Chapter 9. Sector Costs and Co-Benefits of Mitigation

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Executive Summary

Policies adopted to mitigate global warming will have implications for specific sectors, such as the coal industry, the oil and gas industry, electricity, manufacturing, transportation and households. A sectoral assessment helps to put the costs in perspective, to identify the potential losers, and the extent and location of the losses, as well as to identify the sectors that may benefit. However, it is worth noting that the available literature to make this assessment is limited: there are few comprehensive studies of the sectoral effects of mitigation, compared with those on the macro gross domestic product (GDP) effects, and they tend to be for Annex B countries and regions.

There is a fundamental problem for mitigation policies. It is well established that, compared to the situation for potential gainers, the potential sectoral losers are easier to identify, and their losses are likely to be more immediate, more concentrated, and more certain. The potential sectoral gainers (apart from the renewables sector and perhaps the natural gas sector) can only expect a small, diffused, and rather uncertain gain, spread over a long period. Indeed many of those who may gain do not exist, being future generations and industries yet to develop.

It is also well established that the overall effects on GDP of mitigation policies and measures, whether positive or negative, conceal large differences between sectors. In general, the energy intensity and the carbon intensity of the economies will decline. The coal and perhaps the oil industries are expected to lose substantial proportions of output relative to those in the reference scenarios, but other sectors may increase their outputs yet by much smaller proportions. Energy-intensive sectors, such as heavy chemicals, iron and steel, and mineral products, will face higher costs, accelerated technical or organizational change, or loss of output (again relative to the reference scenario) depending on their energy use and the policies adopted for mitigation. Other industries, including renewables and services, can be expected to benefit in the long term from the availability of financial and other resources that would otherwise have been taken up in fossil fuel production. They may also benefit from reductions in tax burdens, if taxes are used for mitigation, and the revenues recycled as reductions in employer or corporate or other taxes.

Within this broad picture, certain sectors will be substantially affected by mitigation. The coal industry, producing the most carbon-intensive of products, faces almost inevitable decline in the long term relative to the baseline projection. However, technologies still under development, such as carbon dioxide (CO_2) sequestration from coal-burning plant and in-situ gasification, could play a future role in maintaining the output of coal whilst reducing CO_2 and other emissions. The oil industry also faces a potential relative decline, although this may be moderated by (1) lack of substitutes for oil in transportation and (2) substitution away from solid fuels towards liquid fuels in electricity generation. Modelling studies suggest that mitigation policies may have the least impact on oil, the most impact on coal, with the impact on gas somewhere between; these findings are established but incomplete.

The high variation across studies for the effects of mitigation on gas demand is associated with the importance of its availability in different locations, its specific demand patterns, and the potential for gas to replace coal in power generation.

Particularly large effects on the coal sector are expected from policies such as the removal of fossil fuel subsidies or the restructuring of energy taxes so as to tax the carbon content rather than the energy content of fuels. It is a well-established finding that removal of the subsidies would result in substantial reductions in greenhouse gas (GHG) emissions, as well as stimulating economic growth. However, the effects in specific countries depend heavily on the type of subsidy removed and the commercial viability of alternative energy sources, including imported coal; and there may be adverse distributional effects.

There is a wide range of estimates for the impact of implementation of the Kyoto Protocol on the oil market using global models and stylized policies. All studies show net growth in both oil production and revenue to at least 2020 with or without mitigation. They show that implementation leads to a fall in oil-exporting countries' revenues, GDP, income or welfare, but significantly less impact on the real price of oil than has resulted from market fluctuations over the past 30 years. Of the studies surveyed, the largest fall in the Organization of Petroleum Exporting Countries (OPEC) revenues is a 25% reduction in 2010 below the baseline projection, assuming no permit trading and implying a 17% fall in oil prices; the reduction in OPEC revenues becomes just over 7% with Annex B trading.

However, the studies typically do not consider some or all of the following factors that could lessen the impact on oil production and trade. They usually do not include policies and measures for non-CO_2 GHGs or non-energy sources of GHGs, offsets from sinks, and actions under the Kyoto Protocol related to funding, insurance, and the transfer of technology. In addition, the studies typically do not include other policies and effects that can reduce the total cost of mitigation, such as the use of tax revenues to reduce tax burdens, ancillary environmental benefits of reductions in fossil fuel use, and induced technical change from mitigation policies. As a result, the studies may tend to overstate the overall costs of achieving Kyoto targets.

The very likely direct costs for fossil fuel consumption are accompanied by very likely environmental and public health benefits associated with a reduction in the extraction and burning of the fuels. These benefits come from a reduction in the damages caused by these activities, especially the reduction in the emissions of pollutants that are associated with combustion, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and other chemicals, and particulate matter. This will improve local and regional air and water quality, and thereby lessen damage to human, animal and plant health and the ecosystem. If all the pollutants associated with GHG emissions are removed by new technologies or end-of-pipe abatement (for example, flue gas desulphurization on a power station combined with removal of all other non-GHG pollutants), then this ancillary benefit will no longer exist. But removal of all pollutants is limited at present and it is expensive, especially for small-scale emissions from dwellings and cars.

Industries concerned directly with mitigation are likely to benefit from action. These include renewable electricity, producers of mitigation equipment (incorporating energy- and carbon-saving technologies), agriculture and forestry producing energy crops, research services producing energy and carbon-saving research and development (R&D). The extent and nature of the benefits will vary with the policies followed. Some mitigation policies can lead to overall economic benefits, implying that the gains from many sectors will outweigh the losses for coal and other fossil fuels, and energy-intensive industries. In contrast, other less well-designed policies can lead to overall losses.

These results come from different approaches and models. A proper interpretation of the results requires an understanding of the methods adopted and the underlying assumptions of the models and studies. Large differences in results can arise from the use of different reference scenarios or baselines. The characteristics of the baseline can also markedly affect the quantitative results of modelling mitigation policy. For example, f air quality is assumed to be satisfactory in the baseline, then the potential for air-quality co-benefits in any GHG mitigation scenario is ruled out by assumption. Even with similar or the same baseline assumptions, the studies yield different results. As regards the costs of mitigation, these differences appear to be largely a result of different approaches and assumptions, with the most important being the type of model adopted. Bottom-up engineering models assuming new technological opportunities tend to show benefits from mitigation. Top-down, general equilibrium models appear to show lower costs than top-down, time-series econometric models. The main assumptions leading to lower costs in the models are that:

- new flexible instruments, such as emission trading and joint implementation, are adopted;
- revenues from taxes or permit sales are returned to the economy by reducing burdensome taxes; and

- co-benefits, especially from reduced air pollution, are included in the results.

Finally, long-term technological progress and diffusion are largely given in the top-down models; different assumptions or a more integrated, dynamic treatment could have major effects on the results.

It is worth placing the task faced by mitigation policy in an historical perspective. CO_2 emissions have tended to grow more slowly than GDP in a number of countries over the last 40 years. The reasons for such trends vary but include:

- a shift away from coal and oil and towards nuclear and gas as the source of energy;
- improvements in energy efficiency by industry and households; and
- a shift from heavy manufacturing towards more service and information-based economic activity.

These trends will be encouraged and strengthened by mitigation policies.

9.1. Introduction and Progress since the Second Assessment Report

In the Second Assessment Report (SAR) and in the literature, the benefits and costs of mitigation have largely been measured in terms of macro concepts such as gross domestic product (GDP) or total welfare; sectoral effects have not been considered as a central issue. This chapter considers these sectoral implications. For a definition of co-benefits and ancillary benefits and costs, see Chapter 7; for the macroeconomic effects of mitigation policies, see Chapter 8.

The definitions of sectors adopted in this chapter is that of the UN System of National Accounts (1993 ISIC). This is an internationally agreed set of definition, conventions, and accounts which includes the division of the macro economy into industrial sectors, such as manufacturing. The data for sectoral economic models are usually arranged according to these accounts, and the results of the models reported below (in as much as they provide a comprehensive sectoral disaggregation of the macroeconomic effects) will follow these definitions. However, the energy sector is further subdivided in this chapter, since the mitigation effects are so important and distinct for the component industries, namely coal, oil and gas, and electricity.

When assessing the sectoral responses to mitigation policies and measures, a distinction can be made between commercial firms (partnerships or corporations) and persons (such as car drivers and home-owners) as decision makers. Firms are generally expected to be more price-responsive in their fuel use, because of better access to capital, information, and technologies, while persons generally value lifestyles more highly in their fuel use decisions. Although “sectors” are largely taken to be industrial contributors to GDP, households and private motorists are also responsible for large amounts of greenhouse gas (GHG) emissions and are also covered in this chapter.

The effects of mitigation can be divided into the effects in the sector or region that undertake the mitigation policies and measures and the further, consequential effects, or spillovers, on other sectors or regions. More investment in energy-efficient equipment or in technology to develop a renewable source of energy may lead to technological spillovers on other sectors. Such spillovers are considered below.

This chapter continues with reviews of results from multisectoral studies (9.2.1), followed by those on each major sector in turn (coal, petroleum and gas, non-fossil-based energy, agriculture and forestry, manufacturing, construction, transport, service industries, and households in sections 9.2.2 to 9.2.11). Section 9.3 reviews the literature on sectoral spillover effects of mitigation in one country or region on the rest of the world. Co-benefits associated with particular sectors or with sectoral mitigation policies are covered in sections 9.2.2 to 9.2.11. Section 9.4 considers why the macro and sectoral studies come to different conclusions. Section 9.5 suggests areas for further research.

9.2. Economic, Social and Environmental Impacts of Policies and Measures on Prices, Economic Output, Employment, Competitiveness and Trade Relations at the Sector and Sub-sector Levels

Studies of the impact of mitigation policies on sectors can be divided into those which adopt a general approach and cover all the sectors of the economy in question, and those which concentrate on one sector or group of sectors, leaving aside indirect effects on the rest of the economy. The general studies are discussed in 9.2.1, and the sector studies are considered in the sections that follow.

The studies can also be arranged according to the methodology of the analysis:

(1) top-down studies, that capture general effects on the economy and tend to consider price-driven policies such as carbon taxes rather than technology policies;

(2) bottom-up studies that do not consider general effects but examine technology-driven options[1]; and
(3) financial cost-benefit analyses of individual mitigation measures, which do not include impacts on social factors, but sometimes do include the ancillary benefits (e.g., ADB-GEF-UNDP, 1998a).

The general studies tend to be top-down, although there have been major comprehensive bottom-up studies (e.g., Krause *et al*., 1992). Many of the individual sector studies are bottom-up or cost-benefit. The top-down and bottom-up methodologies are compared in section 9.4.1.1.

9.2.1 Impacts from Multisectoral Studies

These studies tend to use large-scale models as a framework for the analysis. Important differences between the studies arise from the type of model being used (computable general equilibrium [CGE] or econometric), the method chosen for the recycling of any tax revenues, and the treatment of the world oil market. Two topics, the effects of carbon taxes (and more recently traded emission permits) and the removal of energy subsidies, have been assessed in some detail.

9.2.1.1 Effects of Carbon Taxes and Auctioned Emission Permits

Table 9.1 gives some details of studies of mitigation policies for which sectoral effects are available. These are all at a country or world-region level (e.g., the European Union). The table also shows the outcomes of different policies on carbon dioxide (CO_2) emissions, GDP and sectoral outputs. For some studies a range of outcomes is shown, corresponding to the range published for GDP depending on some critical assumption, such as the method chosen to recycle government revenues. The effects are shown as differences from the reference scenario or the base in the final year of the projection. Note that the macroeconomic results of these studies are covered in Chapter 8.

Several conclusions are well established in this literature.

1) The nature of the recycling of revenues from new taxes or permit schemes is critical to the sectoral effects (and the overall GDP effects - see Chapters 7 and 8 for a detailed discussion of the recycling literature). In some of the studies (e.g. Garbaccio *et al*., 1999 and 2000), GDP is increased above the reference scenario when rates for some burdensome tax are reduced. Those studies that report reductions in GDP do not always provide a range of recycling options, suggesting that policy packages that increase GDP have not been explored.
2) Reductions in fossil fuel output below the reference case will not impact all fossil fuels equally. Fuels have different costs and price sensitivities, they respond differently to mitigation policies, energy-efficiency technology is fuel and combustion device specific, and reductions in demand can affect imports differently from output. Large effects on gas output are discussed below in section 9.2.3.2
3) In most instances the relative decline in output does not imply an absolute decline of the sector; rather it implies a decline in its rate of growth. This is particularly true for the oil sector, where under present technology there is a captive market in the use of oil for personal transportation, which is expected to increase substantially over the foreseeable future. (This is not shown in *Table 9.1*, but reflected in the literature)
4) The sectoral results suggest that agriculture usually benefits[2]. The effects on manufacturing are mixed and the reasons for these results are explored below. Finally, the service sectors generally increase their output as a result of the policy shifts; since services are such a large proportion of GDP, if the overall economy has higher output this usually implies that services have higher output.

[Insert Table 9.1 Some Multisectoral Studies …]

It is worth placing these results and the tasks faced by mitigation policy in an historical perspective. CO_2 emissions have tended to grow more slowly than GDP in a number of countries over the last 40 years (Proops *et al*., 1993; Price *et al.,* 1998; Baumert *et al.,* 1999). The reasons for such trends vary but include:
- a shift away from coal and oil, and towards nuclear and gas as the source of energy
- improvements in energy efficiency by industry and households
- a shift from heavy manufacturing towards more service and information-based economic activity.

These trends will be encouraged and strengthened by mitigation policies.

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[1] U.S. National Academy of Sciences (1992) reviews a number of studies on this debate.

[2] The reason for the major reduction of –7% in the DRI (1994) results for EU-6 agricultural net output is that the scenario contains a wide range of environmental policies in addition to climate change policies, and many of these impinge heavily on agriculture.

9.2.1.2 Reducing Subsidies in the Energy Sector

Empirical and theoretical studies indicate that no-regrets policies can result from the removal of subsidies from fossil fuels or from electricity that relies on fossil fuels. The UN Framework Convention on Climate Change (UNFCCC article 4.2e (ii)) calls for Annex I Parties "to identify and periodically review its own policies and practices which encourage ... [greater emissions] than would otherwise occur". The Kyoto Protocol calls for such Parties to "implement … measures ... such as ... progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention …".

The extent of the impact of reducing subsidies will depend on the specific characteristic of each country, the type of subsidy involved, and the international co-ordination to implement similar measures. Most countries introduce subsidies in order to accomplish several policy objectives. In the case of energy, these are usually in order to:

- secure domestic energy supplies,
- ensure that power supply is sufficient to meet demand,
- provide access to energy for low-income households,
- maintain or slow the loss of employment in mining communities, and
- retain the international competitiveness of domestic industry.

Coal subsidies have encouraged high production of coal in a number of industrial countries and high coal consumption in numerous developing and transition economies (OECD, 1997c). For example, a complete measure of the total support to producers can be estimated in the form of the producer subsidy equivalent (PSE), which has been calculated annually by the International Energy Agency (IEA) for several countries since 1988 (IEA, 1998b). DRI (1994) used revised versions of the IEA's coal PSE estimates (shown in *Table 9.2*) to model the effects of removing subsidies. These subsidies tend to increase GHG emissions and more general pollution.

[Insert Table 9.2 Producer Subsidy Equivalents…]

In recent years many countries have changed their energy policy, from a focus on energy self-sufficiency, to broader policy objectives, oriented towards encouraging economic efficiency and taking into account environmental problems. Subsidies are currently under review by many countries, and in some cases reforms have already taken place. Nevertheless, large subsidies remain in both Annex I and non-Annex I countries.

In theoretical terms, polluting activities, such as coal mining and coal burning, could be taxed in order to achieve economic efficiency. Economic theory indicates that the optimal policy would be to replace those production and consumption subsidies with optimal taxes. According to global studies, even without adding new taxes, removing the subsidies and trade barriers at a sectoral level would create a win-win situation, improving efficiency and reducing the environmental damage (Burniaux *et al*., 1992; Hoeller and Coppel, 1992; Larson and Shah, 1992, 1995; Anderson and McKibbin, 1997). It is a well-established finding that removal of these subsidies would result in substantial reductions in GHG emissions, as well as stimulating economic growth. Local studies also indicate that removing support to the production and use of coal and other fossil fuels can result in substantial reductions in CO_2 emissions in the main coal-using countries, at the same time as reducing the cost of electricity production (DRI, 1994; Shelby *et al*., 1994; Golub and Gurvich, 1996; Michaelis, 1996; OECD, 1997c, Appendix A). *Table 9.3* is a review of the quantitative results of these case studies, along with the global studies. Note, however, that these analyses adopt different methodologies, so that the figures are not directly comparable.

In spite of these results, it is not wise to generalize about the environmental and economic effects of removing subsidies in the energy industry (OECD, 1997c). For example, the effect of removing subsidies to coal producers depends heavily on the type of subsidy removed and the availability and economics of alternative energy sources, including imported coal. Removing some electricity sector subsidies may have very little effect on GHG emissions or may even increase emissions, for example, when subsidies to electricity supply industry investment are supporting the use of less polluting energy sources. Finally, there may be cases where removing a subsidy to an energy-intensive industry in one country would lead to a shift in production to other countries with lower costs or environmental standards, resulting in a net increase in global GHG emissions (OECD, 1997c). The issue of carbon leakage is addressed in greater detail in Chapter 8.

[Insert Table 9.3 on Summary Results from Energy Subsidy Removal]

9.2.1.3 Sectoral Impacts of the Kyoto Mechanisms

The effects of the Kyoto Mechanisms at the sectoral level are complex. The available studies have looked at the effect of international emissions trading, but there have been no comprehensive studies on the sectoral effects of the Clean Development Mechanism (CDM) or joint implementation (JI). Countries buying assigned amount units (AAUs), or funding CDM and JI projects, may have less need to reduce fossil fuel consumption. Therefore, the sectors in these countries that depend on fossil fuel production or use may experience smaller economic impacts (Brown *et al*., 1999). This would also reduce the impact on fossil fuel producers, both at the domestic and international level. However, countries selling credits, or hosting JI and CDM projects, will have to generate these AAUs through either reduction of GHG emissions or enhancement of sinks. The economic impact on sectors within those countries will vary depending on the source of the credits. Some sectors will benefit, while others may see reduced rates of growth. Until the rules for implementation of the Kyoto mechanisms have been decided, sectoral impacts of their use will remain speculative.

9.2.2. Coal

Coal remains one of the major global and long-term energy resources and is likely to continue being so as long as economically exploitable reserves are widely available. Though its relative importance has declined in industrialized countries during the last century, mainly as a result of the advent of oil and gas, 36% of world electricity is generated from coal and 70% of world steel is produced using coal and coke. Global hard coal production in 1998 was about 3750Mt, mostly used to generate electricity, with reserves estimated at in excess of 1000 billion tonnes (WCI, 1999; IEA, 1998b, 1999). The dependence on coal use in electricity generation in developing countries is expected to continue. Depending on the efficiency of this power generation and the degree of substitution for direct coal combustion, fuel substitution can assist in reducing GHG emissions, for example when electrification reduces coal use by households (see Held *et al.,* 1996, Shackleton *et al.,* 1996 and Lennon *et al*., 1994 for a discussion of the South African electrification programme).

The Special Report on Emissions Scenarios (Nakicenovic, *et al*., 2000) suggests that there is a very large range in the global primary energy demand expected to come from coal even in the absence of additional climate change policy initiatives. For example, in 2100, scenario A2 has a coal demand of some 900EJ, but scenario B1 has only 44EJ (the 1990 level is estimated to be 85-100EJ).

GHG mitigation is expected to lead to a decline in coal output relative to a reference case, especially in Annex B countries. Indeed the process may have already started; recent trends in coal consumption indicate a 4% reduction in OECD countries and a 12.5% increase in the rest of the world in 1997 versus 1987 (WCI, 1999). The process may lead to higher costs, especially if the change is rapid, but there are also substantial co-benefits. Chapter 3 discusses the wide variety of mitigation options that exist for the production and use of coal. These involve reducing emissions directly from the coal mining process, replacing coal with other energy sources or reducing coal utilization (directly through efficiency of coal combustion or indirectly via the more efficient use of secondary energy supplies).

Some of the options detailed in Chapter 3 could represent a “win-win” situation for GHG mitigation and the coal sector. For example, GHG mitigation can be achieved by reducing the coal sector’s own energy consumption, beneficiation and coal-bed CH_4 recovery, whilst maintaining coal production. Other options have clear, but often non-quantifiable, costs and/or ancillary benefits, attached to them. The study Asia least-cost GHG abatement strategy (ALGAS)-India (ADB-GEF-UNDP, 1998a) reports that Indian CO_2 abatement would be primarily achieved by fuel switching and, to some extent, by a shift to more expensive but more efficient technologies. The most affected sector is coal as its consumption is modelled to decrease in power generation, followed by the industrial and residential sectors. The study concludes that this could lead to a significant reduction in labour employment in the coal sector. For China, using a dynamic linear programming model, Rose *et al*. (1996) find that CO_2 emissions may be reduced substantially by conserving energy and switching away from coal, without hindering future economic development.

9.2.2.1. Costs for the Coal Sector of Mitigation Options

Apart from the direct loss of output there are numerous other costs for the coal sector associated with mitigation. These costs relate mainly to the impact of the long-term reduction in coal consumption and hence coal production. In the short to medium term, these impacts will be moderate as global coal consumption is anticipated to continue to increase, albeit at a lower rate. Whilst limited work has been undertaken in this area, macro impacts identified by the IEA (1997a and 1999) and the WCI (1999) include:

- reduced economic activity in coal-producing countries owing to reduced coal sales;

- job losses in the coal mining, coal transport, and coal processing sectors – especially in developing countries with high employment per unit of output;
- potential for the "stranding" of coal mining assets as well as coal processing assets;
- closure of coal mines, which are very expensive to re-open;
- higher trade deficits caused by reductions in coal exports from developing countries;
- reduction in national energy security resulting from an increased reliance on imported energy sources where local energy options are primarily coal based;
- negative impacts of mine closure on communities where the mine is the major employer; and
- possible slowdown of economic growth during the transition from coal to other energy sources in countries with a heavy reliance on coal.

Kamat *et al.* (1999) modelled the impact of a carbon tax on the economy of a geographically defined coal-based region, namely the Susquehanna River Basin in the USA. Their results indicated that maintaining 1990 emissions with a carbon tax of about US$17 per tonne of carbon could have a minor impact on the economy as a whole, however, the negative impacts on the energy sector could be considerable. In this regard the model indicates a decrease in total output of the coal sector of approximately 58%. Exports are also severely affected with resultant production cutbacks and job losses.

At the global level, Bartsch and Müller (2000) report results that suggest a significant reduction in the Organization for Economic Co-operation and Development (OECD)'s demand for coal under a Kyoto-style scenario against a baseline scenario. Coal demand is modelled to fall by 4.4mboe[3] per day from this baseline in 2010 and 2020. Knapp (2000) indicates a substantial potential for relocation of the steel industry from Annex B countries to the rest of the world as coal becomes more expensive. Whilst compromising overall emission reduction objectives, this could be viewed as a positive equity contribution with economic benefits for non-Annex B countries. Knapp also indicates that the reduction in coal exports to Annex B countries for thermal power generation will severely impact some coal-exporting countries. In particular Colombia, Indonesia, and South Africa will incur substantial losses in export income with attendant job and revenue losses. These costs could, to an extent, be reduced through the use of the Kyoto CDM and technological innovation. The CDM could, for example, be used to transfer highly efficient clean coal technology to non-Annex B countries, as well as promote economic diversification to less energy-intensive economic activity and the relocation of energy-intensive industries. To achieve full benefits the latter would have to be accompanied by efficiency improvements through the application of state of the art technology.

Pershing (2000) notes that internal economic growth could offset the negative export impacts within 5 years for Colombia and Indonesia, but not for South Africa. In this regard he reports that South Africa could feel the greatest impacts of the major non-Annex B coal-exporting countries. In particular, he forecasts revenue losses for Indonesia and South Africa as being as high as 1% and 4% of gross national product (GNP) respectively. Dunn (2000) reports that the coal industry has been shedding jobs for several years now and this trend is likely to continue in the coal industry as GHG mitigation actions take effect. Pershing (2000), however, suggests that such impacts may not materialize as a result of the implementation of the Climate Convention or Kyoto Protocol commitments. For example, most projections are based on the use of macroeconomic models - most of which do not take into account fossil fuel distribution effects at the national level, or the use of CO_2 sinks or non-CO_2 GHG mitigation options. Pershing also suggests that some of these impacts may be offset by other aspects of future energy and development paths. For example, in a world in which climate change mitigation policies have been taken, investment in non-conventional oil supply might be deferred - lowering the impacts on conventional fuel exporters.

9.2.2.2. Co-benefits for Coal Production and Use of Mitigation Options

The main co-benefits associated with reduction in coal burning, namely public health impacts, are considered in Chapter 8. However, there are also some ancillary benefits of mitigation directly affecting the coal industry. Mitigation could increase energy efficiency in coal utilization (Tunnah *et al.*, 1994; Li *et al*., 1995). The uptake of new, high efficiency, clean coal technologies (IEA, 1998b) could lead to enhanced skills levels and technological capacity in developing nations. Further benefits include increased productivity as a consequence of increased market pressures, as well as the extension of the life of coal reserves. The costs of adjustment will be much lower if policies for new coal production also encourage clean-coal technology. Mitigation also may favour coal production in non-Annex B countries as a result of the migration of energy-intensive industries to developing countries (carbon leakage), although estimates of the scale of such leakage are highly dependent on the

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[3] mtoe means million tonnes oil equivalent; 1 tonne oil equivalent (toe) equals 45.37 GJ.

assumptions made in the models (Bernstein and Pan, 2000). There are also potential benefits in enhancing research and development (R&D) in the coal industry, especially in finding alternative and non-emitting applications for coal (IEA, 1999).

9.2.3. Petroleum and Natural Gas

Petroleum and natural gas are discussed in a single section, because they are often produced in the same countries and marketed by the same companies. In terms of value, petroleum is the largest single commodity traded on the world market. Coal, by comparison, is typically used in the country in which it is produced. Approximately 55% of the oil produced worldwide is exported, compared with 20% for gas and 12% for hard coal. The three fuels have quite different patterns of demand and different carbon contents per unit of useful energy.

9.2.3.1. Petroleum

Global production of crude oil in 1998 totalled 3516Mt (approx. 147EJ). In 1997, 56% of oil was consumed in the transport sector, up from 42% in 1973 (IEA, 1997b). The emission scenarios in the Intergovernmental Panel on Climate Change (IPCC) Special Report (Nakicenovic *et al*., 2000) show a wide range in demand for oil in 2100, from 0.5EJ in the A2 marker scenario to 248EJ in the illustrative scenario A1FI. Cumulative oil use between 1990 and 2100 in scenario A1FI is 29.6ZJ, about 200 times 1998 production, which is close to the combined conventional and unconventional resource base known today (see chapter 3).

Oil is exported by more than 40 countries worldwide with 11 of which are members of the Organization of Petroleum Exporting Countries (OPEC). OPEC accounts for 76% of world crude oil reserves, 41% of world production and 55% of world exports (BP Amoco, 1999). On the other hand, around 54% of the world's downstream refining capacities are in the OECD, which controls 30% of the world's crude production. The petroleum industry is divided into two sectors, the "upstream" which involves finding and producing crude oil, and the "downstream" which involves refining crude oil into petroleum products and marketing those products to end-users. The distinction between OPEC and/or non-OPEC and upstream and/or downstream aspects of the market and industry is useful in assessing the impact of mitigation on prices, output and wealth.

9.2.3.1.1. The global oil market

The market for crude oil is global, and a reduction in demand will affect all exporters via the price mechanism. However, the national economic impact of reduced demand varies greatly depending on the actual cost of production of crude oil and the degree to which the economies of individual producer countries are dependent on oil exports. It should be noted that the cost of production for crude oil can be very different from the market price, which includes royalties paid to government, transportation costs, and profit. Low-cost producers will be able to tolerate declines in the price of crude oil better than high-cost producers will. The more dependent a country is on oil and gas exports, the more its economy will be impacted if the value of these exports decreases.

Different top-down models have been used to study the effects of CO_2 abatement on the oil market.[4] Few macroeconomic models have explicitly examined the economic impact of CO_2 abatement on energy-exporting countries. Most of the models (OECD's computable general equilibrium model [GREEN], OPEC's world energy model [OWEM], the IEA model, the international integrated assessment model [IIAM], and Whalley and Wigle's model [WW]) cover different world geographic regions or country groupings.

Wit (1995) surveys such models and concludes that they should be treated with caution, as hardly any of the global models have been constructed primarily to examine the economic impact of CO_2-abatement policies on energy exporters. The sensitivity of the parameters used in the surveyed models is high, which underlines the uncertainties with regard to the results. In three of the models (OWEM, GREEN, and WW) the CO_2-abatement policies would result in the energy exporters suffering the greatest welfare losses. (See Chapter 7 for a discussion on welfare losses.) The cumulative losses of a 1990 CO_2 emissions stabilization target range between 3 to 12% of GDP for energy exporting countries by 2010.

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[4] With the exception of Bartsch and Mueller (2000), all of the economic studies discussed in this section assume adequate supplies of conventional crude oil to 2020 and beyond, the generally accepted position on the availability of this resource. However, there are analysts who predict oil supply shortages before that date (Campbell, 1997). If such shortages were to develop, oil use, and therefore CO_2 emissions, would decline without the imposition of GHG mitigation policies. See chapter 3 for an assessment of the literature on fossil fuel reserves and resources.

Pershing (2000) also surveys a number of model results for impacts of implementation of the Kyoto Protocol on oil exporting countries (*Table 9.4*). Direct comparison of the model results is difficult, because each model uses a different measure of impact, and many use different groups of countries in their definition of oil exporters. However, the studies all show that use of the flexibility mechanisms will reduce the economic cost to oil producers.

[Insert Table 9.4 – Costs of Kyoto Protocol implementation for Oil Exporting Countries]

These and other studies show a wide range of estimates for the impact of GHG mitigation policies on oil production and revenue. Much of these differences are attributable to the assumptions made about: the availability of conventional oil reserves, the degree of mitigation required, the use of emission trading, control of GHGs other than CO_2, and the use of carbon sinks. However, all studies show net growth in both oil production and revenue to at least 2020. As Pershing (2000) points out, these studies show significantly less impact on the real price of oil than has resulted from market fluctuations over the past 30 years. This feature (well-established) is illustrated in *Figure 9.1*. This figure shows the projection of real oil prices to 2010 from the IEA's 1998 World Energy Outlook (IEA, 1998b) and the effect of implementing the Kyoto Protocol from the G-cubed study (McKibbin *et al*., 1999, p. 326), the study which shows the largest fall in OPEC revenues in *Table 9.4*. The 25% loss in OPEC revenues in the non-trading scenario implies a 17% fall in oil prices shown for 2010 in the figure; this is reduced to a fall of just over 7% with Annex B trading.

[Figure 9.1: Real oil prices 1970 to 2010 and the Kyoto target]

Many of the studies addressing the impact of CO_2 mitigation on oil producers are worth describing in more detail. Rosendahl (1996) uses a competitive dynamic model of the oil market with oil as an exhaustible resource. A constant unit cost of extraction and fixed amount of the oil resource are assumed in analyzing the impact of constant unit carbon tax. The model finds that a US$12/barrel carbon tax would reduce global oil wealth (defined as the net real value of accumulated oil production) by 33- 42% and non-OPEC oil wealth 40- 54%, with the lower figure reflecting an assumed low price elasticity of -0.5[5]. Doubling the carbon tax would reduce global oil wealth by 58- 74% and non-OPEC wealth by 70- 96%. The average producer could lose about 10% of their wealth at the low tax assumption (US$3/barrel) and around two-thirds of their wealth at the high tax assumption (US$24/barrel). The marginal carbon tax increase would reduce the producers' price, or the resource rent, by 33-50%, and increase the consumer price by 50-67% of the tax increase.

Berg *et al*. (1997) examine the effect of a global CO_2 tax on the global oil, gas and coal markets using Statistics Norway's PETRO model. They use an optimizing, intertemporal equilibrium model with three demand regions (OECD-Europe, rest-OECD and non-OECD) and two supply regions (OPEC and the competitive fringe). They find that in the first 40 years starting in 1995, given a US$10/barrel oil-equivalent (boe[6]) carbon tax and assuming OPEC exercised market power, OPEC's oil wealth would be reduced by 20% and non-OPEC's oil wealth by 8%, and the tax revenue would be collected by consuming countries. The tax reduces CO_2 emissions by 20% below the baseline levels over the first 50 years, and then eliminates fossil fuel combustion altogether by 2110; this comes about through an assumption of a falling real price for backstop (carbon-free) technology. Lindholt (1999) follows up this study, looking at the implications of a CO_2 tradable auctioned permit scheme to meet (a) Kyoto-style targets interpreted as CO_2 (not GHG) targets and (b) a global reduction below 1990 levels of 5.2% with emissions held constant 2010 to 2100. OPEC's production in (a) is reduced by 10% relative to the baseline in 2010 (the permit price is US$6.2/boe) rising sharply after 2040 before falling to zero in 2070, but oil prices are maintained to 2010; in (b) the reduction is 22% by 2010. Again for 2010 most of the permit revenues go to Annex B countries.

Donovan *et al*. *(*1997) model the economic impact of two CO_2 emission reduction scenarios compared to a reference case with no limits on emissions. In their less stringent scenario, Annex B countries stabilize their CO_2 emissions from fossil fuels at 1990 levels by 2010; in their more stringent scenario, they reduce their emissions to 15% below 1990 levels by 2010. Their model projections show oil use in 2010 reduced by 3.7% and 5.9% respectively in the less severe and more severe scenarios. These relatively small reductions are attributed to the

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[5] Estimates of the price elasticity of crude oil demand for the long and short terms differ across regions and sectors. A survey (Huntington, 1991) of inferred price elasticities from 11 world models found the OECD short-term elasticity to be –0.06 to –0.20 (average –0.12) and the long-term elasticity to be –0.35 to –0.80 (average –0.47). The corresponding estimates for the non-OECD short-term elasticity are –0.04 to –0.14 (average –0.11) and for the long term –0.17 to –0.54 (average –0.30). The world average elasticity in the short term is –0.10 and in the long term –0.38.

[6] 1 barrel oil equivalent (boe) equals 6.12GJ.

fact that most oil is used in the transport sector where there is relatively little opportunity for substitution. In 2010, in the less stringent case, the value of oil exports from non-Annex B to Annex B countries declines by about 8%.

Jacoby *et al.* (1997) use an emissions predictions and policy analysis (EPPA) model, a CGE model derived from the OECD GREEN model. The world is divided into 12 trading regions, 8 production sectors, including 5 energy sectors, and 4 consumption sectors, as well as government and investment sectors. Model results show that when a quantitative emissions reduction is applied to the OECD region, all other regions suffer welfare loss from the reduction in economic activity and energy use in OECD, as well as the associated adjustment in prices of energy and the consequences on international trade. The welfare losses in energy exporting countries are no greater than that in other regions owing to the influence of backstop technologies on crude oil price and the net oil exports of the energy exporters. The OECD’s lower production of the backstop (carbon intensive heavy oil) leads to increased demand for crude oil; in addition the oil price is higher. Without the backstop technology constraint, the energy exporters suffer the largest welfare loss of all the regions.

Ghanem *et al.* (1998) use OWEM, an econometric model, to analyse the potential impacts of the Kyoto Protocol on OPEC members to 2020. The reference case for this study assumes a real oil price of US$17.4/barrel (1997$) in 2000, growing at 1.5%/year in real terms after that, and an average autonomous energy efficiency improvement of 1%/year, with higher rates in China and the economies in transition (EIT). The world economy is assumed to grow at 3.3%/year from 2000 to 2020. OPEC's production in 2020 is projected at 51.6M barrels/day (crude + natural gas liquids), and its share of world oil production is projected at 51.2%. Two scenarios are examined: firm oil prices, i.e., remaining at the reference level, and soft oil prices, US$16.9/barrel from 2000 to 2020. World oil demand in 2020 is projected at 100.7M barrels/day in the reference case, dropping to 81.1M barrels/day (OPEC at 33M barrels/day) in the firm oil price case and 83.6M barrels/day (OPEC at 37.8) in the soft price case. In the firm oil price case, OPEC has a cumulative loss in revenue compared to the base case of 20.6% (US$659bn), declining to 17.9% with trading. The loss rises to 27.2% (US$870bn) when oil prices are lower.

Brown *et al.* (1999) use the global trade and environment model (GTEM), a general equilibrium model of the world's economy, to evaluate the impact of the Kyoto Protocol's commitments, with and without unrestricted international emissions trading. The study does not consider the enhancement of sinks or the use of the CDM as mitigation policies. GTEM seeks the minimum cost for mitigation of 3 GHGs (CO_2, methane [CH_4] and nitrous oxide [N_2O]) and up to 54 economic sectors, covering 45 countries. GTEM results show that trading significantly reduces the losses in oil production in 2010 for all countries or regions reported. Because of the many assumptions that have to be made and the sector-specific impacts of emissions trading, only low confidence can be assigned to specific numerical results, but the benefits of unrestricted international emissions trading for oil producing countries has been confirmed in many studies.

Bartsch and Müller (2000) use CLIMOX, a global economic-environmental simulation model based on GREEN and GTAP, to simulate the effects of two Kyoto scenarios on the global oil market. The “most likely” scenario assumes the implementation of the Protocol and its extension to the year 2020, with the policy instruments relying heavily on CO_2 trading permits among Annex B countries. Oil production declines by 3% in 2010 and 5% in 2020, and global oil revenues fall by an average of 12%. The model assumes supplies of conventional oil peaking in 2015 and a CH_4 leakage tax raising the price of natural gas.[7] The “global compromise” scenario assumes a global agreement to be achieved after 2012 incorporating all countries with world oil demand falling by 8% in 2020. Oil revenues fall by 19% in 2020 and by 32% in the absence of international emissions trading.

A number of studies (Kassler and Paterson, 1997; Ghasemzadeh, 2000; Pershing, 2000) have considered how impacts on oil producing countries might be alleviated. Options include: use of emissions trading and the CDM; removal of subsidies for fossil fuels that distort market behaviour; energy tax restructuring according to carbon content; increased use of natural gas, since many oil exporters are also major gas exporters; and efforts to diversify the economies of oil exporting countries.

Finally, Pershing (2000) points out that studies of the impact of GHG mitigation policies on the oil industry typically do not consider some or all of the following policies and measures that could lessen the impact on oil exporters:

- policies and measures for non-CO_2 GHGs or non-energy sources of all GHGs;
- offsets from sinks;
- industry restructuring (e.g., from energy producer to supplier of energy services);

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[7] Methane has a Greenhouse Warming Potential (GWP) of 21 for a 100 year time horizon, making even small leaks significant contributors to potential impacts on climate.

- the use of OPEC’s market power; and
- actions (e.g., of Annex B parties) related to funding, insurance, and the transfer of technology.

In addition, the studies typically do not include the following policies and effects that can reduce the total cost of mitigation:

- the use of tax revenues to reduce tax burdens or finance other mitigation measures;
- ancillary environmental benefits of reductions in fossil fuel use; and
- induced technical change from mitigation policies.

As a result the studies may tend to overstate both the costs to oil exporting countries and overall costs.

9.2.3.1.2. The US oil market

The US Energy Information Agency (EIA, 1998), using NEMS, an energy-economy model of the US, projects that implementation of the Kyoto Protocol would lower US petroleum consumption by 13% in 2010, and lower world oil price by 16% relative to a reference case price of US$20.77/ barrel.

Laitner *et al*. (1998) argue that an innovation-led climate strategy would be beneficial to the US economy and manufacturing. However, they project a loss of 36,000 jobs in the US oil and gas extracting industry (11% of 1996 employment) and of US$8.7bn (1993$) in contribution to GDP (about 18% of the 1996 level) (US Department of Commerce, 2000; US Bureau of Labor Statistics, 2000). Losses in the petroleum refining industry are smaller, namely 1000 jobs (1% of 1996 employment) and US$0.5bn in contribution to GDP (about 2% of the 1996 level).

Sutherland (1998) reports on a study of the impact of high energy prices on six energy-intensive industries, including petroleum refining. Prices of refined petroleum products are increased in two steps: US$75/tC in 2005 and US$150/tC in 2010. The mechanism of the price increase is not described; thus there is no discussion of who receives the revenues or how they are handled. The study finds that these price increases reduce the US demand for refined products by about 20%. The cost of other energy sources is also increased, which along with decreased demand, raises the cost of refining in OECD countries and intensifies the on-going shift of refining capacity from OECD to non-OECD countries. Shifting refining capacity to non-OECD countries reduces employment in, and increases imports by, OECD countries. Reductions in fuel use results in reductions in the emissions of local air pollutants.

9.2.3.2. Natural Gas

Global production of natural gas in 1998 totalled 2379bn cubic meters (approx. 93 EJ). In 1997, 45% of natural gas was consumed by industry, including for electric power generation, while 51% was consumed in other sectors, which include residential, commercial, agriculture, public service, and unspecified uses (IEA, 1998b). The emission scenarios in the IPCC Special Report on Emission Scenarios all show increased demand for natural gas in 2100, ranging from 127EJ in the B1 marker scenario to 578EJ in the A1F1 illustrative scenario (Nakicenovic *et al*., 2000). These scenarios are baseline scenarios, which do not include policies to limit GHG emissions.

World gas demand has grown by 3.2%/year over the past 25 years, compared to 1.6%/year for oil and 0.6%/year for coal. Most of the growth has been in power generation where it grew by 5.2%/year. This growth has increased in recent years in response to a variety of technological advantages and policy actions to reduce local air pollutants, particularly sulphur oxides (SO_x), a trend that is expected to continue through 2010, independent of policies to reduce GHG emissions (IEA, 1998b). IEA projects that demand for natural gas will grow at 2.6%/year from 1995 to 2020, 1.7%/year in OECD countries and 3.5%/year in non-OECD countries.

The IEA's projections to 2020 show that, while there is considerable further scope for switching from coal or oil to natural gas in OECD countries, the contribution of fuel switching to the further growth of gas demand in these countries is likely to be more modest than in the past (IEA, 1998b). It is unlikely that there will be any significant switch from oil to natural gas in the transport sector during this period. Residential use of natural gas for space and water heating is reaching saturation. But it is uncertain whether natural gas demand for electricity generation will increase or decrease.

Natural gas has the lowest carbon content of the fossil fuels, and it is generally assumed that its use will increase as the result of efforts to reduce CO_2 emissions. Because of this and the possibilities for substitution in the power generation sector away from coal, Ferriter (1997) shows an increasing demand for natural gas in the two carbon tax scenarios and the efficiency-driven scenario compared to the reference case. Switching towards natural gas - especially high efficiency combined cycle and co-generation - is likely to be a very important part of reaching

Kyoto targets in some countries. However, other studies (IEA, 1998b; IWG, 1997; EIA, 1998) conclude that the emissions limits set by the Kyoto Protocol will require reductions in total use of electricity and replacement of older generating capacity with non-fossil fuel units, either renewables or nuclear, decreasing the demand for natural gas.

Another uncertainty is the growth in demand from gas in non-Annex B countries. The IEA projects rapid growth in the use of natural gas in many of the non-Annex B countries e.g., 6.5%/year in China, 5.8%/year in South and East Asia, and 4.9%/year in Latin America. Bartsch and Müller (2000) also see a significant growth in gas demand in China and India to 2020, but Stern (2000) questions whether the investments in the necessary infrastructure can be made. The Kyoto Protocol's provisions on JI and the CDM could lead to further growth of natural gas use in EIT and developing nations. However, until the details of these mechanisms are agreed, it will be difficult to estimate their impact on natural gas demand.

Recent general modelling studies by Donovan *et al. (*1997) and Bernstein *et al.* (1999) suggest that, in Annex B countries, policies to reduce GHGs may have the least impact on the demand for oil, the most impact on the demand for coal, with the impact on the demand for natural gas falling in the mid-range. These results are different from recent trends, which show natural gas usage growing faster than use of either coal or oil, and can be explained as follows.

- Current technology and infrastructure will not allow much switching from oil to non-fossil fuel alternatives in the transport sector, the largest user of oil, before about 2020.
- The electric utility sector, the largest user of coal, can switch to natural gas, but the rate of switching will be limited by regional natural gas availability.
- Given the above considerations, modelling studies suggest that Annex B countries are likely to meet their Kyoto Protocol commitments by reducing overall energy use, which is likely to result in a reduction in natural gas demand.

Given the agreement in the modelling studies and the logic that can be used to support the conclusions, this finding is established, but incomplete.

The GHG mitigation benefits of using natural gas depend on minimizing losses in its use. CH_4, the chief constituent of natural gas, is a GHG, and will be emitted to the atmosphere in natural gas leaks, most of which occur in older, low pressure distribution systems. CH_4 losses also are often a by-product of coal production. A full comparison of the benefits of switching from coal to natural gas, a step often included in mitigation strategies, requires a lifecycle analysis of CO_2 and CH_4 emissions for both fuels.

Brown *et al*. (1999) used GTEM, a general equilibrium model described above, to evaluate the impact of the Kyoto Protocol's commitments, with and without unrestricted international emissions trading, on the production of natural gas. They found the effect of emissions trading on projected natural gas production is mixed, with some countries seeing higher production rates and others, lower production rates. Because of the many assumptions that have to be made and the sector-specific impacts of emissions trading, only low confidence can be assigned to specific numerical results.

Table 9.5 summarizes a number of global economic modelling studies which project the impact of measures to mitigate CO_2 emissions on the demand for natural gas, expressed as the ratio in change in gas demand to the change in CO_2 emissions. The results are highly variable; the mean ratio is 0.14 with a standard deviation of 0.88. *Table 9.5* shows that some studies have pointed towards stronger gas demand of CO_2-abatement measures compared to the reference cases.

[Insert Table 9.5 Changes in CO_2 Emissions and Gas Demand]

Longer term, natural gas would be the easiest of the fossil fuels to convert to hydrogen. This would significantly increase demand for natural gas. For technical details see Chapter 3.

9.2.3.3. Co-benefits of GHG Mitigation in the Oil and Gas Industry

If, as projected, GHG mitigation policies reduce the growth in demand for crude oil they will result in several co-benefits: the rate of depletion of oil reserves will be slowed; and air and water pollution impacts associated with oil production, refining and consumption will be reduced, as will oil spills. Reduced growth in demand for natural gas will have similar benefits: slower rate of depletion of this natural resource, less air and water pollution associated with this industry, and less potential for natural gas explosions.

9.2.4 Non-fossil Energy

This section covers the effects of mitigation on non-fossil-fuel-based energy production and use (electricity and biomass), and the co-benefits and costs associated with mitigation using non-fossil energy.

9.2.4.1. Electricity Use and Production Fuel Mix

World electricity demand in 1998 was 12.6bn MWh, about 60% of which (7.5bn MWh) was consumed in the industrialized countries (EIA, 2000a). Fossil fuels used for electricity generation account for about one third of the CO_2 emissions from the energy sector worldwide (EIA, 2000b). Globally, about 60% of all electricity is produced with fossil fuels. However, the fraction of electricity generated from fossil fuels varies across countries, from as little as 1% in Norway to 95% in the Middle East, and 97% in Poland (EIA, 2000a). Nuclear reactors are producing electricity with a global capacity of around 351GWe (IAEA, 1997), with each having an average of nearly 800MWe of installed capacity. Half of this total is concentrated in three countries: the USA with 25%, and France and Japan with 12.5% each (IAEA, 1997, pp. 10-11).

Recent projections show that electricity use will grow 37% to 16.8bn MWh by 2010, and 76% to 21.6bn MWh by 2020. About two thirds of this growth will occur outside the developed countries (EIA, 2000b). The IPCC Special Report on Emissions Scenarios (SRES) projections (Nakicenovic *et al*., 2000) are similar, with worldwide electricity demand projected to more than double between 1990 and 2020 in marker scenarios A1B, A1F1 and B1, and to double between 1990 and 2020 in marker scenarios A2 and B2. Beyond 2020, the growth in electricity demand projected in the four marker scenarios diverges. A1B shows the highest growth, more than 20 times between 1990 and 2100, while B1 shows the lowest growth, slightly less than 6 times between 1990 and 2100.

Much of this new power will be generated with fossil fuels. Globally, use of gas for electricity generation is projected to more than double by 2020. Global use of coal for generation is projected to grow by more than 50%, with about 90% of the projected increase occurring in the developing countries. In Asia, nuclear power is still expected to increase to meet the increasing electric power demand mainly because of resource constraint issues (Aoyama, 1997; Matsuo, 1997). *Table 9.6* shows the estimates of nuclear electrical generating capacity by region to 2010.

[Insert Table 9.6 projected nuclear energy capacity (MW)]

Uncertainty is reflected in the wide range in the long-term projections for nuclear energy capacity. The World Energy Council (WEC, 1998) projects a range of 520 to 1770mtoe[8] in 2050 as shown in *Figure 9.2*.

[Insert Figure 9.2 projected nuclear energy capacity (mtoe)]

9.2.4.2. Impacts of Mitigation on the Electricity Sector

Given the extensive use of fossil fuel in the production of electricity, it is not surprising that a variety of proposals have been put forth to mitigate GHG emissions in this sector. Many countries have proposed renewable technologies as one solution for GHG mitigation (Comisión Nacional de Energía, 1993; SDPC *et al*., 1996; Bogach *et al*., 1997; European Commission, 1997). In some European countries such as Sweden and Austria, carbon taxes have been introduced. In Japan, nuclear power is planned to supply 480TWh in 2010, or 17.4% of total primary energy supply, to help meet the Kyoto target (Fujime, 1998). In contrast, in Sweden, a policy under debate to phase out nuclear power and restrict CO_2 emissions to 1990 levels by other means would result in significantly higher electric prices (Anderson and Haden, 1997)

In general, mitigation policies work through two routes. First, they either mandate or directly provide incentives for increased use of zero-emitting technologies (such as nuclear, hydro, and other renewables) and lower-GHG-emitting generation technologies (such as combined cycle natural gas). Or, second, indirectly they drive their increased use by more flexible approaches that place a tax on or require a permit for emission of GHGs. Either way, the result will be a shift in the mix of fuels used to generate electricity toward increased use of the zero- and lower-emitting generation technologies, and away from the higher-emitting fossil fuels (Criqui *et al.* 2000).

Quantitative analyses of these impacts are somewhat limited. *Table 9.1* above presents published results from multisectoral models. Other multi-regional models used to assess the impacts of GHG reduction policies appear to have the capability to quantify these impacts on the electricity sector (Bernstein *et al*., 1999; Cooper *et al*., 1999;

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[8] 1 tonne oil equivalent (toe) equals 45.37 GJ

Kainuma *et al*., 1999a, b and c; Kurosawa *et al*., 1999; MacCracken *et al*., 1999; McKibbin *et al*., 1999; Tulpule *et al*., 1999). However, the focus of the studies conducted with these models has generally been on broader economy-wide impacts, and many do not report results for the electricity sector. McKibbin *et al.* reported the price and quantity impacts on electric utilities if the US unilaterally implements its Kyoto commitments. Under this scenario, electricity prices in the US increase 7.2% in 2010 and 12.6% in 2020, while demand drops 6.2% and 9.5% in those years, respectively. The Australian Bureau of Agricultural and Resource Economics (ABARE, 1995) reported shifts in fuel share for Annex B under a policy where this group of countries stabilizes emissions at 1990 levels by 2000. They show that the share of coal in the generation of electricity for most Annex B countries would drop by 10 to 50%, with the combined shares for nuclear and renewables increasing 14 to 46%.[9] (See *Table 9.7* for detailed results.) They note that such a policy may require substantial structural changes in the industry and are likely to involve significant costs, but do not elaborate or quantify.

[Insert Table 9.7 Changes in shares …]

There are a number of analyses for the US only that report detailed impacts on the electricity sector. Charles River Associates (CRA) and Data Resources International (DRI) (1994) assessed the potential impact of carbon taxes of US$50, $100, and $200 per tonne carbon, phased in to these levels over 1995 to 2000. By 2010, imposition of such taxes has increased prices of electricity by 13%, 27%, and 55% for the US$50, $100, and $200 tax, while sales dropped 8%, 14%, and 74%, respectively.

More recently, a group of studies assessing the impacts of the Kyoto Protocol on the US have reported electricity sector impacts (EIA, 1998; WEFA, 1998; DRI, 1998). These studies all use a flexible mechanism, such as tradable emissions permits, as the implementation policy. Taken together, the studies reflect a range of assumptions about the level of emissions reductions that would need to come from the domestic energy sector. The range of results for the EIA study for 2010 is summarized here, however, the results from all three studies are generally consistent. Key impacts in 2010, all of which increase as emissions reduction requirements increase, include the following.

- Electricity prices were projected to increase 20% to 86% above baseline levels.
- Electricity demand was projected to decrease 4% to 17% below baseline levels.
- Prices of natural gas were projected to increase by 35% to 206% over the baseline levels. Prices of coal for electricity production were projected to increase to about 2.5 to 9 times the baseline levels. And, despite a 7% to 40% decrease in fossil generation, fossil fuel expenditures increase 81% to 238% over baseline levels.
- About 9% to 43% of total generation will shift away from coal relative to the baseline. The large shift over this limited time period would reflect significant structural changes and potentially large stranded costs. Roughly half of this is replaced by natural gas generation, while most of the remainder is not replaced as a result of reduced demand. Renewable generation beyond baseline levels generally does not enter the mix until at least 2020.

None of the studies quantify the potential stranded costs associated with the premature retirement of existing generation.

9.2.4.3 Co-benefits Associated with Mitigation in the Electricity Industry

The co-benefits expected from the increased use of new generating technologies adopted to achieve GHG mitigation would be sales and employment growth for those who manufacture and construct the new generation facilities. There could also be income and employment growth in the production of fuels for this new generation. The co-benefits associated with use of non-fossil energy for thermal applications would be similar.

Co-benefits of increased use of renewable sources have been described by several experts (Brower, 1992; Johansson *et al*., 1993; Pimental *et al*., 1994; UNDP, 1997; Miyamoto, 1997). These include:

- further social and economic development, such as enhanced employment opportunities in rural areas, which can help reduce rural poverty and decrease the pressures to migrate to urban areas;
- land restoration activities such as improvement of degraded lands and associated positive impacts on farm economics, new rural development opportunities, prevention of erosion, habitats for wildlife;
- reduced emissions, in certain instances, of local pollutants;
- potential for fuel diversity; and
- elimination of the need for costly disposal of waste materials, such as crop residues and household refuse.

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[9] They note that their results should only be viewed as indicative of the broad direction of the magnitude of impacts, and that they do not account for any barriers to the expansion of nuclear in the U.S., Canada, the EU, and Japan.

9.2.4.4 Co-costs Associated with Mitigation in the Electricity Industry

There are also co-costs associated with actions to mitigate GHGs in the electricity sector. The growth experienced by those who benefit from mitigation would be offset by a decline in sales and employment for those who would have produced and constructed the facilities that would have been built without the mitigation activity. Similarly, there will be a loss of income and jobs for those that would have provided the fuel for those facilities no longer being built (i.e., the coal industry). The specifics of the mitigation policy and action will effect whether the net effect of this shifting of economic activity will be positive or negative.

There are also environmental issues associated with some of the renewable technologies. For example, concern has been raised about the ecological impacts of intensive cultivation of biomass for energy, the loss of land and other negative impacts of hydro electricity development, and the noise, visual interference, and potential for killing birds associated with wind generation (Brower, 1992; Pimental *et al*., 1994; IEA, 1997a; Miyamoto, 1997; UNDP, 1997; IEA, 1998a).

Nuclear power might be expected to increase substantially as a result of GHG mitigation policies, because power from nuclear fuel produces negligible GHGs. The construction of nuclear power stations, however, does lead to GHG emissions, but over the lifecycle of the plant these are much lower than those from comparable fossil fuel stations.

In spite of the advantages, nuclear power is not seen as the solution to the global warming problem in many countries. The main issues are (1) the high costs compared to alternative combined cycle gas turbines, (2) public concerns about operating safety and waste disposal, (3) safety of radioactive waste management and recycling of nuclear fuel, (4) the risks of nuclear fuel storage and transportation, and (5) nuclear weapon proliferation (Hagan, 1998). Whether the full potential for nuclear power development to reduce GHGs can be realized will be determined by political and public responses and safety management.

9.2.5 Agriculture and Forestry

The sectoral effects of mitigation on agriculture and forestry are described in detail in Chapter 4. This section covers co-benefits for agriculture.

9.2.5.1 Co-benefits for Agriculture from Reduced Air Pollution

GHG mitigation strategies that also reduce emissions of ozone precursors, i.e., volatile organic compounds (VOC) and nitrogen oxides (NO_x), may have co-benefits for agriculture. Elevated concentrations of tropospheric ozone (O_3) are damaging to vegetation and to human health (EPA, 1997). GHG mitigation strategies which increase efficiency in energy use or increase the penetration of non-fossil-fuel energy are likely to reduce NO_x emissions (the limiting precursor for O_3 formation in non-urban areas) and hence O_3 concentrations in agricultural regions.

Studies of the adverse impacts of O_3 on agriculture were first conducted in the United States in the 1960s, with major studies in the 1980s (EPA, 1997; Preston *et al*., 1988) and later in Europe (U.K. DoE, 1997) and Japan (Kobayashi, 1997). These studies indicate that, for many crop species, it is well established that elevated O_3 concentrations result in a substantial reduction in yield. The US Environmental Protection Agency (EPA) funded the National Crop Loss Assessment Network (NCLAN) from 1980 to 1986, which developed O_3 dose-plant response relationships for economically important crop species (Heck *et al*., 1984a and b). Results of this study are shown in *Figure 9.3*. The basic NCLAN methodology was used in 9 countries in Europe between 1987 to 1991 on a variety of crops including wheat, barley, beans, and pasture for the European Crop Loss Assessment Network (EUROCLAN) program. EUROCLAN found yield reductions to be highly correlated with cumulative exposure to O_3 above a threshold of 30-40 parts per billion (ppb) (Fuhrer, 1995).

[Insert Figure 9.3: Impact of O_3 …]

The World Health Organization (WHO) uses the AOT 40 standard to describe an acceptable O_3 exposure for crops. AOT 40 is defined as the accumulated hourly O_3 concentrations above 40 ppb (80 mg/m^3) during daylight hours between May and July. A cumulative exposure less than 6000 mg/m^3.hrs is necessary to prevent an excess of 5% crop yield loss (European Environment Agency, 1999). Observations indicate that this limit is exceeded in most of Europe with the exception of the northern parts of Scandinavia and the UK (European Environment Agency, 1999). Median summer afternoon O_3 concentrations in the majority of the eastern and southwestern United States presently exceed 50 ppb (Fiore *et al*., 1998). As shown in *Figure 9.3* these concentrations will result in yield reductions in excess of 10% for several crops. IPCC Working Group (WG)I (Chapter 4) predicts that, if emissions follow their SRES A2 scenario, by 2100 background O_3 levels near the surface at northern mid-latitudes will rise to nearly 80ppb. (However, scenario B1 has only small increases in O_3 emissions.) At the higher O_3 concentrations the yield of soybeans may decrease by 40%, and the yield of corn and wheat may decrease by 25% relative to crop yields at pre-industrial O_3 levels. Within a crop species, the sensitivity of individual cultivars to O_3 can vary (EPA, 1997), and it is possible that more resistant strains could be utilized. However, this would impose an additional constraint on agriculture.

An economic assessment of the impact of O_3 on US agriculture, based on data from the NCLAN study, found that when O_3 is reduced by 25% in all regions, the economic benefits are approximately US$1.9billion (bn) (1982 dollars) (Adams *et al*., 1989). Conversely, a 25% increase in O_3 pollution resulted in costs of US$2.1bn (Adams *et al*., 1985). Two recent studies found that crop production may be substantially reduced in the future in China owing to elevated O_3 concentrations (Chameides *et al*., 1999; Aunan *et al*., 2000, forthcoming). China's concerns about food security may make GHG mitigation strategies that reduce surface O_3 concentrations more attractive than those that do not.

9.2.5.2 Co-benefits from Carbon Sequestration

Chapter 3 considers new technologies for using biomass, such as sugar cane, to replace fossil fuels. Such mitigation may have considerable associated benefits, particularly for sustainable development in creating new employment (*see 9.2.10.4 below*).

Alig *et. al* (1997) through modelling alternative carbon flux scenarios using the forestry and agricultural sector optimization model (FASOM) estimated the welfare effects of carbon sequestration for the US. They estimate total social welfare costs to range from US$20.7bn to $50.8bn. In the case of the agricultural sector, the consumer's surplus decreases in all scenarios.

9.2.6 Manufacturing

The effects of GHG mitigation on manufacturing sectors are likely to be very mixed, depending on the use of carbon-based fuels as inputs, and the ability of the producer to adapt production techniques and to pass on increases in costs to customers. Different manufacturing processes and technologies use carbon-based inputs in very different amounts in relation to output. High carbon-intensive sectors (using the UN System of National Accounts 1993 ISIC, p. 594-5) include basic metals (aluminium, steel), other non-metallic mineral products (cement, bricks, glass) and some chemicals (bulk chemicals). Low carbon-intensive sectors include office machinery (electronics) and other chemicals (pharmaceuticals). Several large sectors (food, textiles, machinery, and vehicles) are somewhere between these extremes.

If the Kyoto Protocol is ratified, manufacturing sectors in Annex I countries can expect to face mitigation policies to meet national targets. The possible options for the firms are basically: (1) energy conservation (adoption of more efficient technologies), (2) shift to products with lower carbon intensities, (3) accept extra taxation or emission permits and the possible effect on profits and/or product sales and (4) shift production abroad as foreign direct investment or joint ventures.

Generally, adopting these options will create ancillary benefits and costs. Speculative ancillary benefits include:
- the adoption of energy conservation technologies that mitigates local air pollution similar to the case of transportation sector;
- the accumulation of scientific and technological knowledge that contributes to the development of new products and processes; and
- the internationalization of manufacturing that stimulates technology transfer to developing regions and greater equity in wealth distribution.

If production is transferred to non-Annex B countries, ancillary costs include:
- losses in Annex B manufacturing employment; and
- increases in non-Annex B emissions.

Thus, the assessment of the effects of climate policy on manufacturing could take into account the interactions between sectors and economies. Multisectoral and multi-regional models have been used to evaluate them (see 9.2.6.1 below).

9.2.6.1 Effects on Manufacturing from Multisectoral Top-down Studies

Manufacturing sectors show mixed results in the multisectoral studies (see *Table 9.1* above). Reflecting industrial and financial globalization, recent studies tend to involve international trade on both goods and capital. In the main example, McKibbin *et al*. (1999) evaluate the potential sectoral impacts of the Kyoto Protocol using the G-Cubed model, mainly focusing on the real and the financial trading structure. In case of unilateral action by the US, the effects on manufacturing industries show at most 1.4% and 1.2% decrease in quantity and price, respectively, although the effects on the energy industry sectors are large, e.g., 56% down in the coal mining industry with a 375.6% price increase in 2020.

9.2.6.2 Mitigation and Manufacturing Employment

Some mitigation policies would increase output and employment in the energy equipment industries. In 2010 under an innovation scenario for GHG mitigation of 10% relative to 1990, GDP for the US is projected to increase by 0.02% (Laitner *et al*. 1998). Wage and salary earnings are shown to rise in 2010 by 0.3% and employment (jobs) by 0.4%. From another perspective, these net job gains might be all provided by new small manufacturing plants in the US; in that case, the redirected investments in energy-efficient and low-carbon technologies would produce additional employment equivalent to the jobs supported by about 6200 small manufacturing plants that open in the year 2010. While these impacts are small in relation to the larger economy, it is because the scale of investment is also relatively small. The anticipated extra energy-efficiency and renewable-energy investments in the year 2010 is less than 3% of US total investment in that year.

9.2.6.3. Mitigation Measures and Technology Strategy

Some bottom-up studies assess the relationships between climate policy and technological strategy. For instance, the implementation of a carbon tax or subsidies will strongly affect the investment decisions in manufacturing sectors. Kainuma *et al*. (1999a) assess how a subsidy affects the adoption of energy conservation technologies to meet Kyoto targets using AIM/ENDUSE model of Japan. *Figure 9.4* shows the contribution of technologies undertaken by firms to reduce carbon emissions in 2010. Subsidies of US$30/tC compare with a carbon tax of US$300/tC to meet Kyoto targets without subsidies (using a rate of 100yen/$) (Kainuma *et al.,* 1997, 1999a).

[Insert Figure 9.4 Contribution to CO_2 emission reduction by technology options in Japan in 2010 in MtC]

For developing countries, environmental policy is often linked to technological improvement. Jiang *et al*. (1998) assess the potential for CO_2 emission reductions in China based on advanced energy-saving technology options under various tax and subsidy measures. For example, they consider the adoption of advanced coking-oven systems by the iron and steel industry in China. Without changes in policy only 15.9% of existing ovens will be replaced by advanced ones by 2010. With a carbon tax, but without a subsidy, the replacement share rises to 62%. With a tax and subsidies for energy-saving technologies, the share rises to 100%, i.e. the advanced ovens will be fully adopted by the industry. They also mention that taxes with subsidies do not give the best solutions for other sectors. They conclude that a carbon tax with subsidy could have reduced CO_2 emissions by 110Mt of carbon-equivalent in 2000 and 360Mt in 2010, from the baseline case of 980Mt in 2000 and 1380Mt in 2010.

Energy-saving technologies across the sectors, such as material and thermal recycling have a large potential to reduce carbon emission. Yoshioka *et al*. (1993) employed input-output analysis to evaluate the potential contribution of blast-furnace cement to reduce CO_2 emissions: improved technology for the utilization of 1 tonne of blast furnace slag to produce cement could reduce CO_2 by 0.85 tonnes. In the same manner, Ikeda *et al*. (1995) estimated that the utilization of by-products in the steel and iron industry, and of steel scrap could reduce CO_2 emissions by 2.4% in Japan in 1990.

9.2.7 Construction

This section is concerned with the impact of mitigation on the construction industry, rather than with the options for mitigating energy use in buildings, which are considered in Chapter 3. One of the main products of the construction sector are buildings which require energy for a number of services such as lighting, space heating and cooling, and electricity for equipment. Energy consumption in buildings reaches nearly one-third of total primary energy consumption in the US, and hence their importance for GHG emission reductions. Mitigation will lead to changes in the materials used, and in design and heat control, all tending to increase the quantity (output) and improve the quality of buildings. Most renewable energy investments, such as hydropower and electricity from biomass, also require inputs from the construction sector.

Multisectoral modelling suggests that carbon tax and permit policies will have little impact on construction output and employment; this finding is established in the literature, but incomplete. *Table 9.1* shows that according to three different macroeconomic models (Garbaccio *et al.* 1998, Jorgenson *et al.*, 1999; and Barker, 1999) construction will increase its output by about +1%. Two other models in the same table (Bertram *et al.*, 1993; Cambridge Econometrics, 1998) find 0% variation in the construction output.

9.2.8.Transport

Transport energy use has been growing steadily worldwide, with the largest increases occurring in Asia, the Middle East and North Africa, and it is projected to grow more rapidly than energy use in other sectors through at least until 2020 (Michaelis and Davidson, 1996; IEA, 1997b; Schafer, 1998; Nakicenovic *et al*., 2000). There are few options available to reduce transport energy use which do not involve significant economic, social or political costs. Governments presently find it difficult to implement measures to reduce overall demand for mobility (IEA, 1997b). Singapore is an exception to this general rule as a result of a comprehensive set of policies dating from 1975 to limit traffic (Michaelowa, 1996).

Almost all transport energy is supplied from oil, and the growing demand for transport seems inconsistent with macroeconomic studies that project decreased demand for oil as the result of GHG mitigation policies. Further research is needed to resolve this apparent inconsistency (Bernstein and Pan, 2000).

Local concerns, traffic congestion and air pollution, are currently the key drivers for transport policy (Bernstein and Pan, 2000). Measures to reduce traffic congestion also reduce CO_2 emissions, since they involve either reducing the number of vehicles on the road or increasing the average speed and fuel efficiency at which vehicles travel through urban areas. Policies to reduce traffic congestion include: improvements in mass transit, incentives for car pooling, and fees for entering city centres (Bose, 2000), as well as employer-based transport management, parking management, park-and-ride programmes, and road use pricing. One approach has been to assess the external (social) costs of transport, including contribution to global warming, as a guide to the level of taxes or user charges by transport modes that would internalize these costs, and hence improve the efficiency of the system (ECMT, 1998).

An “information society” based on a digital information network is sometimes projected to replace a substantial proportion of physical travel. However, historical data show that the telegraph and telephone did not affect the steady growth of transportation in France (see *Figure 9.5*). Mokhtarian *et al.* (1995) conclude that telecommuting, one aspect of the information society, does reduce transportation energy use. However, the reductions are smaller than often assumed, because they are partially offset by increased household energy use, and because some telecommuters do so only for part of their working day. Care must be taken in extrapolating future reductions from the limited case studies currently available; the behaviour of early-adapters may be different from that of later telecommuters. In the medium term, macro view, information technologies appear to be complementary to transportation (Gruebler, 1998); but in the longer term an “information society” could significantly replace travel and associated impacts, although this remains speculative.

[Figure 9.5: Historical trends in transport and communication volume indices for France]

9.2.8.1 Aviation

In 1999, in response to a request from the International Civil Aviation Organization (ICAO), the IPCC prepared a Special Report, *Aviation and the Global Atmosphere*, which included a comprehensive review of the potential impacts of aviation on the climate system (Penner *et al*., 1999). The demand for air travel, as measured in revenue passenger-kilometres, is projected to grow by 5%/year for the next 15 years, but improvements in efficiency and operations are projected to hold the growth in CO_2 emissions to 3%/year. Aircraft also emit water vapour, NO_x, SO_x and soot, and trigger the formation of condensation trails (contrails) and may increase cirrus cloudiness -- all of which contribute to climate change. (Penner *et al*., 1999).

Penner *et al.* present several growth scenarios for aviation that provide a basis for sensitivity analysis for climate modelling. These scenarios, which assume the scope for switching from air travel to other modes of travel is limited, show radiative forcing resulting from subsonic aircraft emissions growing from the 1992 level of

0.05Wm^{-2} to between 0.13 and 0.56Wm^{-2} by 2050. The scenario with economic growth equal to the IS92a reference scenario indicates that aviation may contribute 0.19 Wm^{-2}, or about 5% of anthropogenic radiative forcing, by 2050. More supersonic aircraft would substantially increase this contribution, although there is considerable uncertainty whether any such fleet will be developed. The growth scenarios do not consider air space and infrastructure limitations; however, recent experience in both Europe and North America indicates that the air traffic system is reaching saturation. Penner *et al.* assume that by 2050 all currently identified improvements in aircraft efficiency and operations will be implemented. However, turnover time in the aviation industry is long. Individual aircraft will be operated by commercial airlines for 25 years or more, and a successful product, including its derivatives, will be produced for possibly 25 years or longer. Thus, the overall life of an aircraft type can exceed 50 years.

Penner, *et al.* conclude:
"Although improvements in aircraft and engine technology and in the efficiency of the air traffic control system will bring environmental benefits, these will not fully offset the effects of increased emissions from the projected growth in aviation. Policy options to reduce emissions further include more stringent aircraft emissions regulations, removal of subsidies and incentives that have negative environmental consequences, market-based options such as environmental levies (charges and taxes) and emissions trading, voluntary agreements, research programmes, and substitution of aviation by rail and coach. Most of these options would lead to increased airline costs and fares. Some of these approaches have not been fully investigated or tested in aviation and their outcomes are uncertain (Penner *et al*., 1999, p. 11)."
The need for further research in this area is explored at the end of the chapter.

9.2.8.2 Passenger Cars

Chapter 3, section 3.4 discusses the status of low-GHG-emission technology for passenger cars. This section will discuss the effects of mitigation policies on the use of this technology and more generally on the use of passenger cars.

Government policies aimed at reducing passenger car fuel use, such as the US corporate average fuel economy (CAFE) standards, and the high tax placed on gasoline in many countries, have been in place for many years. These policies have been driven by two considerations: the cost of importing crude oil, and/or the desire to improve local environmental quality. The auto industry has responded to these policies with the introduction of successive generations of technology to improve passenger car efficiency. However, total passenger car fuel use has increased steadily as improvements in vehicle efficiency have been overwhelmed by increases in car sizes and car traffic. The number of passenger cars in use worldwide has risen from 193 to 477 million between 1970 and 1995, and total kilometres travelled have risen from 2.6 to 7.0 trillion vehicle-kilometres between 1970 and 1995 (OECD, 1997b). While growth in passenger car numbers has slowed in OECD countries, it is expected to continue to rise at a rapid rate in the rest of the world. Passenger car numbers in China are expected to increase 20-fold from 1995 to 2015 (Dargay and Gately, 1997).

Because gasoline is already taxed at a very high level in many countries, and the cost of fuel is a small portion of the total cost of driving, even fairly substantial increases in the cost of the fuel (as a GHG mitigation policy) may have little impact on vehicle use. The net present cost to the consumer of a tax equivalent to US$300/tC is approximately 5% of the capital cost of a typical new vehicle, assuming an initial cost of US$20000, 12000 km/year, and a 10-year life (IEA, 1997b). Furthermore, the users of company and/or government-provided cars may not be responsive to the increase in fuel cost at all, a typical case of principal-agent problem (see chapter 3 and chapter 6).

Initiatives to improve fuel economy continue, often with the express intention of reducing GHG emissions. European car manufacturers have voluntarily agreed to reduce the fuel consumption of new cars by 20% by 2010. In 1993, US car manufacturers entered into a partnership for a new generation vehicle (PNGV) with the US government aimed at developing a passenger car with triple the current fuel economy (to about 80 miles per gallon), by 2004, with no increase in cost or loss of performance compared with current vehicles. The incremental costs of these vehicles have been estimated to be as low as $2500/car (DeCicco and Mark, 1997) to as high as more than $6000/car (Duleep, 1997; OTA, 1995). Since these vehicles will be designed to meet the emissions standards anticipated to be in effect when they are produced, no ancillary local air pollution benefit is expected.

However, much of the increase in fuel efficiency may be taken up in increased demand for fuel if the lower operating costs are translated into increased ownership and use of vehicles. In addition, Dowlatabadi *et al.* (1996) find that increasing fuel economy to 60 miles per gallon had little beneficial effect on urban ozone concentration, and could decrease the safety of passenger cars unless offsetting steps were taken. Wang,*et al*. (1998) estimate the capital investment required in the US through to 2030 for fuel production and distribution to be (1) US$100bn (1995$) or less if the fuel for PNGV cars is reformulated gasoline or diesel, ethanol, methanol, liquefied petroleum gas (LPG), or liquefied natural gas (LNG); (2) approximately US$150bn for di-methyl ether; and (3) in the order of US$500bn for hydrogen. No estimate was made of the cost of applying this technology outside the US.

The Australian Bureau of Transport and Communications Economics (BTCE, 1996) examine the social costs of 16 measures to reduce GHG emissions from the transport sector. In the longer term, five of these measures: (1) metropolitan road user charges, (2) reduced urban public transport fares, (3) city-wide parking charges, (4) labelling of new cars to inform buyers of their fuel efficiency, and (5) shifting inter-capital freight from road to rail were found to be “no-regrets” options, i.e., they had zero or negative costs to society as a whole. Together these measures could reduce emissions from the Australian transport sector by about 5 to 10% of total projected emissions. A carbon tax on motor fuels and accelerated introduction of fuel-saving technology for commercial vehicles are no-regrets measures if applied at a low level, but incurred positive social costs if applied more broadly. Planting trees to offset transport emissions, scrapping older cars, and accelerating the introduction of energy efficiency technology for passenger cars and aircraft are found to be low-to-medium cost measures. Scrapping older commercial vehicles, compulsory tuning of passenger car engines twice a year, resurfacing highways, and increasing the use of ethanol as a motor fuel are found to be high cost measures.

Many parts of the developing world are faced with severe environmental problems caused in part by a rapid growth in the use of personal vehicles (scooters, motor cycles, mopeds, and cars). Many of these vehicles are old and poorly maintained, use two-stroke engines, and operate on inadequate road systems. The result is traffic congestion, greater fuel consumption, and noise and air pollution that degrade the urban environment. Bose (1998) finds that improving public transportation to meet as much as 80% of travel demand, and promoting cleaner fuels and improved engine technologies (i.e., phasing out two-stroke engines, increasing the share of cars equipped with three-way catalytic converters, using unleaded gasoline, electric vehicles, and vehicles fuelled with compressed natural gas) in six Indian cities can significantly reduce both emissions and fuel consumption. Total fuel savings for the six cities is 0.83m toe in 2010 to 2011, and automotive emissions are reduced 30 - 80% compared with a baseline case.

9.2.8.3 Freight Trucks, Rail, and Shipping

Freight transportation has been growing rapidly as a result of the growth of international merchandise trade, which has surpassed the growth in the world economy over the last two decades (IEA, 1997b). EIA (1998) consider the impacts of carbon fees to reduce US carbon emissions to 3% below 1990 levels, the amount estimated by the US administration as necessary to meet its Kyoto Protocol commitments when reductions in the emissions of other gases were taken into account. These fees raise the cost of diesel fuel by US$0.68/gallon, but result in only a 4.9% reduction in US freight truck travel, most of which is a result of lower economic activity. US rail transport is projected to decline by 32%, largely as the result of a 71% reduction in the demand for coal. The cost of marine fuel is projected to rise by US$0.84/gallon, nearly twice the reference price, but domestic shipping is projected to decline by only 10% (EIA, 1998).

9.2.8.4 Co-benefits from Reduced Road Traffic

Nations may choose to include GHG mitigation along with improvements in urban air quality and other traffic-related damages as objectives for policies designed specifically to reduce road traffic. The policies have co-benefits in terms of:

- reduced air emissions associated with less fuel use (e.g., Ross, 1999), and therefore consequent reductions in the damages caused by these emissions;
- reduced congestion;
- fewer traffic crashes;
- less noise; and
- less road damage.

The co-benefits from less noise and road damage are only likely to be large for substantial levels of mitigation (see ECMT, 1998 for valuations of these benefits for some European countries).

9.2.8.4.1 Air pollution associated with road traffic

There are likely to be substantial GHG co-benefits from some policies mainly aimed at reducing air pollution;

these are mostly considered in Chapter 8.

Today 3 out of 4 of the world's highly dense megacities are in the rapidly developing countries, where traffic congestion is often high, involving highly polluting and inefficient vehicle fleets (WRR, 1998). Because of this, reducing traffic and congestion will also lower potential exposures to known hazards from the burning of road fuels, especially to those living near to congested roadways. Children are at high risk from the damaging neurological effects of pollution. A recent report from the WHO and the European Environment Agency estimates that 21,000 deaths annually are tied with air pollution from traffic in Central Europe (WHO, 1999).

The total of health damage costs from road traffic is significant. A recent study jointly produced by agencies of the Swiss, French and Austrian ministries of health, environment, and economy estimates that the annual number of deaths linked to traffic based pollution in these countries exceeds those that occur because of traffic crashes alone. This study uses a willingness-to-pay approach to economically evaluate traffic-related air pollution health effects. In all three countries, the total air pollution related health costs are US$49.7bn[10], with $26.7bn coming from road traffic-related pollution. As a percentage of GDP, such costs in these countries range from 1.1%-5.8% (Sommer *et al*., 1999). A recent study from Sao Paulo (Miraglia *et al*., forthcoming), estimated that by 2020, 35300 avoidable deaths from air pollution will occur if current trends in transportation continue and about 150,000 children will be admitted to the hospital or visit the emergency room.

9.2.8.4.2 Road congestion

The research done on the ancillary benefits of GHG mitigation policies on road transport suggests that the value of the consequent reduction in congestion may be one of the most significant of such benefits (Barker *et al*., 1993). Traffic congestion also contributes to increased exposure to pollutants by passengers during periods of congestion, with levels inside private vehicles found to be 2-8 times those in the surrounding air (Fernandez-Bremauntz and Ashmore, 1995). Action to reduce this congestion can be expected to lower risks associated with such exposures, as well as lessen public health impacts of associated pollutants more generally.

9.2.8.4.3 Road traffic crashes

Section 9.2.8.2 lists several options for transport policies to mitigate GHGs. Some of these options, such as expanded reliance on mass transit and shifts away from individual passenger vehicles, can be expected to decrease the number of traffic crashes. The total number of damages resulting from crashes is substantial. With respect to traffic deaths and disabilities, the World Bank reports that traffic crashes are already the leading cause of death for young males and the 5th leading cause of death for young females worldwide. About 75% of all deaths occur in developing countries, although they have less than ¼ of all vehicles. If present trends continue to 2020, one fourth of all health costs in developing countries may be spent on treating road injuries alone (Ross, 1999). However, policies that encourage the use of smaller vehicles could have increased death and injuries caused by traffic crashes (Dowlatabadi *et al*., 1996).

The extent to which these total damages may be affected by various climate policies remains unknown, but is likely to be nontrivial and to vary in developed and developing countries. For instance, shifting travel from personal vehicles to mass transportation for large populations in the megacities of Sao Paulo and Shanghai (MacKenzie, 1997) has been projected to yield two sets of co-benefits:
(1) less net GHG emissions from transport, and
(2) lower incidence of traffic-accident-related morbidity and mortality.

9.2.9.Services

Since services employ more people and since they are much more employment-intensive than energy and manufacturing, employment usually increases as a result of GHG mitigation. However, the effects are small and diffused, and there is hardly any literature on specific sectoral effects for the service industries apart from the multisectoral studies reviewed in section 9.2.1 above.

9.2.10. Households

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[10] The original calculations are in euro and a rate of $1=1euro has been used for conversion.

The impact of mitigation on households comes directly through changes in the technology and price of household use of energy for heat, light, and power, and indirectly through macroeconomic effects, particularly on the income of households and the employment of their members. An important ancillary benefit for households is the potential improvement in quality of indoor, local, and regional air.

Most studies analyze the effect of mitigation strategies on GDP, which is often taken as an indicator of welfare. However, this measure does not capture the effects on the distribution of income between households. There are some studies that look at private consumption and other constructed indices of welfare, but these are few in number. This literature concentrates more on the developed economies, as these are the countries that would be taking actions first to reduce the emissions. The effect on developing economies is indirect through the trade effects and energy price effect.

9.2.10.1 Distributional Effects of Mitigation

These are mainly discussed in Chapter 8 (section 8.2.2.3). There are a number of studies on the domestic income distributional effects of carbon taxation, mostly for developed countries (Johnson *et al.*, 1990; Chandler and Nicholls, 1990; Poterba, 1991; Bertram *et al*., 1993; Hamilton and Cameron, 1994; Symons *et al*., 1994; Cornwall and Creedy, 1996). These studies show a regressive effect of carbon taxes, but a progressive effect if revenues are returned to disadvantaged groups. As the share of household expenditure on energy and the dependence on high-carbon fuels of the lower income groups is high, the impact of a carbon tax would be disproportionately higher on these lower income groups (Goldemberg and Johansson, 1995; Yamasaki and Tominaga, 1997). Barker and Köhler (1998) review a number of studies on impact of carbon taxation on households. Their analysis of an EU carbon tax indicates that taxation on domestic energy is regressive and taxation on road fuels is weakly progressive. They also show that revenues recycled through employer taxes could increase disposable income for all income groups in the study.

9.2.10.2 Electricity and Demand-side Management

A number of studies point out that power sector deregulation and competition will improve the efficiency of operations as well as management, which will result in a reduction in electricity rate charged to the end users (Hsu and Tchen, 1997). Demand-side management (DSM) instituted by electric utilities would increase electricity prices, but could lead to a reduction in total bills to participating customers (Hirst and Hadley, 1995), although the increased electricity prices could deter companies from using these measures in a competitive market. Parker (1995) indicated that DSM measures could lead to job creation from production and installation of equipment.

9.2.10.3 Effects of Improvement in Energy Efficiency

Improvements in the efficiency of energy production may have substantial impacts on households. Bashmakov (1993) reports a reduction in energy bills for end users and a substantial reduction in environmental costs for Russia. The study also reports that every rouble invested in energy efficiency generates 5 times more jobs than investments in energy production. On the other hand, Gaj *et al.* (1997) report a high social cost of economic transition caused by macroeconomic reforms, which indirectly reduce GHG emissions, because employment in non-competitive sectors is high in Poland.

9.2.10.4 Co-benefits for Households

A major co-benefit of GHG mitigation is reductions in the emissions of local air pollutants. Glomsro *et al*. (1990) have indicated that improved health conditions as a consequence of improved air quality, etc., could offset roughly two-thirds of the calculated GDP loss arising out of policies to reduce emissions. Alfsen *et al*. (1995) indicate a 6 to 10% reduction in SO_2 and NO_x emissions by the year 2000 as a result of an energy tax of US$3/barrel in 1993 and increasing by US$1 in each subsequent year to 2000.

Transport sector mitigation could imply substantial price increases with associated negative political, economic, and social implications, such as hardship for low-income rural motorists without access to public transport (Koopman and Denis, 1995; Dargay and Gately, 1997). But the option of using public transport could benefit the lower income sections of society, especially in developing countries, along with associated reduction in emission of CO, NO_X and SO_2 (Bose and Srinivasachary, 1997). Lower fuel use by road transportation could have substantial health benefits in urban areas (Pearce , 1996; Zaim, 1997;).

Some of the indirect benefits of GHG mitigation of fuel switching and efficient devices in the household sectors, typically in developing countries, include:

- improved indoor air quality,
- higher quality of life (simplifying household chores, better hygiene, and easier cleaning),
- reduced fuel demand with economic and time-saving benefits to the household (one study in Tanzania reported that women using wood as fuel spend 12 hours a week to collect it [Gopalan and Saksena, 1999]),
- increased sustainability of local natural resources, and
- reductions in the adverse effects of biomass use on human health (WHO, 1992)

These points are particularly relevant in the case of biomass-burning stoves (Sathaye and Tyler, 1991; Smith 1996). Gopalan and Saksena (1999) report that the level of exposure to key pollutants in rural households can be 10 to 100 times higher than the health-related guidelines of the WHO.

The results of a study on potential fuelwood use in 2020 for Austria, Finland, France, Portugal, and Sweden reveal that upstream emissions from fuel extraction are generally higher for fossil fuels than biofuels (Schwaiger and Schlamadinger, 1998). However, some research indicates that local negative environmental implications may be greater for use of wood than fossil fuel (Radetzki, 1997). An associated impact of increased diversion of land for growing wood would be on agriculture production and hence the commodity prices (Alig *et al.*, 1997). The economic benefits of afforestation also include benefits from increase in supply of non-timber forest products (Mors, 1991; ADB-GEF-UNDP, 1998a). These options in developing countries would greatly increase the wood supply and address the forest degradation issue but viability is an important issue as incomes are too low in rural areas for sizeable numbers of the population to buy wood.

Mitigation strategies in rural domestic energy use range from use of more efficient appliances, installation of PV solar, fuel-switching and use of bio-gas (ADB-GEF-UNDP, 1998a). Such strategies for developing countries are constrained by high capital costs (Biswas and Lucas, 1997). The ancillary benefits of lower use of traditional biomass are decreased deforestation, and lower loss of crop-nutrient from the system through use of agricultural residue as fuel (Bala, 1997). The ancillary environmental benefits that are associated with such strategies do not form a major factor in energy decisions of the household (Aacher and Kammen, 1996); it is the cost that is the important factor. And some mitigation measures at home, such as reduction of air leaks, tend to worsen indoor air quality (Turiel, 1985).

9.2.10.5 The Asia Least-cost Greenhouse Gas Abatement Strategy Studies

ALGAS was a regional technical assistance project of the Asian Development Bank (ADB) which enabled 12 Asian countries:

- to prepare an inventory of anthropogenic emissions and sinks of GHGs,
- to evaluate the costs and effectiveness of measures available to reduce GHG emissions or enhance sinks, and
- to develop national action plan policy responses that will be required to implement the measures that are identified.

The ALGAS country reports highlight the forestry sector options: forest protection and reforestation will have both socio-economic benefits and environmental benefits. These forestry options will increase rural incomes, increase equity of income, and increase the availability of biomass (ADB-GEF-UNDP 1998b, c, d and f). These studies also emphasize that the forestry options would reduce the pressure on forested land and have indirect benefits of reducing soil erosion in hilly terrain. However, some of the studies (ADB-GEF-UNDP 1998c and e) indicate that these changes are short term and do not have a significant effect.

The ALGAS-Bangladesh (ADB-GEF-UNDP 1998d) study also reports that the options in the agricultural sector of reducing CH_4 emission from paddy fields and enteric fermentation in animals have direct benefits in terms of increased incomes, and also improve foodgrain production and availability.

9.3. International Spillovers from Mitigation Strategies

International spillovers[11] arise when mitigation in one country has an impact on sectors in other countries. The main factors are:

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[11] Spillover effects can be defined as interdependencies between countries, sectors or firms that take the form of technological synergies and flows of stimuli and constraints that do not entirely correspond to commodity flows (Dosi, 1988). The concept originates in the literature on technical change, in order to account for the non-appropriability of scientific and technological knowledge, which reduces the incentive to private R&D and thus motivates public investment in R&D (Arrow, 1962).

(1) improvement in the performance or reduction in the cost of low-carbon technologies;
(2) changes in the international prices, exports and outputs of fossil fuels, especially oil; and
(3) relocation of energy-intensive industries.

Table 9.8 shows how different policies and measures may give rise to such spillovers. These effects may be included in the design and assessment of policies, particularly in the search for internationally equitable strategies. Chapter 8 considers the macro aspects of spillovers; this section considers the sectoral aspects.

[Insert Table 9.8 Typology of potential international spillovers from mitigation strategies]

9.3.1. Technology Policies

In the sectoral perspective of this chapter, it appears that there are three routes by which technology policies in one country affect sectoral development in others (see section 8.3.2.5 for a global perspective). First, R&D may increase the knowledge base and this will benefit every country. Second, increased "market access" for low-CO_2 technologies, through niche-markets or preferential buyback rates in one country may induce a generic improvement in technology in others. Box 9.3.1 explains how this process can be modelled. Third, domestic regulations on performance and standards, whether imposed or voluntary can create a strong signal for foreign industrial competitors (Gruber *et al*., 1997). For example, the ratio of emission standards for carbon monoxide, hydrocarbons, and NO_x for automobiles in the EU relative to those in the US has been reduced from a factor of more than 3 in the seventies to a factor 1.5 to 2 in the nineties (Anderson, 1990; IFP, 1998).

Box 9.3.1. International technological spillovers in the national energy modelling system model of the US energy sector

The rate of international spillovers largely depends on the nature of the technology, the degree of internalization of the market, and the competitive structure of the industry. The NEMS model of the US energy sector is one of the rare models explicitly incorporating spillover effects. It is assumed, based on historical experience, that power plant development outside the US will also help to decrease costs in the US. Thus, one unit installed abroad is incorporated in the experience curve, but only up to a fraction of the same unit in the US. The corresponding factor (from 0 to 1) depends on the proximity of the country and firm developing this power plant. It gives the measure of the expected international spillover rate (NEMS model documentation, DOE-EIA; see Kydes, 1999).

9.3.2. Tax and Subsidy Policies

Spillover effects from tax and subsidy policies for mitigation are less direct. The global economic impacts of the policies are examined, both in a theoretical and in a modelling perspective, in Chapter 8 (8.3.2.1 to 8.3.2.4). Their impacts on sectors are also analyzed in section 9.2 above. The sectoral effects of these policies can be summarized as follows.
(1) They will reduce the demand for carbon-based fuels, and thus introduce a downward pressure on their prices e.g., in the world price of crude oil.
(2) They may reduce the industrial competitiveness of sectors with higher costs in the mitigating country, raising competitiveness and hence market shares for sectors in other countries.
(3) They may create an incentive to industrial relocation and thus give rise to "carbon leakages".
(4) However, they may also stimulate the development of alternative technological solutions.

The effects of carbon taxation on international competitiveness are reviewed by Ekins and Speck (1998) and Barker and Johnstone (1998). Clearly, a carbon tax will raise the cost of production of some sectors of the economy, causing some consumers to switch from their products to the products of the sectors in other countries, changing international trade. National losses (and/or gains) for price competitiveness will be the net sum of the sectors' losses (and/or gains) for price competitiveness. The outcome for a particular sector will depend on the policy instruments used, how any tax revenue has been recycled, and whether the exchange rate has adjusted to compensate at the national level. The conclusions from these surveys are that the reported effects on international competitiveness are very small, and that at the firm and sector level, given well-designed policies, there will not be significant loss of competitiveness from tax-based policies to achieve targets similar to those of the Kyoto Protocol.

These conclusions are confirmed by later studies, although in general the effects of environmental taxation in one country on sectors in other countries are not well covered by the literature. Using an econometric model (E3ME), Barker (1998a) assesses policies reducing CO_2 emissions in 11 EU member states at the level of 30 industries and 17 fuel users, comparing unilateral with co-ordinated policies. The carbon tax reduces imports of oil and increases imports of carbon-intensive products. However, the results for trade are negligible.

Ban (1998) assesses the effects of an *ad-valorem* tax on coal (20%), oil (10%), and gas (10%) using an applied general equilibrium model (GTAP) with 12 world regions and 14 industry sectors. He has three taxation cases, (a) Japan only, (b) OECD only, and (c) the world, with revenues used to increase government expenditure. The results are all shown against a reference case for 1992. *Table 9.9* shows the effects on the industrial output in Japan: the effects are very small when the tax is for Japan only, but they are even smaller when the taxation is at the OECD or world level, illustrating the size of the competitiveness effects. These results depend critically on the assumptions adopted as Ban points out.

[Insert Table 9.9: Effects on sectoral output of Japan of an ad-valorem fuel tax]

There are other aspects to spillovers not well captured in existing models. As energy efficiency is generally higher in Annex B countries than in the rest of the world, some studies suggest that relocation of industry to developing regions would increase global CO_2 emissions (e.g., Shinozaki *et al*., 1998). However, this conclusion would be altered if the relocated industry used up-to-date technologies rather than the average technology in developing countries. The international diffusion of improved technologies in response to CO_2 constraints is not captured in existing models and would tend to counteract the negative environmental aspects of spillovers.

9.4. Why Studies Differ

This section consolidates the explanations for the different findings in both the macro studies reviewed in Chapter 8 and the sectoral studies in this chapter. It extends and complements the methodological discussion in the SAR (Hourcade *et al*., 1996, pp. 282-92), particularly in the role of assumptions leading to differing results.

In assessing the economy-wide effects of mitigation, considerable use has been made of top-down models (macroeconomic, general equilibrium, and energy-engineering), while specific sectoral studies use both top-down and engineering-economic bottom-up models. Critical differences in the results come from the type of model used, and its basic assumptions. Repetto and Austin (1997), in a meta-analysis of model results on the costs of mitigation for the USA, show that 80% of predicted impacts come from choice of assumptions. They find that four assumptions are critical in leading to lower costs of mitigation. These are that:

- the economy responds efficiently to policy changes at least in the long run,
- international joint implementation is achieved,
- revenues from taxes or permit sales are returned to the economy through reducing burdensome taxes, and
- any co-benefits from reduced air pollution are fully included.

They conclude that under reasonable assumptions, the predicted economic impacts from the models for the USA in stabilizing CO_2 emissions at 1990 levels through to 2020 would be neutral or even favourable (p. 16).

Most early studies are focused on the costs, rather than on the benefits of mitigation[12]. More recently, top-down modellers have studied the impact of using the revenues collected from carbon taxes (or from auctions of carbon permits) to correct economic distortions in some sectors of the economy (typically to reduce taxes on labour, taxes on incomes and profits, or taxes on investment).

9.4.1. The Influence of Methods

9.4.1.1. Top-down and Bottom-up Modelling

The adoption of top-down or bottom-up methods makes a significant difference to the results of mitigation studies (see 8.2.1 and 8.2.2 for discussion and results). In top-down studies the behaviours of the economy, the energy system, and their constituent sectors are analyzed using aggregate data. In bottom-up studies, specific actions and technologies are modelled at the level of the energy-using, GHG-emitting equipment, such as power-generating

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[12] More formally, the studies impose taxes on the carbon content of energy as a factor of production (with labour and capital as other factors) in a production function; depending on the precise assumptions chosen this has the inevitable implication that output and GDP will fall. See Boero *et al.* (1991), Hoeller *et al.* (1991), Cline (1992), Ekins (1995), Mabey *et al.* (1997) for surveys of the assumptions and results of the modelling in this area.

stations or vehicle engines, and policy outcomes are added up to find overall results. The top-down approach leads easily to a consideration of the effects of mitigation on different broad sectors of the economy (not just the energy and capital goods sectors), so that the literature on these effects tends to be dominated by this approach.

Table 9.10 compares the methodologies. They have a fundamentally different treatment of capital equipment and markets. Top-down studies have tended to suggest that mitigation policies have economic costs because markets are assumed to operate efficiently and any policy that impairs this efficiency will be costly. Bottom-up studies tend to suggest that mitigation can yield financial and economic benefits, depending on the adoption of best-available technologies and the development of new technologies. Some hybrid models include both approaches (see Laroui and van Leeuwen, 1995, for an example).

9.4.1.2. General Equilibrium and Time-series Econometric Modelling

There are two main types of macroeconomic models used for medium- and long-term economic projections[13]: resource allocation models (i.e.,, CGE) and time-series econometric models. Their main differences being the assumptions made about the real measured economy, aggregation, dynamics, equilibrium, empirical basis, and time horizons, among others.

The main characteristic of CGE models is that they have an explicit specification of the behaviour of all relevant economic agents in the economy. In the mitigation applications they have usually adopted assumptions of optimizing rationality, free market pricing, constant returns to scale, many firms and suppliers of factors, and perfect competition in order to provide a market-clearing equilibrium in all markets. Econometric models have relied more on time-series data methods to estimate their parameters rather than consensus estimates drawn for the literature. Results from these models are explained not only by their assumptions but also by the quality and coverage of their data. It is usually argued that CGE models are more suitable for describing long-run steady-state behaviour, while econometric models are more suitable for forecasting the short-run. However, the models have increasingly incorporated long-run theory and formal econometric methods, and several now include a mix of characteristics, from both resource allocation and econometric models; see Jorgenson and Wilcoxen (1993), McKibbin and Wilcoxen (1993, 1995), Barker and Gardiner (1996), Barker (1998b) and McKibbin *et al*. (1999).

9.4.2.The Role of Assumptions

9.4.2.1. Baseline

A critical point for the results of any modelling is the definition of the baseline (or reference or business-as-usual) scenario. The SRES (Nakicenovic *et al*., 2000) explores multiple scenarios using six models and identifies 40 scenarios divided into 6 scenario groups. As OECD (1998) points out, among the key factors and assumptions underlying reference scenarios are:

- population and productivity growth rates;
- (autonomous) improvements in energy efficiency;
- adoption of regulations e.g., those requiring improvements in air quality; if air quality is assumed to be satisfactory in the baseline, then the potential for air quality co-benefits in any GHG mitigation scenario is ruled out by assumption;
- developments in the relative price of fossil fuels; some of the underlying factors are supply-side issues, for example oil and gas reserves, development of gas distribution networks, the relative abundance of coal; energy policies also play a role, particularly tax and subsidy policies;
- technological change, such as the spread of combined cycle gas turbines;
- supply of non-fossil fuel based electricity generation (nuclear and hydro); and
- the availability of competitively priced new sources of energy, so-called backstop fuels, for example solar, wind, biomass, tar sands.

Differences in the reference scenarios lead to differences in the effects of mitigation policies. Most notably, a reference scenario with a high growth in GHG emissions implies that all the mitigation scenarios associated with that reference case may require much stronger policies to achieve stabilization.

Nevertheless, even if reference scenarios were exactly the same, there are other reasons for changes in model results. Model specification and, more importantly, differences in model parameters also play a significant role in determining the results.

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[13] See Shoven and Whalley (1992), Dervis *et al.* (1982), Jorgenson (1995a, 1995b), Holden *et al.* (1994), Barro and Sala-i-Martin (1995) for different methods of long-term modelling.

9.4.2.2. Costs and Availability of Technology

If any fuel becomes perfectly elastic in supply at a given price (i.e., the backstop technology), the overall price of energy will be determined independently of the level of demand, which will then become the critical determinant of mitigation costs. Hence, the assumption of a backstop technology strongly determines mitigation costs. Models without a backstop technology will tend to estimate higher economic impacts of a carbon tax, because they rely completely on conventional fuels, so that the tax rate has to rise indefinitely to keep carbon concentrations constant, to offset the effects of economic growth.

9.4.2.3. Endogenous Technological Change

The treatment of technology change is crucial in the macroeconomic modelling of mitigation. The usual means of incorporating technical progress in CGE models is through the use of time trends, as exogenous variables constant across sectors and over time. These trends give the date of the solution. Technical progress usually enters the models via two parameters: (i) autonomous energy efficiency (AEEI) (if technical progress produces savings of energy, then the value share of energy of total costs will be reduced); and (ii) as changes in total factor productivity. The implication of this treatment is that technological progress in the models is assumed to be invariant to the mitigation policies being considered. If in fact the policies lead to improvements in technology, then the costs may be lower then the models suggest.

9.4.2.4. Price Elasticity

In assessing the effects of mitigation, estimations of price-induced substitution possibilities between fuels and between aggregate energy and other inputs can be crucial for model outcomes. All such substitutions become greater as the time for adjustment increases. The problem is that estimates of substitution elasticities are usually highly sensitive to model specification and choice of sample period. There is little agreement on the order of magnitude of some of the substitution elasticities, or even whether they should be positive or negative, e.g., there is debate whether capital and energy are complements or substitutes. If energy and capital are complements, then increasing the price of energy will reduce the demand in production for both energy and capital, reducing both investment and growth. Most CGE models consider very different possibilities of substitution, for example WW, Global 2100, and Norhaus's DICE/RICE models assume capital and labour as substitutes, while GREEN assumes capital and energy as direct substitutes.

9.4.2.5. Degree of Aggregation

There are many different products, skills, equipment, and production processes; many important features are missed when they are necessarily lumped into composite variables and functions. A basic difference among models and their results is the level of aggregation. Indeed, in practice, different goods have different energy requirements in production, and therefore any changes in consumption and production patterns will affect them differently. Hence, a highly aggregated model will miss some potentially major interactions between output and energy use, which is precisely the purpose of the analysis. For example, sectoral disaggregation allows the modelling of a shift towards less energy-intensive sectors, which might reduce the share of energy in total inputs. In the same way, when a carbon tax is introduced, it could reduce the estimated costs of abatement by allowing substitution effects of energy-intensive goods by less energy-intensive goods.

9.4.2.6 Treatment of Returns to Scale

Constant returns to scale represent a common assumption on the economic modelling of climate change. However, in practice, economies of scale seem to be the rule rather than the exception. Indeed, there are several reasons for economies of scale, see Pratten (1988), and Buchanan and Yoon (1994). For example, many electricity-generating stations benefit from economies of scale, utilizing a common pool of resources including fuel supply, equipment maintenance, voltage transformers, and connection to the grid. In spite of this fact, the impact of the effects of increasing returns and imperfect competition (IC) in the modelling of climate-change strategies has consistently been neglected in the literature. Most of the global models, if not all, assume explicitly perfect competition, for example, see DICE/RICE, G-Cubed, Global 2100, GREEN, GTEM, WorldScan, and WW.

9.4.2.7 Treatment of Environmental Damages

Most models are not able to incorporate the benefits of preventing climate change (or of the costs of doing nothing). Instead, modellers have only considered the economic impact of meeting some emission standard, which implicitly assumes (in the base situation) that climate change would have no economic impacts. Nevertheless, the potential costs caused by climate change are likely to be huge (even though some favourable effects are also expected) regarding: loss of human well-being, damage to property including agriculture and forestry, ecosystem loss, and risk of disaster, see Nordhaus (1991), Cline (1992, Ch 3), Fankhauser (1995), Fankhauser and Tol (1995). This situation has been caused to some extent by two factors, the difficulties of economists in valuing environmental impacts, and the scientific uncertainty of predicting the physical effects of climate change[14].

9.4.2.8 Recycling of Tax Revenues

Carbon taxes will generate significant tax revenues. The effects of these revenues in the economy will depend on how this money is recycled into the economy (in practical terms, some mechanism for recycling is always needed in order to avoid a general deflationary impact). If it is assumed that revenues will not be fully recycled, the models tend to find that any carbon tax will reduce GDP. Usually, modellers have tried to separate the economic impacts arising from this environmental policy from those arising from a tax cut, assuming that revenues will be returned in the form of lump-sum rebates (an unrealistic assumption). The alternative is to assume that revenues collected from the carbon tax are used in correcting economic distortions in the economy, e.g. taxation of employment, which would benefit society not only by correcting the externality but also by reducing the costs of the distorting taxes (the so-called “double dividend”). Obviously, if the benefits from reducing existing taxes on labour are incorporated into the modelling, the projected economic impacts can be substantially more optimistic than if a lump-sum revenue recycling is assumed, although the size of the effect depends on model specification[15].

9.4.2.9 International Environmental Policy

Environmental policy to reduce climate change will be economically efficient when the incremental cost of emission reductions is equal in all complying countries. A way of achieving cost savings in the abatement policy is to allow emission sources to contract with each other to meet required emission reductions. In this sense, flexible instruments such as international emissions trading and JI are more efficient than a situation in which each country has to achieve its own emission reduction[16]. Usually, international emissions trading is modelled as if all countries set the same carbon tax rate, so that cost-effective emission reductions are advantageous to undertake in whatever country they arise. Hence, if models consider economic instruments for environmental regulation, the overall cost of controlling emissions should be lower as a consequence of cost savings in the control produced by these instruments[17].

It is important to point out that this kind of modelling implicitly assumes an ideal scenario. However, in practice some problems arise with the basic theory, involving the operation and design of the market. Some important considerations here are:

- the degree of competition in the market (i.e., that neither buyers nor sellers have sufficient weight to influence the price of the permit);
- fairness in allocating the emission permits (auctioning versus “grandfathering”); and
- the institutional and administrative costs of implementing the system (are the costs negligible?)[18].

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[14] In the same way, models should incorporate other benefits of limiting GHG emissions, but again the complexity of modelling and valuing of these benefits are substantial. The ancillary benefits associated with the abatement policies usually include reductions in damages from other pollutants jointly produced with GHGs (see chapter 8 and Barker 1993, Barker *et al.* 1993 and OECD 2000) but also include the conservation of biological diversity.

[15] Nevertheless, in general the research on double dividend of environmental taxes have resulted in conflicting and confusing conclusions. See Bohm (1997) for a clear statement of the issues and O'Riordan (1997) for several reviews of theoretical and practical evidence of the dividends from environmental taxation.

[16] In general terms, from the economists' point of view, environmental regulation should rely on economic instruments instead of command –and-control policies, considering the cost-effective allocation of the control responsibility of the former ones, which have proven to be efficient in simple settings, see Bohm and Russell (1985), Baumol and Oates (1988), Montgomery (1972).

[17] See Tietenberg (1990), Barrett *et al.* (1992), Barrett (1991), Rose and Tietenberg (1993). See also the studies reported to the OECD expert workshop on Climate Change and Economic Modelling, September 1998.

[18] In terms of the Kyoto Protocol, for example, a specific problem of modelling IET is the possibility that target emissions will be below the base-year emissions. In the same way, variations from the full unrestricted trading systems may change cost estimations. Two clear variations are: the definition of trading entities (i.e. bubbles), and the limits of the amount of trading.

9.5. Areas for Further Research

The literature on sectoral economic costs and benefits is limited and additional research would be beneficial in all areas. Specific issues identified in this chapter (not in order of priority) include:

- Additional research on the impacts of climate change policies on the fossil fuel industries is needed. Questions include:
    - the apparent anomaly between studies indicating significant decreases in the demand for oil in Annex B countries, and studies indicating significant increases in the demand for transportation fuels, the major user of oil;
    - whether in the medium term (10 to 30 years) reserves of conventional oil are limited, which would soften the impact of climate change policies, or whether they are plentiful; and
    - whether the demand for natural gas will decrease as a result of a general decrease in the demand for fossil fuels, or increase, as a result of fuel switching from higher carbon content fuels and growth in demand in non-Annex B countries.

- The impacts of climate change policies on the financial industries have not been analyzed. McCarthy *et al.* (2001) details the potential impacts, positive and negative, of climate change on the financial industries, but there appears to be no literature evaluating the degree to which mitigation policies would affect these impacts.

- The applicability of existing climate policies, and their impacts on the aviation industry and the shipping industry have not been adequately studied. Further analysis is needed to determine the efficiency, effectiveness, and equity of various policy options, particularly involving taxation, on limiting GHG emissions from aviation and shipping. This would include the difficulties involved in changing the current treaty structure to allow for the taxation of aviation fuel. The International Maritime Organization is studying GHG emissions from shipping. The International Civil Aviation Organization is currently analyzing policy options for aviation and is expected to complete its evaluation by September, 2001.

- Further study would be helpful to determine the degree to which employment growth in the industries that would benefit from climate change policies (e.g., renewable energy) would offset the decrease in employment in industries that would suffer as the result of climate change policies (e.g., fossil fuels). These studies could also consider frictional unemployment.

- More generally, an assessment is needed of how sectoral costs of mitigation can be minimized and distributed more equitably, both at the national and the global levels. Babiker *et al.* (2000) found that macroeconomic costs for the US increased when climate change policies excluded one or more economic sectors. However, this study did not indicate the benefits, if any, to the protected sector.

- More research is needed on the co-benefits of GHG mitigation and other objectives of transport policies (reductions in air pollution, lower levels of traffic congestion, fewer road crashes).

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Table 9.1 Some multisectoral studies of carbon dioxide mitigation

Region or country	China	EU-6	EU-11	New Zealand	UK	US	US	US
Reference	Garbaccio et al (1999)	DRI (1994)	Barker (1999)	Bertram et al (1993)	Cambridge Econometrics (1998)	CRA and DRI (1994)	Jorgenson et al (1999)	McKibbin et al (1999)
Funding body	US Dept of Energy	EC	EC	NZ Min of Environment	FFF-FOE	Electric Power Research Institute		US EPA
Model		DRI-models	E3ME	ESSAM	MDM-E3	DRI	JWS	G-cubed
Model type	Static CGE	Macro	Macro	CGE	Macro	Macro	Dynamic CGE	Dynamic CGE
Policy	Carbon tax	Carbon tax	Carbon tax	Carbon & energy taxes	Carbon tax	Carbon Tax	Emission permits	Emission permits
Recycling mode	All other taxes	Employer taxes	Employer taxes	Corporate tax	Employer taxes	Lump-sum	Personal income tax	Lump-sum
Industries	29	20-30	30	28	49	About 100	35	12
Fuel types	4	17	11	4	10	4	4	5
Period	1992 to 2032	1992 to 2010	1970 to 2010	1987 to 1997	1960 to 2010	1990 to 2010	1996 to 2020	1996 to 2020
Effect year	2032	2010	2010	1996/97	2010	2010	2020	2010
Model run	15%	INT	Mult-coord.	324	C72F11	$100/tC	Personal	Unilateral US
CO_2	-15%	-15%	-10%	-46%	-4.4%	-15.3%	-31%	-29.6%
GDP	+1%	+0.9%	+1.4%	+4.6%	+0.1%	-2.3%	+0.6%	-0.7%
Output: coal	-19%	Energy -7%	-8%	-24%	0%	-25%	-52%	-40%
: refined oil	-2		-17	-22	-0	-6	-4	-16
: gas			-4	-41	-4	-18	-25	-14
: electricity	+3 (year 1)		-3	-17	-1	-17	-12	-6
: agriculture	+0 (year 1)	-7	+3	+4	+0		+4	-1
: forestry	..	..	..	+5	..		..	-1
: food, etc.	+0 (year 1)	Manufacturing +1	+2	+3	+0		+5	Nondurables –1
: chemicals	+1 (year 1)		+2	+6	-0		-0	..
: steel	+1 (year 1)		+1	-26	-1	-5	-3	Durables –1
:construction	+1 (year 1)	..	+1	+0	+0		+1	..
: transport	+1 (year 1)	-2	+0	+5	+0	-4	+1	-2
: services	+0 (year 1)	+1	+1	+6	+0	-2	+3	-0
:consumer's expenditure	+0.8%			+6.7%	+0.1%	-1.9%	+0.7%	-0.4%

Notes: (1) “Multisectoral models” are defined as those in which GDP is divided into production sectors. Definitions of sectors differ between studies.
(2) .. denotes not available or not reported.

Table 9.2 Producer Subsidy Equivalents for Coal Production in OECD Countries in 1993

	PSE per tonne $/tce	Total PSE M$	Budgetary Support	Price Support Mtce	Subsidized Production
France	43	428	100%	0%	10.0
Germany	109	6688	40%	60%	61.5
Japan	161	1034	12%	88%	6.4
Spain	84	856	37%	63%	10.2
Turkey	143	416	100%	0%	2.9
UK	15	873	2%	98%	57.4
US	0	0	0	0	0

note: PSE is Producer Subsidy Equivalent; tce = tonne of coal-equivalent; Mtce = million tce. 1 tce = 29.308 GJ
Source: OECD (1997c), original source: IEA and DRI, 1994.

Table 9.3 Summary results from case studies on energy subsidy removal
(note that subsidies are defined in various ways and are not comparable)

Study	Subsidy or group of subsidies removed	Monetary equivalent of distortion (US$ million, various years, 1988 –to 1995)	Decrease in annual CO_2 emissions relative to reference scenarios resulting from reforms by 2010 million tonnes	Other economic effects of removing subsidies
Larsen and Shah (1995)	Global price subsidies to consumers of fossil fuels (difference between domestic and world prices) [(b)]	215,000	1366 [(a)]	Enhanced economic growth
GREEN	Global price subsidies to consumers of fossil fuels (difference between domestic and world prices) [(b)]	235,000	1800 in 2000 15000 in 2050	Enhanced economic growth in most regions, largest in CIS. Improved terms-of- trade for non-OECD countries.
DRI (1994)	Coal PSEs in Europe and Japan	5800	10 (DRI estimate) >50 (OECD estimate)	Job loss in coal industry, increased coal trade
Böhringer	Coal in Germany	6700	NQ	Nearly 1% GDP increase. Job loss in coal industry, increased coal trade.. Cost of using subsidies to maintain jobs is 94-145,000 DM per job/year. Reduces cost of meeting CO_2 target.
Australia	State procurement/planning	133	0.3	Reduces cost of meeting CO_2 target
	Barriers to gas and electricity trade Below-market cost financing	1400 NQ	0.8 NQ	Reduces cost of meeting CO_2 target
Italy	Net budgetary subsidies to the electricity supply industry (ESI)	4 000 300	12.5 0.6	Reduces cost of meeting CO_2

Study	Subsidy or group of subsidies removed	Monetary equivalent of distortion (US$ million, various years, 1988 –to 1995)	Decrease in annual CO_2 emissions relative to reference scenarios resulting from reforms by 2010 million tonnes	Other economic effects of removing subsidies
	VAT below market rate Subsidies to capital Excise tax exemption for fossil fuels use by ESI	1500 700	3.3 5.9	target/makes CO_2 tax more effective.
	Total net and cross-subsidies	10,000	19.2	
Norway	Barriers to trade	NQ	8 for Nordic region	
Russia	Direct subsidies and price control for coal	3600	120	1% drop in employment
	Price control/debt forgiveness for electricity consumers	6000	(about half caused by shift from coal to other fuels, half to reduced final energy demand)	(but note that model included no subsidy recycling mechanism)
UK	Grants and price supports for coal and nuclear producers	2500	0 to 40	
	VAT on electricity below general rate	1200	0.2	
US	DFI (1993) analysis of federal subsidies	8500 (c)	10	
	DJA (1994) analysis of federal subsidies	15,400 (c)	64	GNP increased 0.2% if revenue used to reduce capital taxes

Source: OECD (1997c)

(a) The model used is comparative static: emission reduction is calculated using mostly 1991 market data.

(b) This measure of "subsidies" is a crude one, and does not necessarily indicate the existence of any particular government policy.

(c) The two studies analyze different sets of energy supports and use slightly different estimates for some of them: these figures are not a reliable indication of total US federal energy subsidies. See Appendix A, Table 14, OECD (1997c) for details. Results are sensitive to assumptions regarding the future structure of the US electricity supply industry.

NQ = not quantified

Table 9.4 Costs of Kyoto Protocol implementation for oil exporting region/countries (a)

Model (b)	**Without Trading** (c)	**With Annex-I Trading**	**With "Global Trading"**
G-Cubed	-25% oil revenue	-13% oil revenue	-7% oil revenue
GREEN	-3% real income	"substantially reduced loss"	N/a (d)
GTEM	0.2% GDP loss	<0.05% GDP loss	N/a
MS-MRT	1.39% welfare loss	1.15% welfare loss	0.36% welfare loss
OPEC Model	-17% OPEC Revenue	-10% OPEC Revenue	-8% OPEC Revenue
CLIMOX	N/a	-10% some oil exporters' revenues	N/a

Source: Pershing (2000)

(a) The definition of oil exporting country varies: for G-Cubed and the OPEC model it is the OPEC countries, for GREEN it is a group of oil exporting countries, for GTEM it is Mexico and Indonesia, for MS-MRT it is OPEC + Mexico, and for CLIMOX it is West Asian and North African oil exporters.

(b) The models are all considering the global economy to 2010 with mitigation according to the Kyoto Protocol targets (usually in the models, applied to CO_2 mitigation by 2010 rather than GHG emissions for 2008 –to 2012) achieved by imposing a carbon tax or auctioned emission permits with revenues recycled through lump-sum payments to consumers; no co-benefits, such as reductions in local air pollution damages, are taken into account in the results. See Weyant (1999).

(c) "Trading" denotes trading in emission permits between countries.

(d) N/a denotes "not available".

Table 9.5 Changes in carbon dioxide emissions and gas demand from the reference case in alternative emissions abatement studies

	Change in CO_2 Emissions (%)	Change in natural gas Demand (%)	Ratio of Changes in Gas Demand to Changes in CO_2 Emissions$^{(d)}$	Year	Region
DRI (1992)	-11.7	-7.2	0.62	2005	EC
Hoeller *et al.* (1991)	-49.2	-27.4	0.56	2000	World
Bossier and De Rous (1992)	-8.2	3.0	-0.37	1999	Belgium
Proost and Van Regemorter (1992)	-28.8	15.3	-0.55	2005	Belgium
Burniaux *et al.*(1991)	-53.6	0.0	0.0	2020	World
Barker (1995)	-12.8	-6.2	0.48	2005	UK
IEA (1993)	-8.8	23.0	-2.61	2010	OECD
Ghanem *et al.*(1998)	-30.7	-20.1	0.65	2010	World
Baron (1996)(a)	-8.5(b)	-4.0	0.47	2000	USA
Birkelund *et al.* (1994)	-10.7	-8.0	0.75	2010	EU
Bernow *et al.* (1997)	-17.8	-5.4	0.30	2015	Minnesota
Gregory *et al.* (1992)	-8.4	-5.2	0.62	2005	UK
WEC (1993) Scenario B	-11.1	0.0	0.0	2020	World
Kratena and Schleicher (1998)	-29.0	-36.4	1.26	2005	Austria
Mitsubishi Research Institute (1998)	-11.3(c)	9.2	-0.81	2010	OECD

(a) Citing a study by US Congressional Budget Office (CBO)
(b) Estimated.
(c) Change in fossil fuel demand.
(d) Median ratio (Column 3): 0.47
Mean ratio: 0.16
Std.dev.of ratio: 0.92

Table 9.6 Projected nuclear energy capacity (MW)

Country	1997	2007	2010
Japan	45248	49572	54672
South Korea	10316	19716	22716
China	2100	9670	11670
Taiwan, China	5148	7848	7848
India	1845	3990	4320
Pakistan	139	600	600
North Korea	0	2000	2000
Total	64796	93396	103826

Source: Hagan (1998)

Table 9.7 Change in shares (percentage points) of alternative energy sources in electricity generation under stabilization relative to the baseline in 2010

	Coal	**Oil**	**Gas**	**Nuclear**[(a)]	**Renewables**
United States	-18.1	-0.6	- 1.6	+14.1	+ 6.3
European Union	-21.2	-1.0	+ 1.7	+16.3	+ 4.2
Japan	-10.8	-8.0	- 8.2	+18.3	+ 8.6
Canada	-12.4	-1.0	- 0.3	+ 2.9	+10.8
Australia	-50.5	+2.2	+ 3.0	0.0	+45.4
New Zealand	- 2.4	-0.1	-14.0	0.0	+16.5

Source: ABARE, 1995

Note: (a) These results do not take into account any barriers to the expansion of nuclear power in the US, Canada, the EU, and Japan.

Table 9.8 Typology of potential international spillovers from mitigation strategies

Spillovers / Policies and Measures	Benefits from technology improvement	Impacts on energy industries activity and price	Impacts on energy intensive industries	Resource transfers to sectors
Public R&D policies	Increase in the scientific knowledge base	↑		
"Market access" policies for new technologies	Increase in know-how through experience, learning by doing			
Standards, subsidies, Voluntary Agreements	New cleaner industry / product performance standards			
Carbon taxes	↑ Price-induced technical change and technology diffusion	Reduction of activity in fossil fuel industries Lower international prices, negative impacts for exporters, positive for importers, possibility of a "rebound effect"	Carbon leakages, positive impacts for activity, negative for envir. in receiving country	
Energy subsidy removal			Reduced distorsions in industrial competition	
Harmonised carbon taxes				
Domestic emission trading		↓	Distorsion in competition if differentiated schemes (grandfathered vs. auctionned)	
Joint Implementation, Clean Development Mechanism				Technology transfer
International emission trading				Net gain when permit price is superior (not equal) to average reduction cost

Table 9.9 Effects on sectoral output of Japan (in per cent) of an ad-valorem fuel tax

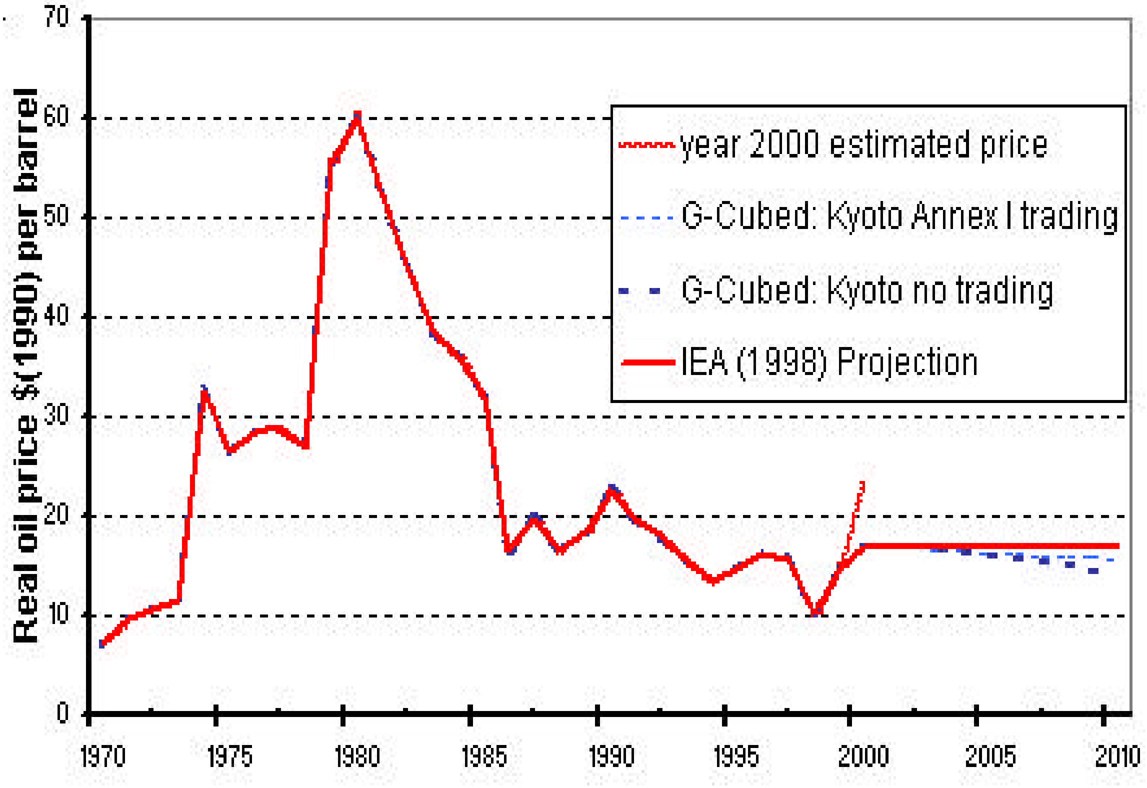
		change of output (%)	
sector	Japan only	OECD	World
Agriculture	0.0998	0.0649	-0.0295
forestry	0.1744	0.2044	0.0687
mining	0.0488	0.1311	0.1415
oil and coal	-0.3983	-0.1212	0.6689
chemistry	-0.5143	-0.3929	-0.3884
metal	-0.1619	-0.1032	0.0126
other manufacture	-0.0604	-0.0065	-0.05
elec. water, gas	-0.3081	-0.3145	-0.308
transportation	0.0548	0.048	0.0364
other services	0.0349	0.0376	0.0364
capital goods	0.0007	0.0797	0.1078

Source: Ban, 1998.

Table 9.10 A comparison of top-down and bottom-up modelling methodologies

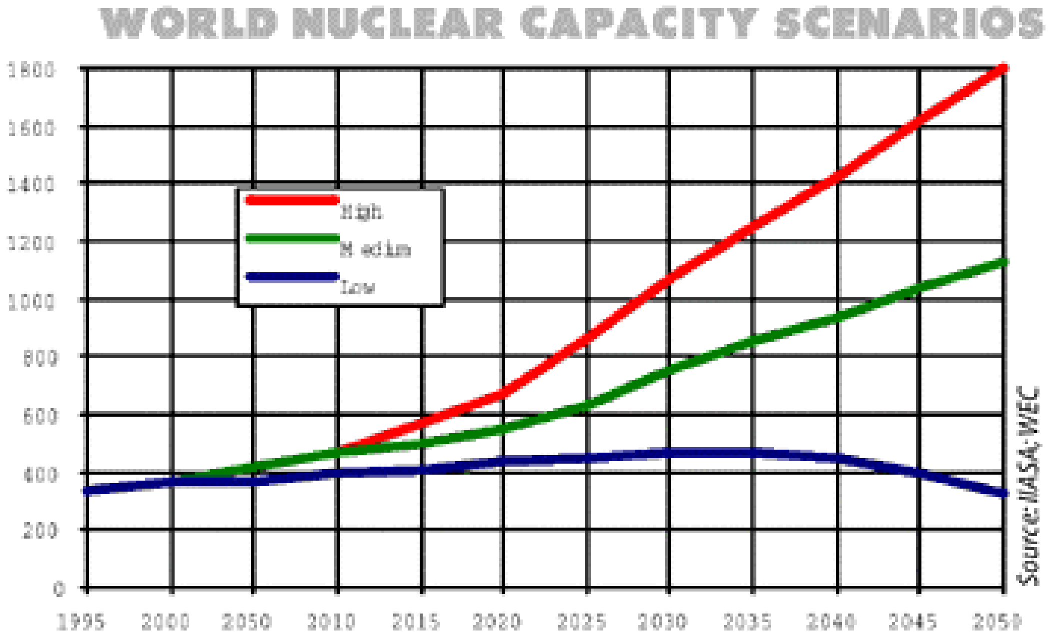
Treatment	Top-down	Bottom-up
Concepts and terms	Economics-based	Engineering-based
Treatment of capital	Homogeneous and abstract concept	Precise description of capital equipment
Treatment of technical change	Trends rates (usually exogenous)	Menu of technical options
Motive force in the models	Responses of economic groups via income and price elasticities	Responses of agents via discount rates
Perception of the market in the model	Perfect markets are usually assumed	Market imperfections and barriers
Potential efficiency improvements	Usually low with assumption of all negative cost opportunities utilized	Opportunities for no-regret actions identified

Source: Bryden *et al*. (1995)



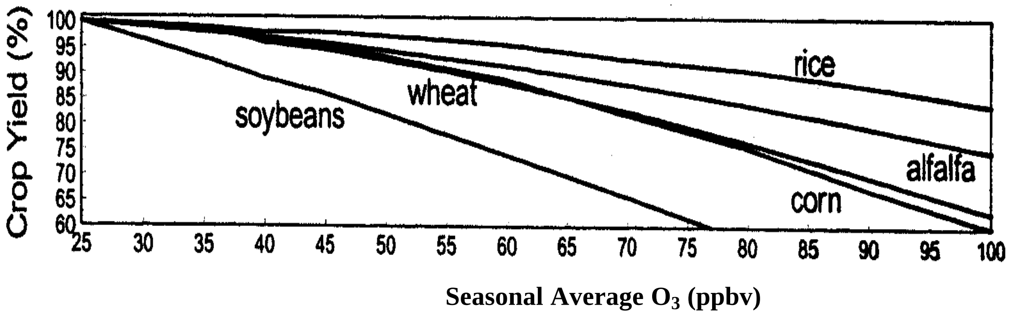
Note: The oil price shown is that of UK Brent deflated by the US GDP deflator. The year 2000 estimated price is based on actual prices January to August and futures prices September to December.
Sources: IMF, International Financial Statistics, August 2000 and various earlier issues, IEA (1998b) and McKibbin *et al.* (1999).

Figure 9.1: The real world oil price and the effects of achieving the Kyoto target.



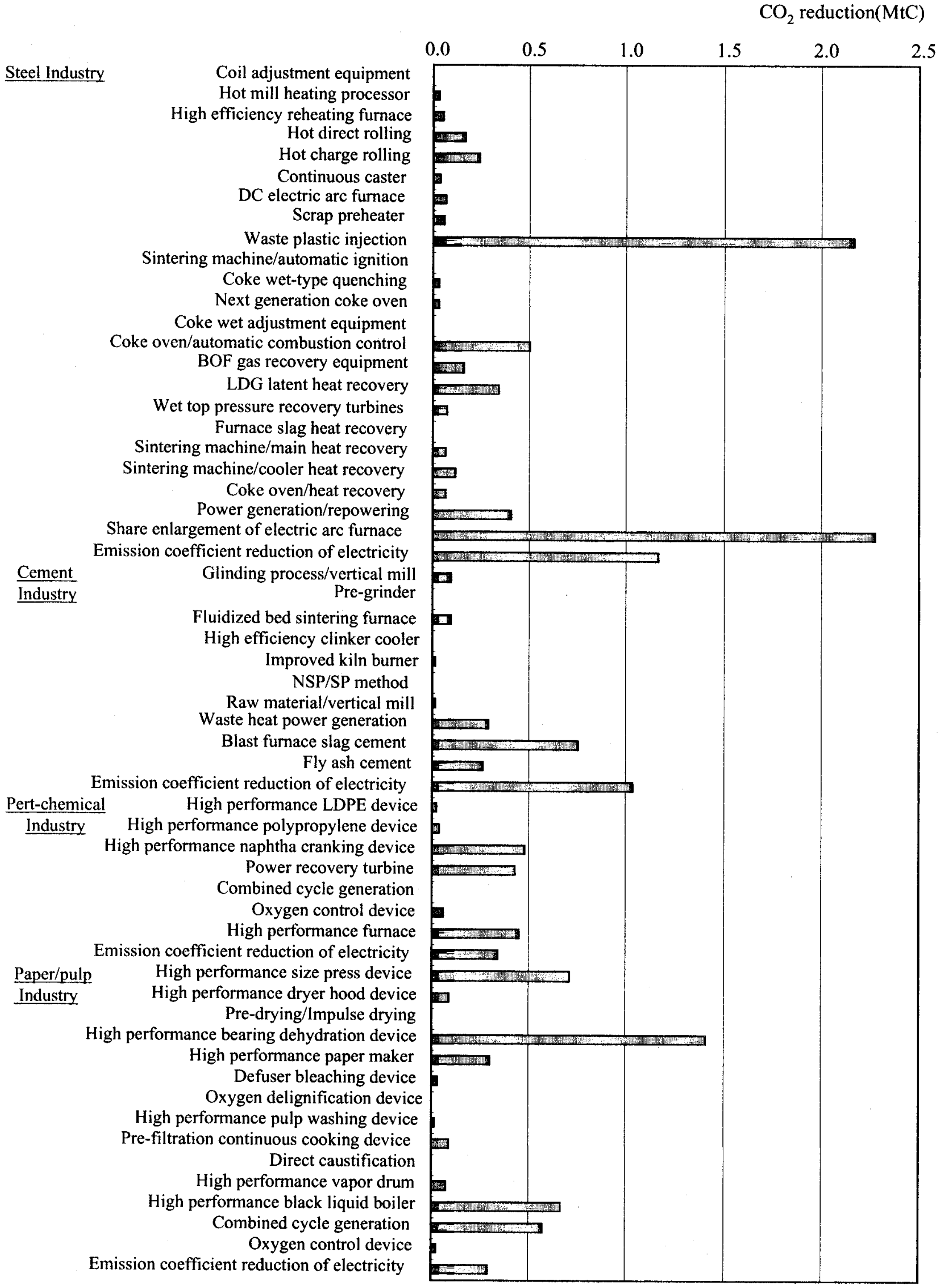
Source: World Energy Council, “Global Energy Perspectives”, Cambridge University Press, 1998.

Figure 9.2: Projection of world nuclear capacity to 2050 in million tonnes of oil equivalent (WEC, 1998)



Source: China-MAP *et al*. (1997)
Note: Wiebull Parametric Fit of data from Adams *et al*., (1989)

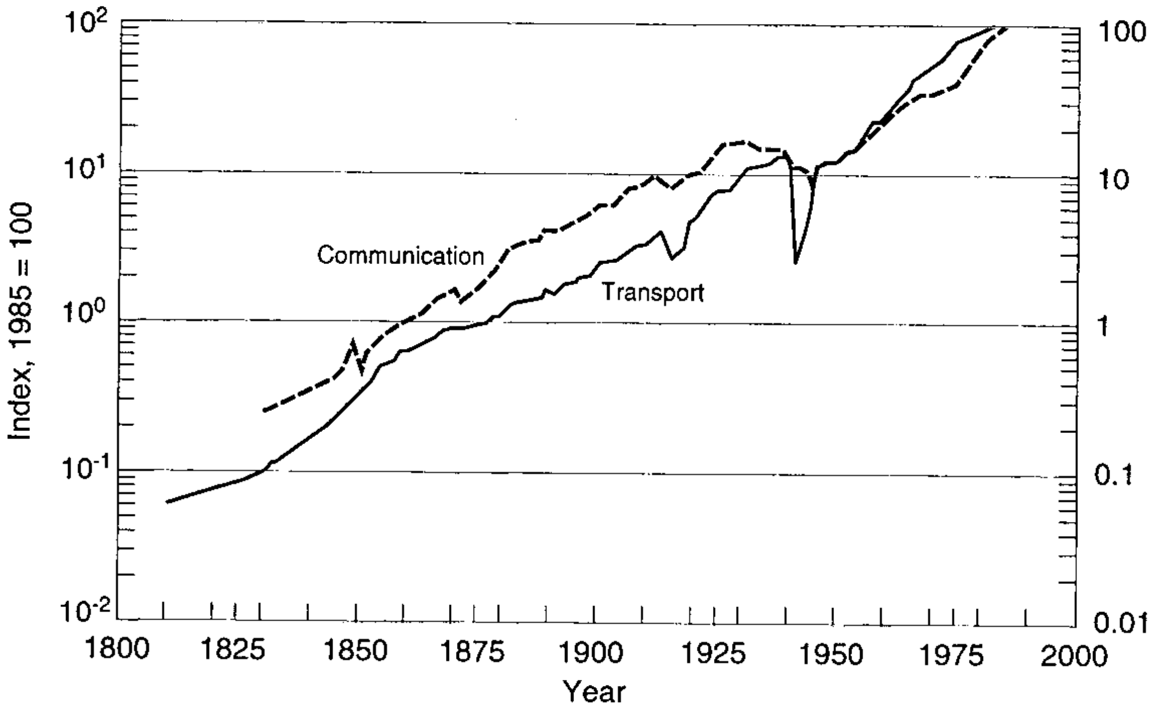
Figure 9.3: Impact of ozone on agricultural crop yields



Source: Kainuma *et al.*, 1999a.

DC: Direct Current; BOF: Basic Oxygen Furnace; NSP: New Suspension Preheater; LDPE: Low Density PolyEthylene; LDG: Linz & Donawitz Gas (The name of the developper's company name); NSP/SP: New Suspension Preheater/ Suspension Preheater

Figure 9.4: Contribution to carbon dioxide emission reduction by technology options in Japan in 2010



Source: Gruebler, 1998: Chapter 7.

Figure 9.5: Historical trends in transport and communication volume indices for France