels by 2012. By 2020, the UK wants to reduce greenhouse gas emissions by 26 to 32 per cent against the 1990 baseline, and the long-term target for 2050 is a greenhouse gas reduction of 60 per cent. In order to meet these targets, the British government adopted the 'Climate Change Programme 2006' and the 'Energy White Paper 2007' (DTI, 2007). The British government has set the goal to supply 10 per cent of total electricity by renewable energy in 2010, and 20 per cent in 2020. This target should be achieved by the 'Renewables Obligation' that requires suppliers to source a specific share of their energy supply from renewable energy. Another important measure for British climate policy is the ‘Climate change levy’ which is linked to voluntary agreements of the British industry. Hence, firms are not taxed if they make voluntary agreements with the government (Defra, 2006). Although the UK is involved in the European emissions trading system (ETS), the majority of policies and measures are based on command and control.

3.3.2 The power producing sector

In this section, the simulated model results for the British electricity sector are compared to the data for 2005, currently reported by the IEA. The results are analysed in the discussion part. Finally, the results of a simulation for 2020 are presented.

3.3.2.1 Model results and analysis

In order to simulate model results for 2010, the same assumptions as those of the original Triptych model are made (see section 2.2.2). Linear interpolation was applied for simulating the emission allowance for 2005. The interpolated assumptions are summarised in the middle column of Table 10. The input data for 1990 and 2005 are taken from the ‘Electricity Information 2006’ of the International Energy Agency (IEA, 2006; see left hand column of Table 9). In 1990, emissions from electricity generation were 217 Mt CO_2.

Table 9 UK: Electricity production by fuel in 2005: model results vs. real data

	Gross electricity production in 1990 (input data; IEA, 2006)		Gross electricity production in 2005 (IEA, 2006)		*model results for 2005 (model output data)*	
	PJ	%	PJ	%	*PJ*	*%*
Solid fossil fuels (coal)	743	65	498	35	*548*	*42*
Liquid fossil fuels (oil)	125	11	21	1.5	*97*	*7.4*
Natural gas	18	1.6	559	39	*524*	*40*
Renewables and waste	28	2.4	53	3.7	*98*	*7.4*
Nuclear power	237	21	294	20	*241*	*18*
Share of CHP[49]	-	-	*181*	*12.6*	*148*	*11.3*
Total electricity	1,151		1,438		*1,317*	

Source: IEA (2006), EC (2006), Phylipsen et al. (1998), *own calculations*

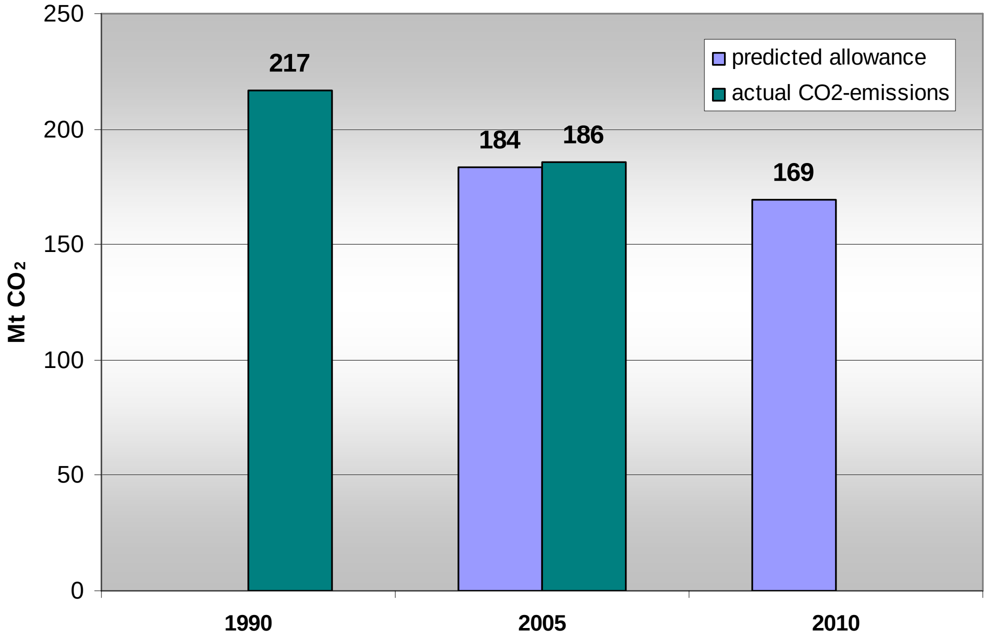
The fuel shares predicted in the model are compared to the actual development in Table 9. By 2005, the United Kingdom has shown a significant switch in fuel mix compared to 1990. The use of solid fossil fuels declined significantly by one third, and liquid fossil fuels were reduced to 16 per cent of 1990 levels. In contrast to it, the amount of electricity generated by renewable energy has almost doubled by 2005. The use of nuclear power has increased by 24 per cent. The most significant change is observed with the use of natural gas which has increased to more than a thirty-fold in 2005. This development is known as the 'gas-switch' that took place in the United Kingdom during the 1990's since the domestic gas reserves of the UK Continental Shelf (UKCS) in the North Sea have been exploited intensively (IEA, 2006).

Linear interpolation of the assumptions made in 2.2.2 yields the model results listed in the right hand column of Table 9. Comparing these numbers, the actual amount of total electricity production in 2005 was 9 per cent over the electricity amount predicted by the model. The actual use of coal in the UK is 9 per cent below the model projection, and oil combustion is

[49] The CHP indicator as percent of electricity from CHP was taken from EC (2006). In the model, the amount of electricity produced from CHP is included in total electricity production. In the actual figures, electricity produced from CHP is not included total electricity. CHP is reported as share of total electricity production.

only one fifth of the simulated amount. The use of natural gas is 7 per cent over the predicted value, and the generation of electricity from CHP is 22 per cent over it. However, the amount of electricity generated by renewable energy reached only half of the predicted amount.

Figure 17 UK: Energy-related CO_2-emissions of the power producing sector vs. model results



Source: IEA (2006), own calculations

Figure 17 illustrates the model results under Triptych assumption in comparison to the actual emissions based on IEA data. The United Kingdom almost met the predicted 184 Mt CO_2 with 186 Mt CO_2 emitted from electricity production in 2005. The predicted allowance for 2010 is 169 Mt CO_2.

Table 10 compares the assumptions made in the model with the developments reported by recent data. The left hand column summarises the original assumptions made for the year 2010, the middle column lists the interpolated assumptions for 2005, and the right hand column compares the model assumptions to the actual fuel mix reported by the IEA (2006).

Table 10 UK: Comparison of model assumptions to real results

Assumptions in per cent	Original Triptych assumptions for 2010	*interpolated assumptions for 2005*	2005 results reported by IEA (2006)
Annual growth in electricity production	0.9	*0.9*	1.5
Share of solid fuels based on 1990 levels	65	*74*	67
Share on liquid fuels based on 1990 levels	70	*77.5*	16
(Additional) share of renewable energy[50]	2.5 +8%-points	*2.5+6%-points*	2.5+2.5%-points
	= 10.5	*= 8.5*	= 5
Share of CHP	15	*11.3*	12.6

Source: Phylipsen et al. (1998), IEA (2006), EC (2006)

Comparing the actual numbers on fuel shares in the United Kingdom in 2005 to the assumptions made in the model gives the following results:

1.) The assumed annual growth rate of electricity production was significantly exceeded.

2.) The United Kingdom considerably reduced the use of solid fossil fuels in comparison to 1990 levels. The assumptions made in the Triptych model were even exceeded. Instead of the assumed share of 74 per cent, the use of coal was only 67 per cent of 1990 levels. This is an important reason for the achieved emission reduction.

3.) The use of liquid fossil fuels was drastically reduced. The share decreased to only 16 per cent of 1990 levels, instead of 78 per cent assumed in the model.

4.) In the United Kingdom, the Triptych assumption on a fuel switch to gas was met perfectly. By 2005, the amount of gas used for electricity production exceeded the amount simulated by the model. Natural gas covers the largest share of fuels with 39 per cent of total electricity production. Hence, it is the major contributor to the emissions reduction of the British power sector.

[50] The result is the share of electricity produced from renewable energies in the year 2005 based on total electricity production in the year 1990.

5.) The expected increase in renewable energy was not met. Although electricity generated by renewables has almost doubled since 1990, the expected increase of 6 per cent points over 1990 levels did not take place. In 2005, electricity generated by renewable energy was only 5 per cent of total electricity production in 1990. Hence, there is scope for the increased use of renewable energy sources, as for instance, wind power.

6.) The assumed share of electricity from combined heat and power was exceeded with 13 per cent in the year 2005. The United Kingdom is on track to meeting the assumed share of 15 per cent by 2010.

Despite the missing extension of renewable energy potentials and the exceeded growth in electricity production, the United Kingdom met the assumptions, made in the Triptych model.

3.3.2.2 Simulations for 2020

In order to simulate CO_2-emissions in the British electricity sector for the year 2020, two scenarios were developed. First, the 'Climate policy' scenario considers the policies and measures of British climate policy. Second, the 'Baseline' scenario extrapolates the current trend that had been observed in this from 1990 to 2005. In the '2007 White Paper on Energy' the British government formulates a detailed action plan that should enhance energy efficiency and promote the low carbon society in the UK. The measures are e.g. the 'Renewables obligation', the promotion of microgeneration, combined heat and power (CHP), and improved research and development in renewable energy technology. As many coal fired power plants will be closed over the next 20 years the government wants to create favourable conditions for investments in low carbon technologies. This should happen by strengthening the EU emissions trading scheme and improved investment security (DTI, 2007).[51] Hence, the development of Britain's fuel mix will depend on the future price of carbon and the investment conditions. Therefore, the 'Climate policy scenario' assumes a share of 50 per cent of coal combustion in comparison to 1990 levels. The 'Climate policy scenario' considers the policy goal of 20 per cent renewable energy by 2020 and the energy saving targets of the British government (see middle column of Table 11). The simulation result is 155 Mt CO_2-emissions

[51] This means that uncertainties on energy and climate policy should be reduced.

in 2020, which is 17 per cent less than the emissions in 2005 (186 Mt CO_2). An extrapolation of the current trend yields 206 Mt CO_2-emissions for 2020.[52] This figure exceeds emissions in 2005 by ten per cent, because the high production growth rate is no longer compensated by the fuel switch to gas.

Table 11 UK: Comparison of the assumptions made for 2020 and simulation results

Assumptions	'Climate policy' scenario	'Baseline' scenario
Annual growth in electricity production (%)	1.0	1.5
Share of solid fuels based on 1990 levels (%)	50	67
Share of liquid fuels based on 1990 levels (%)	12	16
Share of renewable energy in 2020 (%)	20	8
Share of CHP in 2020 (%)	20	13
Simulated CO_2-emissions in 2020	155 Mt CO_2	206 Mt CO_2

Source: own calculations

3.3.3 Heavy industry

3.3.3.1 Model results and analysis

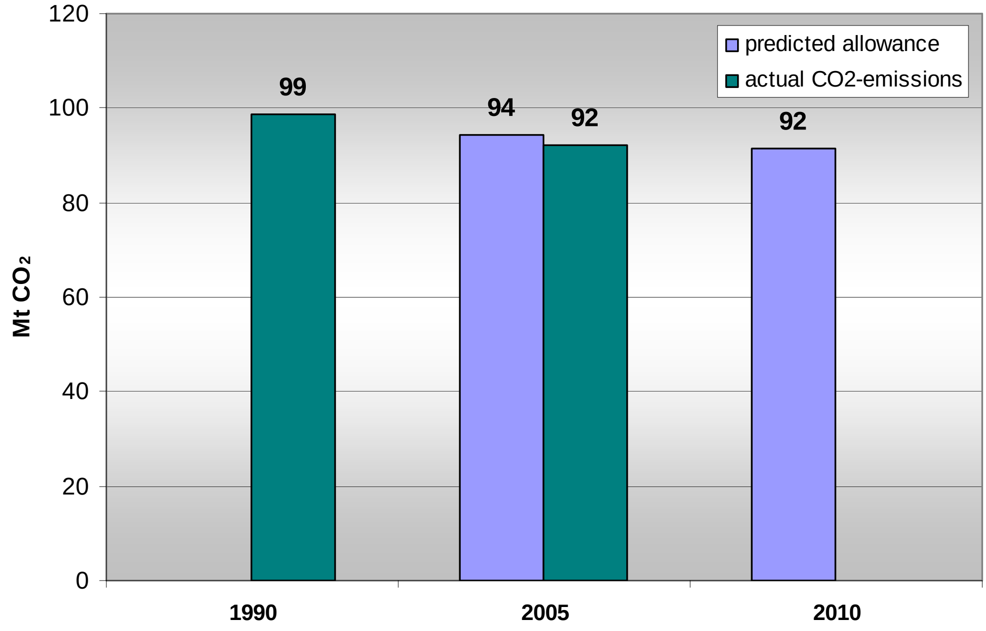
For calculating the partial allowances for 2005 and 2010, the assumed annual productivity growth rate, the efficiency improvement rate, and the decarbonisation rate are applied to the objective function (3) in section 2.2.3 (see Table 12 for assumptions). The emissions input data of the heavy industry was taken from the British National Inventory, reported to the UNFCCC (2007, see Annex 8.3). Emissions of the British heavy industry were 99 Mt CO_2 in 1990.

The input data and the model assumptions applied to the sectoral objective function (1) of section 2.2.3, yield 94 Mt CO_2-emissions for the year 2005. Figure 18 compares the model results to the actual emissions data reported by the UNFCCC. The actual emissions of the

[52] This scenario assumes 8 per cent share of renewable energies instead of 5 per cent in order to take into account the 'Renewables obligation' law. Nuclear power is assumed constant in both scenarios.

British heavy industry (92 Mt CO_2) went slightly below the predicted allowance of 94 Mt CO_2. Hence, the UK has already achieved the predicted target for the year 2010 which is also 92 Mt CO_2.

Figure 18 UK: Energy-related CO_2-emissions of the heavy industry vs. model results



Source: UNFCCC (2007), own calculations

Table 12 UK: Model assumptions on heavy industry vs. real data

% p.a.	Original Triptych model	Real data (Eurostat, 2007; EC, 2006)
Physical production growth rate (1990-2005)	1.1	0.55
Energy efficiency improvement (1990-1994)	0.7	0.38
Energy efficiency improvement rate of 1995[53]	1.5	- 0.41
decarbonisation rate	0.17	-

Source: Phylipsen et al. (1998), Eurostat (2007), EC (2006)

[53] Energy intensity indicators between 1995 and 2005 are taken from EC (2006).

Table 12 compares the assumptions of the Triptych model to the actual development in the United Kingdom. The physical production growth rate of 1.1 per cent per year was not met by the British industry. According to Eurostat (2007), value added in the British industry grew only by 0.55 per cent per year. The energy efficiency improvement between the years 1990 and 1994 was only 0.38 per cent per year, and between 1995 and 2005, it was negative with 0.41 per cent p.a. (EC, 2006).[54] However, the British heavy industry exceeded its predicted emission allowance. It is likely that the loss resulting from decreasing energy efficiency was compensated by the low growth of physical production in the heavy industry. Otherwise, a decarbonisation process could have influenced the results. Actually, carbon intensity decreased by 19 per cent between 1990 and 2005 (EC, 2006). This could be an important driver to the decline of emissions in the heavy industry. The emissions reduction achieved by the heavy industry is based on voluntary agreements that exempt companies from the British climate change levy (AEA Technology, 2001; Defra, 2006). Moreover, the voluntary emissions trading period in Britain from 2001 to 2006 could have induced further emission reductions.

3.3.3.2 Simulation for 2020

Referring to the ‘PRIMES’ model, presented in the ‘Energy and transport scenarios’ of the European Commission (EC, 2006), an average efficiency improvement rate of one per cent can be assumed for the British industries between 2005 and 2020. Furthermore, the model assumes an annual decline in carbon intensity of 0.63 per cent. According to the past experiences, a relatively low production growth rate of 0.8 per cent is assumed. Applying these assumptions based on the emissions in 2005, the model predicts 81.3 Mt CO_2-emissions for 2020. This corresponds to a further reduction of 10 million tonnes or 12 per cent in comparison to the emissions of 2005.

---

[54] This is a contradiction to the data on energy intensity for the whole economy reported by Eurostat. They report 202 kg toe per 1000€$_{1995}$ for the United Kingdom in 2005 (252 toe in 1995), Eurostat (2007). Accordingly, energy intensity in the UK decreased by 2.1 per cent between 1995 and 2005. The difference could be explained by the expansion of the tertiary sector, in particular, the financial and commercial sectors, in the British economy. Value added in this sector increased considerably and is less energy intensive than production in the manufacturing industries of which output remained rather stable (Defra, 2006; EC, 2006).

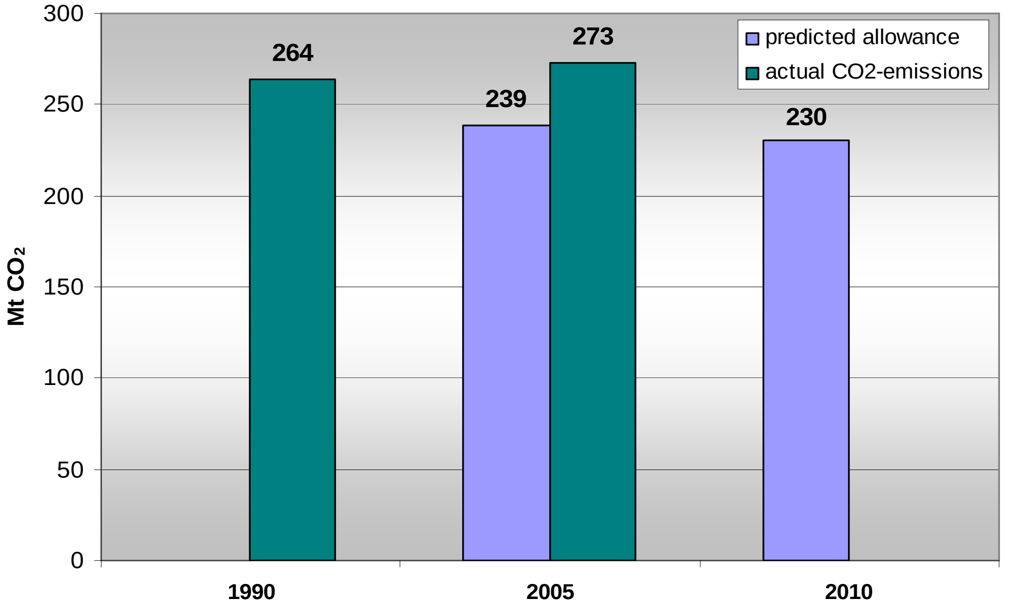
3.3.4 Domestic sectors

3.3.4.1 Model results and analysis

For the domestic sectors, the Triptych model assumes convergence of emissions per capita among EU member states by 2030 (see section 2.2.4). According to the emissions data of the UNFCCC, energy-related CO_2-emissions were 264 Mt CO_2 in Britain's domestic sectors in 1990 (see Table 25 in Annex 8.4).

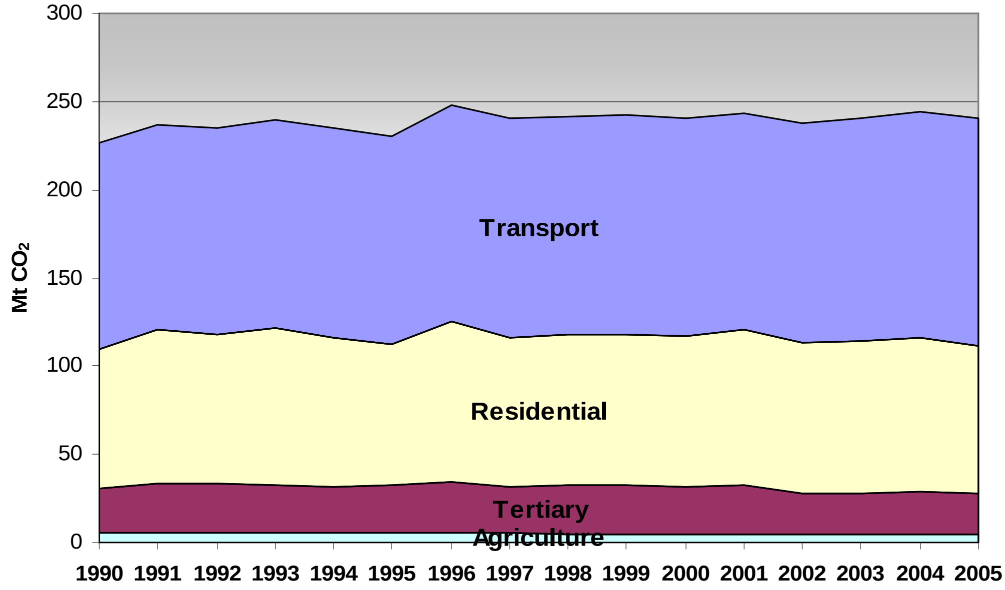
Figure 19 compares the model results to the actual figures reported to the UNFCCC (2007). Emissions per capita in the domestic sectors were 4.6 t CO_2 per inhabitant in 1990. Linear interpolation of the convergence level yields emissions of 4.0 t CO_2 per capita for 2005 (see Table 13). This number, multiplied with the population size of 59.9 Mio inhabitants (Eurostat, 2007), yields the emissions allowance of 239 Mt CO_2 for 2005. In contrast to the assumed decline, emissions per capita remained almost constant at 4.5 t CO_2. Hence, total emissions increased correlated to the population size. Hence, the actual emissions in the British domestic sectors were 273 Mt CO_2 which is 34 Mt more than the allowance calculated by the model. The predicted allowance for the year 2010 is 230 Mt CO_2 assuming a population size of 60.9 million people (Eurostat, 2007) and interpolated emissions of 3.8 t CO_2 per capita in the UK.

Figure 19 UK: Energy-related CO_2-emissions in the domestic sectors vs. model results



Source: UNFCCC (2007), own calculations

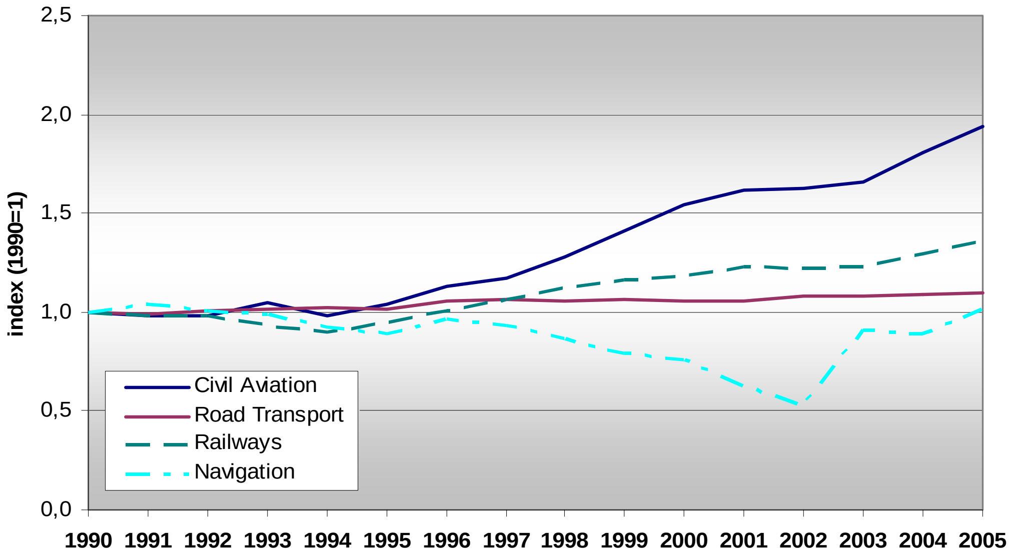
Figure 20 UK: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005



Source: UNFCCC (2007)

Figure 20 shows the emission paths in the British domestic sectors between 1990 and 2005. The total emissions of these sectors remained nearly stable between 1991 and 2005 (241 Mt CO2). More than half of the emissions were produced in the transport sector, 35 per cent in the residential sector, and almost ten per cent in the tertiary sector. In comparison to 1990, emissions in the tertiary sector decreased by almost ten per cent, whereas emissions in the residential sector increased by six per cent. Emissions from transport have increased by more than ten per cent. The greatest share of transport emissions is produced by road transport, accounting for 93 per cent of total emissions. They grew by ten per cent between 1990 and 2005. Actually, the British drive on average more kilometres per person than the German or the Spanish, although the country is relatively dense populated (EC, 2006). However, emissions from rail transport increased by one third, and emissions from civil aviation almost doubled by 2005. The European Commission observed slight decrease in energy efficiency between 1990 and 2005, which is projected to increase afterwards (EC, 2006). Figure 21 shows the index of emission paths in the transport sector between 1990 and 2005 by fuel.

Figure 21 UK: Index for emissions from transport by transport meaning



Source: UNFCCC (2007)

3.3.4.2 Simulation for 2020

Provided the common convergence level of 3 t CO_2 per capita in 2030, emissions in the British domestic sectors are interpolated to 3.4 t CO_2 per capita in 2020. Assuming 62.9 million people living in the UK (Eurostat, 2007), the predicted emission allowance for the domestic sector would be 212 Mt CO_2 for 2020 (see Table 13). This is less than 80 per cent of the actual emissions of 2005 and would, therefore, imply increased policy effort to reach this goal. Actually, the British government plans a great variety of policies and measures enhancing energy savings and fuel switch in the domestic sector. As for instance, the ‘Buildings Regulation,’ the ‘Renewable Transport Fuel Obligation,’, vehicle excise duties, standards for new cars, or the CHP strategy promoting decentralised microgeneration. The official energy saving target of the British government is 9 per cent by 2016 (Defra, 2006). The strict implementation of these measures could actually push the United Kingdom towards lower emissions per capita in its domestic sectors. In particular, the planned integration of aviation into the European emissions trading scheme could enhance emission reductions.

Table 13 UK: Model assumptions and predicted allowances in the domestic sectors

	1990	2005	2010	2020
Population (Mio)	57.4	59.9	60.9	62.9
t CO_2 per capita	4.6	4.0	3.8	3.4
Predicted CO_2 emissions (Mt)[55]	(264.2)	238.8 (272.5)	230.3	212.0

Source: Eurostat (2007), own calculations

3.3.5 Summary for the UK

The United Kingdom is well on track to reach its Kyoto target of 12.5 per cent greenhouse gas reduction by 2012. According to current projections, the UK will even exceed the target with 18.8 per cent emissions reduction with existing policies and measures (EEA, 2006). However, the UK will not reach the initial target of 20 per cent emission reduction suggested by the original Triptych approach (see section 2.2.5). In 2005, the greatest share of CO_2-emissions is produced in the domestic sector (50 per cent), followed by the power producing sector (34 per cent), and the heavy industry (17 per cent). The British power producing sector and the heavy industry reach the simulated emissions allowance for 2005, whereas the domestic sectors

[55] Real data in brackets (UNFCCC, 2007)

exceed their allowance.[56] The assumed fuel switch to natural gas took place in the UK. Hence, the power producing sector almost achieved the emissions allowance simulated by the model for 2005. Voluntary agreements linked to the carbon levy were the basis for the emissions reduction achieved by the British heavy industry. Finally, more effort should be made in the domestic sector. In particular road transport and civil aviation are important causers of emissions of the domestic sectors in Britain.

3.4 Spain

3.4.1 National circumstances

3.4.1.1 Economy

In 2005, Spain had a population of 42.9 million people. As a consequence to increased life expectancy and migratory movements, the Spanish population is expected to grow to 44.2 million people by 2010 (Eurostat, 2007; MMA, 2006). The Spanish economy has been growing considerably since Spain joined the EU in 1986. GDP per capita increased by around 70 per cent from 8,500 $€_{1995}$ in 1985 to 15,100 $€_{1995}$ in 2005. Spains real GDP grew by almost 60 per cent between 1990 and 2005 (655 billion $€_{1995}$ in 2005). Since 1995, annual growth rates reached 5 per cent (Eurostat, 2007; see Annex). This take-off of the Spanish economy since 1986 significantly reduced Spains income gap in comparison to other EU members. In 2000, almost two thirds of gross value added was produced in the service sector, which has been growing by 26 per cent since 1990. The most important branch of the Spanish economy is tourism earning 11.4 per cent of the Spanish GDP in 2003 (MMA, 2006).

3.4.1.2 Energy

Spain’s total primary energy supply (TPES) was 136 Mtoe in 2003. Since 1990, it has grown by almost 50 per cent at an average growth rate of 3.1 per cent p.a. In 2003, the largest share of

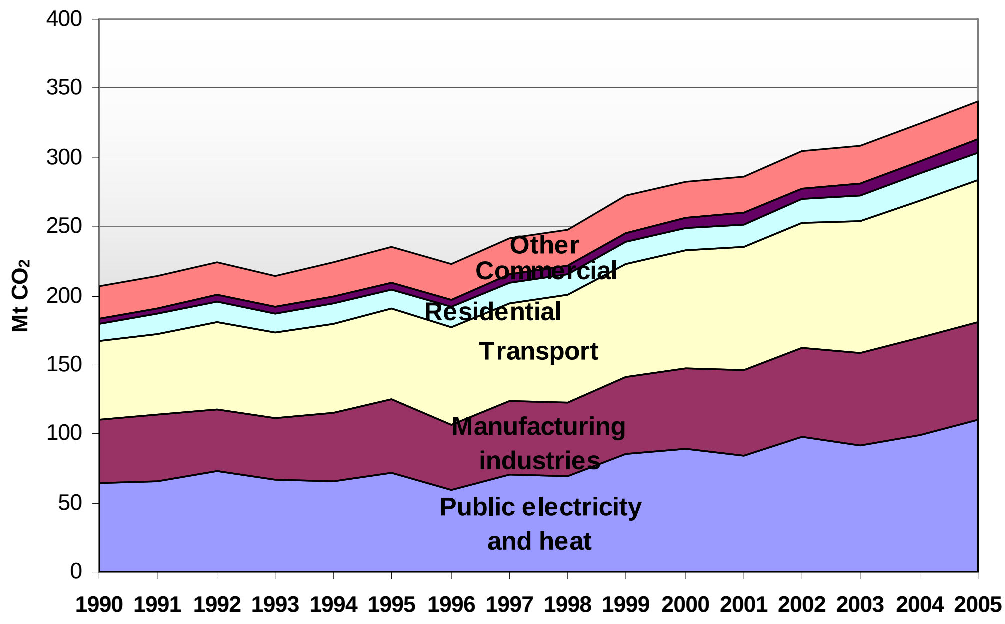
[56] However, the results depend on the industry share of heavy industry assumed by Capros (1995). If the industry shares changed by 2005, the emissions situation of the heavy industry and the domestic sector changes, too.

TPES was covered by oil (51 per cent), followed by natural gas and coal (both 15 per cent), nuclear power and renewable energy. Spain's main domestic fuel resource is renewable energy. The country is heavily import-dependent with 75 per cent imported fuels. Total final consumption increased by 60 per cent between 1990 and 2003 (100 Mtoe), which reflects the rapid economic growth Spain had experienced during that period. In 2003, 38 per cent of TFC were consumed by the Spanish industries, 35 per cent by the transport sector, and 24 per cent in the residential, service and primary sector.

3.4.1.3 Emissions

Figure 22 illustrates energy-related CO_2-emissions in Spain. Total CO_2-emissions increased by 64 per cent, from 207 Mt CO_2 in 1990 to 340 Mt CO_2 in 2005. In 2005, the largest share of emissions was produced by public electricity and heat production (32 per cent), followed by transport (30 per cent), and the manufacturing industries (21 per cent).The residential and the commercial sectors accounted for only 6 and 3 per cent.

Figure 22 Spain: Energy-related CO_2-emissions by sector



Source: UNFCCC (2007)

3.4.1.4 Climate policy

In Spain, the Ministry of the Environment (MMA) and the Spanish Office of Climate Change are primarily responsible for climate policy. In order to comply with the Kyoto target of 15 per cent emissions increase, the Spanish government implemented the 'E 4 Action Plan 2005-2007.' According to it, emissions should be stabilised at a level of 24 per cent over the 1990 baseline by 2012. The resulting difference should be achieved by the use of carbon sinks and the flexible mechanisms of the Kyoto Protocol, in particular with the enhanced use of the Clean Development Mechanism in Latin America (IEA, 2005). In contrast to the United Kingdom and Germany, the Spanish government has not formulated any long-term emissions target, yet. The measures formulated in the 'E 4 Action Plan' are rather soft and mostly non-binding. The particular focus is put on the extensive deployment of renewable energy and the use of biofuels. Hence, the 'Renewable Energies Plan 2005-2010' formulates the goal that at least 12 per cent of TPES should be met by renewable energy in 2010 (MMA, 2006).

3.4.2 The power producing sector

In this section, the simulated model results for Spain's electricity sector are compared to the data for 2005, currently reported by the IEA. The results are analysed in the discussion part. Finally, the results of a simulation for the year 2020 are presented.

3.4.2.1 Model results and analysis

In order to simulate model results for 2010, the same assumptions as those of the original Triptych model are made (see section 2.2.2). Linear interpolation was applied for simulating the emission allowance for 2005. The interpolated assumptions are summarised in the middle column of Table 15. The input data for 1990 and 2005 are taken from the 'Electricity Information 2006' of the International Energy Agency (IEA, 2006; see left hand column of Table 14). In 1990, emissions from electricity generation were 63 Mt CO_2.

Table 14 compares the fuel shares predicted by the model to the current development reported by the IEA (2006). In contrast to 1990, total electricity production in 2005 almost doubled. Since 1990, the share of solid fuels increased by more than thirty per cent, the use of liquid fuels has tripled, nuclear power generation increased slightly by 6 per cent. The use of natural gas increased tremendously to more than a fifty-fold, and the use of renewable energy more than doubled by the year 2005. The share of electricity generated from combined heat and power increased to 5.2 per cent. Hence, all kind of fuels were exploited in order to generate the exceeded amount of electricity production. Linear interpolation of the assumptions made in 2.2.2 yields the model results listed in the right hand column of Table 14. Comparing these numbers, the actually produced amount of total electricity was 47 per cent over the amount projected by the model in 2005. The actual use of coal exceeds the model result by 70 per cent. Oil combustion reached almost the four-fold, and the use of natural gas was twice the predicted value. Electricity from CHP was almost a threefold the simulated amount for 2005. Finally, the use of renewable energy exceeds the model predictions by 63 per cent.

Table 14 Spain: Electricity production by fuel: model results vs. real data

	Gross electricity production in 1990 (input data; IEA, 2006)		Gross electricity production in 2005 (IEA, 2006)		*Model results for 2005 (output data)*	
	PJ	%	PJ	%	*PJ*	*%*
Solid fossil fuels (coal)	219	40	287	27	*169*	*23*
Liquid fossil fuels (oil)	31	5.6	91	8.6	*24*	*3.3*
Natural gas	5	0.9	284	27	*133*	*18*
Renewables and waste	97	18	212	20	*130*	*18*
Nuclear power	196	36	207	20	*188*	*26*
Share of CHP[57]		-	*223*	*21*	*82*	*11.3*
Total electricity	547		1,062		*725*	

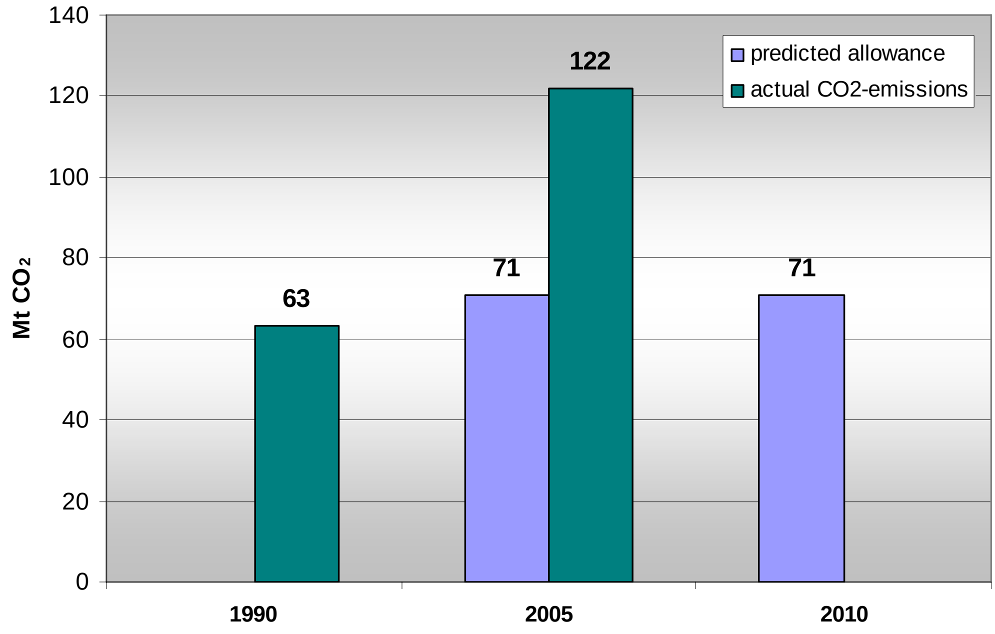
Source: IEA (2006), EC (2006), Phylipsen et al. (1998), *own calculations*

Figure 23 compares the model results to the actual development reported by the IEA (2006). The predicted emissions of 71 Mt CO_2 were exceeded significantly in 2005. According to the

[57] The CHP indicator as percent of electricity from CHP was taken from EC (2006). In the model, the amount of electricity produced from CHP is included in total electricity production. In the actual figures, electricity produced from CHP is not included total electricity. CHP is reported as share of total electricity production.

IEA (2006), 122 Mt CO_2 was emitted in the power producing sector in 2005. This is 72 per cent more than predicted by the model. For 2010, the model predicts an allowance of 71 Mt CO_2, too. The increased electricity production assumed in 2010 should be compensated by a switch to less carbon intensive fuels. These two effects outweigh each other so that the emissions allowance for 2010 is slightly below the allowance for 2005.

Figure 23 Spain: Energy-related CO_2-emissions in the power producing sector vs. model results



Source: IEA (2006), own calculations

Table 15 compares the assumptions made in the original Triptych approach to the developments observed with current data. Comparing the actual developments in Spain to the model assumptions leads to the following conclusions:

1.) The assumption on the annual growth of electricity production was considerably exceeded in Spain. Even though the model assumed a higher growth rate for Cohesion fund countries, like Spain, a growth rate of 1.9 per cent was not sufficient. According to its high GDP growth rates, electricity production in Spain has grown by 4.5 per cent p.a. since 1990. This increase in electricity demand can be explained by increased economic production, increased living standards and a larger use of technical appliances. Cooling for instance, becomes a more and more important factor for increased electricity demand.

2.) In light that total electricity production in Spain doubled by 2005, the assumption that coal combustion should be reduced to 78 per cent of 1990 levels could not be met. Indeed, the share of solid fossil fuels increased to 131 per cent of 1990 levels.

3.) The use of oil in electricity production almost tripled by 2005. Oil combustion for electricity production increased to 293 per cent of 1990 levels instead of an assumed decrease to 78 per cent of 1990 levels.

4.) The assumption that natural gas would cover the growing electricity demand was met considerably in Spain, even if gas could not fill the whole gap. Nevertheless, the share of natural gas increased from less than one per cent in 1990 to almost 27 per cent of electricity production in the year 2005. Hence, natural gas became, next to coal, the most important fuel in Spain's electricity generation capacity.

5.) Spain also exhibits a considerable increase in use of renewable energy. The initial share of 18 per cent electricity generated from renewables in 1990 increased to 39 per cent of the total electricity amount produced in 1990. This is 15 per cent points more than expected in the model.

7.) The share of combined heat and power reached already 21 per cent of total electricity production in 2005. This is almost 10 per cent more than assumed by the model.

Although Spain increased its electricity production tremendously, the main policies assumed in the model, i.e. the switch to gas, extension of renewable energy use and combined heat and power, were met. In contrast to Germany, Spain increased its share of natural gas in electricity production. In contrast to the UK, Spain could considerably increase its potential of renewable energy, too. Spain has a well-balanced fuel mix of electricity production in comparison to Germany and the UK. Despite the accelerated economic growth over the last decade, Spain's fuel mix could give rise to a sustainable development.

Table 15 Spain: Comparison of model assumptions and real results in the power producing sector

Assumptions (%)	Original Triptych assumptions for 2010	*interpolated assumptions for 2005*	2005 results according to IEA (2007)
Annual growth in electricity production	1.9	*1.9*	4.5
Share of solid fuels based on 1990 levels	70	*77.5*	131
Share of liquid fuels based on 1990 levels	70	*77.5*	293
Share of renewable energy of total electricity production in 1990[58]	17.7 + 8%-pts	*17.7 +6%pts*	17.7 +21.3%-pts
	= 25.7	*= 23.7*	= 39
Share of CHP	15	*11.25*	21

Source: Phylipsen et al. (1998), IEA (2006), EC (2006), *own calculations*

3.4.2.2 Simulations for 2020

In this section, two possible scenarios for the Spanish fuel mix of electricity production by 2020 are compared. As the Spanish government does not formulate any long-term policy targets, the assumptions made for the 'Climate policy' scenario are rather random. The shares of coal and oil combustion are supposed to be slightly lower than in 2005, with 120 per cent and 250 per cent of the 1990 level.[59] Considering Spain's ambitious renewable energy target of 29 per cent of total electricity production by 2010, a share of 40 per cent is assumed for renewables by 2020. Combined heat and power (CHP) is assumed to increase to 30 per cent. 3 per cent annual productivity growth is assumed. Table 16 compares the assumption of the 'Climate policy scenario' to a 'Baseline' scenario that extrapolates the current trend in productivity growth (4.5 per cent). It assumes slightly higher shares in coal and oil combustion with 150 per cent and 300 per cent of 1990 levels. The share of renewable energy is supposed to grow to 25 per cent of total electricity production in 2020, and the share of CHP is assumed to be constant (21 per cent). As result, emissions from electricity production would be 113 Mt CO_2 in the 'Climate policy scenario' and 190 Mt CO_2 in the 'Baseline' scenario. The first

[58] The result is the share of electricity produced from renewable energy in 2005 based on total electricity production in 1990.

[59] As amount of nuclear power, the value for 2010 reported in the Conventional Wisdom Scenario is assumed (183 PJ).

result would be 7 per cent less than the emissions in 2005. The baseline would imply a further increase of emissions by 56 per cent compared to 2005 level.

Table 16 Spain: Comparison of the assumptions for 2020 and simulation results in the power producing sector

Assumptions	'Climate policy' scenario	'Baseline' scenario
Annual growth in electricity production (%)	3.0	4.5
Share of solid fuels based on 1990 levels (%)	120	150
Share on liquid fuels based on 1990 levels (%)	250	300
Share of renewable energy in 2020 (%)	40	25
Share of CHP in 2020 (%)	30	21
Simulated emissions in 2020 (Mt CO_2)	113	190

Source: own calculations

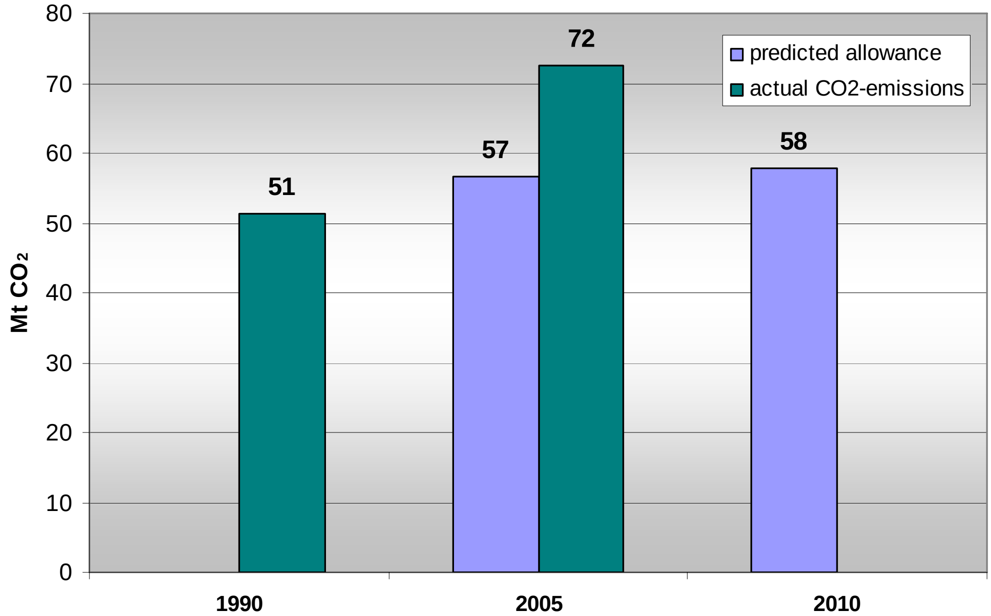
3.4.3 Heavy industry

3.4.3.1 Model results and analysis

As Spain belonged to the less developed Cohesion Fund countries in the year 1990, a higher annual physical production growth rate of 2.1 per cent is assumed. For calculating the partial allowances for 2005 and 2010, the assumed annual productivity growth rate, the efficiency improvement rate, and the decarbonisation rate are applied to the objective function (3) in section 2.2.3 (see Table 17 for assumptions). The emissions input data of the heavy industry was taken from the Spanish National Inventory, reported to the UNFCCC (2007, see Annex 8.3). In Spain, emissions from the heavy industry were 51 Mt CO_2 in 1990.

Figure 24 compares the model results to the actual emissions data reported to the UNFCCC. The Spanish heavy industry has exceeded its predicted allowance of 57 Mt CO_2 by 15 Mt (26 per cent). In 2005, CO_2-emissions in the heavy industry sector were 72 Mt CO_2. The predicted allowance for the year 2010 is 58 Mt CO_2.

Figure 24 Spain: Energy-related CO_2-emissions in the heavy industry vs. model results



Source: UNFCCC (2007), own calculations

Table 17 compares the assumptions made in the Triptych model to actual developments reported by Eurostat (2007) and the European Commission (2006). The assumed production growth rate of 2.1 per cent was not reached, but it was indeed higher than the growth rates of the United Kingdom (0.55 per cent) and Germany (1.5 per cent). Energy efficiency did not increase in Spain. From 1990 to 1995 it decreased by 0.57 per cent and even by 1.5 per cent after 1995.[60] Hence, total emissions increased as expected by the model.

[60] However, energy intensity in Spain decreased by 0.17 per cent p.a. between 1994 and 2005. It was 219 kgoe per 1000 $€_{1995}$ in 2005 (in comparison to the UK with 203 kgoe and Germany with 157 kgoe; Eurostat, 2007).

Table 17 Spain: Model assumptions on the heavy industry vs. real data

% p.a.	Original Triptych model	Real data
Physical production growth rate	2.1	1.86
Energy efficiency improvement (1990-1995)	0.7	- 0.57
Energy efficiency improvement rate of 1995[61]	1.5	-1.5
decarbonisation rate	0.17	-

Source: Phylipsen et al. (1998), Eurostat (2007), EC (2006)

3.4.3.2 Simulation for 2020

Two scenarios are developed for Spain's heavy industry. On the one side, the past development is extrapolated under the assumption of 1.86 per cent annual production growth zero energy efficiency improvement and a decarbonisation rate of 0.17 per cent per year. Based on the emissions in 2005, this would yield 93 Mt CO_2-emissions in 2020. On the other side, the same production growth rate but an efficiency improvement of 0.5 per cent and decarbonisation of 0.5 per cent are assumed reflecting soft climate policy measures for Spain. This would yield 82 Mt CO_2-emissions in 2020.

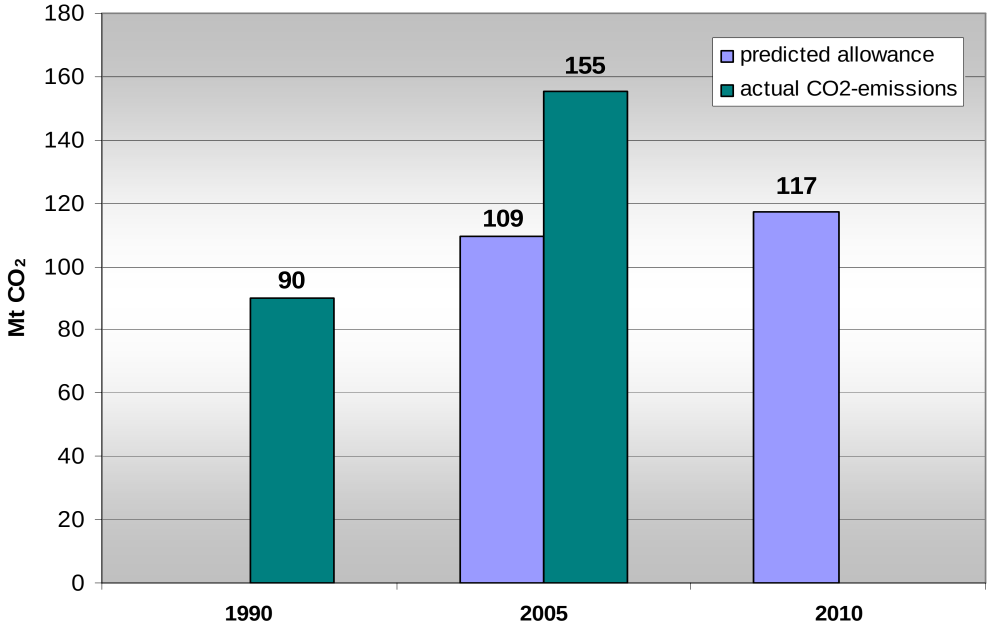
3.4.4 Domestic sectors

3.4.4.1 Model results and analysis

For the domestic sectors, the Triptych model assumes convergence of emissions per capita among EU member states by 2030 (see section 2.2.4). According to the UNFCCC, energy-related CO_2-emissions were 90 Mt CO_2 in Spain's domestic sectors in 1990 (see Table 25 in Annex 8.4).

[61] Energy intensity indicators between 1995 and 2005 are taken from EC (2006).

Figure 25 Spain: Energy-related CO_2-emissions in the domestic sectors vs. model results

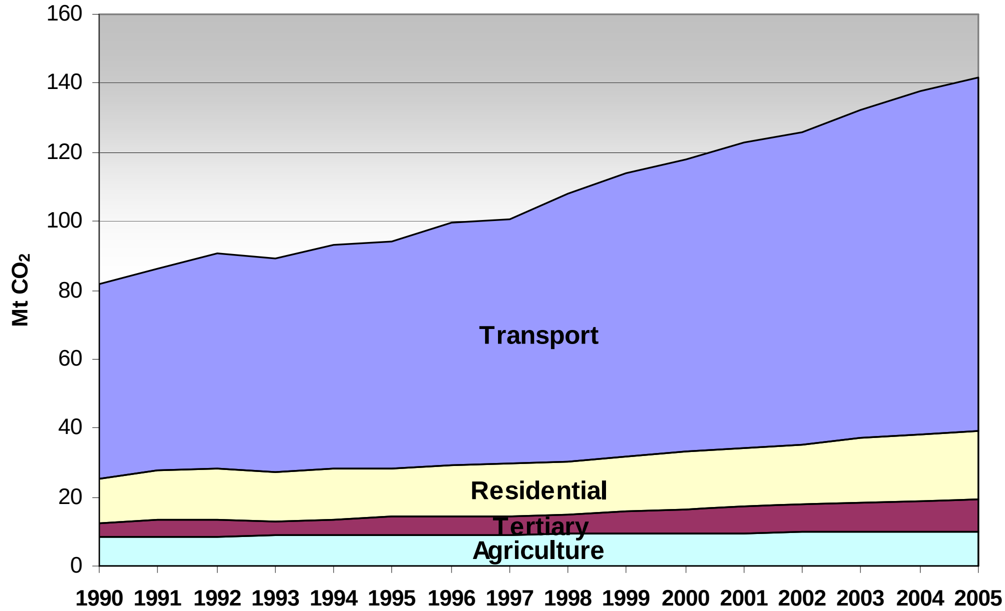


Source: UNFCCC (2007), own calculations

Figure 25 compares the actual emissions data reported to the UNFCCC (2007) to the results predicted by the model. With population of 39 million people, emissions per capita were 2.3 t in Spain's domestic sectors in 1990. Linear interpolation yields 2.55 t CO_2 per capita for 2005. This predicts an allowance of 109 Mt CO_2-emissions for 2005 given population of 42.9 million people (see Table 18). However, actual emissions were 155 Mt CO_2 in 2005 which exceeds the calculated allowance by 42 per cent (46 Mt). The predicted allowance for 2010 is 117 Mt CO_2 assuming population of 44.6 million people (Eurostat, 2007) and CO_2-emissions of 2.63 t per capita. This would be 38 Mt CO_2 less than in 2005.

Figure 26 shows the emission paths of the domestic sectors in Spain as they were reported to the UNFCCC (2007). The transport sector accounts for the largest share of emissions in the Spanish domestic sectors (72 per cent) and for almost one third of Spain's total CO_2-emissions in 2005 (102 Mt CO_2). Since 1990, emissions from transport have grown by 79 per cent. Indeed, the number of cars per 1000 people increased by 24 per cent from 479 in 1995 to 596 in 2003 (MMA, 2006). The number of person-kilometres almost doubled between 1990 and 2005. Hence, the Spanish travelled more kilometres per person than the Germans in 2005 (EC, 2006). Figure 27 maps the development of transport emissions by transport means in Spain (UNFCCC, 2007). The highest increase is made by road transports that almost doubled during that period. In 2005, road transport produced 91 per cent of total transport emissions. Furthermore, civil aviation and inland navigation increased by more than two thirds of 1990 levels, but their emissions account only for 6.7 per cent and 2.5 per cent of the domestic sectors. However, passenger transport efficiency increased by 12 per cent between 1990 and 2005 (EC, 2006).

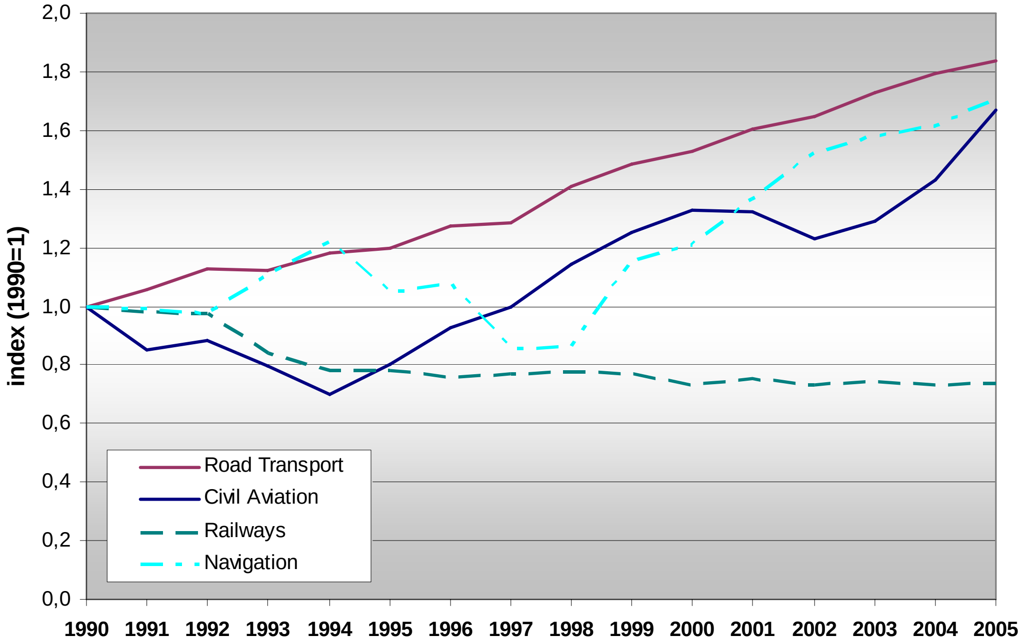
Figure 26 Spain: Energy-related CO_2-emissions in the domestic sectors from 1990 to 2005



Source: UNFCCC (2007)

Considering Figure 26 and Figure 27, it is obvious that (road) transport is the main driver of these increasing emissions in Spain’s domestic sectors. Although emissions in the residential (+52 per cent) and the tertiary sector (+260 per cent) were increasing, their small shares do not visibly influence the overall result. The Spanish government is aware of that problem and aims to improve the structure of public transport means with its ‘Strategic Plan for Infrastructure and Transport.’ Moreover, 5.8 per cent share of biofuels should be reached by 2010. An important issue in Spain’s future energy demand will be the need for cooling. With increasing living standards air conditioning becomes affordable. This would increase electricity demand.

Figure 27   Spain: Index of emissions from transport by transport means



Source: UNFCCC (2007)

3.4.4.2 Simulation for 2020

Table 18 shows the assumptions on population size and emissions per capita made for the simulations for 2010 and 2020. The predicted emissions allowance for the year 2020 would be 128 Mt CO_2 which had already been exceeded in 2005. In the same year, emissions per capita in Spain's domestic sectors were already 3.6 t CO_2. Hence, the pace of convergence per capita emissions assumed in the Triptych model develops too slowly. Put differently, the Spanish economy grew faster than assumed by the model. However, climate policy action in Spain is less advanced than in the UK or Germany. In contrast to those countries, no long-term climate policy targets and less stringent policy measures are formulated in Spain.

Table 18 Spain: Model assumptions and predicted allowances in the domestic sectors

	1990	2005	2010	2020
Population (Mio)	39.0	42.9	44.6	45.6
t CO_2 per capita	2.3	2.55	2.63	2.8
CO_2-emissions (Mt CO_2)[62]	(89.9)	109.4 (155.3)	117.4	127.5

Source: Eurostat (2007), own calculations

3.4.5 Summary for Spain

Spain is going to fail its Kyoto target of 15 per cent additional greenhouse gas emissions over the 1990 baseline. In 2010, emissions are projected to be 51 per cent over the 1990 level, with existing policies and measures (EEA, 2006). In 2005, 45 per cent of energy-related CO_2-emissions were produced by the domestic sector, 35 per cent by the power producing industry, and 21 per cent by the heavy industry. CO_2-emissions in Spain have been increasing by 64 per cent between 1990 and 2005. However, total CO_2-emissions in Spain were less than half of the CO_2-emissions produced in Germany and less than two thirds of CO_2-emissions in the UK (UNFCCC, 2007). The main drivers of increasing emissions in Spain were accelerated economic growth and, consequently, increasing living standards. Hence, emissions per capita increased at higher pace in Spain than assumed by the model. In particular road transport has a strong impact on increasing emissions in the domestic sector. No improvements in energy efficiency could be observed in the heavy industry. In comparison to Germany and the UK, less effort was made in Spanish climate policy. However, despite its considerably increasing energy demand, Spain has a well-balanced fuel mix with a high share of renewably energy, combined heat and power, and natural gas combustion. This result could give rise to sustainable development in Spain.

[62] Real data in brackets (UNFCCC, 2007)

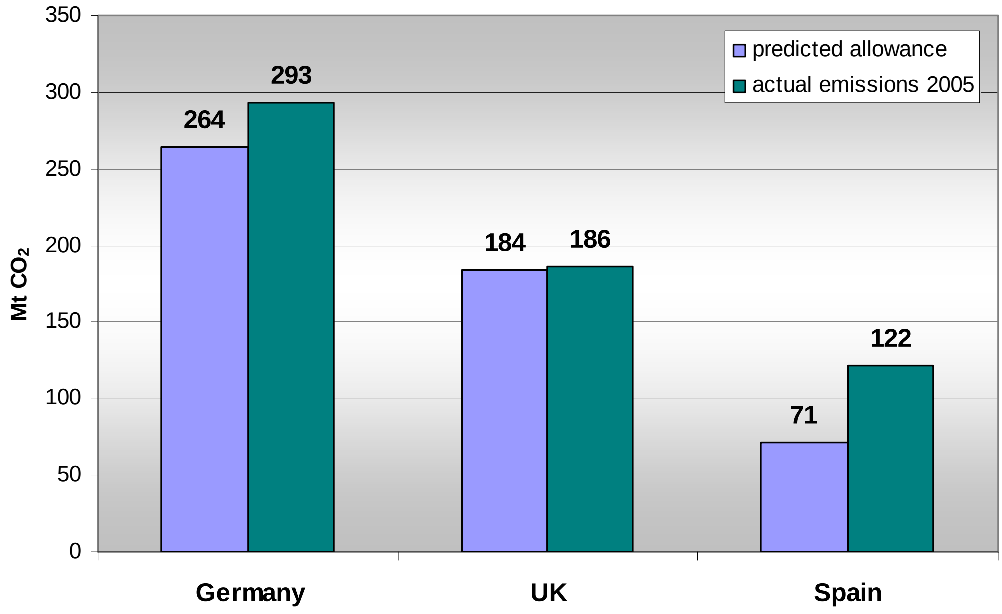
4 Model evaluation

In this chapter, the model results presented in the preceding sections are summarised and compared for each sector by country. The purpose of this chapter is to evaluate the applicability of the Triptych model and give recommendations on further developments of this approach.

4.1 The power producing sector

The power producing sector models the fuel mix of each member state taking into account specific emission reduction potentials and different starting points in 1990. Therefore, a switch to gas combustion, the extended use of renewable energy and combined heat and power is assumed for all EU states. Figure 28 compares the model results for 2005 to the actual emissions based on IEA data (2006). The best result was achieved in the United Kingdom, where the assumptions made on fuel mix fits best. The actual emissions almost met the simulated allowance in 2005. The UK, benefiting from the switch to gas, confirms the assumptions made in the Triptych model. In contrast to the UK, Germany exceeded its allowance by more than ten per cent. Although Germany made considerable efforts in its use of renewable energy, coal combustion still holds the greatest share of electricity combustion. The country is far from a considerable switch to natural gas. However, the assumption made on annual productivity growth was met best in Germany. In contrast to it, emissions in Spain exceed the simulated allowance for 2005 by 72 per cent. This development is driven by the high productivity growth rate of 4.5 per cent p.a. that is correlated to economic growth rates in Spain. Hence, the assumption on enhanced growth rates for Cohesion Fund countries was appropriate, but the assumed production growth rate was not sufficient. Despite its strong increase in emissions, the Spanish power sector meets the assumptions on fuel switch best. The use of natural gas increased tremendously, and Spain has the highest share of renewable energy and CHP, too. Spain has a well-balanced fuel mix with almost equal shares of coal, gas, nuclear power and renewable energy.

Figure 28 Comparison of predicted emission allowances to actual emissions in the power producing sectors of Germany, the UK and Spain



Source: IEA (2006), own calculations

Comparing the results, it seems countries tend in particular to use their domestic energy resources: coal in Germany, natural gas in the UK, and renewable energy in Spain. This can be explained by the historical paths of nationally regulated energy policy formulating security of supply as primary objective.

One shortcoming of the original Triptych approach is that heat production is not modelled. Energy for heat is a substantial element in energy policy considerations and should therefore be included in the simulations of CO_2-emission allowances. Moreover, a convergence approach for generation efficiencies of power plants measures as it was already applied by Groenenberg (2002) and in this simulation (see Annex), is a useful assumption. Convergence in generation efficiency reflects the implementation of technology standards for power plants in the European Union. The assumption to increase shares of renewable energy at flat-rate makes sense at a low level but it does not consider the renewable energy potentials of the countries. Hence, a particular burden sharing agreement based on technical potentials should be integrated into this model. Finally, instead of differentiated growth rates in electricity production, convergence in electricity production based on GDP per capita could be assumed. This would reflect the convergence assumption that is made for the residential sector.

Summarising these results, the methodology applied to the power producing sector is a good framework in order to consider the improved assumptions that were made in this section. Hence, electricity production could be modelled under the convergence assumption, and the fuel mix would consider renewable energy potentials. The switch to gas and increased rates of CHP should be assumed, as well. This methodology combines top-down targets in a bottom-up framework in a sophisticated way. The advantage of the sectoral model is that it can be extended anyway. Hence, it is easy to integrate EU community policy into the Triptych framework, as for instance, by implementing the burden sharing agreement for renewable energy.[63]

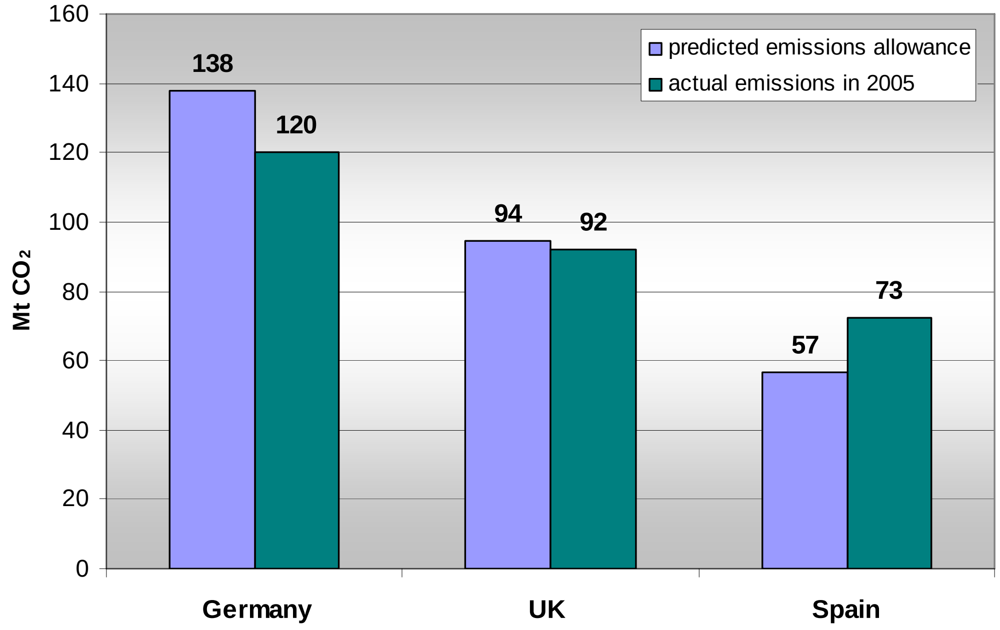
4.2 The heavy industries

Figure 29 compares the simulated results for the heavy industries to the actual emissions in 2005. Germany and the UK went under their emission allowances, whereas Spain exceeded the simulated allowance. The assumption on production growth rates was met differently. Germany exceeded the assumed growth rate, and the UK went under it. However, the model assumed a higher productivity growth rate for Spain, which was reached in reality. Nevertheless, 2.1 per cent productivity growth was chosen generously. In all three cases, the assumed improvement in energy efficiency was not reached. However, the heavy industries performed considerably well. Hence, a third variable, as carbon intensity, for instance, must explain emission reductions, too.[64] In this case, the assumed decarbonisation rate of 0.17 per cent p.a. was too low.

[63] This could consider the community targets of 20 per cent renewable energy of primary energy or 20 per cent energy savings by 2020 (BMU, 2007).

[64] Carbon intensity would also reflect the fuel mix, whereas energy efficiency only considers the energy savings potential.

Figure 29 Comparison of results for the heavy industries in Germany, the UK and Spain



Source: UNFCCC (2007), own calculations

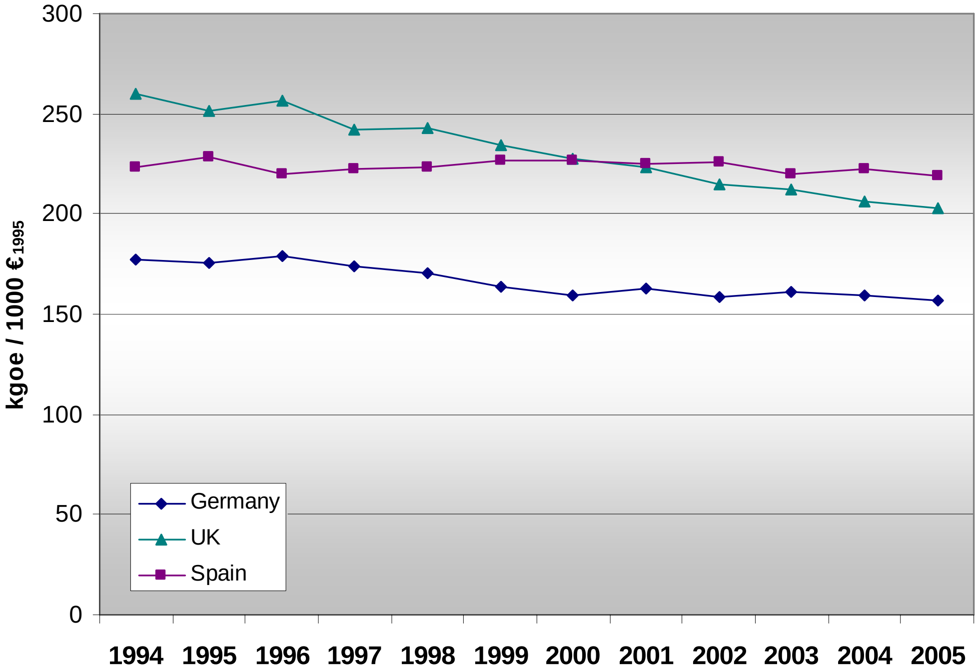
Considering the implementation of technology standards in the European Union, and the European economic integration, a convergence approach in carbon intensity could be implemented in the heavy industry sector. The reason is increasing marginal abatement costs. Hence, the more energy efficiency improvements were already made the more expensive additional improvement is. Put differently, more improvement can be achieved at lower costs in non-renovated facilities. Hence, energy efficiency improvements could be made at different rates in EU countries. Therefore, a particular level of carbon intensity could serve as convergence level in a certain convergence year. The interpolated carbon intensity would be multiplied with the amount of emissions in the base year.

Figure 30 shows the paths of energy intensity for Germany, the UK and Spain as they are reported by Eurostat (2007).[65] Accordingly, Spain would have to improve energy efficiency at the highest pace, Germany at the lowest. This procedure could be applied to the heavy industry based on carbon intensity ratios to calculate national emission allowances within the Triptych

[65] These numbers include the whole economy and depend therefore on the sectoral economic shares, too. Hence, decreasing energy intensity in the UK is rather due to its growing financial sector than to increasing energy efficiency in the manufacturing industries.

framework. If necessary, particular industry branches could be treated differently. EU community policy, as energy efficiency improvements, can be easily implemented into this model framework.

Figure 30 Energy intensity in Germany, the UK and Spain



Source: Eurostat (2007)

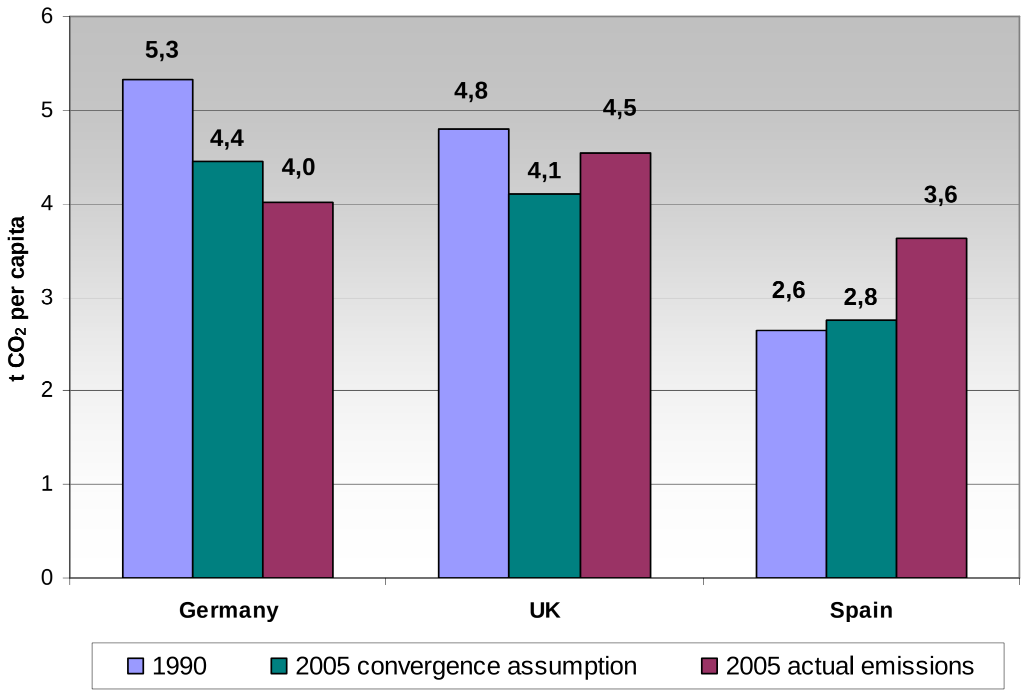
However, normative assumptions become unnecessary if the carbon market is launched. Then, firms abate emissions at the lowest cost. The only thing that had to be negotiated would be the ‘cap,’ which is the total amount of emissions reduction that must be achieved in the emissions trading sector, versus the amount that must be reduced in the non-trading sector (see chapter 5).

Summarising these results, the methodology applied in the Triptych approach predicts emissions reduction of the heavy industry well on average. However, the real results were either driven by different explanatory variables, or the data provided by the PRIMES model was not appropriate. Based on the data that were available for this analysis, emissions reductions must be explained by decreasing carbon intensity or by any missing variable instead of energy efficiency improvements in the heavy industry.

4.3 Domestic sectors

The domestic sectors were modelled under the assumption that per capita emissions will converge in Europe. The common convergence level that should be reached in each country would be 3 t CO_2 per capita by 2030.

Figure 31 CO_2-Emissions per capita in the domestic sectors in Germany, the UK and Spain



Source: UNFCCC (2007), own calculations

Figure 31 compares per capita emissions in 1990 and 2005 to the simulated assumptions for 2005. The assumed amount was met in Germany, but exceeded in the UK and in Spain. However, there is convergence of per capita emissions taking place in Europe. Germany and the UK that started from a high level reduced their emissions, whereas Spain, starting from a low level, increased emissions. The interesting result is that Germany reduced per capita emissions at higher pace than the UK. Emissions per capita in Spain increased faster than assumed by the model, which could be explained by the high growth rates in GDP per capita reflecting increasing living standards in Spain. However, emissions from road transport have increased tremendously in Spain since 1990. Actually, in 2005, the Spanish travelled more kilometres per person then the Germans but less than the British (EC, 2006).[66] Hence, public transport could be the key to emissions reduction in the domestic sectors. Moreover, the integration of air transport into the emissions trading system will be necessary in order to restrain the further increase of emissions from civil aviation.

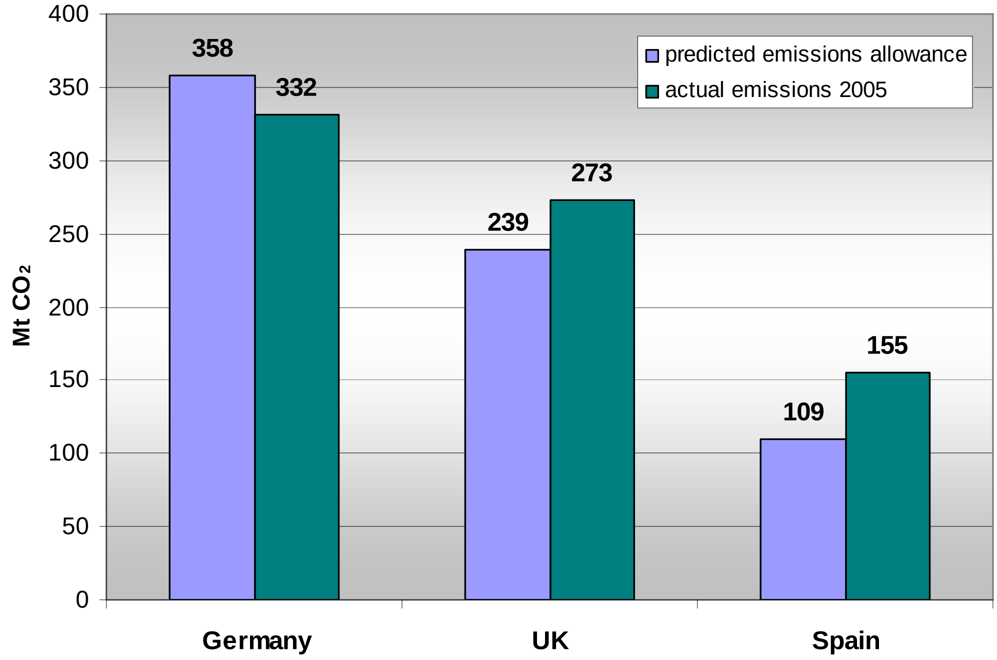
Figure 32 compares the results of emission allowances simulated for the domestic sectors to the emissions reported to the UNFCCC for 2005 (2007). According to emissions per capita, Germany reached its sectoral target, the UK and Spain exceed their allowances.[67]

Summarising these results, the assumed convergence of emissions per capita fits comparatively well for the domestic sectors. However, Germany and Spain converged at higher pace. Hence, another convergence year that is a bit closer to the present than 2030 could have been chosen.

[66] Travel per person: Germany: 11,568 km per capita, UK: 13,930 km per capita, Spain: 12,558 km per capita in 2005 (EC, 2006).

[67] However, the results depend on the share of the light industry reported by Capros (1995), too. Though the shares of the light industry in the domestic sectors are rather small (7.5 per cent in Germany, 12 per cent in the UK, 6 per cent in Spain; see Annex 8.4), the results could be biased.

Figure 32 Comparison of results for the domestic sectors in Germany, the UK and Spain



Source: UNFCCC (2007), own calculations

4.4 Revised Triptych assumptions

The Triptych model is a sophisticated approach implementing top-down targets into a bottom-up framework in order to calculate emissions allowances for the EU burden sharing agreement. With its sectoral structure, the model allows different treatments for the specific emission units of the economies, i.e. power production, heavy industry and domestic sectors. The application of different methods within each sector allows to consider different emission reduction potentials under detailed assumptions. Hence, it is always possible to extend this framework to more detailed analysis or different methodologies. The bottom-up structure of the model made it politically successful as it considers different national circumstances and potentials of the EU members. Therefore, the Triptych model was perceived as 'fair,' and became politically accepted. However, recent analysis suggests that the assumptions made in the original Triptych approach imposed a relatively heavy burden to some countries (Sweden, Belgium, the Netherlands, Spain and Portugal), whereas other countries (Germany, the United Kingdom, France) had a rather light burden (Sijm et al., 2007). Hence, the assumptions made in the original model should be adjusted. The Triptych approach could serve as framework for sectoral agreements implementing top-down targets: 1) The power sector could imply the burden sharing agreement for renewable energy, technology standards for conventional power plants and a common share on CHP capacity, assuming convergence in electricity production per GDP per capita. 2) The heavy industry sector could assume convergence in energy intensity. 3) The domestic sectors assume convergence in per capita emissions.

However, from an economist's point of view, the Triptych model can rather be perceived as a subsidy mechanism. In light of the European integration process, living standards and technology standards converge between EU countries. Firms operate internationally, and should therefore get no preferential treatments among countries. There is little reason to change framework conditions for firms within national borders. Moreover, the harmonisation of goods, services, labour and money movements within the EU requires harmonised polices and framework conditions. Hence, the first best solution to tackle emissions reduction in a cost-effective way is the implementation of the European carbon market. For the reasons mentioned in chapter 2, the market cannot be applied to all economic sectors as it would take high transaction costs and monitoring for emissions trading in the domestic sectors, for instance. This gives raises the issue, how the EU emissions trading system could be implemented into the future burden sharing agreement after 2012.[68] This issue is discussed in chapter 5.

[68] This reflection results from the experience that politicians rely on national targets and different national policies and measures. Perfect harmonisation of policy within the European Union is far from reality in 2007 (UBA, 2007).

5 Future burden sharing agreement

The future burden sharing agreement for EU-27 has to cope with new challenges. First, the extension of the EU to 27 member states with greater differences in economic power, institutional framework and emission reduction potentials will be the greatest challenge for the new agreement. Second, the central element of the future EU burden sharing agreement will be the European emissions trading system (ETS). Emissions' trading is the most efficient way to reduce emissions at lowest cost resulting in the environmentally effective amount of emission permits (the 'cap').

5.1 The European emissions trading system

The first period of European emissions' trading went from 2005 to 2007. The system collapsed with carbon prices falling to less than 1€ in 2006. The reason was that the amount of assigned allowances, allocated by national governments, was too high. This section deals in particular with the allocation method applied in EU-15 countries.

5.1.1 Grandfathering

In the first trading period, at least 95 per cent of total emission allowances had to be grandfathered by national governments to their industries (directive 2003/87/EC; BMU, 2004).[69] Grandfathering means the free allocation of emission permits based on historic emissions. In Germany, permits for 499 Mt CO_2 were allocated to the industry. As a consequence of free allocation, the companies passed their opportunity costs through to their consumers earning so-called 'windfall profits.' This adverse distributional effect is just one argument against grandfathering (Sijm et al., 2007). Moreover, the free allocation corresponds to a subsidy on carbon-intensive technology favouring the status quo of fuel mix. Due to the free allocation based on historic emissions, carbon-intensive producers have no incentive to

[69] In EU-25, almost all countries grandfathered 100 per cent of emission permits, except Denmark (5 per cent), Hungary (2.5 per cent), Lithuania (1.5 per cent) and Ireland (0.75 per cent) auctioning small shares of permits.

reduce emissions. Incumbents are preferentially treated towards new entrants to the market. Lobbying activities and the poor data situation led to over-allocations inducing the collapse of the carbon market. Finally, grandfathering is less transparent and more complicated than other allocation methods, as it causes high administrative costs, i.e. transaction costs (Sijm et al., 2007).

5.1.2 Auctioning

The allocation method preferred by economists is auctioning. Auctions are the most efficient allocation mechanism. It considers the polluter-pays principle. Auctioning creates fair conditions for new entrants and treats all participants the same, equal way. Windfall profits and over-allocation is excluded. Hence, it avoids a price collapse. Moreover, auctions have lower transaction costs and are more transparent. They enhance management awareness on carbon costs and set long-term price signal, creating thus investor-friendly conditions for low-carbon investments. Finally, revenue is generated for the public sector, which can be used to substitute taxes and, hence, reduce welfare losses (Sijm et al., 2007).

The most efficient auction is the Vickrey auction. It is a second-price sealed-bid auction, where the winner pays the price of the second bid. This gives the incentive to bid truthfully and avoids the winner's curse (Wolfstetter, 2002). However, the Vickrey auction does not maximise the revenue of the seller.

5.2 Options for a future EU burden sharing agreement

The challenge of the future burden sharing agreement of EU-27 will be the integration of the twelve new member states. The emissions trading sector could be excluded from the non-trading sector. National emission targets could be developed for the non-trading sectors, based on the convergence assumptions made in Triptych.

In climate policy, the prinicpal issue of the future burden sharing agreement will be the implementation of EU climate policy targets and the European emissions trading system (ETS). Therefore, the current debate is on the segregation of the trading sector from the non-trading sector. The simplest solution would be to exclude the ETS sector from the conventional burden sharing agreement, which is based on national emission reduction targets. Consequently, the ETS sector would cover one share of the overall EU emissions target, and the non-ETS sectors would have national targets within the burden sharing agreement (Sijm et al., 2007).

The economic efficient solution would be the integration of as many sectors as possible into the European ETS, and the application of harmonised allocation rules. In light of the European economic integration, harmonised conditions in institutional frameworks, e.g. taxation laws, technology standards, labour markets and climate policy regulation, are necessary, in order to avoid competitive disadvantages of single countries. The cap of the ETS should be set as an environmentally effective quality target. Emission permits should be auctioned by the European Communities, and the revenue should be used to compensate the external costs arising from climate change impacts. In addition to emissions' trading, binding standards for energy efficient technology, such as 'top-runner,' should create the institutional framework of climate policy in the EU.[70]

However, national governments do not want to give up their sovereignty in favour of common European energy and climate policy. Hence, the EU members claim the revenue that accrues from auctioning emission permits for their own fiscal policies. This raises, again, the issue of sharing revenue among EU members in a way that would be perceived as 'fair.' Therefore, the German Federal Environment Agency proposes the 'Double Burden Sharing' approach formulating national targets for the ETS and the non-ETS sector (UBA, 2007). Accordingly, each EU country is assigned an amount of emission permits of the EU ETS that it can allocate to the industry. The sum of national permits is the total cap of the EU ETS. In addition, EU burden sharing targets for renewable energy could be implemented, in order to achieve the common goal of 20 per cent renewable energy of primary energy production by 2020.

[70] This means normative policy targets as the 10 per cent share of biofuels, 130g CO_2/km for newly build cars, conversion efficiency standards for power plants etc.

6 Summary and Conclusions

The goal of this thesis was to find reasons for the deviations of EU countries' greenhouse gas emissions from their targets established in the greenhouse gas burden sharing agreement of the European Union. The agreement is based on the Triptych approach, a bottom-up model that derives sectoral allowances, which sum up to the national emission allowance. For the analysis, interpolated allowances for 2005 were compared to the recently reported developments of actual emission paths. Germany, the UK and Spain were selected as representative examples for countries that are either on track to meet or fail their emission targets. The results suggest that there exist various reasons for different developments of emission paths.

In the power producing sector, the model assumptions were hardly achieved. The results of the case studies suggest that EU countries seem to prefer their domestic fuel mix. The dominant fuels are coal in Germany, natural gas in the United Kingdom and renewable energy in Spain. In Germany and the UK, this could be due to historically regulated energy policy in EU countries, claiming security of supply as principal objective. As result of the fuel switch to natural gas, the emission target was met best in the UK. Moreover, the results suggest that the introduction of the feed-in tariff for renewable energy in Germany and Spain in fact accelerated the development and deployment of renewable energy.

In the heavy industry, the assumptions made on energy efficiency improvements were not met either. However, the heavy industry performed considerably well in Germany and the UK, where voluntary agreements were linked to carbon taxes. Hence, decarbonisation or any other missing variable must explain emission reductions in the heavy industry.

In the domestic sectors, the assumed convergence in emissions per capita could be confirmed. However, emissions per capita converged at higher pace in Spain and in Germany. In all countries, road transport holds the largest share of emissions in the domestic sectors. The UK and Spain show higher emissions from transport per capita than Germany. In all countries, emissions from civil aviation have been increasing significantly over the last decade. Hence, air transport should be integrated into the European emissions trading system in order to limit further the increase of emissions. In contrast to the transport sector, CO_2-emissions in the commercial and the agricultural sectors have been reduced significantly.

Germany is projected to almost meet its Kyoto target with existing policies and measures. The heavy industry and the domestic sector go below their simulated emission allowance for 2005. In particular the heavy industry succeeded in reducing emissions, based on voluntary agreements. In the domestic sectors, emissions per capita were substantially reduced. In particular with the introduction of the eco tax in 1999, emissions decreased visibly in the domestic sectors. However, road transport still is the main contributor to emissions in the domestic sectors, and emissions from civil aviation have been increasing significantly. Although the 'Renewable energy law' boosted the development and deployment of renewable energy in Germany, more effort must be done for the substitution of solid fossil fuels in Germany. Actually, there is a discrepancy between investment decisions of power producers and climate policy objectives in Germany. Actually, the extended use of coal combustion threatens reaching the Kyoto target in Germany.

The United Kingdom is on track of meeting its Kyoto target, though the initial emission reduction target, calculated in the original Triptych approach in 1997, will not be met with existing policies and measures. In the power producing sector, the fuel switch to natural gas was pushing the UK towards a low carbon economy. However, renewable energy still holds a very low share of electricity production in the UK. Emissions in the heavy industry were sufficiently reduced, which is mainly based on voluntary agreements that are linked to the climate change levy. In comparison to Germany and Spain, the British drive the greatest number of kilometres per person by car. Moreover, civil aviation is an emerging driver of increasing emissions in the British domestic sectors. More effort could be done for the development of renewable energy and the promotion of public transport meanings. However, the UK developed a variety of policies and measures and should therefore be on track of reaching further emission reductions.

Spain will not reach its Kyoto target, which is mainly due to its accelerated economic growth. However, hardly any energy efficiency improvements could be observed in the Spanish heavy industry. Emissions in the domestic sectors, in particular road transport, increased tremendously in Spain. Less action can be observed in Spanish climate policy than in Germany or the UK. Hence, more effort should be done for developing binding climate policy targets and measures. However, Spain has a well-balanced fuel mix, which leaves scope for sustainable development.

Finally, the intrinsic meaning of the assumptions made in Triptych is to develop a subsidy mechanism for less developed countries in the European Union. Actually, in light of the European economic integration, the assumed convergence of living standards took place within the EU-15. The European Economic Community needs a harmonised institutional framework in order to create market conditions for producing economic favourable results. This framework will consist of the European carbon market, technology standards within a harmonised institutional framework. For the emissions trading sector, an ambitious cap should be negotiated in order to make low carbon technology profitable. Hence, the further operation of renewable energy would be induced. Emission reduction in the non-trading sectors would be achieved by the implementation of harmonised legacy and technology standards in the EU. The overall challenge of future burden sharing in EU-27 will be the integration of the twelve new member states, taking into account their specific national circumstances, different economic potential and political interests.

7 Literature

ABARE (1995): Global climate change: Economic dimensions of a cooperative international policy response beyond 2000, Australian Bureau of Agriculture and Resource Economics, Canberra (Australia).

ACEA (1998): ACEA and its voluntary agreement to reduce CO_2 emissions – What has exactly been agreed? Press release, http://www.acea.be/acea_1998_commitment_what_has_been_agreed (08.10.2007), The European Automobile Manufacturers Association, Brussels (Belgium).

AEA Technology (2001): Climate change agreements – sectoral energy efficiency targets. Version 2. AEA Technology plc, Oxfordshire (UK).

BDI (2004): Freiwillige Vereinbarungen und Selbstverpflichtungen. Bestandsaufnahme freiwilliger Selbstverpflichtungen und Vereinbarungen im Umweltschutz (Stand: Dezember 2004). Bundesverband der Deutschen Industrie e.V., Berlin (Germany).

Blankart, C. (2001): *Öffentliche Finanzen in der Demokratie*. Eine *Einführung in die Finanzwissenschaft*, 4th ed., Verlag Franz Vahlen, München (Germany).

Blok, K., Phylipsen, G.J.M. and Bode, J.W. (1997): The Triptique Approach: Burden differentiation of CO_2 emission reduction among European Union member states, Department of Science, Technology and Society, Utrecht University, Utrecht (the Netherlands).

BMU (2007): Eckpunkte für ein integriertes Energie- und Klimaprogramm. The German Federal Ministry for he Environment, Nature conservation and Nuclear safety, Berlin (Germany).

BMU (2007): Cabinet adopts climate and energy package, Press release, http://www.bmu.bund.de/english/current_press_releases/pm/39956.php (24.08.2007), The German Federal Ministry for he Environment, Nature conservation and Nuclear safety, Berlin (Germany).

BMU (2007): Minister Gabriel welcomes the results of the EU summit, Press release, http://www.bmu.de/english/current_press_releases/pm/38874.php (12.10.2007), The German Federal Ministry for he Environment, Nature conservation and Nuclear safety, Berlin (Germany).

BMU (2007): Erneuerbare Energien in Zahlen – nationale und internationale Entwicklung. Stand: Januar 2007 – Internet-Update, The German Federal Ministry for he Environment, Nature conservation and Nuclear safety, Berlin (Germany).

BMU (2006): Umweltbewusstsein in Deutschland 2006, The German Federal Ministry for the Environment, Nature conservation and Nuclear safety, Berlin (Germany).

BMU (2006): Climate protection pays, http://www.bmu.de/english/climate/downloads/doc/37944.php (08.10.2007), The German Federal Ministry for the Environment, Nature conservation and nuclear safety, Berlin (Germany).

BMU (2004): Nationaler Allokationsplan für die Bundesrepublik Deutschland 2005-2007, The German Federal Ministry for the Environment, Nature conservation and nuclear safety, Berlin (Germany).

BMWi (2007): Energiedaten – nationale und internationale Entwicklung, http://www.bmwi.de/BMWi/Navigation/Energie/energiestatistiken.html (08.10.2007), The German Federal Ministry of Economics and Technology, Berlin (Germany).

BUND (2007): BUND-Übersicht: 25 neue Kohlekraftwerke in Deutschland, http://vorort.bund.net/klimaschutz/publikationen/publikationen_80/files/2573_uebersichtkohleseptember07.pdf (22.09.2007). Bund für Umwelt und Naturschutz Deutschland e.V., Berlin (Germany).

Capros et al. (1995): Energy scenarios 2020 for the European Union. Report to the European Commission, Athens (Greece).

Das Parlament (2005): Koalition will Top-Runner-Programm, Press release, http://www.bundestag.de/dasparlament/2005/21/plenumundausschuesse/002.html (08.10.2007), Das Parlament, Berlin (Germany).

Deutscher Bundestag (2004): Kerosinsteuer-Privileg der gewerblichen Luftfahrt kostet 373 Millionen Euro, http://www.bundestag.de/aktuell/hib/2004/2004_191/01.html (08.10.2007), The German Parliament, Berlin (Germany).

Defra (2007): UK Energy Efficiency Action Plan 2007, The British Department for Environment, Food and Rural Affairs, London (UK).

Defra (2006): 4 NC. The UK's Fourth National Communication under the United Nations Framework Convention on Climate Change, The British Department for Environment, Food and Rural Affairs, London (UK).

Dinan, D. (1998): *Encyclopedia of the European Union*, 2nd ed., Palgrave Macmillan Press, New York (USA).

Destatis (2006): Bevölkerung Deutschlands bis 2050. Übersicht der Ergebnisse der 11. koordinierten Bevölkerungsvorausberechnung – Varianten und zusätzliche Modellrechnungen. The German Federal Statistical Office, Wiesbaden (Germany).

DTI (2007): Meeting the energy challenge - A White Paper on energy, May 2007, The British Department of Trade and Industry, London (UK).

EEA (2007): EEA greenhouse gas data viewer, http://dataservice.eea.europa.eu/dataservice/viewdata/viewpvt.asp (07.07.2007), The European Environment Agency, Copenhagen (Denmark).

EEA (2006): Greenhouse gas emission trends and projections in Europe 2006. European Environment Agency, Copenhagen (Denmark).

European Commission (2006): European Energy and Transport – Trends to 2030 – update 2005, The European Communities, Luxembourg (Luxembourg).

Eurostat (2007): Eurostat indicators, http://epp.eurostat.ec.europa.eu (08.10.2007), The European Commission, Brussels (Belgium).

Groenenberg, H. (2002): Development and Convergence – A bottom-up analysis for the differentiation of future commitments under the Climate Convention, Utrecht University, Utrecht (the Netherlands).

Groenenberg, H. et al. (2001): Differentiating commitments world wide: Global differentiation of GHG emissions reductions based on the Triptych approach – a preliminary assessment.

Grubb, M. (1989): The greenhouse effect: Negotiating targets, Royal Institute of International Affairs, London (UK).

Grübler, A. & Y. Fuji (1991): Inter-generational and spatial equity issues of carbon accounts, *Energy Policy*, **16** (11/12), pp. 1397-1416

Grübler, A. & N. Nakicenovic (1994): International burden sharing in greenhouse gas reduction, IIASA, Laxenburg (Austria).

Höhne et al. (2007): Factors underpinning future action. 2007 update. Report for the British Department for the Environment, Food and Rural Affairs (DEFRA; UK), ECOFYS GmbH, Cologne (Germany).

Höhne (2003): Triptych 6.0, (unknown).

IEA (2007): *Energy policies of IEA countries - Germany 2007 review*, The International Energy Agency, OECD/IEA, Paris (France).

IEA (2007): *Energy policies of IEA countries - The United Kingdom 2006 review*, The International Energy Agency, OECD/IEA, Paris (France).

IEA (2006): *Electricity information 2006,* The International Energy Agency, OECD/IEA, Paris (France).

IEA (2005): *Energy policies of IEA countries - Spain 2005 review*, The International Energy Agency, OECD/IEA, Paris (France).

El Ministerio de Medio Ambiente (2006): Cuarta comunicación nacional de Espana, The Spanish Ministry for the Environment, Madrid (Spain).

Neij et al. (2003): Experience curves: A tool for energy policy assessment. EXTOOL Final Report, Lund University, Lund (Sweden).

Öko-Institut et al. (2007): Politikszenarien für den Klimaschutz IV. Szenarien bis 2030 für den Projektionsbericht 2007. Final Report for the Federal Environment Agency (UBA) by Öko-Institut e.V., Forschungszentrum Jülich, DIW Berlin, Fraunhofer Institut System- und Innovationsforschung, Berlin, Karlsruhe, Jülich (Germany).

Germanwatch (2007): Germanwatch raises complaint against Volkswagen - Climate Damaging Business Strategy Violates OECD Guidelines for Multinational Enterprises, http://www.germanwatch.org (08.10.2007), Germanwatch, Berlin (Germany).

Perman et al. (2003): *Natural resource and envrionmental economics.* Pearson Education Ltd., Essex (UK).

Phylipsen, D. et al. (2004): Implementing Triptych 6.0 – Technical Report, Ecofys.

Phylipsen, D. et al. (1998): A Triptych sectoral approach to burden differentiation; GHG emissions in the European bubble. *Energy Policy* **26** (12), pp. 929-943.

Phylipsen, D., et al. (1998b): The EU burden sharing after Kyoto – Renewed Triptych calculations, Department of Science, Technology and Society, Utrecht University, Utrecht (the Netherlands).

Ridgley, M. & F. R. Rijsberman (1994): Setting targets for climate policy: An approach to develop equity targets, Associates for Natural Resources Management Consulting, Delft.

Sijm, J.P.M., et al. (2007): Options for post-2012 EU burden sharing and EU ETS allocation, ECN report ECN-E-07-016, Energy Research Centre of the Netherlands, Petten (the Netherlands).

UBA (2007): Internal information provided by the department ‘Climate protection and Energy,’ The German Federal Environment Agency, Dessau (Germany).

UNFCCC (2007): National Inventory submissions 2006, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3734.php (28.06.2007).

UNFCCC (2005): *United Nations Framework Convention on Climate Change*. UNEP/IUC/2005, Geneva.

UNFCCC (2005): *The Kyoto Protocol to the Convention on Climate Change.* UNEP/IUC/2005, Geneva.

Wolfstetter, E. (2002): *Topics in Microeconomics – Industrial organisation, auctions and incentives*, Cambridge University Press, Cambridge (UK).

8 Annex

8.1 The United Nations Framework Convention on Climate Change and the Kyoto Protocol

8.1.1 Annex-I countries to the United Nations Framework Convention on Climate Change

Australia
Austria
Belarus
Belgium
Bulgaria
Canada
Croatia
Czech Republic
Denmark
European Economic Community
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Japan
Latvia
Liechtenstein
Lithuania
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Poland
Portugal
Romania
Russian Federation
Slovakia
Slovenia
Spain
Sweden
Switzerland
Turkey
Ukraine
United Kingdom of Great Britain and Northern Ireland
United States of America

8.1.2 Kyoto targets of Annex-I countries

Table 19 Emission reduction targets of Annex-I countries mentioned in Annex B of the Kyoto Protocol

Country	Kyoto target (1990– 2010)[71]
EU-15, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	- 8%
United States of America	- 7%
Canada, Hungary, Japan, Poland	- 6%
Croatia	- 5%
New Zealand, Russian Federation, Ukraine	0
Norway	+ 1%
Australia	+ 8%
Iceland	+10%

Source: UNFCCC (2007)

8.2 The power producing sector

8.2.1 Model equations

For calculating the total emission allowance for the power producing sector in year t, first, electricity production is modelled under the assumptions made in section 2.2.2, (see Table 20 for a summary of the assumed fuel shares).

Total electricity production:

$$EL_{total,t} = EL_{total,1990}\,(1+g)^{t-1990}$$

[71] 2010 is the average of 2008 to 2012 and will be used as Kyoto target year in the following. Some countries have other base years than 1990.

Electricity production by fuel:

$$EL_{solid,t} = s_t \, EL_{solid,1990}$$

$$EL_{liquid,t} = l_t \, EL_{liquid,1990}$$

$$EL_{renewable,t} = EL_{renewable,1990} + r_t \, EL_{total,1990}$$

$$EL_{CHP,t} = c_t \, EL_{total,t}$$

$$EL_{gas,t} = EL_{total,t} - EL_{solid,t} - EL_{liquid,t} - EL_{renewable,t} - EL_{CHP,t} - EL_{nuclear,t}$$

$EL_{nuclear,t}$: *according to Conventional Wisdom Scenario assumptions* (*see* 8.2.2)

The amount of electricity by fuel is converted into primary energy use by fuel:

$$PE_{solid,t} = \frac{EL_{solid,t}}{n_{solid,t}}$$

$$PE_{liquid,t} = \frac{EL_{liquid,t}}{n_{liquid,t}}$$

$$PE_{gas,t} = \frac{EL_{gas,t}}{n_{gas,t}}$$

$$PE_{CHP,t} = \frac{EL_{CHP,t}}{n_{gas,t}}$$

Primary energy use by fuel multiplied with the fuel emission factor yields the partial allowances by fuel:

$$A_{solid,t} = e_{solid} \, PE_{solid,t}$$
$$A_{liquid,t} = e_{liquid} \, PE_{liquid,t}$$
$$A_{gas,t} = e_{gas} \, PE_{gas,t}$$
$$A_{CHP,t} = e_{CHP} \, PE_{CHP,t}$$

The total allowance is the sum of partial allowances:

$$A_{power,t} = A_{solid,t} + A_{liquid,t} + A_{gas,t} + A_{CHP,t}$$

Where:

EL = electricity production,

PE = primary energy use,

A = emission allowance,

g = annual growth rate of electricity production,

s = the assumed share for fossil fuels of solid fuel use in 1990,

l = the assumed share for liquid fuels of liquid fuel use in 1990,

r = the assumed share for renewable energy of total electricity in 1990,

c = the assumed share for CHP of total electricity in year t,

n = generation efficiency,

e = emission factor,

t = the year 2005 or 2010.

Table 20 Summary of the model assumptions made on fuel shares

shares	s		l		r	c
	2005	2010	2005	2010		
Germany	0.63	0.5	0.78	0.7	0.08	0.15
Spain	0.78	0.7	0.78	0.7	0.08	0.15
UK	0.74	0.65	0.78	0.7	0.08	0.15

Source: Phylipsen et al. (1998), own calculations

8.2.2 Fuel input data for model simulations of the power producing sector

Table 21 Gross electricity production by fuel in PJ provided by the 'IEA Electricity information 2006' (IEA, 2006)

Fuel type	Germany		UK		Spain	
	TWh	PJ	TWh	PJ	TWh	PJ
Coal	322	1158	206	743	61	219
oil	10	37	35	125	9	31
Gas	41	146	5	18	2	5
Comb. Renewables and waste	5	18	1	3	1	3
Nuclear	153	549	66	237	54	196
hydro	20	71	7	26	26	94
Other renewables	0	0	0		0	0
total	550	1980	320	1151	152	547

Source: IEA (2006)

8.2.2 Electricity production by nuclear power

Table 22 Electricity production by nuclear power plants in Conventional Wisdom Scenario

PJ_e	Electricity production 1990	CW projection for 2010	Growth compared to 1990 (%)
Germany	549	501	-7
Spain	202	183	-10
United Kingdom	237	242	+2

Source: Blok et al. (1997)

8.2.3 Generation efficiencies and emission factors

Table 23 Assumptions on generation efficiencies and emission factors by fuel and by country

Fuel type	Emission factors (kg CO_2/GJ)	Generation efficiencies					
		Germany		United Kingdom		Spain	
		2005	2010	2005	2010	2005	2010
Solid	94	0.4	0.41	0.4	0.41	0.4	0.41
liquid	75	0.39	0.41	0.4	0.41	0.39	0.4
Natural gas	56	0.48	0.51	0.48	0.51	0.43	0.47

Source: Groenenberg (2002), UBA (2007), Phylipsen et al. (1998)

8.3 The heavy industry

Table 24 Energy related CO_2-emissions in Mt: Input data for the heavy industry provided in the CRF-tables of the UNFCCC

Mt CO_2	Category	Germany[72]	UK	Spain
I.A.1b	Petroleum refining	20	18	11
I.A.1c	Manufacture of solid fuels and other energy industries	39	14	2
I.A.2a	Iron and Steel	10	24	9
I.A.2b	Non-ferrous metals	1	-	1
I.A.2c	Chemicals	-	-	6
I.A.2d	Pulp, paper and print	0	-	3
I.A.2f[73]	Other non-specified	78	43	20
	Total	148	99	52

Source: UNFCCC (2007)

[72] The base year for Germany is 1994. The base year for the UK and Spain is 1990.

[73] This category contains the emissions of the categories that were not reported. The data was multiplied with the share of heavy industry provided by Capros (1995): 74 per cent in Germany, 57 per cent in the UK, and 81 per cent in Spain (Phylipsen et al., 1998)

8.4 The domestic sector

Table 25 Energy-related CO_2-emissions in Mt: Input data for the domestic sectors provided in the CRF-tables of the UNFCCC

Mt CO_2	Category	Germany	UK	Spain
I.A.2e	Food processing and beverages	2	-	3
I.A.2f[74]	Other non-specified	31	32	5
I.A.3	Transport	163	117	57
I.A.4	Other sectors	204	110	25
I.A.5	Other	12	5	-
	Total	412	264	90

Source: UNFCCC (2007)

[74] Emissions of the category I.A.2f were multiplied with the share for the light industry provided by Capros (1995; Phylipsen et al., 1998)

8.5 Energy-related CO_2-emissions reported to the UNFCCC

Table 26 Energy-related CO_2-emissions in Germany provided in the CRF tables of the UNFCCC

Energy-related CO_2-emissions (Mt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Public electricity and heat	336	329	317	308	308	303	315	301	306	297	310	322	323	338	334	325
Manufacturing industries	154	133	123	113	112	112	108	108	103	101	98	95	93	96	102	103
Transport	162	166	172	177	173	177	177	177	181	186	182	179	177	171	171	164
Residential	129	132	123	134	129	129	142	138	132	120	118	131	121	124	118	113
Commercial	64	65	58	55	51	53	63	54	53	49	45	52	49	49	46	45
Other	101	91	78	76	71	67	62	53	50	48	47	44	45	44	45	45
total	948	915	871	863	843	841	867	831	824	801	800	823	808	822	816	795

Source: UNFCCC (2007)

Table 27 Energy-related CO_2-emissions in the United Kingdom provided in the CRF tables of the UNFCCC

Energy related CO2-emissions (Mt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Public electricity and heat	205	204	191	172	167	164	164	150	154	145	156	166	162	171	171	173
Manufacturing industries	100	100	97	96	96	93	94	95	93	95	95	95	86	87	85	85
Transport	117	116	117	119	119	118	123	124	123	124	123	123	125	126	128	129
Residential	79	87	85	89	84	80	91	84	86	85	86	88	85	86	88	84
Commercial	26	28	28	27	27	27	29	27	27	28	27	27	23	23	24	23
Other	49	48	49	51	51	53	55	54	52	51	49	49	51	50	49	49
total	574	583	567	554	545	535	556	534	536	527	536	548	533	544	544	544

Source: UNFCCC (2007)

Table 28 Energy-related CO_2-emissions in Spain provided in the CRF tables of the UNFCCC

Energy-related CO_2-emissions (Mt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Public electricity and heat	64	65	73	67	66	72	59	70	70	85	90	84	98	91	100	110
Manufacturing industries	46	49	46	44	49	53	48	53	53	56	58	62	63	68	70	71
Transport	57	59	63	62	65	66	70	71	78	82	85	89	91	95	99	102
Residential	13	14	14	14	15	14	15	15	15	16	17	17	17	19	20	20
Commercial	4	5	5	4	5	5	5	6	6	6	7	8	8	9	9	10
Other	23	23	23	23	25	25	25	26	26	27	27	27	27	26	28	27
total	207	215	224	215	224	235	223	241	248	272	283	286	304	308	325	340

Source: UNFCCC (2007)

Erklärung zu Urheberschaft

(Eigenständigkeitserklärung)

Hiermit erkläre ich, dass ich die vorliegende Arbeit allein und nur unter Verwendung der aufgeführten Quellen und Hilfsmittel angefertigt habe.

Alexandra Börner

Berlin, 18. Oktober 2007