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Climate policy futures, energy markets, and technology: Implications for Norway

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Abstract

This paper is part of the joint CICERO and Fridtjof Nansen Institute (FNI) project “Towards a cost-effective climate policy: The international framework and Norwegian policy framework” (“Mot en effektiv klimapolitikk: Internasjonale rammebetingelser og norsk virkemiddelbruk”). The project, financed by the Norwegian Research Council, started in 1999 and is poised to end in 2001.

We explore two possible climate policy futures up to 2020. The first is a Climate-Stagnation scenario where the Kyoto Protocol does not enter into force, and the second is a Kyoto-Success scenario where the Kyoto Protocol enters into force and developing countries take on binding commitments to reduce their greenhouse gas emissions through a global burden-sharing scheme after 2012. We include a global oil and coal market and regional markets for gas. We argue that the two scenarios affect these international markets for fossil fuels and prices differently. In this paper, we first describe the analytical model we use, and then link different energy price paths to different paths of technological development, with a focus on scenarios from a European Commission study. Finally, we analyze both the economic implications for Norway through changes in oil and gas revenue, as well as implications for Norwegian climate policy formulation.

Key words: Kyoto Protocol, numerical model, fossil fuel markets, technological development, burden sharing, Norway, climate policy

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Contents

1 Introduction

Norway's ability to implement an efficient climate policy in Norway depends on a number of national and international conditions. The aim of this paper is to analyze the changing international setting for Norwegian climate policy as markets for fossil fuels are influenced by implementation of the Kyoto Protocol and the development of energy technologies. Two other important conditions, the development of the climate policy regime and the effects of other countries' choice and implementation of climate strategy, are covered by other papers in the project. This study is part of the joint CICERO and Fridtjof Nansen Institute (FNI) project "Towards a cost-effective climate policy: The international framework and Norwegian policy framework" ("Mot en effektiv klimapolitikk: Internasjonale rammebetingelser og norsk virkemiddelbruk").

To the extent that international environmental agreements seek to lower emissions related to energy use, which is the case for the Kyoto Protocol, their implementation affects energy markets and prices. In this study two possible climate policy futures up to 2020 are explored. First a Climate-Stagnation scenario is presented, where the Kyoto Protocol does not enter into force. The second scenario, a Kyoto-Success scenario, is based on the assumption that the Kyoto Protocol enters into force and developing countries are assumed to take on binding commitments through a global burden-sharing scheme in a second commitment period after 2012. The study covers the time period from 1990 until 2020, which is divided into two sub-periods. The first is from 1990 until 2012, and covers the first Kyoto Protocol period. The second sub-period is from 2013 until 2020. The economic model employed by the study is run first until 2010 and then to 2020 to represent the longer time horizon. Obviously the uncertainties associated with this study increase with the time horizon. In the case of a time horizon of 2020, the span of possible technology scenarios and potential energy market developments are significantly larger than in the case of the shorter time horizon of 2010.

Many scenarios between the Climate-Stagnation and Kyoto-Success scenarios, where the Kyoto Protocol is only partly implemented, are possible. The Kyoto Protocol has not yet entered into force and the probability of the Kyoto-Success scenario might not be large. The entry into force of the Protocol is strongly dependent on the USA's position. The USA has demanded "meaningful participation" by developing countries. This position seems to be non-negotiable, but might be left if no restrictions are placed on the use of the Kyoto mechanisms. The disagreement on developing country participation and rules for the Kyoto mechanisms might be strong enough to leave it stranded, as we have assumed in our Kyoto-Stagnation scenario. However, a potentially more likely outcome is a "Kyoto-Light" scenario in which some elements from the Kyoto Protocol are included and further developed. Examples of this are the Kyoto Protocol's structure and the mechanisms. The "Kyoto-Light" scenario could operate at different regional levels, e.g. the EU and the OECD. The "Kyoto-Light" scenario is outside the scope of this paper, but is an interesting area for further research.

The model used in this paper is a numerical, partial equilibrium model developed by Bjart Holtsmark at CICERO. It has for the purpose of this paper been expanded to include major developing countries and new emission commitments in 2020. The model specifies international markets for oil and coal, as well as regional markets for natural gas, in a world with 32 countries and group of countries.[1] The model determines equilibrium prices of fossil fuels and greenhouse gas emissions permits, as well as trade patterns in the permit and the fossil fuel markets as emission reduction targets are implemented.

Other studies (e.g. Bartsch and Müller (2000)) have shown that the Kyoto Protocol is likely to have significant impacts on the fossil fuels markets and on energy prices since emissions of carbon dioxide have to be reduced significantly. Fossil fuel prices will be significantly affected, even given an extensive use of the Kyoto mechanisms – international emissions trading, Joint Implementation, and the Clean Development Mechanism.[2] These mechanisms were established to make abatement measures as cost-effective as possible. Obviously such a development affects Norway's oil and gas wealth and affects possible policy choices in Norwegian climate policy. The economic consequences for Norway of changes in oil and gas wealth is likely to be larger than the consequences of reducing Norwegian greenhouse gas emissions either domestically through abatement measures in Norway, or internationally through the Kyoto mechanisms.

The development of international energy markets and energy prices will represent important conditions for the Norwegian economy and industry. In recent years, the European electricity markets have been gradually liberalized, particularly in Scandinavia and Northern Europe. This development has lowered electricity prices in the region. Continued liberalization will be important for Norway as a large producer of hydropower. A similar liberalization trend can be seen in the European gas market, and is likely to influence future gas prices. The market conditions for Norwegian energy-intensive industries will be heavily influenced by changing energy prices, which, due to political aims to preserve employment in rural areas of Norway, may further affect Norway's choice of climate policy. The energy-intensive industries could lose competitiveness compared to companies in developing countries not subject to emission reduction targets, at least until 2012, when only industrialized countries have binding targets. Furthermore, the emission of greenhouse gases will be affected by changes in energy consumption patterns that result from a shift in energy prices. This will then affect the costs of meeting the Kyoto Protocol target. Next, increased fossil fuel prices for consumers lead to substitution from fossil fuels to alternatives such as various types of renewable energy, and substitution from energy to labor and capital. This substitution effect is stronger the longer the time horizon. Finally, a likely consequence of increased energy prices is reduced economic growth.

Future technological opportunities for energy production and reduced emissions of greenhouse gases will influence the cost and feasibility of implementing the Kyoto Protocol, and in particular influence the feasibility space for new emission targets after 2012. Abatement costs can be reduced significantly in the longer run. The Kyoto Protocol is likely to strengthen incentives for progress in both energy production and energy consumption technologies. However, an extensive use of the Kyoto mechanisms may to some extent hamper such technological development in industrialized countries. Nevertheless, in this study it is assumed that implementation of the Kyoto Protocol has a positive effect on technological development in general. The analysis is based on scenarios from a European Commission study describing improvements in energy efficiency and energy technologies as a consequence of implementation

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[1] To simplify the model, some countries have been grouped together and are treated as a single country.

[2] See for example Holtsmark (1998).

of environmental policies.[3] The choice of climate policy tool can influence incentives for technological development. Commonly it is assumed that incentive-based policy tools, such as taxes and tradable permits, give stronger incentives for technological development than “command and control,” but there are studies indicating the opposite relationship.[4]

In the next chapter, the numerical model used in this study is described in more detail while chapter three presents technological developments associated with the two scenarios. The BAU scenario, denoted the Climate-Stagnation scenario, is described in more detail in chapter four. Chapter five describes the Kyoto-Success scenario, where the Kyoto Protocol targets are implemented in the first commitment period, and a preference score method from Bartsch and Müller (2000) is employed to establish emission reduction targets in the second commitment period, 2013–2020. The consequences of emissions trading and implications for fossil fuel markets are analyzed with the help of the numerical model. The implications for Norway are discussed in chapter six. Finally, in chapter seven the findings of the study in terms of implications for choice of Norwegian climate policy strategy are summed up. Appendixes include a summary of projected development of energy production technologies and detailed data tables.

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[3] European Commission (1996).

[4] See e.g. Maleug (1989) and Milliman (1989).

2 Model description

The analytical model used in this paper is a numerical model developed at the Center for International Climate and Environmental Research in Oslo (CICERO). The model is denoted "ACT" and is used as the basis for the paper "An analysis of links between the market for GHG emission permits and the fossil fuel markets" by Bjart Holtsmark and Ottar Mæstad.[5] In this analysis, the model has been expanded to include major developing countries as well as a second commitment period with a focus on the year 2020.

The model is a partial equilibrium model, modeling the markets for natural gas, oil, and coal with endogenous prices. Basically the model determines equilibrium prices of fossil fuels and greenhouse gas emissions permits as well as trade patterns in the permit and fossil fuel markets as the Kyoto Protocol and its successor are implemented. There are three regional gas markets in addition to global oil and coal markets. One gas market is in North America, where both the USA and Canada are producers of gas but where there is a net export of gas from Canada to USA. Russia and Europe are included in a second gas market. The third gas market is found in the East-Asian/Pacific region. Because of the high transportation costs, it is assumed that there is no direct gas trade between these three gas markets.

The model applied in this paper assumes that the Annex I countries establish domestic emissions permit markets. In the scenario with free emissions trading, these domestic markets are assumed to be fully integrated, giving rise to equal marginal abatement costs in all the involved countries. In the case without transboundary emissions trading, the national governments are nevertheless assumed to establish domestic permit markets, but no transfer of permits from one domestic market to another is allowed. Non-Annex I countries will establish domestic emission permit markets for the second commitment period after 2012.

The model divides the world into 32 countries and group of countries. Most Annex I countries are treated individually in order to provide a realistic picture of the emissions permit market. The model is calibrated to a business-as-usual scenario for one period in 2010 and for a second period in 2020.

In each of the 32 countries and group of countries, there is a set of demand functions for oil, coal, and natural gas, as well as demand functions for the right to emit non-CO_2-gases. The arguments in these functions are the consumer prices of the fossil fuels and the emissions permit price(s). The permit price(s) are added to the after-tax prices of these fuels. To the extent that there is production of oil, coal, and natural gas in the 32 countries and group of countries, there are linear supply functions for the fossil fuels. We have followed Golombek and Bråten (1994) assuming supply elasticities of 2.0 for coal production and 0.75 for both gas producers and for competitive oil producers. The producers of fossil fuels are generally assumed to be price takers. OPEC is, however, assumed to have constant marginal costs in oil production and to adjust its oil production in order to maximize its profit. It should be said that modeling oil supply in a static model is in itself problematic because it is impossible to take into account the future-oriented strategies of the large oil and gas producers. For a discussion of OPEC's strategies, see Berg et al. (1996) and Berg et al. (1998).

For several reasons, not least due to lack of reliable data from several countries, the model does not include CO_2 emissions and removal from land use, and land use change and

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[5] The following model description is to a great extent extracted from the above-mentioned paper.

forestry. However, emissions of non-CO_2 gases are included and put into one group using Global Warming Potential (GWP) 100 as weights.[6]

GHG abatement costs vary between the different countries because marginal abatement costs, as a result of the model concept and in agreement with economic theory, are equal to the sum of excise taxes and the permit price, i.e. the total 'tax' wedges. This means that the marginal abatement costs as a starting point are equal to the excise taxes. However, if the excise taxes could be assumed to have been set at an optimal level from a fiscal point of view, then the permit price, which in the free-trade case is the same in all countries, is the relevant indicator for the marginal abatement costs. The demand elasticities determine how rapidly the abatement costs increase.

The model assumes linear marginal abatement costs, which is equivalent to a linear demand for each fossil fuel.[7] The shape of the abatement cost function has been calibrated by imposing a measure of the elasticity of demand for each fuel in each country. There is no consensus in the literature about elasticities in fossil fuel markets. Estimates range from –0.15 (Smith *et.al*, 1995) to greater than –1.0 (Golombek & Bråten 1994; Golombek, Hagem and Hoel 1995). For lack of decisive evidence, we have chosen a middle road by assuming average demand elasticities of –0.5 for all fossil fuels. Demand elasticities for oil and coal have been differentiated across countries in order to reflect the differing structure of fuel demand (see table A2.1 in the appendix). The following procedure has been followed for this purpose: By using detailed information from the IEA statistics, the consumption of oil and coal in each country has been divided into two categories—inelastic and elastic. Oil demand for transport is assumed to be inelastic relative to other demand components. Similarly, coal used as input in the industry sector is assumed to be inelastic relative to other demand components (such as power generation). In those countries where the share of inelastic (elastic) demand components are greater than the world average, demand is assumed to be less (more) elastic than –0.5. The degree of adjustment of elasticities is arbitrarily chosen to be of the same relative magnitude as the relative variation in the share of elastic demand components. In this way, the model takes into account that marginal abatement costs differ among countries.

Consumer prices in the BAU scenario are obtained by adding existing fiscal taxes to the producer prices. The estimated average tax rates are taken from ECON (1995), which presents average fossil fuel taxes in the OECD countries up to 1994. The tax rates presented there are based on weighting energy taxes by product and sector. The information on taxes is based on IEA's *Energy Prices and Taxes* (1995). The information on taxes has been supplemented with EU's oil price statistics, "Oil Bulletin" and with direct contact with national administrations. The weights are based on "Basic Energy Statistics." The Basic Energy Statistics have been supplemented with oil industry information and EU statistics on the use of leaded and unleaded gasoline and on the breakdown of heavy fuel oil according to sulfur content (relevant for countries differentiating heavy fuel oil taxes according to sulfur content). The calculation of the average taxation by sector takes into account the exempted use of energy within the sector. The

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[6] GWP is a method based on the different greenhouse gases' radiative forcing. The accumulated radiative forcing over 100 years of a pulse emission of a GHG is compared to accumulated radiative forcing of a CO_2 emission of the same size.

[7] The assumption of linear marginal abatement costs is a simplification compared to quadratic marginal abatement cost functions. Linear marginal abatement costs are easier to model, and will be an acceptable approximation as long as the range of emission reductions is not too wide.

taxes are for premium gasoline. Taxes for leaded and unleaded gasoline (where relevant) have been weighted with the consumption of the two qualities. For countries differentiating the tax between high and low sulfur, taxes are represented by the tax on the typical quality in industry and power generation.

It must be emphasized that the present analysis does not take into account that the Clean Development Mechanism (CDM) is established, cf. Article 12 of the Kyoto Protocol. In other words, we have ignored the industrialized countries' opportunity to acquire emission permits from developing countries through CDM. Generally this means that we are overestimating the level of the permit prices because the CDM will represent a supply of emission permits. The reason why CDM is not included is the large degree of uncertainty related to the how CDM will be implemented and consequently how the relevant supply of emission quotas from CDM should be modeled.

With respect to the weaknesses of the model, it should be mentioned that markets other than fossil fuel markets would also be affected by implementation of the Kyoto Protocol. How these other markets respond would be important also for the final effects on the fossil fuel markets. A general equilibrium model would be necessary in order to incorporate such effects. This means, for example, that not all types of carbon leakage are included here, only the type of leakage related to increased consumption of fossil fuels in regions not subject to emission reduction commitments.

3 Technological development

Implementing the Kyoto Protocol and new commitment periods is likely to increase the incentives for technological development, both in energy production and energy consumption. Technological progress is a potent force that can change both the rate and the pattern of energy production and use throughout the world. New and improved energy technologies can and will most likely play a key role in reducing future GHG emissions, especially CO_2 emissions, and reduce the cost of emission reductions. However, the model used in this study does not include technology as an endogenous variable. Hence, we must present and discuss the matter of technological development adjacent to and not as an integral part of the model.

In this chapter we will present some assumptions about the impact of technological development on climate policy futures. The assumptions are based on two scenarios from the European Commission Study (1996) *European energy to 2020*: the Conventional Wisdom (CW) scenario and the Forum (FO) scenario. The CW scenario is used to calculate the BAU projections for consumption and production of fossil fuels and CO_2 emissions in our study. This scenario is therefore directly comparable to our BAU scenario. On the other hand, there is no direct link between the FO scenario and our Kyoto-Success scenario. However, they are comparable because of their inherent environmental ambitiousness. The FO scenario describes a possible pattern of technological development similar to what can be expected from the implementation of ambitious climate policies. Below, we will describe the CW and FO scenarios more thoroughly. Moreover, a general description of various technologies and energy sources is given in appendix 1. First, however, we will briefly discuss the drive of technological change and the issue of modeling technological change.

3.1 The drive of technological change

Technological development can influence energy markets and climate policy futures in various ways. At the same time, climate and environmental policies can influence technological development. The future progress and penetration of new energy technologies is probably one of the greatest uncertainties in any analysis of energy futures. In an ambitious climate scenario, new technologies will be required to ensure the development of renewable energies, with their promise of abundant clean energy. Moreover, new ways of using fossil fuels to maximize efficiency of use and hence minimize environmental impacts is necessary. However, the rate of penetration will depend heavily on the level of public policy supporting research and development.

Technological impact is likely to be cumulative and not necessarily specific. Examples in this regard are the steady improvements in offshore oil production and the increased efficiency of combined-cycle gas turbines.[8] Likewise the impact of technology on the demand side of energy use is an equally important component of the improving energy intensity of the economy. There is a need to consider how constraints, regulations, standards, advice, education, subsidies,

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[8] A good example is the development in energy efficiency and energy use attained by petroleum producers on the Norwegian continental shelf.

and investment incentives can contribute positively to improving technological development and energy efficiency (European Commission 1996: 117).

On the demand side, many energy-efficient technologies have been developed and new innovations are appearing regularly. However, their widespread proliferation is often delayed by the requirement for short-term paybacks and other market barriers. This implies that the various components of technology policy need more effective integration with other policy instruments (such as Command and Control, mandatory standards, voluntary codes, taxes and subsidies). In order to be effective, policy instruments should be “well targeted, fine-tuned and mutually reinforcing” (ibid.).

A change of the structure in energy markets is also apt to provide new constraints and opportunities. Indeed, liberalization and privatization policies in the natural gas and electricity sectors could lead to dramatic changes in the roles and incentives of the major players – governments, utilities, and equipment suppliers. Companies that manage to innovate successfully would have a considerable advantage in the more competitive international marketplace (ibid: 118).

New energy technology could also facilitate addressing environmental and energy security concerns without compromising economic goals. Indeed, ambitious environmental goals within the realm of climate change can be expected to be a driving force for technological innovation and thus enhanced prospects for long-term economic growth. Hence, the “conventional wisdom” that there are necessary tradeoffs involved in the simultaneous pursuit of economic and environmental goals can be overturned.

The possibility of a pleasant technological surprise can on no accounts be discounted completely. Energy technologies can be changed fundamentally, consequently creating a new energy economy. The innovation of a new low-cost and clean-energy technology could be feasible during the next 20 years. History offers many examples of unexpected advances in technology occurring when all conventional options are exhausted. This implies that fossil fuels can be substituted by more climate-friendly renewable energy sources and hence eliminate many of the difficulties related to abatement of greenhouse gases. As of today, however, no renewables can compete with fossil fuels with respect to price.

There are, however, uncertainties regarding the likely longer-term contributions from renewable energy sources, especially if energy prices are forecast to remain relatively low. The present cost disadvantage of these and of alternative technology paths appears likely to be reduced over time as the technologies improve. Thus timescales are important in formulating an energy technology strategy. To convince policy makers of the case for such expenditures, it is important that benefits should be seen to accrue in the medium and long term.

3.2 Modeling technological change

Technological development and choices determine to a large extent the long-term characteristics of industrial society, but the treatment of technology is in most models highly stylized. Most models of long-term economic development treat technology as exogenous, and most analyses proceed in practice as if most technological change cannot be anticipated and modeled. This is despite that most analysts see technological change as crucial. It is not rare to see studies that include only marginal and gradual technological changes. This is often through an aggregate trend parameter such as the annual rate of efficiency improvement. Macroeconomic modeling tools that are frequently used in global change studies do therefore not capture particular technologies, but merely technological changes that are marginal extensions of the present (Grübler et al. 1999).

Models with exogenous technological change do therefore not capture endogenous mechanisms that are important for technological change. One example of an endogenous mechanism is learning curves and rates. These typically show the decline in unit costs of production as experience is gained. Learning curves generally take the form of a power function where unit costs decrease exponentially as a function of cumulative output. The learning rate is the percentage decrease in costs per doubling of accumulated experience. Identifying systematic properties of technological change in the historical record can therefore ease the work of adding technological change to models (ibid).

Figure 3.1 describes ten energy technologies that reflect differences in cost and stage of development (Grübler et al. 1999). The "mature" technologies have reached pervasive diffusion and have well-known characteristics. Such technologies can change or improve under competitive pressure, but costs and general performance tends to be stable. The "incremental" technologies are more costly and are found in niche markets. They will however, offer some performance advantages and a potential for significant cost reductions if investments are continued. The "radical" technologies are more uncertain regarding their potential for improvement and whether they will become commercially available at all. Radical technology is by definition not widely employed, but radical improvements in performance and costs could occur.

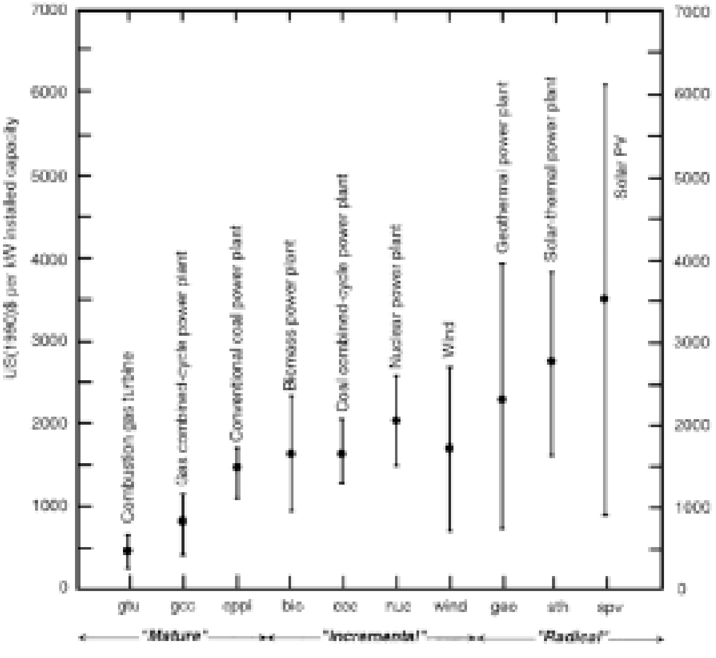

Figure 3.1 Cost of selected electricity-generating technologies[9]

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[9] Values (mean plus/minus one standard deviation) are taken from IIASA's comprehensive technology database. Data are for approximately *ceteris paribus* conditions (eg. coal plants include de-SO_x and de-NO_x equipment). Mature technologies in widespread use have lower costs with lower variance; the costs of radical new technologies are higher and more variable. Variability of costs is also an indicator of the uncertainty of technology costs. Radical

Technological change is in itself a complex process, and modeling such changes is therefore no easy task because it is necessary to determine which technologies are likely to mature and to what extent. The time lags between invention and innovation and between innovation and adoption are in most cases very long. Difficulties also arise because technological progress can proceed autonomously, or be stimulated by environmental or other relevant policies.

3.3 Technology scenarios

The ACT model used in this study has no endogenous technology component, but technological change is included exogenously through the scenarios used to calculate the future patterns of production and consumption of fossil fuels. Moreover, the technologies are implicitly defined by the choice of price elasticities. The scenarios from the European Commission study (1996) include an aggregate trend parameter through improvements in energy efficiency. The European Commission study differs from many other studies by also including assumptions of specific technologies. It has a scenario-based approach, which reflects the uncertainty and sense of transition that characterizes the energy sector today. Four contrasting scenarios are used to reflect different global societal and economic trends, namely Conventional Wisdom, Forum, Battlefield, and Hypermarket.[10] Conventional Wisdom is found to be in line with our Climate-Stagnation scenario and Forum is similar to our Kyoto-Success scenario.

Conventional Wisdom (CW) represents the BAU world, advocating a conventional wisdom view of events. Economic growth is assumed to gradually weaken as demographic changes mean slower growth in the labor force. Many of the world's structural social and economic problems remain, but some progress is made. Energy policy remains fragmented as a combined result of different national targets and unresolved conflicting objectives. The penetration of new, more efficient demand and supply technologies is limited, but commercial development of new technologies will take place. These technologies are partly driven by public standards and partly by industrialists' aim at increased industrial competitiveness. Energy demand is assumed to continue in its present trend, although with some increased concern about increasing efficiency. In this scenario, fossil fuels remain low-cost options and hence climate friendly renewables are less likely to compete. The CO_2 problem remains unresolved, and the requirement for cheap power combined with advances in new technology enable fossil fuels for power generation and transport use to maintain their strong positions (European Commission 1996).

In *Forum (FO)* the world moves more to consensus and cooperative international structures with a strong role for public administration and intervention. It is acknowledged that long-term goals of environmental protection cannot be met without the development and application of new technology as well as further development of existing technology. Strong penetration of new, more efficient demand and supply technologies is expected in this scenario, mainly driven by public standards on a world-wide scale, leading to a high level of technological transfer. Commercial development of new technologies will take place, but market solutions will not suffice on their own. Some degree of public policy impulsion will be required in order to

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technologies are little tried and their potentials for cost reductions are uncertain, and thus so are estimates of their cost (Grübler et al. 1999, Struebegger and Reitgruber 1995).

achieve the needed advances as imposed by the climate policy regime. This will require the development of a new framework for energy technology policy with substantial changes in the level and direction of technology funding, as well as the creation of new institutional structures (ibid.).

The results from the European Commission study (1996: 73) illustrate a very attractive energy future in the Forum scenario. Spectacular shifts in the anticipated trends for CO_2 emissions are achieved, even in the short term. On the other hand, Forum has the highest end-user energy costs, with high taxes on energy counter-balancing the lowering of world energy prices. The pivotal driving force of this scenario is the achievement of important efficiency gains in energy use and a transition to new energy sources. This results in only a moderate increase in energy demand that avoids any excessive use of fossil fuels. The deployment of carbon-free resources is facilitated through tax policy and industrial policy-support. It is expected that nuclear energy is further expanded. Moreover, it is expected that biomass will become a new energy carrier, that hydrogen and fuel cells will become significant in the longer run and complement the broad adoption of gas combined-cycle and cogeneration technologies, and that renewables (mainly wind) will make impressive gains (ibid.).

Forum is hence an ecologically driven scenario comparable to the Kyoto-Success scenario, where public policy and concern for the environment significantly affect energy policies and technological development. One question remains to be answered, however, and that is how technological development will influence our energy market scenarios.

3.3.1 Energy intensity

Energy intensity is strongly influenced by the level and quality of the capital equipment. Reductions in energy intensity gains are expected to continue in the years to come, but the rate of improvement is uncertain. Higher energy prices can be seen as a primary driving force as they provide an incentive to replace more costly energy. Low energy prices are therefore likely to slow down reductions in intensity.

Energy intensity does, as shown in figure 3.2, vary considerably around the world. The regions with highest energy intensity are China, the former Soviet Union (FSU), Asia, and the Central and Eastern European Countries (CEEC). Energy intensity is expected to decrease in all regions in the period from 1990 to 2020. The improvements in energy intensity may not be clear from figure 3.2 because of the large differences in energy intensities. Figure 3.3 therefore presents the expected annual percentage improvements from 1990 for both the CW and the FO scenarios across regions.

The FO scenario will clearly bring about larger improvements in energy intensity than the CW scenario. The regions that in figure 3.2 are identified as energy intensive are also expected to have the largest improvements in the period 1990 to 2020. The OECD region will have some of the smallest improvements in energy intensity, but the energy intensities are already at a low level in this region. The OECD region as a whole is expected to have annual improvement rates of 0.9% and 1.5% in the CW and FO scenarios, while the specific rates for the EU are 1.1% and 1.7%, and for the US 0.8% and 1.4%.

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[10] In the Battlefield scenario, the world reverts to isolationism, power blocks, and protectionism. Under Hypermarket the predominant themes are market forces, liberalism, and free trade; there is a minimum of intervention from government and public administrators.

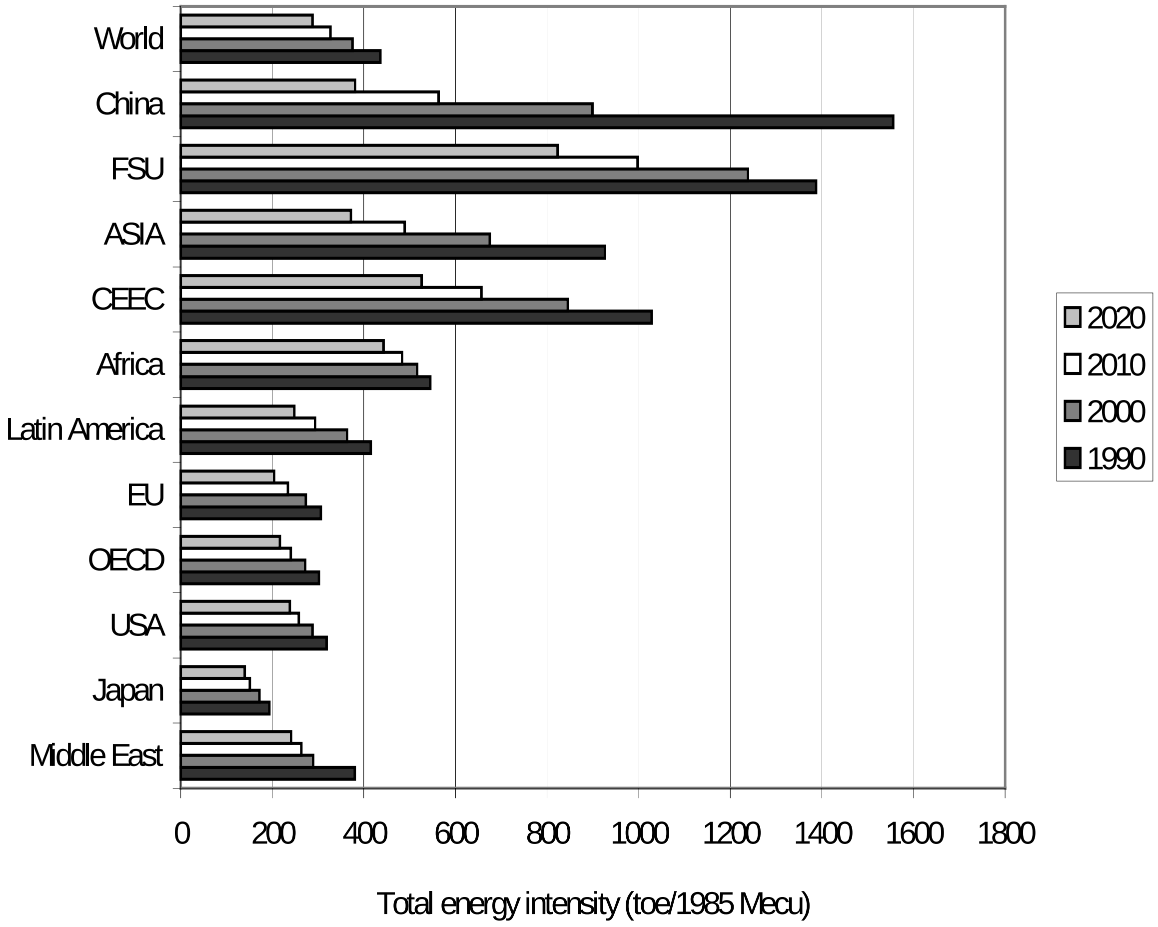

Figure 3.2 Total energy intensity in the CW scenario

These findings are very much in line with one of the new emission scenarios from the IPCC (SRES, 2000). The so-called SRES scenarios (Special Report on Emission Scenarios) cover four scenario families that draw different pictures of the future with respect to population, resource availability and use, and technology, etc. The annual improvements in energy intensity for the B2 scenario are nearly identical to the improvements in the CW scenario at a global and regional basis. The B2 scenario is a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a heterogeneous world with less rapid and more diverse technological change, but a strong emphasis on community initiative and social innovation to find local, rather than global solutions. Technological frontiers are pushed less than other SRES scenarios, and the rate of technical change is only intermediate. The innovations are also regionally more heterogeneous. Globally, investment in R&D continues its current declining trend, and mechanisms for international diffusion of technology and know-how remain weaker than in other scenarios. The availability of fossil energy resources in the B2 marker scenario is consistent with the gradual change in line with the "dynamics as usual" (SRES, 2000).

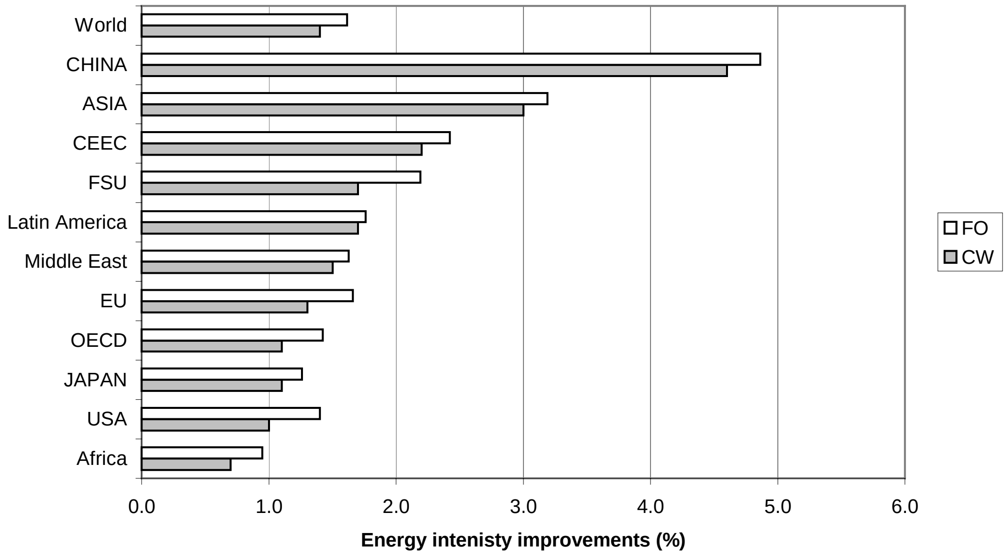

Figure 3.3 Annual energy improvement rates between 1990 and 2020 for the CW and FO scenario

3.3.2 Replacement and expansion of electricity in Europe

The electricity-generating sector is an important sector because of its energy intensity and size. It is a major contributor to GHG emissions, and important issues in this sector are the possibilities of a substitution from high-carbon to low-carbon fuels, the potential for enhanced energy effectiveness, and the development of alternative energy sources.

The prevailing trend in the CW scenario is the considerable penetration of natural gas combined-cycle plants. It is expected that it will rise from 16 GWe in 1995 to 159 GWe in 2020 in the EU, and more than 25% of new plants in the EU will be such plants. They are also built for cogeneration of power and heat (CHP). Conventional thermal plants will still remain important, but the past trends are clearly reversed. New thermal plants emerge, mainly integrated gasification combined-cycle using coal, lignite or fuel oil, but also biomass. Fuel cells also emerge in this scenario. Nuclear energy, on the other hand, will have a smaller share of total power capacity, falling from 22% in 1995 to 12.5% by 2020. The installation of a large amount wind-power capacity is the most noticeable development in renewable energies for power generation. Hydroelectric plants will not expand much because of the limited availability of new hydro sites in Europe. Figure 3.4 shows the main technologies in the expansion and replacement in electricity generation in the EU as percentage of capacity expansions.

Spectacular changes in power generation occur in the FO scenario compared to the CW scenario. The changes are related to nuclear energy, the use of new fuels, and the penetration of renewable technologies and gains in thermal efficiency. Low discount rates, combined with fossil fuel taxation, favors nuclear energy plants for the base load. Nuclear capacity represented 23.4% of total installed capacity in 1992, and the share is expected to be 23.2% in 2020.

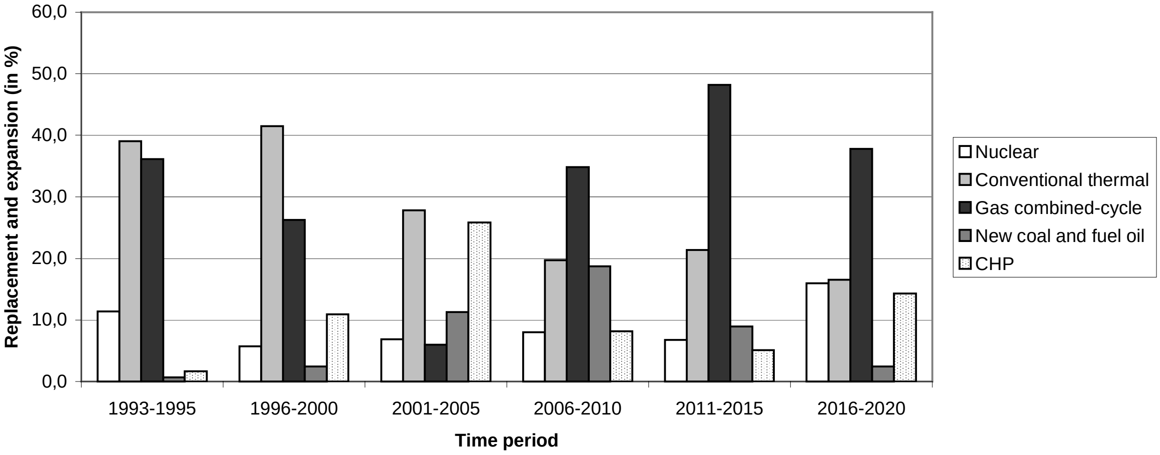

Figure 3.4 Replacement and expansion in electricity generation (CW scenario)

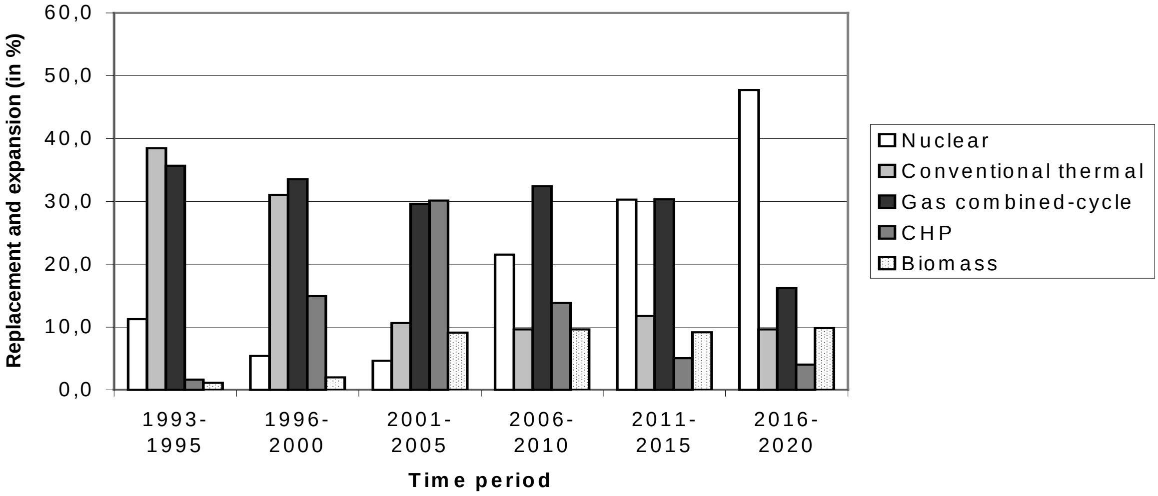

Figure 3.5 Replacement and expansion of electricity generation (FO scenario)

Gas combined-cycle plants will outrank all other options but nuclear, and there is a massive shift to them. The expected capacity building of such plants between 1992 and 2020 is slightly more than in the CW scenario. Biomass is also important as agricultural policies promote the use of biomass for power generation in integrated combined cycles. Considerable penetration of heat in end-uses drives the need for new CHP plants. Renewable energies also progress, but clean coal technologies do not succeed in expanding the power generation. This is mainly due to the taxation policy and also because of the increased role of nuclear energy.

3.4 The impact of technological development on energy markets

New technology can decisively influence the future shape of the fuel mix. The future will most likely convey improved technical efficiencies in the use of conventional energy and the innovation of new path-breaking environmentally sound energy sources. Innovation is part of the market process; it is a dynamic component of the economy. As mentioned earlier, commercial development of new technologies will take place in both scenarios, but strong commitments as imposed by the climate regime will constitute a decisive impetus to technological improvement.

In the Climate-Stagnation scenario, we expect no major impacts on the energy markets from technological advances. Technological advances will certainly take place. This is because technological progress can proceed autonomously or as a result of other relevant policies. In the absence of any such policies, it is often the possibility of cost reductions that drives technological change. However, technological innovation will not be stimulated by strict climate policy goals. It is uncertain whether or not research will convey new technology that overturns the use of conventional energy sources. New technologies will become available, but low prices for conventional fuels will limit their penetration in the medium term. Surprises can occur, however, and a new climate-friendly energy source that can compete in price can evolve and revolutionize the energy market.

In the Kyoto-Success scenario, we expect increased focus on and increased funding of technological research. Strong emissions reduction commitments will compel the industry to invest more resources in the development of energy saving technology, as well as emissions reducing technology. The research on and adoption of renewable energy sources is expected to intensify. Increased fossil fuel prices imply that other energy sources can become competitive in the international market and thus create a shift from a fossil fuel based energy system to a more climate-friendly energy system.

The economic system has generally two main options to respond to the imposition of a carbon constraint: reducing energy intensity and/or changing the fuel mix to reduce the carbon intensity of its energy system. The European Commission (1999) finds in a recent study that for the period up to 2010, it is expected that significant reductions in emissions will be achieved through a reduction in energy consumption (i.e. energy intensity). [11] This effect declines somewhat in 2020 because increased substitution among fuels (i.e. reducing the carbon intensity) is expected to be more cost effective than reducing the energy intensity further.

Reductions in energy intensity are clear from figure 3.3, which shows that the FO scenario assumes larger improvements in energy intensity than the CW scenario. Substitution of fuels is also evident in this study, and chapter five demonstrates that the demand for coal, the most carbon intensive fossil fuel, will decrease significantly. This can be linked to the changes observed in figures 3.4 and 3.5, which show that the conventional thermal plants have a diminishing share of the replacement and expansion in the electricity generation sector. There is some substitution to conventional alternatives, but also to new energy technologies. Renewables and nuclear energy expand as the carbon constraint develops, but the use of the latter expands more than the former, particularly for the FO scenario as shown in figure 3.5.

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[11] This study aims, to some extent, to update the study "European Energy to 2020" which was published in 1996.

The FO scenario was created prior to the Kyoto Protocol, and it is difficult to find a specific emissions reduction objective. However, it is clear that the European Community is the only region to show an emission reduction in the FO scenario, and the difference in emissions compared to the CW scenario is 800 million metric tons of CO_2. More ambitious emission reductions would most likely drive the technological development further, enabling more efficient technologies and more renewable energy technologies to break through. Even if this will increase abatement costs in the short term, it will most likely reduce the costs and the difficulties of complying in the long term.

4 Climate-Stagnation Scenario

In order to estimate the consequences of implementing the Kyoto Protocol and even more ambitious climate policies in the period after the first Kyoto period, it is necessary to have an idea about how the world will appear in 2010 and 2020 in the absence of new climate policies. That is, some idea about how the production and consumption of oil, coal, and gas will develop during the next twenty years is needed. Moreover, it is necessary to establish a trajectory of the development in GHG emissions. These two projections are to a great extent interweaved.

The Climate-Stagnation scenario (BAU) is the reference scenario and refers to a situation where it proves to be impossible to carry out the Kyoto Protocol. It is assumed that climate-relevant policies existing before Kyoto remain in place and that no new policies are adopted to reduce the emission of energy-related greenhouse gases. The background for such a scenario might be the absence of a 2/3 majority in the US Senate needed to ratify the Kyoto Protocol.[12] This situation might become reality if developing country Parties refuse to accept "meaningful participation," and/or if the EU gathers enough support to put restrictions on the use of the Kyoto mechanisms, namely emissions trading, Joint Implementation, and the Clean Development Mechanism. [13, 14] The USA, Norway, and the other members of the so-called umbrella-group oppose restrictions on the use of the mechanisms. This stance is based on the fear that restrictions will reduce the cost-efficiency of the treaty and *de facto* imply a renegotiation of the Annex B commitments in the Kyoto Protocol.

The Climate-Stagnation scenario is hence based on an assumption of business as usual in the absence of a ratified and implemented Kyoto Protocol. Nevertheless, the various countries are expected to uphold already existing and implemented climate-friendly policies, but no new measures are introduced. One example from Norway is that the carbon tax is sustained at the present level, implying that it is neither increased nor broadened in scope. Moreover, it precludes the introduction of a domestic carbon-trading scheme for the emissions intensive industries, which at the present are omitted from the carbon tax.

4.1 Production and consumption of oil, coal, and gas

The BAU scenario is important because it will be the baseline against which the Kyoto-Success scenario is compared. Production and consumption of fossil fuels are of special interest, as they determine the market price for fuels and account for most of the of CO_2 emissions. As a

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[12] The entry-into-force provision of the Protocol does not only require ratification by 55 Parties, but also employs a "double trigger," which specifies that as an addition, the ratifying Annex-I Parties must represent at least 55% of the total Annex-I CO_2 emissions in the year 1990. USA alone represents 36% of CO_2 emissions in Annex I in 1990.

[13] The Byrd-Hagel resolution (passed unanimously in the US Senate) tells the president not to sign a Kyoto treaty putting limits on the industrialised countries' emissions unless it also commits the developing countries to "meaningful participation" (Senate Resolution 98: 1997).

[14] The EU has suggested introducing a cap on the use of the Kyoto mechanisms. The cap is meant to be applied on both the supply and buyer side in order to secure that the Parties implement domestic strategies to abate emissions, to stimulate the development of green technology, and to restrain so-called "hot-air" from Russia and Ukraine. This cap implies that half or more of the required emission abatement must be carried out domestically.

baseline, the figures for 1990 production and consumption of oil, coal, and gas are reproduced from BP-Amoco's *Statistical Review of World Energy 1999* (BP-Amoco 1999). To arrive at the subsequent projections, growth-rates for the periods 2010 and 2020 are calculated from the Conventional Wisdom scenario in *European Energy to 2020* (European Commission 1996) and applied on the 1990 figures. In the Conventional Wisdom scenario, growth rates are given for each EU member country. Hence, the calculations for the EU are rather straightforward. In the case of Norway, production and consumption figures were derived from the most recent parliamentary reports (*St.meld.* no. 1:1999-2000, *St.meld.* no. 29:1997-98).[15] In order to calculate the projections for the remaining countries, regional data from the Conventional Wisdom Scenario is applied. For the OECD (excluding EU and Norway) the growth-rates for the OECD as a whole are used as point of departure. However, the figures for the EU and Norway (both in 1990 and 2010) are subtracted, and a residual growth-rate for the rest of the OECD is calculated. This residual growth-rate is then used to calculate the 2010 figures for North America, Australia, and New Zealand. The growth-rates in the extra-OECD countries and regions are derived from the regional projections. The growth rates for individual countries are derived from their respective regions.[16]

To calculate the 2020 figures, the Conventional Wisdom scenario was used in the same manner as above. However, the remaining OECD projections were calculated excluding only the EU. Norwegian production rates in 2020 were collected from *St.meld.* no. 4:1996-97. We could not, however, obtain any figures for Norwegian consumption. Hence, Norwegian consumption is derived from remaining OECD growth rates. As for the North American natural gas projections, they were calculated on the basis of the Conventional Wisdom figures for the OECD–EU. Both the EU and Norway were excluded in an attempt to calculate growth rates, but the resulting figures were not found to be realistic when compared with the existing literature.

The world production of oil is estimated to increase by 16% from 1990 to 2010 and by 8% between 2010 and 2020. The production of coal is estimated to increase by 22% between 1990 and 2010 and by 10% between 2010 and 2020. The largest relative increase in production is however, expected in the gas sector, as it is estimated to increase by 59% between 1990 and 2010, and by 30% between 2010 and 2020.

Table 4.1 Global production growth rates for oil, coal, and gas (in %)

Time period	*Oil*	*Coal*	*Gas*
1990–2010	15.9	21.9	58.9
2010–2020	7.9	9.7	29.8
1990–2020	25.1	32.8	106.2

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[15] For Norway, figures on production in 2010 are collected from the Department of Finance (by phone – Ottar Mæstad). It is possible to extract the number from a graph in the state budget for 2000 (*Nasjonalbudsjettet for 2000*). The graph operates with best estimates, but the mean for 2010 is approximately 151 Mtoe. The figures on consumption are collected from *St.meld.* 29:1997-98. The figures are, however, not given explicitly. The figures in the table are calculated from expected CO_2 emissions in 2010.

[16] In deriving the figures for OPEC, Indonesia is subtracted from production and consumption, while Venezuela's figures are added, based on the figures from BP-Amoco (1999). In deriving the growth rates for OPEC, figures from the Middle East in the Conventional Wisdom scenario are used.

In a global perspective, non-Annex I countries dominated the oil production in 1990 and their share is expected to increase in 2010 and 2020. Annex I countries produced nearly 60% of the coal in 1990, but their share will fall below 50% in 2010 and 2020. Annex I countries also dominate natural gas production, but their share will decrease both in 2010 and 2020. The largest oil producers in 1990 were the Middle East, Russia, the USA, and China. Of these, all but the USA will increase their production in 2020, compared to 1990. The major coal-producing countries will be the USA, China, and Russia. All but Russia will increase their production in 2010 and 2020. The production of gas will, as mentioned earlier, increase substantially from 1990 to 2010 and 2020. On a global scale, the main gas-producing countries will be Russia, the USA, and the Middle East.

The non-Annex I countries may dominate the production of oil, but the Annex I countries account for more than 50% of the oil and gas demand in the world. Their share is, however, expected to decrease as a result of the increased demands in non-Annex I countries. The demand for coal was largest in Annex I countries in 1990, but this will no longer be the case in 2010 and 2020. The single largest consumer of fossil fuels is the USA. In 1990, it accounted for 25, 21, and 27% of the global demand for oil, coal, and gas, respectively. These shares will more or less remain the same in 2010 and 2020.

Projected producer prices in 2010 and 2020 are taken directly from the European Commission study (1996), except in the case of the gas market, where the EU study reports only one gas price. We have taken the gas price from the EU study as the European gas price, while the other gas prices have been calculated under the assumption that relative gas prices between the three markets will be as projected by the IEA in their *World Energy Outlook* (1998a).

The producer prices in 2010 for fossil fuels are expected to be 73 USD/t CO_2 for oil and 22 USD/t CO_2 for coal. The regional gas markets settle at 97 USD/t CO_2 in the American market, 98 USD/t CO_2 in the European market and 135 USD/t CO_2 in the Asian market.

Table 4.2 Producer prices for fossil fuels in 2010 and 2020 in BaU (USD/t CO_2)

	Oil	*Coal*	*Gas, America*	*Gas, Europe*	*Gas, Asia*
2010	73.02	21.76	97.39	98.38	134.67
2020	78.05	21.76	104.10	105.16	143.96

The price of oil will increase by 7% from 2010 while the coal price will remain stable at the 2010 level. The regional prices of gas will increase and reflect that the price of gas is strongly correlated to the price of oil.

4.2 Emissions

Emission projections for Annex I countries in 1990 and 2010 are based on a working paper by Alfsen, Holtsmark and Torvanger (1998). The working paper has used the National Communications from the United Nations Framework Convention on Climate Change (UNFCC) for the 1990 emissions and the growth rates up to 2010. A study by Grubb and Vrolijk (1997) was used to fill in missing data.

Projected emissions from National Communications for 2010 and 2020 were used when available, but very few parties have estimated their 2020 emissions. The reported estimated growth rates in the emissions of CO_2, CH_4, and N_2O from 2010 to 2020 were therefore used as an average for those countries with no reported 2020 emissions. The growth rate in the N_2O emissions was adjusted because of the reported growth in France, which clearly differed from the other countries' projections. The growth in N_2O emissions was therefore determined by the average growth in those countries that reported 2020 emissions. The emissions of HFCs, PFCs, and SF_6 were assumed to be identical to the 2010 emissions.

The emission figures for CO_2, CH_4, and N_2O in certain non-Annex I countries (India, Indonesia, China, and Brazil) in 1990, 2010, and 2020 are based on several sources. The 1990 emissions are based on National Communications (UNFCCC, 1999), Olivier et al., (1996), IEA (1998a) and Bartsch and Müller (2000). The CO_2 emissions in 2010 and 2020 are based on the regional growth rates in IEA (1998a). The emissions of CH_4 and N_2O in 2010 and 2020 are projections based on economic growth, population growth, and the new scenarios from the IPCC. Data on emissions of HFCs, PFCs, and SF_6 in China, Indonesia, India, and Brazil were not available. The new B2 scenario from IPCC was used to calculate emissions in the rest of the world for 1990, 2010, and 2020 (SRES, 2000).

The aggregate picture is that emissions of greenhouse gases are projected to increase substantially in the following years, especially in the non-Annex I countries. Emissions are expected to increase by 27% between 1990 and 2010, and by 13% between 2010 and 2020 (see table 4.3). By comparing the 1990 emissions with the projected BAU emissions in 2020, it is clear that the emissions are projected to increase by 44%.

Table 4.3 Global GHG emissions in 2010 and 2020 (Mt CO_2 equivalents[17])

Region/year	*1990*	*2010*	*2020*
Annex I	17,816	19,388	20,790
Non-Annex I	14,727	21,980	26,023
Total	32,543	41,369	46,814

The developing countries' share of global GHG emissions is undoubtedly increasing. In 1990, 45% of the emissions originated within developing countries. This share is expected to increase to 53% and 56% in 2010 and 2020, respectively. CO_2's share of total GHG emissions is approximately 70% both in 2010 and 2020.

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[17] Based on GWP-100.

5 Kyoto-Success Scenario

In the Kyoto-Success scenario we assume that a sufficient number of parties ratify the Kyoto Protocol so that it becomes operative before 2005. All Annex I Parties are expected to achieve their reduction objectives in the first commitment period, that is, 2008–2012. According to the Kyoto Protocol, their aggregate goal is a 5.2% reduction from 1990-levels. The EU member countries may cooperate to fulfill their obligations under the Kyoto Protocol, and each country has received differentiated obligations under the "EU-bubble." Countries outside the EU, however, must fulfil their obligations as set out in the Kyoto Protocol. The reduction objectives reflect the Berlin Mandate in that only industrialized countries are subjected to binding commitments, while developing countries are relieved of any commitments thus far. Hence, no participation by developing countries is assumed in the first Kyoto-period.

Three different cases will be evaluated under the Kyoto-Success scenario. In all three cases, we assume that the Parties meet their commitments to limit GHG emissions by implementing domestic tradable permit systems.[18] Case 1 is based on the assumption that no restrictions are placed on emissions trading. For the USA and a number of other Annex I countries, free trade is seen as an important feature of the Kyoto Protocol. Furthermore, it is assumed that all national permit markets are fully integrated into an international free trade scheme. In case 2 we assume that the EU capping, where the possibility of purchasing and selling emission permits is limited, is implemented. The proposal suggests that net acquisitions of Assigned Amount Units (AAUs) must not exceed the higher of two ceilings:[19]

- Five percent of the average of its base year emissions and its number of AAUs, or
- Fifty percent of the difference between its annual actual emissions in any year of the period from 1994 to 2002 and its number of AAUs.

The EU proposal also includes a limit on net transfers, as it states that net transfers of AAUs must not exceed 5% of the average of its base year emissions and its number of AAUs. However, the ceiling may increase if a party carries out domestic abatement, at least in the same amount as they are exporting permits. In such situations there will be no limits on their export.[20]

An international trading scheme is yet to be established. The Parties to the Convention have, thus far, not been able to agree on a framework for international emissions trading. Case 3 is based on the assumption that the Kyoto Protocol is ratified, but without the possibility of international emissions trading or use of the other Kyoto mechanisms. In such a situation, the national emissions trading markets will be completely segregated and hence result in different permit prices in the various markets.

In this study we assume that the period 2018–2022 constitutes a second commitment period (and the third 5-year Kyoto Protocol period), with a midpoint in 2020. Furthermore, we assume that new commitments are negotiated before the start of the first commitment period

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[18] Tradable permits will in the following chapters be referred to as permits.

[19] AAUs will in the following chapters be referred to as permits.

[20] See Holtsmark and Mæstad (2000) for further details on the EU proposal to limit acquisitions and transfers.

and more ambitious reduction objectives are agreed upon. Moreover, developing country Parties are subjected to commitments in the second commitment period. The aspect of including developing countries in a reduction scheme unquestionably complicates the question of how to share the burden. In this study we will apply a burden-sharing scheme developed by Benito Müller, which has been applied in the study, *Fossil Fuels in a Changing Climate* (Bartsch and Müller 2000).[21] The second commitment period is based on a new burden-sharing scheme with assigned emissions quotas for both Annex I countries and non-Annex I countries. Three cases are also examined in the second commitment period: first, free trade with the assigned quotas, then a case in which the major exporters of permits voluntarily reduce their assigned emission quotas, and finally, no trade.

5.1 The first commitment period

The Annex I countries' reduction objective of 5.2%, compared to 1990-levels, is equivalent to a 14.7% reduction compared to their projected BAU emissions in 2010. The global reduction, on the other hand, will only be 5.5% relative to the BAU emissions, since non-Annex I countries are relieved of any obligations. Given that the Kyoto Protocol is enforced, it will inevitably have consequences for the production and consumption of fossil fuels and consequently on fossil fuel prices. The three different cases will illuminate various impacts of the Kyoto Protocol on emissions trading and the fossil fuel markets.

5.1.1 Emissions trading

In the case of free emissions trading, we find that the international price on emission permits is 15.1 USD/t CO_2-equivalent in 2010. A large export of emission permits is expected from Eastern Europe to North America, with Russia, the Ukraine, and Poland as the main exporters. The USA is the main importer along with Japan and Canada, but the EU is also expected to be a net importer of emission permits. Nevertheless, domestic reductions of emissions will also be necessary, and we find that the largest domestic reductions will take place in the USA, Russia, Germany, and Japan.

The EU capping proposal will be effective in its attempt to limit emissions trading, as limits are put on both the purchasing and selling of emission permits. The simulations suggest that the proposal will almost exclusively put constraints on the supply side of the market. This will reduce trading with so-called "hot-air," resulting from a reduction in emissions caused by economic recession in Eastern Europe rather than abatement measures. By imposing restrictions on trading, the international permit price is forced up from 15.1 to 23.4 USD/t CO_2-equivalent. Most Annex I countries will not be restricted quantitatively by the EU proposal, and their marginal abatement costs are therefore identical to the permit price. Another effect of the EU proposal is that the higher permit price will give the Parties incentives to undertake more domestic emission reductions. This is more in line with the Kyoto Protocol, which states that emissions trading is to be considered a supplement to domestic reductions.

In the case of no trade, countries are forced to fulfill all their obligations domestically. Domestic reductions will in most countries naturally be larger than they would have been under free trade and the EU proposal, and marginal abatement costs will vary widely among countries.

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[21] The burden-sharing scheme will be described thoroughly below.

For example, the analysis shows that the USA and Canada will have marginal abatement costs above 25 USD / t CO_2-equivalent, while the marginal costs in France and Germany will be about 10 USD lower.

5.1.2 Implications for fossil fuel markets

By comparing the results from the Kyoto-Success scenario with the BAU scenario, we can illustrate the impacts of the different cases on the fossil fuel markets. We find that the consumer prices of fossil fuels in Annex I countries will increase because they will reflect the cost of emitting GHGs. In figure 5.1 we can see that the increases in consumer prices for oil ranges from 10.3 to 14.9%, coal from 34.9 to 69.8% and gas from 9.1 to 15.9%, in the various cases. Free trade will, as expected, have the least impact on consumer prices, while no trade will have the largest impact. The relatively high increase in the consumer price of coal can be explained by three factors. First, coal is much more carbon intensive than the other fossil fuels. Second, the supply of coal is fairly elastic, implying that the consumers must bear a relatively large share of the burden. Finally, most countries have low fiscal taxes on coal, especially when compared to the taxes on oil products. Putting a price on carbon emissions will hence lead to a larger relative increase in the coal price, compared to the other fossil fuels.

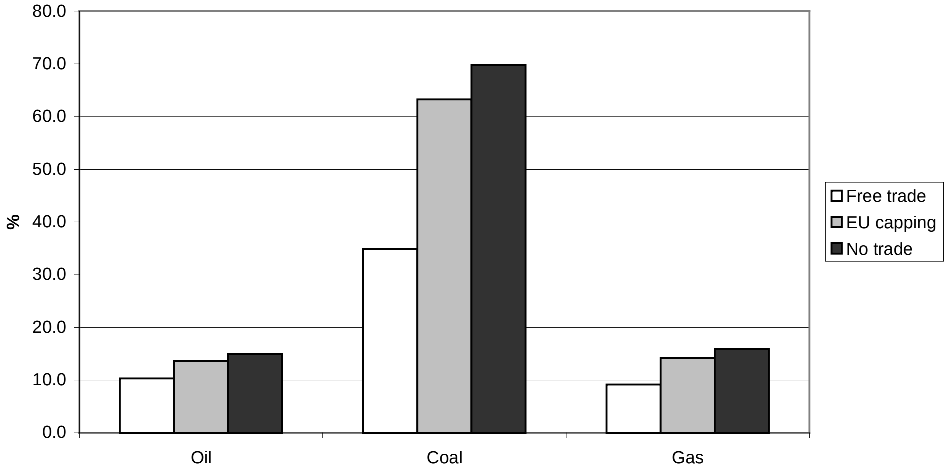

Figure 5.1 Change in consumer prices for fossil fuels in Annex I countries relative to BAU in 2010

The overall picture is that the global demand for all three fossil fuels will decrease with the implementation of the Kyoto Protocol, regardless of the case considered. The relatively large increase in coal prices will lead to a substitution towards oil and gas. Globally, the demand for coal is projected to fall by 13.8–17.9%, oil by 2.8–3.7%, and gas by 1.9–2.2%, in the various cases. Other studies have shown that the reduction in demand for gas will be larger than the reduction in demand for oil. Different model structures and assumptions can explain these differences. It is worth mentioning that reductions in demand are larger if we consider only the Annex I countries. This is because the consumer prices in non-Annex I countries will decrease with the implementation of the Kyoto Protocol. Demand in non-Annex I countries is thus stimulated and will increase. Among Annex I countries, we find that the demand for oil is reduced by 5.4–7.2%, coal by 33.7–44.0% and gas by 2.7–3.1%. We therefore expect some substitution from oil to gas, but not as much as one could expect on the basis of the relative carbon intensities. This can be explained by the fact that fiscal taxes are much higher on oil than gas. The price increase of oil, compared to gas, is therefore smaller than suggested by the underlying emission factors.

Figure 5.2 illustrates the changes in demand for fossil fuels with the implementation of the Kyoto Protocol simulated for the EU countries. Coal is once again the fuel that is most affected, as the demand is projected to fall by 31.8–43.8%, compared to the BAU projections. The effect on the demand for oil and gas is much smaller. The demand for gas will under the given circumstances not fall by more than 8% while the fall in demand for oil is below 6%. This implies that there will be some substitution from gas to oil, as the international prices on emission permits rise under the EU restriction case and marginal abatement costs rise under the no-trade case.

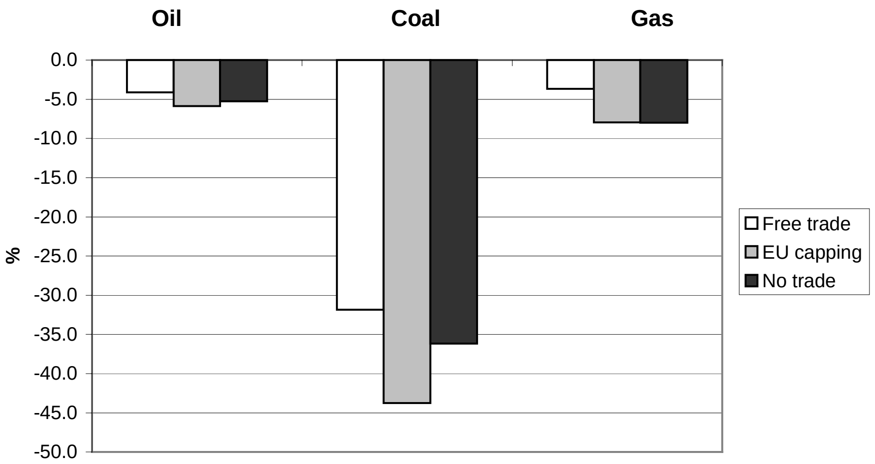

Figure 5.2 Changes in demand for fossil fuels in EU relative to BAU in 2010

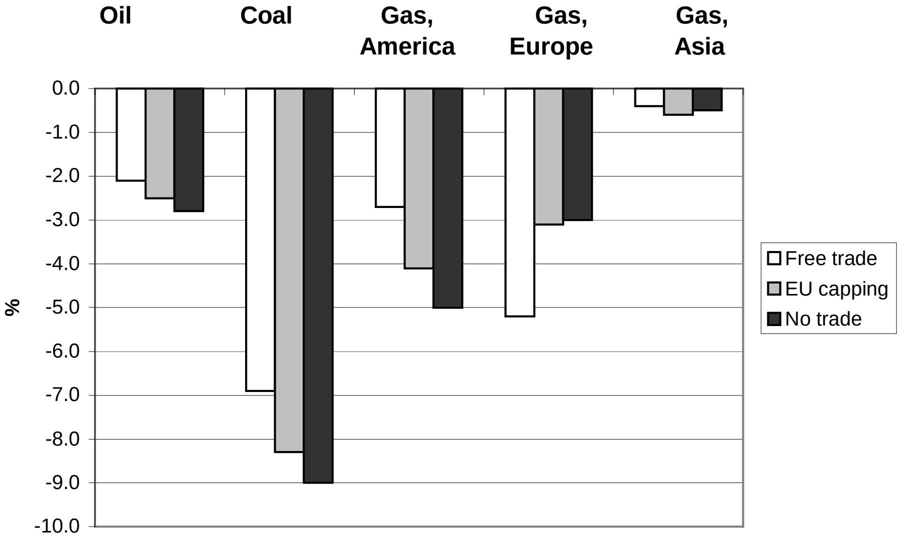

Figure 5.3 Producer price changes for fossil fuels relative to BaU in 2010

The analysis also shows that there will be lower producer prices. In figure 5.3 we can see that the coal price will decrease by between 6.9 and 9.0% compared to BAU, depending on the case. The oil market will face 2.1–2.8% lower prices, while the regional gas market in East Asia will under no circumstances decrease by more than 0.6%. This is due to the fact that Japan is the only Asian country with commitments under the Kyoto Protocol. The two other regional gas markets, North America and Europe, will experience reduced producer prices, ranging from 2.7 to 5.0% and from 3.0 to 5.2%, respectively.

In most cases, the producer prices are reduced when there are restrictions on trade. The reason is that less “hot air” from Eastern Europe is released into the permit markets and this tends to increase the average costs of emissions. The European gas market, however, does not follow this pattern. We find the largest reduction in producer price in the case of free trade. In this case the price falls by 5.2%, whereas the smallest reduction in producer prices appears in the no trade case, with only 3.0%. The explanation is that Europe as a whole is a large net exporter of emission permits in the free-trade case because of the “hot air” in Eastern Europe. With unconstrained trading with “hot air,” there will be less substitution towards the fossil fuel containing the least carbon, gas. European gas demand is therefore relatively low, causing a downward pressure on the gas price. As emissions trading becomes restricted or banned, there will be more substitution towards gas, forcing the gas price up relative to the free-trade case. European gas producers will therefore benefit from restricting emissions trading (Holtsmark and Mæstad 2000).

5.2 The second commitment period

Negotiating emission reductions for the second commitment period will complicate the issue of burden sharing—particularly since we assume that developing countries will be given commitments. The Kyoto Protocol takes the different possibilities and capabilities of industrialized countries into consideration. The burden sharing described in Annex B of the Protocol is not based on any particular allocation scheme but rather resulted from negotiations between the individual delegations and chairman Raúl Estrada. The final allocation scheme seems to be based on recognition of both responsibility and capacity. The notion of “responsibility” reflects the belief that the cost of solving a problem should be distributed in proportion to the role that each actor has played in causing the problem (Cf. the Polluter Pays Principle, see OECD 1974). The notion of “capacity” suggests that the costs should be distributed in proportion to the capacity of an actor to contribute to solving the problem. As applied to the climate change negotiations, the two principles leave the bulk of the responsibility with the rich, industrialized countries. It will be difficult to extend this allocation scheme to also apply in the subsequent Kyoto periods. In the following we will thus present some issues regarding burden sharing before a plausible allocation scheme is presented.

5.2.1 Burden sharing

Some observers assert that a more systematic approach to allocating reduction objectives will facilitate future negotiations, particularly when including developing countries (Torvanger & Godal 1999: 7; Ringius et al. 1998: 777). Bringing developing countries into an abatement scheme will arguably change the criteria for burden sharing somewhat. Burden allocation will to a larger extent be affected by differing views of what is equitable, including perceptions of responsibility for past and current contributions to the problem. Arguments about the equity of each cost-sharing plan will clearly be important as tactical instruments in negotiations, but they will also have an intrinsic role and impact on the structure of the agreements (Grubb et al. 1992: 308).

Equity is a rather elusive concept and can be complicated by different world-views in the form of cultural and societal assumptions about ethics, the environment, and development (Bruce et al. 1996: 86). Different countries have different ideas about equity that can be shaped by "cultural values, by precedent and by the specific types of goods and burdens being distributed" (Young 1994: xii). Countries differ substantially in vulnerability, wealth, capacity, and resource supplies. Therefore, the costs of damages, adaptation, and mitigation may be borne inequitably, unless the distribution of these costs is addressed explicitly. When bargaining, every country will presumably use the notion of equity to justify their stance. Different countries will give different interpretations and definitions of equity, and each country will try to influence the negotiations to yield a policy as close as possible to its own perceptions and interests. If every party in the negotiation simply demands the minimum burden for himself, there is high plausibility that the process will end in deadlock.

In the course of the climate change negotiations, several burden-sharing criteria have been introduced, based on different notions of equity. Both flat-rate reduction targets and differentiated targets have been proposed.[22] Flat-rate targets are believed to place an unfair economic burden on some classes of countries because countries differ in terms of abatement costs, energy efficiency, emission rates, wealth, population, resource endowments, etc. Differentiation was hence introduced as a tool to ameliorate these dissimilarities. Several principles of equity have been identified as relevant in the context of climate change, including the egalitarian, sovereignty, horizontal, vertical, and "polluter pays" principles. The egalitarian principle implies that every individual has the same right to use the atmosphere and should be allowed the same right to emit greenhouse gases. The sovereignty principle implies the implementation of flat-rate reduction commitments. The principle of horizontal equity implies equal treatment of the members that belong to a group. Vertical equity refers to the ability to pay and implies greater economic burden to be carried by richer countries. And finally, the "polluter pays" principle implies that the burden is distributed in accordance with an individual's contribution of emissions (see e.g. Ringius et al. 1998 and Rowlands 1997 for a more thorough elaboration of the principles).

These principles are considered to be ideal-types and are found to place varying economic burdens on different world regions. Accordingly, scholars have examined how several combined criteria can be incorporated into a single multi-criteria, burden-sharing rule.[23] Such multi-criteria rules are found to be advantageous and more robust in the sense that a smaller gap is expected to be found between the smallest and the largest target for a country (Kawashima 1996). In short, they are better able to take into consideration the peculiar circumstances in individual countries than single-criteria burden sharing rules.

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[22] Flat-rate reduction targets imply a uniform abatement objective for the parties involved, for example equal percentage reduction of emissions compared to a base year.

[23] Several studies have been conducted that compare various multi-criteria burden-sharing rules. Torvanger & Godal (1999) have compared three multi-criteria and three single-criteria rules selected as the most promising of 25 different proposals. They find that the multi-criteria rules are the most promising and yield the most equitable results. Ringius et al. (1998) have made a comparison of three multi-criteria formulas for burden-sharing among OECD countries.

5.2.2 Preference score

Considering the heterogeneity of the Parties involved in the climate change negotiations, it is necessary to apply a burden-sharing scheme that has a plausible chance of being accepted and adopted. Most Annex I countries have given voice to joining an abatement regime if the allocation of assigned quotas are allocated under a *grandfathering* scheme.[24] On the other hand, we find the developing countries organized in the G77/China, which support the principle that quotas should be allocated on a *per capita* basis.[25] Such an allocation is pivotal for their participation. Hence, the issue is under what conditions various parties are willing to accept caps on their emissions (Bartsch and Müller 2000: 230f). The problem is, however, that the above-mentioned preconditions are incompatible.

A compromise between the two preconditions is therefore necessary. The fact that both camps regard their position to be based on considerations of equity does not necessarily create an atmosphere conducive to compromise. Bartsch and Müller (2000: 231) suggest combining the two incompatible proposals by means of establishing a “socially weighted” arithmetic mean between them. They suggest a *preference score formula*, where a Party’s assigned amount is decided by:

$$PS = w_{GF} * GF + w_{PC} * PC$$

GF and PC are the assigned quotas the Party would have received under the *grandfathering* and the *per capita* proposals, respectively, while w_{GF} and w_{PC} are weights reflecting the “social desirability” of these proposals, as determined by a simple preference score procedure carried out by the Parties in question (ibid.). Each of the countries involved would simply vote on the two base proposals (grandfathering and per capita) on the basis of self-interest. The weights for each proposal (w_{GF} and w_{PC}) are then simply the share of total votes. Table A2.7 in the appendix shows how the weights would be determined if each country has a vote (single national score) and when each individual habitant has his/her own vote (global scores). Based on a global score, the weights are found to be as follows:

$$PS = 0.22 * GF + 0.78 * PC$$

The preference score distribution is found to be a plausible compromise. Not on the grounds that everyone is meant to accept it as the most equitable solution, but rather on the grounds that (i) having acknowledged the moral complexity of the situation, the Parties might realize that such a compromise does not need to be a sign of lacking moral fiber, and (ii) they would accept the ‘preference score’ proposal as sufficiently fair for it to be preferable to a break-down in negotiations because of both the transparent and equitable way of determining the score (ibid.: 233f), as well as its *democratic* appearance.

In order to generate sound assumptions about abatement targets for the period after the first Kyoto-period, one has to take two interlinked dimensions into consideration. First, the

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[24] Grandfathering of emissions permits is a method by which permits for greenhouse gas emissions is allocated among countries in an emissions trading regime according to their historical emissions.

[25] Per capita distribution is distribution in proportion to the population figures in some base-line year. Hence it is similar to the egalitarian equity principle described earlier.

allocation of abatement targets certainly involves a distributive problem, where the relative sizes of the allocated quotas will be linked with distributive justice. Second, on the other hand, a quota assignment also involves the choice of an acceptable absolute level of global emissions for the relevant commitment period. In other words, a decision will have to be made about an acceptable overall size of the "cake" that is to be distributed under such an assignment of reduction objectives (ibid: 14).

The Kyoto Protocol is seen as a small, but important step in reducing the emissions of greenhouse gases. However, the Annex I countries' commitment to reduce their emissions by 5.2% does not mean that global emissions are reduced compared to 1990-levels because non-Annex I emissions are increasing rapidly. The global emissions will, in the absence of the Kyoto Protocol, increase by 25.1% from 1990 to 2010. On the other hand, the implementation of the Kyoto Protocol will cause emissions to increase by "only" 17.6%. We assume that the allowed global emissions in 2020 must correspond to a long-term emission profile that will stabilize the atmospheric concentration level of GHG at 550 ppmv. The time scale for stabilizing the atmospheric concentration levels is 200 years, so 2020 will only be a short step in that respect. Nevertheless, we assume that the emission target for 2020 is to stabilize the emissions at the BAU 2010 level. This implies that global emissions will increase compared to 1990 levels, but a reduction of 11.6% will still be required compared to the projected BAU emissions in 2020. Total allowed global emissions in 2020 are thus set to 41,369 million tons CO_2 equivalents. The preference score formula will distribute this "cake" between the Parties.

Table A2.8 in the appendix shows the allocated 2020 quotas for each country/region involved, as well as the quotas that would have been allocated using a grandfathering and per capita scheme. USA's claim of 24.1% of the quotas under grandfathering is a far cry from the 4.6% they would receive under a per capita scheme. The preference score's allocation of 9.0% of the emission quota therefore illustrates that the preference score is a compromise between the two schemes. This distribution of emission quotas has a substantial impact on the industrialized countries, as they must reduce their emissions considerably. Table A2.9 shows that several countries must reduce their emissions by 40% and more compared to their 1990 emissions. New Zealand, for instance, is forced to reduce its emissions to 56.4% below 1990 levels. It is also clear that the major developing countries will receive quotas that exceed their BAU emissions in 2020. One example is India, which receives a quota that is 180% larger than its BAU emissions in 2020. This implies that the country becomes a major exporter of emission permits. The industrialized countries might object to such an allocation, despite the fact that the final allocation is considered to be fair. Such an allocation of quotas will result in a large net transfer of money from industrialized countries to developing countries.

Three cases are also examined in the second commitment period. In case 1, each country receives emissions quotas according to the preference score formula, and we assume free international trade in emissions permits. In case 2, we analyze the effect of limiting the supply of emissions permits from the major developing countries. By withdrawing some of the permits from the market, one can expect a higher international price per permit. Moreover, the developing countries would presumably limit their supply if it would increase their revenues from selling permits. In addition, they would then have permits for sale in the next commitment period, assuming that banking is allowed. Case 2 is therefore based on the assumption that China, Indonesia, India, and Brazil voluntarily reduce their assigned emission quotas by 15%. A further reduction would not benefit Indonesia and Brazil, as this would reduce their revenue from exporting permits. Fifteen percent can therefore be seen as an upper limit for voluntary reductions. But what if the international trade in emissions permits fails to be established? The use of flexible mechanisms under the Kyoto Protocol is yet to be determined, and the Parties may therefore only have domestic emission reductions as an option to meet their obligations. A third case, with no trade, is therefore included. Due to different domestic abatement costs in countries, the free trade and other cases influence the outcome of a burden-sharing rule.

5.2.3 Emissions trading

In our analysis we find that, in the case of free trade, the above allocation of emission quotas will result in an international permit price of 15.0 USD / t CO_2-equivalent. The total supply of permits is calculated to be 7,583 million tons CO_2, of which the four major developing countries will supply 96.6%. The two major suppliers will be India and China, while the main buyers will be the USA, Russia, Canada, and Japan. Major domestic reductions will take place in the USA and China. In case 2, the voluntary reductions in assigned emission quotas in China, Indonesia, India, and Brazil reduce the total supply of permits by 11.5%, that is, to 6,536 million tons CO_2. The four developing countries' share of permits is now reduced to 85%. The reduced supply affects the international price for emission permits, and we find that it will rise to 21.6 USD / t CO_2-equivalent. Potential importers of permits must hence adjust their demand to the higher price and they are forced to undertake larger domestic reductions than under free trade. Countries that under free trade and reduced supply rely on purchasing emission permits will in the case of no trade only be able to undertake domestic reductions to fulfill their obligations. The USA, for instance, will be obligated to undertake approximately three times more domestic reductions than under free trade. The marginal costs of abatement will increase and vary among countries. Marginal abatement costs for New Zealand are calculated to be above 100 USD / t CO_2-equivalent, while the range for most Annex I countries is calculated to be 36–88 USD / t CO_2-equivalent.

5.2.4 Implications for fossil fuel markets

The impact of the new commitment period on the fossil fuel market is, as expected, greater than under the first commitment period of the Kyoto Protocol. The consumer prices will increase compared to the BAU projections, and coal is once again the fuel that is affected the most. The global picture is that the oil price will increase by 10.0–12.4%, the coal price by 49.7–65.4% and the gas price from 8.0–13.0%, depending on the case. In figure 5.4 we can see that the situation in the Annex I countries is more dramatic, as the prices are simulated to increase far more than the global trend. The consumer price of coal will increase from 32.6–152.8%, depending on the case considered. The impact on oil prices is smaller, ranging from 8.5 to 29.9%, while the consumer prices for gas will increase by 7.7–31.6%.

The demand for fossil fuels will certainly decrease with the implementation of the new commitments. The largest decrease in demand will once again be for coal, which on a global basis ranges from 21.0 to 36.1%. The reduction in global demand for oil ranges from 6.2 to 8.9%, and for gas from 2.6 to 4.6%. It should be mentioned that the largest reduction in demand would be in the case where developing countries voluntarily reduce the supply of permits, and not in the case of no trade. This is because the developing countries will not be constrained by the new burden-sharing scheme, since their assigned amounts lie well above their projected BAU emissions. The reduction in demand will be noticeable in Annex I countries, especially under the no-trade case. Reduced demand for oil will range from 4.8 to 14.4%, for coal from 30.2 to 97.7%

and finally from 3.4 to 6.7% for gas. The same applies if we only consider the EU. In figure 5.5 we can see that, in the case of no trade, demand for oil, coal, and gas is reduced by 12.3, 86.5 and 17.8% respectively.

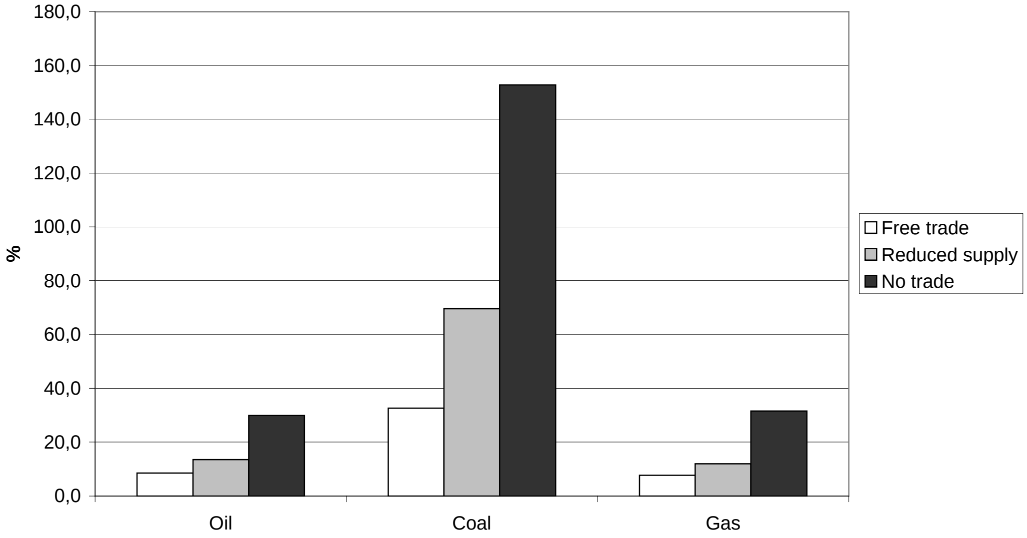

Figure 5.4 Change in consumer prices in Annex I countries relative to BAU in 2020

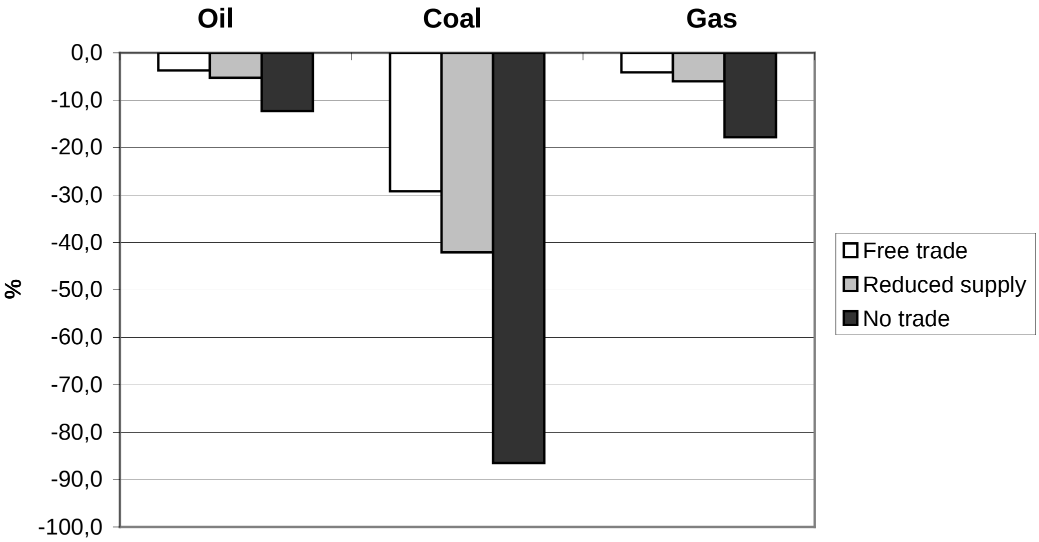

Figure 5.5 Changes in demand in the EU countries for fossil fuels relative to BAU in 2020

The producer prices of fossil fuels will also decrease when we compare them to the prices in the BAU scenario. In figure 5.6 we can see that, in the case of free-trade, the price of coal drops by 12.5%, the price of oil by 4.5%, and the gas prices in the regions of North America, Europe, and Asia drop by 3.5, 5.5 and 3.6%, respectively. In the reduced supply case, the prices of fossil fuels are affected even harder than under free trade. The price of coal is expected to decrease by 18.1%, while the price of oil decreases by 6.4%. The gas prices in the regional gas markets of North America, Europe, and Asia are expected to drop by 5.0, 8.0 and 5.2%, respectively.

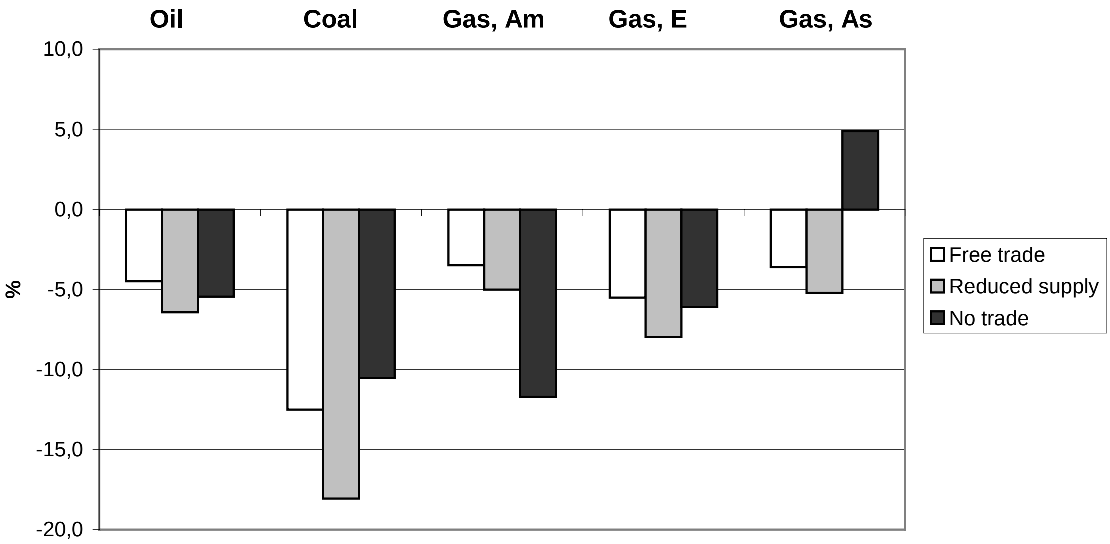

Figure 5.6 Producer price changes in fossil fuels relative to BAU in 2020

We also find that the producer prices on fossil fuels in the no-trade case decrease when they are compared to the prices in the BAU scenario. The price of coal drops by 10.5%, and the price of oil by 5.5%. Gas prices in North America and Europe drop by 11.7 and 6.1% respectively, while the producer price of gas in Asia actually increases by 4.9%. Again this can be explained by the surplus of permits that the developing countries cannot dispose of in a situation of no trade. Nor do they have any obligations or incentives to reduce their emissions. They can, in other words, continue to consume as much fossil fuels as they want. The effect on the global oil and coal markets is too small to influence the world prices. The regional market for gas in Asia will, however, be affected by the increased demand as the producer price increases by almost 5%.

6 Implications for Norway

The climate policy regime will affect Norway in two main areas: (i) The implementation of the Kyoto Protocol in 2010 and the new commitment period in 2020 will, as shown in chapter 3, have impacts on the fossil fuel markets. Globally, the analysis shows that increased consumer prices, reduced demand, and decreased producer prices will be the result of the two climate policy approaches. This will surely affect Norway, which was the seventh largest oil producer in 1998 and second only to Saudi Arabia when it came to oil export. In 1998 the value of Norwegian petroleum export was estimated at NOK 123 billion and accounted for approximately 30% of Norway's export revenues (OED 1999). (ii) Meeting the obligations under the two commitment periods will have costs in terms of domestic reductions and through purchasing emission permits. It might therefore be a trade-off between what is best for Norway as a Party to the Kyoto Protocol and Norway as an oil and gas producer.

6.1 Implications of the Kyoto Protocol (2010)

In the case of free trade, Norway is likely to purchase emission permits in the amount of 5.3 million tons CO_2-equivalents, at a cost of 15.1 USD/t CO_2-equivalent in 2010. Domestic reductions of 4.3 million tons must also be undertaken to fulfill the obligations set forth in the Kyoto Protocol.[26] After reducing 4.3 million tons domestically, the marginal cost of additional domestic reductions will be above the permit price. The effects of restricting trade according to the EU capping case is that the price of emissions permits increases, making it more expensive to comply through purchasing emission permits. More domestic reductions will therefore be undertaken. No international trade implies that no permits can be bought and that Norway must undertake all reductions domestically at an increased marginal cost.

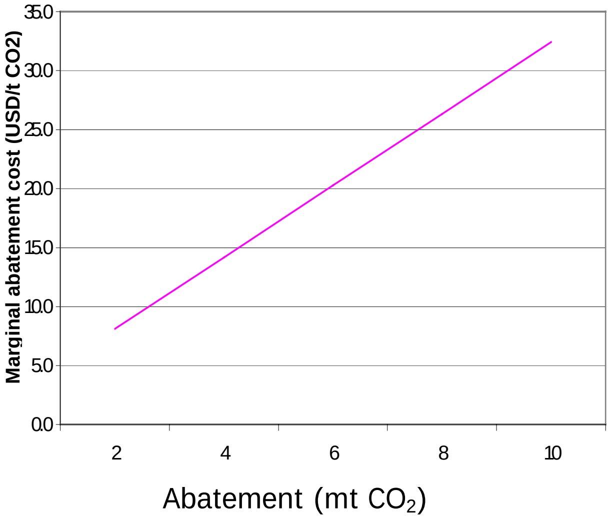

Figure 6.1 Marginal abatement costs for Norway in 2010

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[26] Norway is allowed to increase its emissions of GHGs by 1% compared to its 1990 emissions.

The abatement costs are derived from the marginal abatement costs (MAC) that the model simulations produce. The MAC will, as earlier mentioned be a result of the model concept and, in agreement with economic theory, be equal to the sum of excise taxes and the permit price. The MAC will therefore, as a starting point, be equal to the excise taxes. If the excise taxes are set at an optimal level from a fiscal point of view, the permit price will be the relevant indicator for the MAC. The marginal abatement costs in the model are assumed to be linear, which is equivalent to a linear demand for each fossil fuel (Holtsmark and Mæstad 2000). Figure 6.1 shows the MAC-curve for Norway in 2010 under the Kyoto-Success scenario and reflects that the costs increase as more abatement is required.

The area under the MAC-curve represents the aggregate abatement costs for a certain level of abatement. The cost of undertaking domestic reduction of, for instance, the 4.2 million tons that will be required under free trade is USD 32.3 million. The EU proposal will result in an additional USD 55 million being spent on abatement within Norway. The abatement costs under no trade will naturally be much higher as abatement has to be undertaken at an increasing cost. Free trade will minimize the costs for Norway if we consider the costs of purchasing permits and undertaking domestic reductions. The total costs would be USD 112.3 million, nearly 30% less than what the EU proposal would cost for Norway. The costs of implementing the Kyoto Protocol for Norway with no international trade will only be 3% higher than the EU capping case.

Table 6.1 Quotas and abatement in Norway under the Kyoto Protocol

	Free trade	*EU capping*	*No trade*
Quota import (mt)	5.3	2.5	-
MAC (USD/t CO_2-eq.)	15.1	23.4	31.2
Domestic reduction (mt CO_2-eq.)	4.2	7.1	9.6
Quota cost (million USD)	80.0	58.5	-
Abatement cost of domestic reductions (million USD)	32.3	87.3	150.8
Total cost (million USD)	112.3	145.8	150.8

The marginal abatement costs shown in figure 6.1 are projections of costs in 2010, so there will naturally be some uncertainty as to the precision of these projections. The model's projections can be compared to a study by the Norwegian Pollution Control Authority (SFT), which estimates the costs of more than 70 measures to reduce emissions of GHGs in 2010 (SFT 2000). The MAC-curve in the SFT study is not linear and includes no-regrets options of reducing emission by approximately 2 million tons of CO_2 equivalents at no costs. Our study shows that 6 million tons of CO_2 equivalents can be reduced at a cost less than 20 USD/t CO_2 equivalent. The SFT study concludes that a similar reduction of 6 million tons of CO_2 equivalents can be achieved at a cost lower than approximately 22 USD/t CO_2 equivalent.[27] Similarly, our study shows that a reduction of 10 million tons of CO_2 equivalents can be achieved at a cost less than 32 USD/ t CO_2 equivalent, while the SFT study operates with a cost of less than 44 USD/ t CO_2 equivalent. This reflects the non-linearity of the MAC-curve in the SFT study, which again reflects increasingly higher marginal abatement costs because the least-cost measures have been used.

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[27] Costs are originally stated in NOK, an exchange rate of NOK 9.0 for USD 1 has been used to convert to USD.

Estimating marginal abatement costs will never be entirely correct, as there are many factors that can cause uncertainty. The SFT study concludes that there might be errors in the data basis, and some measures are not included due to insufficient data, such as measures regarding CH_4 and N_2O from agriculture and CO_2-sequestration in forests. The estimates of emission reductions are uncertain, and the projected growth in emissions is also uncertain. A final factor is the external effects of reducing emissions such as improved health. Several measures could be socially efficient if such external effects were included.

The consumer prices for fossil fuels in Norway will, as in other Annex I countries, rise compared to BAU. The consumer price for oil will increase by up to 23.7%, gas by up to 28.7%, and coal by as much as 64.2%. The price increase for all fossil fuels will be smallest under the free-trade case, whereas no trade will lead to the highest increase in prices.

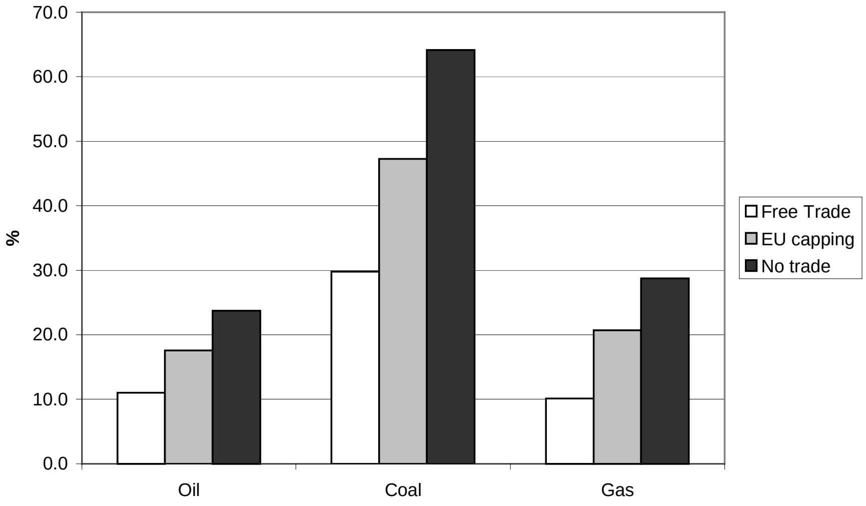

Figure 6.2 Change in consumer prices for fossil fuels in Norway relative to BAU in 2010

The changes in producer prices as shown in figure 5.3 are more interesting because they will affect Norwegian oil and gas revenues.[28] Reduced producer price for oil will lead to a decrease in Norwegian oil production of 1.6, 1.9, and 2.1%, under free trade, EU capping, and no trade, respectively. Norwegian gas production differs somewhat from this trend, as we know that the producer price for gas in Europe will decrease the most under free trade. The largest reduction in production will therefore be 3.9% under free trade. The EU capping and no-trade case will have less impact as production in both cases drops by 2.3%. This can be explained by a shift in consumption from oil to gas, as gas becomes relatively cheaper than oil when trade restrictions are imposed. Figure 5.2 shows that the demand for gas in EU decreases less than the demand for coal, and also less than oil in the free-trade case.

The consequences for the revenues from oil and gas production are that they will decrease for both fuels, but that the losses are greatest under no trade for oil and under free trade for gas. Summing up the reduced revenues suggests that Norway can expect to experience a drop in its revenues from oil and gas production ranging from 4.1 to 4.9%, relative to its BAU

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[28] Revenues are gross revenues, i.e. price multiplied by production. We do not consider production costs.

revenues. The largest reduction in revenues is in the case with no trade (USD 2.4 billion), whereas the free-trade case will give the smallest reduction in revenue (USD 2.0 billion).[29, 30]

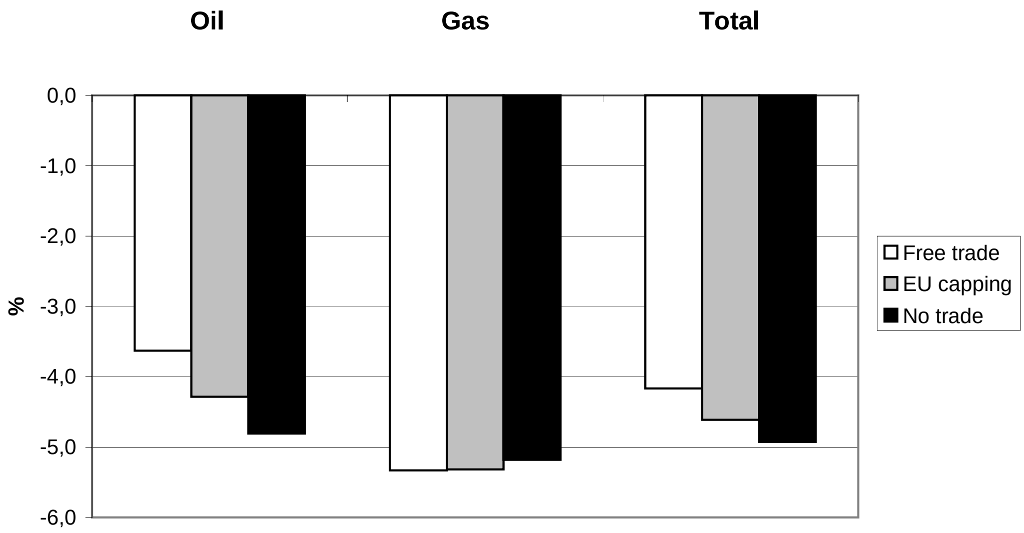

Figure 6.3 Reduction in revenues for Norway from oil and gas production relative to BAU in 2010

Table 6.2 combines the costs for Norway as a Party to the Kyoto Protocol and the costs for Norway as an oil and gas producer. The cost of purchasing permits and abatement is relatively small compared to the expected revenue losses in production. It is also clear that free trade will, all in all, impose the smallest costs for Norway while the no-trade case will incur the largest costs.

Table 6.2 Total costs for Norway under the Kyoto Protocol

Costs (million USD)	*Free trade*	*EU capping*	*No trade*
Quota and abatement costs	112	146	151
Revenue loss	2,046	2,264	2,418
Total costs	2,158	2,410	2,569

The markets for fossil fuels can, however, change rapidly, and it is therefore difficult to predict how the market situation will be ten years from now. This is especially due to the market

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[29] One could argue that the calculated revenue loss should have included only the effect of reduced producer prices, and not include the reduced production. This is because whatever is not produced and sold in one period can be sold at a later time. However, these revenues would have to be discounted.

[30] There might be a substitution towards hydropower since the consumer prices of fossil fuels increases. Hydropower emits virtually no GHG emissions and can become more valuable because of the aim of reducing GHG emissions. This could to some extent reduce the loss Norway will have from the implementation of the Kyoto Protocol and from the second commitment period.

power that OPEC possesses, which may represent a much more important factor than the Kyoto Protocol itself.

6.2 Implications of the second commitment period (2020)

The second commitment period will be a new and large step for the industrialized countries, as their assigned quotas are set well below their BAU emissions in 2020. The consequence for Norway is that the allocated quota is nearly 46% smaller than the projected BAU emissions and represents a reduction from 1990-levels of close to 32%. This is a drastic change from the 1% increase that was allowed in 2010 under the Kyoto Protocol.

Under free trade, Norway will import emissions permits in the amount of 28.1 million tons CO_2 equivalents at the price of 15.0 USD/t CO_2. Furthermore, Norway will have to undertake domestic reductions in the amount of 4.0 million tons in order to meet the new obligations. The voluntary supply reductions in the major developing countries will not affect Norway's implementation much as the price increase to 21.6 USD/t CO_2 only reduces the import to 26.3 million tons. Some more abatement within Norway will then be required. The no-trade case will force Norway to undertake serious domestic abatement, as the required reduction of 32.1 million tons must be fulfilled without international trade.

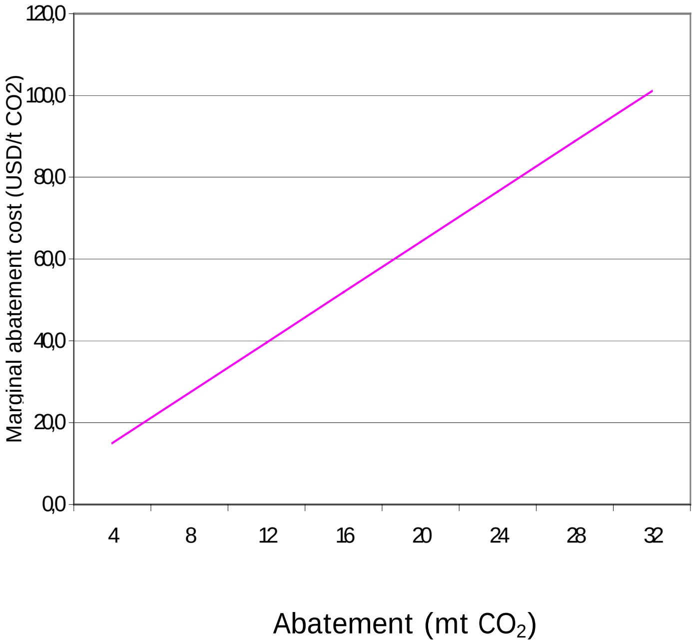

Figure 6.4 Marginal abatement costs for Norway in 2020

The cost of domestic reductions will as in 2010 depend on the marginal abatement costs, which are shown in figure 6.4. Table 6.3 shows that abatement of 4 million tons, which is required in the free-trade case, will cost USD 33.9 million. The large reductions required in the no-trade case will cost close to USD 1.7 billion. The best alternative for Norway would be free trade, which minimizes the abatement cost. The main difference from the Kyoto Protocol is that no trade will be much more costly under the new commitment period than under the Kyoto Protocol.

Table 6.3 Quotas and abatement in Norway under the second commitment period.

	Free trade	*Reduced supply*	*No trade*
Quota import (mt CO_2-eq.)	28.1	26.3	-
MAC (USD/t CO_2-eq.)	15.0	21.6	101.4
Domestic reduction (mt CO_2-eq.)	4.0	5.8	32.1
Quota cost (USD million)	421.5	568.1	-
Abatement cost of domestic reductions (million USD)	33.9	65.9	1,664.4
Total cost (USD million)	455.4	634.0	1,664.4

From figure 6.5 it is obvious that the no-trade case will have severe impacts on consumer prices, particularly for coal. The prices for oil, gas, and coal will increase by 75.9, 90.3, and 217.4%, respectively. The price increases under free trade and reduced supply are nowhere near such levels.

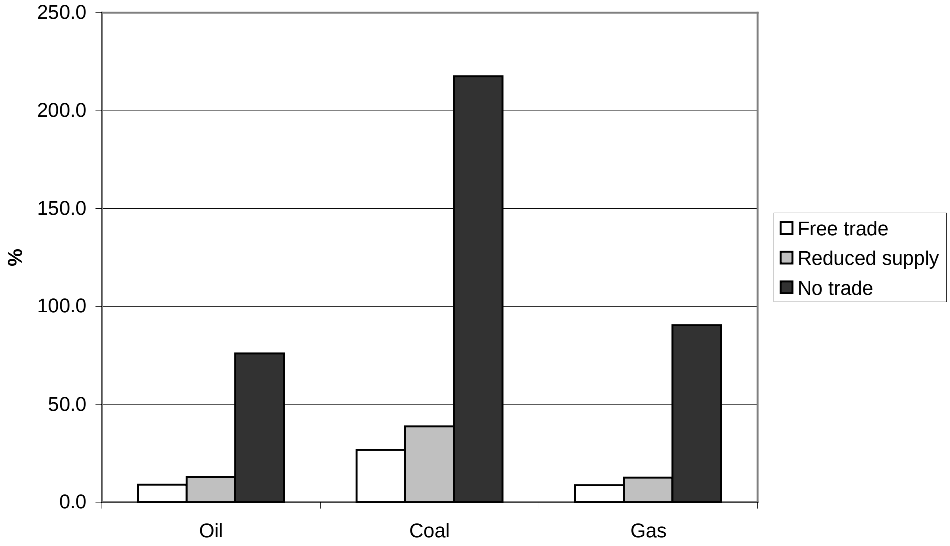

Figure 6.5 Change in consumer prices in Norway relative to BAU in 2020

The reduced producer prices shown in figure 5.6 will lead to a decrease in Norwegian oil and gas production. The oil production will under free trade be 3.3% lower than under BAU, 4.8% lower in the reduced supply case, and 4.1% lower with no trade. The trend is similar for gas production, which under free trade will be 4.1% lower than BAU, while it will be 6.0% lower under the reduced supply case and 4.6% lower with no trade.

The consequences for the revenues from oil and gas production are that they will decrease for both fuels (see figure 6.6). The free-trade case will incur the smallest revenue reductions for Norway, both in terms of oil and gas production. The reduced-supply case will have the largest losses in oil revenue while the no-trade case will lead to the largest reductions in gas revenues. The reason for the losses in oil revenues being smaller in the no-trade case than the reduced-supply case is that the developing countries will have no market for their “excess quotas” under no trade. This will not, however, affect the regional gas market in Europe and the reductions in gas revenues are as expected. Free trade will, all in all, reduce Norway’s revenues from oil and gas production by 8.6%. Reduced supply and no trade will result in 11.3 and 10.8% lower revenues relative to the BAU projections.

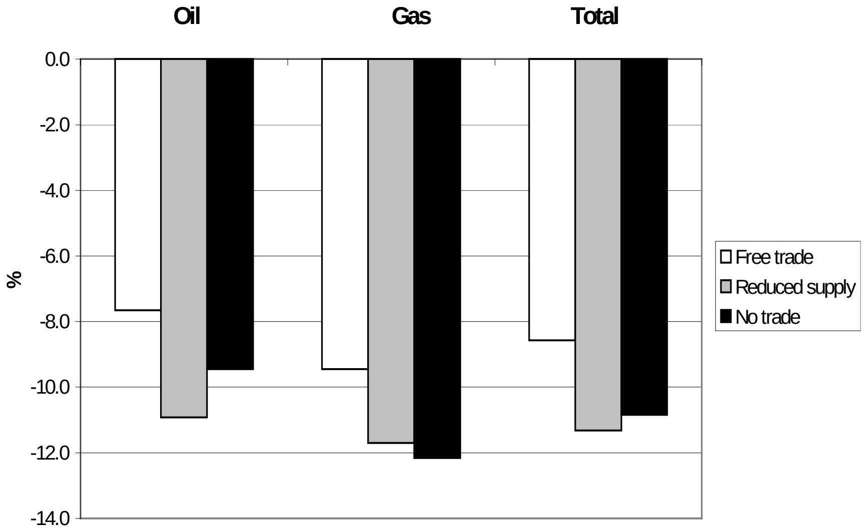

Figure 6.6 Reduction in oil and gas revenues for Norway relative to BAU in 2020

The costs of purchasing permits and domestic abatement are relatively small compared to the revenue losses, particularly in the free trade and reduced supply cases. However, the relative share is higher than under the Kyoto Protocol. This reflects the ambitious reduction target for Norway in 2020 that will require international permit trade and/or domestic abatement. Free trade will, all in all, impose the smallest costs for Norway and stands out as the best alternative. The no-trade case will incur the largest costs for Norway, despite that the revenue losses from oil and gas production are larger in the reduced supply case.

Table 6.4 Total costs for Norway under the second commitment period

Costs (million USD)	*Free trade*	*Reduced supply*	*No trade*
Quota and abatement costs	455	634	1,664
Revenue loss	3,195	4,217	4,037
Total costs	3,650	4,851	5,701

Based on the consequences of restricting trade, it is unlikely that Norway will strive for banning trade or encourage voluntary reductions in emissions permit transfers in the major developing countries. We have seen that the cost of purchasing emission permits and abatement is relatively small compared to the revenue losses from decreased export of oil and gas, but these costs will nevertheless be substantial if international trade is not allowed. The markets for fossil fuels, especially oil, are easily influenced by supply side changes (e.g. the strategy of OPEC) and the prices can vary considerably. The development in these markets is therefore likely to be just as important as, or more important than, how the commitments are implemented.

Another important factor that will influence Norway is technological development, as energy markets are likely to be influenced both on the demand and supply side. This aspect will be important both within Norway, but also among Norway's major trading partners. The energy market development in these and other countries is therefore important to Norway because the demand and supply structure may change in the future. The issue of technological development was discussed in this context in chapter 5.

7 Discussion and summary

A main conclusion to be drawn from the analysis is that Norway's cost of participating in a Kyoto Protocol regime is heavily dominated by reduced oil and gas revenues combined with domestic emission abatement cost and the costs of buying quotas from other countries. The cost of reduced oil and gas revenue is 15.5 to 18 times greater than the abatement and quota cost in 2010, and 2.4 to 7.0 times greater in 2020. Both in 2010 and 2020 the cost difference is largest for the free-trade case and smallest for the no-trade case. Most of the oil and gas revenue loss would occur even if Norway should not ratify and implement the Kyoto Protocol, given that the Protocol enters into force.

A second main conclusion is the importance of free trade to keep the total domestic cost down, which is the sum of abatement cost, quota cost, and oil and gas revenue loss. The free trade regime gives the lowest abatement and quota cost, and the lowest oil and gas revenue loss, both in 2010 and 2020. This is due to the reduction in producer price being lowest in the free-trade case, and only small changes in oil and gas production. There is one exception: the no-trade regime generally implies the smallest producer price reduction for the European gas market in 2010. This effect is caused by the free-trade regime that allows the sale of low-priced hot air quotas from economies in transition. To meet their national Kyoto Protocol targets, Norway and other European countries buy such quotas since they are cheaper than reducing emissions by substituting coal and oil for gas. Thus demand for gas in Europe is reduced, causing a downward pressure on the gas price.

These two conclusions taken together point to the conflicting interests of Norway as an exporter of fossil fuels, on the one hand, and as a nation that wants to promote a green and climate-friendly image at the international level on the other. Nevertheless, we assume that Norway's climate policy strategy is based on supporting the Kyoto Protocol entering into force and implementing the Protocol in Norway, but at the same time, minimizing the total national cost of meeting this objective. The same strategy is chosen for Kyoto periods after 2012.

Given this Norwegian strategy, we discuss how the implementation cost can be reduced through the following strategies: A) reducing abatement cost in Norway, B) reducing international quota prices, and C) reducing oil and gas revenue loss. To minimize the abatement and quota cost, Norway abates emissions domestically until the marginal abatement cost reaches the international quota price. At this point, the abatement and quota cost can be reduced either through a negative shift in the marginal abatement cost curve or through a lower international quota price.

A) Reducing the abatement cost in Norway.

- *Develop new energy technologies that are low-carbon or carbon-free.*

Examples are biomass energy, other solar-based energy sources, and fuel cells. There is a role for publicly supported research and development programs if private investments are too low to be socially optimal. Reasons for too low private investments can be a high degree of risk aversion and/or a high rate of return demanded, or that a large program for green technologies can partly be considered a public good. Furthermore, there can be a number of positive environmental externalities associated with a low-carbon energy system that private companies do not consider in full due to inadequate environmental regulation. Joining efforts with other countries can be an attractive option to finance and carry out large, costly, and long-term programs. Given successful programs, Norwegian enterprises could gain sizeable shares of profitable future markets in green technologies.

- *Involve all activities and economic sectors in abatement efforts.*

Including all sectors implies that all abatement options are included and should constitute the best basis for a cost-effective national policy.

- *Use incentive-based policy tools such as permits and taxes.*

Taxes and permits secure a more cost-effective solution than command-and-control policy tools. Furthermore, taxes and permits provide stronger incentives for technological progress than command-and-control because they encourage companies to reduce emissions below the target.

- *Emphasize revenue recycling.*

The idea is that the government should use greenhouse gas tax incomes and income from the initial sale or auctioning of permits to reduce existing distorting taxes and levies, which would in turn increase economic effectiveness, see Holtsmark (1999). This would lower the cost of Norway's climate policy. This idea is linked to point above on benefits of incentive-based policy tools. Furthermore, a prerequisite for this policy option in a permit system is to avoid free-permits.

B) Reducing the international permit price

- *Support free trade under the Kyoto mechanisms in the climate negotiations.*

This study has shown that total national cost for Norway of implementing the Kyoto Protocol is lowest in the free-trade case. Thus Norway should oppose EU's capping proposal on international emissions trading.

- *Support rules and institutions for the Kyoto mechanisms that reduce transaction costs.*

Examples of elements that influence the transaction cost of the Kyoto mechanisms are rules and institutions for reporting, verification, and certification. Likewise such rules and the design of institutions should reflect an ambition to reduce a number of uncertainties that are likely to increase transaction costs and thus the final permit price.

- *Support rules that make the Clean Development Mechanism more attractive.*

There are many difficulties related to the design of the Clean Development Mechanism, among which baseline definitions and additionality are prominent ones. If one aims at a very high degree of certainty in the validity of credits generated through the Clean Development Mechanism, rules have to be strict, fewer projects will be attractive, and the size of the market will shrink.

- *Support proposals in the climate policy negotiations that induce developing countries to take on binding commitments to reduce their greenhouse emissions after 2012.*

A serious challenge for negotiating greenhouse emission abatement targets after 2012 is the involvement of developing countries. There are fairness considerations between industrialized countries and developing countries to be taken care of, and a number of practical and political feasibility considerations.[31] Developing countries can be given stronger incentives to participate if they are given emissions quotas that have a strong per capita basis, since they then would be able to sell a sizeable amount of quotas to industrialized countries.

C) Reducing the oil and gas revenue loss

- *Invest in research and development programs in green technologies.*

The basic idea is to transform Norway from an oil and gas exporting country to an energy exporting country through a strategic research and development program and investments in green energy technologies. See the first point concerning developing new energy technologies.

- *Develop carbon dioxide sequestration technologies.*

If such technologies can be developed to the extent that the fossil fuel price, plus the sequestration price, become competitive with low-carbon or carbon-free energy sources in the future, the oil and gas wealth of Norway is likely to experience a relatively smaller reduction since tax and quota costs can be reduced.

- *Exert influence on the natural gas price on the European market.*

Norway has some possibility to influence the natural gas price on the European regional market, even if there are other large gas exporters like Russia and Algeria. The idea is to lessen the price reduction for natural gas resulting from the climate policy in industrialized countries. To some extent a price increase can be achieved by lowering Norwegian gas production, but obviously at the cost of reduced earnings resulting from reduced export. A related idea is to indirectly "increase" the gas price through building gas-fired power stations and exporting more electricity in stead of gas, provided that substitution of gas export for electricity export yields an increased revenue for Norway. We assume that there is little opportunity to influence the oil price due to the dominance of OPEC and Norway's relations to big oil importing regions and countries like EU and USA.

There is no simple answer to handling the conflict between Norway's role as a large fossil fuel exporter and its ambitions to be a proponent for an efficient climate policy regime. Participating in a climate policy regime will be more costly for Norway than most other industrialized countries due to the relatively large loss in oil and gas revenue. However, Norway can try to influence future climate policy negotiations according to its interests, employ the Kyoto mechanisms and other policy tools to reduce national costs, and commit to a technology and industry strategy for the future where green and carbon-free energy technologies have their prominent place.

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[31] See Ringius, Torvanger and Underdal (1999).

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9 Appendix 1. Description of Technologies

The different technologies illustrated in figure 3.1 represent mature, incremental, and radical technologies that behave differently and can be difficult to implement in a model. The following section will describe some of these and other technical and economical potentially available technologies within power generation that either exist today or that are likely to be implemented within the next twenty years.

A1.1 Turbines and cycles

Combined-cycle gas turbines (CCGT) have high efficiency and low-pollutant emissions. They also have low construction costs, are available in a range of small to medium sizes, have short construction times (2 to 3 years), and are straightforward to build and operate. Provided that gas is available at a competitive price, CCGTs could account for a significant production of electricity in the near future. This technology is likely to break through in countries and regions where gas is available and/or cheap, such as Europe, North America and the economies in transition (IEA 1998a). There have also been other major developments programs, such as integrated gasification combined cycles (IGCC) for coal, residual oil, and biomass power generation (IPCC 1996a), and coal is likely to retain a strong position in power generation where gas is unavailable or expensive. Coal is favored in those developing countries where coal is abundant, such as China and India, and in locations close to low-cost coal production, such as Australia, South Africa, and parts of North America (IEA 1998a). There is a large potential in developing countries to use clean coal technologies and there are already evident signs of deployment of such technologies (IEA 1997).

A1.2 Fuel cells

The fuel cell technology has existed for approximately 150 years and has often been considered a laboratory technology with too many constraints to become commercial. Fuel cells convert chemical energy into electricity without first burning the fuel to produce heat. This power system is characterized by high thermodynamic efficiency, low levels of pollutant emissions, and that almost all fuel cells currently developed for commercialization use pure hydrogen as the fuel. Electricity from fuel cell systems at small-scale as well as large-scale production gives a conversion efficiency from hydrogen ranging from 40–70% to more than 80% in cogeneration (IPCC 1996a).

It is difficult to define when an experimental technology becomes commercial, but the indications are that fuel cells are crossing the line. Substantial resources have been channeled to fuel cell research and the results have been promising. The installation costs for fuel cells vary considerably, but the cost of a fuel cell has already been reduced down to only a few thousand dollars per kilowatt of generating capacity (The Economist 1999). By 2004, power-generation companies hope to be well established. The most promising variety of fuel cells, the proton-exchange membrane, is expected to soon become competitive with some alternative technologies. Fuel cells could, ten years from now, account for as much as a tenth of the USD 50 billion a year global market for power generation equipment (The Economist 1999). However, the most efficient, high-temperature fuel cells must overcome the challenge of demonstrating long-term reliability, durability, and cost competitiveness (IEA 1997). The environmental performance is probably not much better than conventional power generation with additional cleaning technologies. Fuel cell plants for large-scale power production will therefore have to compete with advanced IGCC and CCGT power plants. The most likely significant market penetration of fuel cell systems is expected in small-scale combined heat and power (CHP) production (IPCC 1996a).

A1.3 Combined heat and power

Replacing separate heat and power generation with CHP offers significant improvements in fuel efficiencies and mitigation of GHG emissions. Producing 1 kWh (and some given amount of heat) from hard coal in a CHP system can reduce emissions by almost 30% compared with producing both separately. Similarly, emissions can be reduced by almost two-thirds if the CHP system utilizes natural gas (IEA 1997). CHP has applications in the industrial, residential, and commercial sectors, and heat-plus-power efficiencies are typically 8090%. Combined production of heat and electricity is possible with all heat machines and fuels from a few kW-rated to large steam-condensing power plants. The employment of CHP is closely linked with the availability or development of district heating (DH). A prerequisite for DH is central heating systems in buildings, and these are customary in most temperate and some subtropical regions. CHP is widespread in Denmark and Finland, and substantial DH exists in Austria, Germany, the Netherlands, Poland, Russia, and Sweden (IPCC 1996a).

A1.4 Heat pumps

Heat pumps can take heat that occurs naturally in the surrounding environment—whether it be from the sun or from waste heat sources such as industrial processes—apply a little more energy, and transfer the heat to a building or industrial application. The process can also be used for cooling. Because they draw on renewable heat sources, heat pumps represent one of the most energy-efficient technologies available today. Heat pumps driven by electricity for heating buildings typically supply 100 kWh of heat with just 20–40 kWh of electricity. But many industrial heat pumps can achieve even higher performance by supplying the same amount of heat with only 3–10 kWh of electricity. Results show that if the fuel used by conventional boilers were redirected to supply power for electric heat pumps, about 35–50% less fuel would be needed (IEA 1998b). Heat pumps are an important technology for reducing emissions of CO_2, SO_2, and NO_x because they consume less primary energy. However, the overall environmental impact depends on how the electricity is produced. Given the improvements in energy efficiency and environmental performance by this technology, it represents an important alternative to traditional heating systems(IEA 1998b).

A1.5 Nuclear power

The investment costs for construction of nuclear units are a major component of the total cost of nuclear-generated electricity. They are sensitive to technical parameters, regulation aspects, and like other capital-intensive options, the interest rate. The direct nuclear electricity generation costs vary across a number of countries from 2.5 to 6¢/kWh_e (IPCC 1996a). There has been progress in modernizing existing nuclear plants, in addressing safety and efficiency issues, and in extending plant lifetimes. Progress in increasing the power of existing plants by 15% and extending their life to 60 years will reduce the costs of nuclear energy (Doucet 1999). New designs are being used in reactors now under construction to provide increased safety and improved economic performance through reduced construction lead times and reduced operation and maintenance costs. Further cost reductions can be obtained by streamlining the reactor's systems and reducing the amount of material and manufactured components required for construction.

Lifecycle analysis show that CO_2 emissions from nuclear power generation are 35 times lower than oil-fired power generation, and six times lower than some wind and solar technologies (IEA 1997). If compared to conventional coal-fired electricity, the mitigation costs of nuclear energy would range from USD 120/t C avoided to negligible additional costs (IPCC 1996b).[32] The continuing concern of many members of the general public and many policymakers is likely to remain a severe constraint on nuclear power generation in many countries (IPCC 1996a). If nuclear plants should become more important in the future, it will be on the grounds of providing energy, not for solving the climate problem.

A1.6 Hydro

Hydroelectricity is the only renewable resource used on a large scale for electricity (IPCC 1996a). The efficiency of hydro power plants is very high, from 70 to 90%. This means that hydro plants convert the potential and kinetic energy stored in the water flow very efficiently into electricity (ABB 1998). The global production of hydroelectricity was in 1995 2,622 TWh (ABB 1998). Based on investment costs for hydro projects in 70 developing countries for the 1990s, the cost of new hydroelectricity delivered to final use is, on average, 7.8¢/kWh_e (IPCC 1996b). The market potential for reducing GHG emissions depends on which fossil fuel hydropower replaces. The GHG emissions for a typical hydro plant in a cold climate are 30 to 60 times less than from a typical fossil fuel plant (IEA 1997). If hydropower replaces modern coal-fired electricity, one would have an average CO_2 reduction cost of USD 120/tC avoided (IPCC 1996b).[33] Hydropower will remain an important source of electricity generation into the foreseeable future. This is because hydropower itself does not produce polluting emissions to the atmosphere, and because hydro resources are in ample supply around the world, especially in the high-growth regions of Asia, Africa, and Latin America, (ABB 1998).

A1.7 Wind energy

Wind energy is the world's fastest growing energy source, but amounts to a only small share of the 3,000 GW of worldwide installed electric capacity. There were 5 GW of installed wind power worldwide at the beginning of 1996, and almost all the growth is taking place in Europe and Asia. The best wind resources are found primarily along continental coastal areas. The overall efficiency of single wind turbines is in the range of 25–35%, and the upper limit to wind turbine efficiency is 59%. A wind turbine is more efficient in converting wind energy density into electricity photovoltaic cells are in converting sunlight into electricity. The general rule is that higher optimum running velocities of a wind turbine gives higher efficiencies (ABB 1998). The cost of energy from wind power has a wide range from 4.3 to 10¢/kWh, but future costs as low as 3.2¢/kWh have been calculated (IPCC 1996a).

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[32] This assumes conventional coal electricity costs of 5¢/kWh_e, nuclear costs between 5.0 and 7.7¢/kWh_e, and emissions avoided of 230 g C/kWh_e

[33] This assumes conventional coal electricity costs of 5¢/kWh_e and emissions avoided of 230 g C/kWh_e.

New turbines are much quieter than earlier models because they rotate at a slower rate. Noise is therefore no longer a primary problem. The impact on birds may have been exaggerated, but this issue is still under investigation. The visual impact of wind turbines, however, is among the most controversial issues. One solution could be to put wind parks in isolated areas or offshore. The future prospects for wind power are very good, and it has been estimated that 10 GW in additional capacity will be installed during the period 1996–2000, mostly in Europe and Asia (ABB, 1998). Based on formulated political goals for the next 20–30 years, the global annual production could add up to 150 TWh (IPCC 1996a).

A1.8 Solar energy

Solar power plants can be categorized as either photovoltaic (PV) plants or solar-thermal plants. The total world electricity generation from solar energy amounts to less than 0.02% of total global production. The general rule is that an insulation of at least 1700 kWh/m^2/year is necessary to reach acceptable production cost levels with large solar-thermal installations. Areas fulfilling this condition are the North African deserts, the Arabian Peninsula, major parts of India, Central and Western Australia, the high plateaus of the Andes, northern Brazil, and the southwestern US. Only southern Spain and some Mediterranean islands meet the criterion in Europe (ABB 1998). The potential applications of PVs range from basic electrification for those without electricity to integration in building structures in developed urban areas. Examples of practical applications in remote areas in developed countries are water pumping, fence electrification, and radio station power supply (IEA 1997).

The photovoltaic cell market is growing at approximately 25% per year, and the main problem the industry faces is getting production costs down and efficiencies up (ABB 1998). PV is already competitive as a stand-alone power source remote from electric utility grids, but has not been competitive in bulk electric grid-connected applications. The system capital costs are USD 7,000–10,000/kW and the electricity cost is 23–33¢/kWh, even in areas of high insulation. However, it is expected that the cost of PV systems will improve significantly through R&D, as well as with economies of scale. Various studies (IPCC 1996a) indicate that generating costs can be significantly reduced from the present level down to 4–7¢/kWh. The future prospects for PV solar electricity are good and increased production is expected. A number of countries (such as the Netherlands and Japan) plan to increase their installed PV capacity considerably (ABB 1998).

A1.9 Biomass energy

The scales at which electricity generation from biomass can take place range from a few kilowatts for rural village or agricultural applications, to tens of megawatts for present industrial applications, to hundreds of megawatts for advanced industrial applications (IPCC 1996a). Biomass residues, wood resources from natural forests, and biomass from managed plantations are all important potential sources of biomass for power production (ABB 1998). Some technological options are not yet commercialized, such as steam-injected gas turbines, intercooled steam-injected gas turbines, and a biomass version of the fuel cell. Technologies that are close to commercialization are integrated gasification and combined cycles (IEA 1997). Future biomass inputs for electricity generation in the Annex I countries are expected to cost around USD 2/GJ. With this cost and small-scale production, electricity can be generated for 10–15 ¢/kWh$_e$ (IPCC 1996b). Electricity can be produced for less than 10¢/kWh$_e$ with low-cost biomass, like for instance 85¢/GJ for a village plantation in south India. This makes this technology an attractive option for applications remote from electric grids where biomass is available (IPCC 1996a). Research on advanced biomass conversion technologies as well as biomass plantations is being conducted, but further R&D will be required for these to become technically mature and economically viable (IPCC 1996b).

There are a number of projects dedicated to the development of better and more efficient biomass power technologies. But the market today is rather small, and it is unlikely that biomass technologies will become mature and competitive on a large scale the next few years.

10 Appendix 2. Data tables and results

Table A2.1 Demand elasticities in BAU-equilibrium

	e.oo	*e.oc*	*e.og*	*e.co*	*e.cc*	*e.cg*	*e.go*	*e.gc*	*e.gg*
USA	-0.33	0.00	0.01	0.01	-0.66	0.27	0.02	0.08	-0.57
Canada	-0.47	0.02	0.13	0.20	-0.60	0.10	0.20	0.01	-0.50
Austria	-0.45	0.01	0.03	0.15	-0.41	0.11	0.10	0.03	-0.48
Belgium	-0.63	0.02	0.12	0.25	-0.40	0.00	0.30	0.00	-0.58
Denmark	-0.47	0.03	0.00	0.16	-0.68	0.05	0.00	0.05	-0.46
Finland	-0.58	0.05	0.04	0.30	-0.58	0.13	0.13	0.07	-0.51
France	-0.52	0.00	0.01	0.01	-0.37	0.15	0.04	0.01	-0.55
Germany	-0.58	0.02	0.02	0.15	-0.61	0.04	0.05	0.02	-0.54
Greece	-0.51	0.03	0.03	0.15	-0.62	0.16	0.13	0.16	-0.70
Ireland	-0.58	0.02	0.02	0.20	-0.67	0.08	0.12	0.04	-0.59
Italy	-0.44	0.00	0.05	0.02	-0.42	0.15	0.10	0.01	-0.60
Netherlands	-0.42	0.00	0.00	0.00	-0.49	0.14	0.00	0.01	-0.51
Portugal	-0.58	0.02	0.04	0.16	-0.57	0.00	0.21	0.00	-0.81
Spain	-0.45	0.00	0.02	0.01	-0.60	0.20	0.09	0.05	-0.69
Sweden	-0.56	0.01	0.00	0.04	-0.35	0.08	0.00	0.03	-0.60
UK	-0.39	0.00	0.01	0.00	-0.58	0.08	0.02	0.01	-0.54
Norway	-0.54	0.00	0.01	0.05	-0.02	0.13	0.04	0.01	-0.54
RestWest	-0.58	0.00	0.00	0.00	-0.05	0.00	0.05	0.00	-0.50
Czech	-0.60	0.08	0.05	0.05	-0.49	0.11	0.05	0.15	-0.50
Ukraine	-0.69	0.03	0.01	0.06	-0.40	0.00	0.00	0.00	-0.53
Poland	-0.43	0.00	0.09	0.00	-0.57	0.07	0.09	0.13	-0.50
Russia	-0.80	0.05	0.00	0.20	-0.59	0.20	0.00	0.02	-0.55
RestEast	-0.80	0.07	0.20	0.20	-0.59	0.20	0.09	0.03	-0.57
Japan	-0.65	0.00	0.08	0.00	-0.35	0.00	0.29	0.00	-0.50
Australia	-0.29	0.03	0.00	0.12	-0.61	0.03	0.00	0.01	-0.52
New Zealand	-0.19	0.00	0.00	0.00	-0.29	0.00	0.00	0.00	-0.45
China	-0.71	0.00	0.00	0.00	-0.38	0.00	0.00	0.00	-0.58
Indonesia	-0.57	0.00	0.01	0.01	-0.46	0.00	0.01	0.00	-0.60
India	-0.54	0.01	0.00	0.01	-0.49	0.06	0.00	0.05	-0.50
Brazil	-0.52	0.00	0.02	0.00	-0.71	0.27	0.10	0.12	-0.50
Middle East	-0.50	-0.00	0.04	-0.20	-0.50	0.00	0.03	0.00	-0.50
ROW	-0.50	0.02	0.02	0.09	-0.50	0.19	0.02	0.04	-0.50

o = oil

c = coal

g = gas

Table A2.2 BAU production and consumption of fossil fuels (Mtoe)

	1990 Production			*1990 Consumption*			*2010 Production*			*2010 Consumption*			*2020 Production*			*2020 Consumption*		
	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas
US	417	561	463	782	481	486	349	692	503	902	581	702	347	700	527	954	603	866
Canada	92	38	89	78	24	56	77	47	280	90	29	81	77	48	440	102	31	100
Austria	0	1	0	11	4	5	1	0	1	13	4	6	0	0	0	13	3	7
Belgium	0	1	0	25	10	10	0	0	0	23	6	14	0	0	0	24	7	17
Denmark	6	0	3	9	6	2	6	0	5	9	5	4	6	0	7	9	3	6
Finland	0	0	0	11	3	2	0	2	0	11	8	6	0	2	0	12	8	7
France	0	8	3	89	19	26	1	1	0	99	11	41	0	1	0	106	11	56
Germany	0	121	14	127	130	54	0	60	12	148	93	87	0	48	7	150	88	105
Greece	0	7	0	16	8	0	0	8	0	13	10	4	0	8	0	15	10	4
Ireland	0	0	0	4	2	2	0	1	0	6	3	2	0	1	0	6	3	3
Italy	5	0	16	94	16	39	4	0	15	86	18	71	4	0	12	87	17	80
Netherlands	0	0	55	35	10	31	1	0	55	25	5	43	2	0	45	24	2	49
Portugal	0	0	0	11	3	0	0	0	0	11	7	4	0	0	0	13	9	4
Spain	0	16	0	49	2	5	1	6	0	54	14	21	1	3	0	56	1	31
Sweden	0	0	0	16	2	1	0	0	0	15	6	12	0	0	0	13	5	13
UK	92	57	41	83	66	47	76	13	70	99	27	105	50	9	60	96	19	117
Norway	82	0	25	9	1	2	151	0	67	11	0	5	77	0	78	12	1	6
RestWest	0	0	0	13	0	2	0	0	0	15	0	2	0	0	0	16	0	3
Czech	0	36	0	8	34	5	0	24	0	6	23	6	0	23	0	6	22	7
Ukraine	0	84	24	63	75	115	0	56	34	42	51	137	0	52	43	44	49	166
Poland	0	94	0	16	80	9	0	63	0	10	55	11	0	59	0	11	52	13
Russia	516	176	538	250	181	378	503	118	784	165	124	450	544	110	984	174	117	546
RestEast	15	34	43	49	48	62	15	23	62	32	33	74	16	21	96	34	31	89
Japan	0	6	2	248	76	46	0	7	2	286	92	79	0	7	2	302	95	98
Australia	28	107	19	32	40	17	24	131	17	36	48	28	23	133	18	39	49	35
New Zealand	0	2	0	5	1	4	0	2	0	6	1	7	0	2	0	6	2	8
China	138	542	13	110	534	13	219	946	60	188	944	59	281	1107	116	218	1100	121
Indonesia	72	7	41	31	4	18	95	13	116	53	7	81	122	15	183	61	8	130
India	35	103	11	58	103	11	46	200	32	99	182	50	60	234	50	115	212	81
Brazil	33	3	3	58	10	3	53	7	20	79	21	13	60	9	33	91	28	20
ROW	522	256	242	556	265	217	625	334	360	796	335	412	796	429	631	889	423	562
Middle East	1127	2	149	191	4	103	1438	2	352	258	13	230	1512	2	364	281	16	341
World	3180	2261	1792	3136	2239	1771	3686	2757	2846	3686	2757	2846	3977	3024	3695	3977	3024	3695

Table A2.3 Global distribution of production of oil, coal and gas (in %)

	1990			*2010*			*2020*		
Region	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas
Annex I	39.4	59.6	74.4	32.8	45.6	67.0	28.8	40.6	62.7
Non-Annex I	60.6	40.4	25.6	67.2	54.4	33.0	71.2	59.4	37.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A2.4 Global distribution of consumption of oil, coal and gas (in %)

	1990			*2010*			*2020*		
Region	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas
Annex I	68.0	59.0	79.3	60.1	45.5	70.3	58.4	40.9	66.0
Non-Annex I	32.0	41.0	20.7	39.9	54.5	29.7	41.6	59.1	34.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A2.5 Business-as-usual emissions in 1990, 2010 and 2020 (Mt CO_2 equivalents)

	1990	*BAU 2010*	*BAU 2020*
US	5847	7481	8110
Canada	561	697	784
Austria	77	85	82
Belgium	149	153	166
Denmark	72	76	69
Finland	65	92	96
France	494	531	635
Germany	1214	1149	1235
Greece	97	102	109
Ireland	57	63	64
Italy	530	589	610
Netherlands	219	248	250
Portugal	63	90	103
Spain	336	349	328
Sweden	73	108	103
UK	732	744	726
Norway	56	66	70
RestWest	57	61	65
Czech	196	149	151
Ukraine	906	803	868
Poland	503	359	356
Russia	3057	2644	2873
RestEast	617	567	610
Japan	1338	1582	1689
Australia	426	517	547
New Zealand	77	85	91
China	3169	5636	6710
Indonesia	277	578	753
India	997	1697	2014
Brazil	298	473	569
ROW	8722	11801	13781
Middle East	1265	1795	2198
World	32543	41369	46814

Table A2.6 The world in 1995, population and emissions

	Population[34]		*CO2 emissions* [35]	
	Million	%	Mill. tons	%
US	265	4.61	5,469	24.09
Canada	30	0.52	436	1.92
Austria	8	0.14	59	0.26
Belgium	10	0.17	104	0.46
Denmark	5	0.09	55	0.24
Finland	5	0.09	51	0.22
France	58	1.01	340	1.50
Germany	82	1.43	835	3.68
Greece	10	0.17	76	0.34
Ireland	4	0.07	25	0.11
Italy	57	0.99	372	1.64
Netherlands	16	0.28	136	0.60
Portugal	10	0.17	52	0.23
Spain	39	0.68	232	1.02
Sweden	9	0.16	45	0.20
UK	59	1.03	542	2.39
Norway	4	0.07	38	0.17
RestWest	7	0.12	39	0.17
Czech	10	0.17	112	0.49
Ukraine	51	0.89	438	1.93
Poland	39	0.68	338	1.49
Russia	148	2.57	1,818	8.01
RestEast	60	1.04	341	1.50
Japan	126	2.19	1,127	4.96
Australia	18	0.31	290	1.28
New Zealand	4	0.07	27	0.12
China	1,215	21.12	3,193	14.06
Indonesia	197	3.42	296	1.30
India	945	16.42	909	4.00
Brazil	161	2.80	249	1.10
Middle East	154	2.68	864	3.81
ROW	1,948	33.85	3,793	16.71
World	5,754	100.00	22,700	100.00

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[34] 1996 figures from the World Bank: World Development Indicators 1998.

[35] 1995 figures from the World Bank, World Development Indicators, 1998. Norwegian emissions corrected for substantially incorrect flaring emissions.

Table A2.7 Preference scores

	Global scores (millions)		*Single National scores*	
Country	Per capita	Grandfathering	Per capita	Grandfathering
US		265		1
Canada		30		1
Austria		8		1
Belgium		10		1
Denmark		5		1
Finland		5		1
France		58		1
Germany		82		1
Greece		10		1
Ireland		4		1
Italy		57		1
Netherlands		16		1
Portugal		10		1
Spain		39		1
Sweden		9		1
UK		59		1
Norway		4		1
RestWest		7		4
Czech		10		1
Ukraine		51		1
Poland		39		1
Russia		148		1
RestEast		60		7
Japan		126		1
Australia		18		1
New Zealand		4		1
China	1,215		1	
Indonesia	197		1	
India	945		1	
Brazil	161		1	
Middle East		154		11
ROW	1,948		101	
Total	4,466	1,288	105	46
PS weights	0.78	0.22	0.70	0.30

Table A2.8 Assigned emission quotas under Preference Score in 2020 (million tons CO_2 equivalents) in case 1.

	Per cap.	*%*	*Grandf.*	*%*	*PS*	*%*
US	1,905	4.61	9,966	24.09	3710	8.97
Canada	216	0.52	794	1.92	345	0.83
Austria	58	0.14	108	0.26	69	0.17
Belgium	72	0.17	189	0.46	98	0.24
Denmark	36	0.09	100	0.24	50	0.12
Finland	36	0.09	93	0.22	49	0.12
France	417	1.01	620	1.50	462	1.12
Germany	590	1.43	1,522	3.68	798	1.93
Greece	72	0.17	139	0.34	87	0.21
Ireland	29	0.07	46	0.11	33	0.08
Italy	410	0.99	678	1.64	470	1.14
Netherlands	115	0.28	248	0.60	145	0.35
Portugal	72	0.17	95	0.23	77	0.19
Spain	280	0.68	422	1.02	312	0.75
Sweden	65	0.16	81	0.20	68	0.17
UK	424	1.03	988	2.39	550	1.33
Norway	29	0.07	69	0.17	38	0.09
RestWest	50	0.12	71	0.17	55	0.13
Czech	72	0.17	204	0.49	101	0.25
Ukraine	367	0.89	799	1.93	463	1.12
Poland	280	0.68	616	1.49	356	0.86
Russia	1,064	2.57	3,313	8.01	1568	3.79
RestEast	431	1.04	621	1.50	474	1.15
Japan	906	2.19	2,054	4.96	1163	2.81
Australia	129	0.31	528	1.28	219	0.53
New Zealand	29	0.07	50	0.12	33	0.08
China	8,735	21.12	5,818	14.06	8082	19.54
Indonesia	1,416	3.42	540	1.30	1220	2.95
India	6,794	16.42	1,656	4.00	5644	13.64
Brazil	1,158	2.80	454	1.10	1000	2.42
ROW	14,005	33.85	6,913	16.71	12418	30.02
Middle East	1,107	2.68	1,575	3.81	1212	2.93
World	41,369	100.00	41,369	100.00	41,369	100.00

Table A2.9 Emissions and quotas (million tons CO_2 equivalents) and percentage differences, case 1

	1990	*BAU 2010*	*BAU 2020*	*2020 Q*	*% reduct. from 2020*	*% reduct. from 1990*
US	5846.6	7480.5	8110.2	3709.6	-54.26	-36.55
Canada	560.7	696.7	784.3	345.1	-56.00	-38.44
Austria	76.8	85.2	82.5	68.8	-16.53	-10.34
Belgium	149.4	152.5	165.7	98.1	-40.76	-34.32
Denmark	71.9	75.5	68.6	50.3	-26.65	-30.05
Finland	64.8	92.4	96.5	48.7	-49.52	-24.86
France	494.1	530.7	634.9	462.4	-27.17	-6.42
Germany	1213.7	1148.6	1235.5	798.3	-35.39	-34.23
Greece	96.8	101.8	108.6	86.9	-19.98	-10.17
Ireland	56.9	62.8	63.8	32.6	-48.92	-42.67
Italy	530.4	588.7	609.7	469.8	-22.95	-11.43
Netherlands	219.0	247.6	249.9	144.7	-42.10	-33.92
Portugal	63.5	89.6	103.4	77.0	-25.52	21.26
Spain	335.7	348.8	327.8	312.1	-4.78	-7.02
Sweden	72.7	108.2	103.0	68.4	-33.55	-5.96
UK	731.7	744.3	725.9	550.4	-24.18	-24.78
Norway	55.5	65.7	69.9	37.8	-45.91	-31.88
RestWest	56.5	61.2	65.4	54.9	-16.09	-2.81
Czech	196.2	148.8	151.1	101.5	-32.82	-48.28
Ukraine	905.8	802.5	867.8	463.4	-46.61	-48.84
Poland	502.6	359.4	355.7	355.5	-0.05	-29.26
Russia	3056.8	2644.5	2872.7	1567.5	-45.43	-48.72
RestEast	616.9	567.2	610.1	473.9	-22.32	-23.17
Japan	1337.6	1582.1	1689.3	1162.8	-31.17	-13.07
Australia	426.4	517.5	547.3	218.7	-60.04	-48.72
New Zealand	76.9	85.4	90.7	33.5	-63.08	-56.42
China	3169.0	5636.2	6709.1	8082.4	20.47	155.05
Indonesia	277.0	578.2	752.1	1220.1	62.23	340.47
India	996.8	1696.6	2014.8	5644.0	180.12	466.21
Brazil	298.0	473.4	568.2	1000.1	76.01	235.60
ROW	8726.0	11801.5	13781.5	12417.7	-9.90	42.31
Middle East	1265.0	1794.6	2197.6	1212.0	-44.85	-4.19
World	33070.2	41368.9	46813.6	41369.0	-11.63	25.09

Table A2.10 Emissions and quotas (million tons CO2 equivalents) and percentage differences case 2.

	1990	*BAU 2010*	*BAU 2020*	*2020 Q*	*% reduct. from 2020*	*% reduct. from 1990*
US	5,847	7,481	8,110	3,710	-54.26	-36.55
Canada	561	697	784	345	-56.00	-38.44
Austria	77	85	82	69	-16.53	-10.34
Belgium	149	153	166	98	-40.76	-34.32
Denmark	72	76	69	50	-26.65	-30.05
Finland	65	92	96	49	-49.52	-24.86
France	494	531	635	462	-27.17	-6.42
Germany	1,214	1,149	1,235	798	-35.39	-34.23
Greece	97	102	109	87	-19.98	-10.17
Ireland	57	63	64	33	-48.92	-42.67
Italy	530	589	610	470	-22.95	-11.43
Netherlands	219	248	250	145	-42.10	-33.92
Portugal	63	90	103	77	-25.52	21.26
Spain	336	349	328	312	-4.78	-7.02
Sweden	73	108	103	68	-33.55	-5.96
UK	732	744	726	550	-24.18	-24.78
Norway	56	66	70	38	-45.91	-31.88
RestWest	57	61	65	55	-16.09	-2.81
Czech	196	149	151	101	-32.82	-48.28
Ukraine	906	803	868	463	-46.61	-48.84
Poland	503	359	356	356	-0.05	-29.26
Russia	3,057	2,644	2,873	1,568	-45.43	-48.72
RestEast	617	567	610	474	-22.32	-23.17
Japan	1,338	1,582	1,689	1,163	-31.17	-13.07
Australia	426	517	547	219	-60.04	-48.72
New Zealand	77	85	91	33	-63.08	-56.42
China	3,169	5,636	6,709	6,870	2.40	116.79
Indonesia	277	578	752	1,037	37.89	274.40
India	997	1,697	2,015	4,797	138.10	381.28
Brazil	298	473	568	850	49.61	185.26
ROW	8,726	11,801	13,782	12,418	-9.90	42.31
Middle East	1,265	1,795	2,198	1,212	-44.85	-4.19
World	33,070	41,369	46,814	38,977	-16.74	17.86

Table A2.11 National abatement, export and import of quotas for with free trade, limited trade and no trade (in million tons CO_2 equivalents).

	Import of quotas			*Domestic reduction*		
	Free trade	Reduced supply	No trade	Free trade	Reduced supply	No trade
US	3370	2917	-	1030	1483	4401
Canada	374	345	-	65	94	439
Austria	8	6	-	6	8	14
Belgium	55	50	-	12	18	68
Denmark	14	12	-	5	7	18
Finland	37	33	-	10	15	48
France	131	113	-	41	59	172
Germany	278	208	-	159	229	437
Greece	6	0	-	15	22	-3
Ireland	24	20	-	8	11	-1
Italy	105	89	-	35	51	140
Netherlands	89	82	-	16	23	105
Portugal	12	5	-	15	21	26
Spain	-3	-11	-	18	27	-5
Sweden	29	27	-	5	8	35
UK	121	97	-	55	79	176
Norway	28	26	-	4	6	32
RestWest	7	5	-	4	6	11
Czech	24	13	-	26	37	-4
Ukraine	314	275	-	90	130	-27
Poland	-73	-105	-	73	105	-12
Russia	1002	868	-	304	437	-86
RestEast	68	39	-	68	98	-14
Japan	368	298	-	159	228	527
Australia	241	202	-	88	127	329
New Zealand	50	47	-	7	10	57
China	-2534	-1831	-	1161	1671	-1373
Indonesia	-522	-363	-	54	78	-468
India	-3756	-2965	-	126	182	-3630
Brazil	-509	-392	-	77	111	-432
ROW	-187	-868	-	1550	2231	1363
Middle East	828	758	-	158	227	986
World	0	0	-	5445	7837	3328