3.4 PROJECTION OF GLOBAL CLIMATE CHANGE UNDER CARBON TAXATION USING COMPREHENSIVE GLOBAL ENVIRONMENTAL MODEL*

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1. BACKGROUND OF MODEL DEVELOPMENT

The Edmonds Rilley Model (ERM) was developed by J.A. Edmonds and J.M. Rilley at Oak Ridge Associated Universities at the request of the United States Department of Energy, for projecting carbon dioxide emissions from fossil fuel on a long-term basis. It was used twice as the standard model by the United States Environmental Protection Agency, when they conducted studies on climate change in 1983 and 1988. IPCC is also using this model as the base of their forecasting work. Today, some revised versions are in wide use, with no fundamental changes, made just some differences in details, compared with the original model. Major changes include the more complicated treatment of conventional energy resources, subclassification of energy consumption sector in the developing countries, coalition with end-use models, and the inclusion of other green-house gases than carbon dioxide. The algorithm for searching the equilibrium point becomes more efficient.

The U. S. Environmental Protection Agency has assembled models and information on the generation, emission and circulation of green-house gases in the earth, and named it atmospheric stabilization framework (ASF). At the center of which is the ERM.

The model discussed in this paper is based on the ASF which is transferred from U.S.EPA. Submodules and input data of the model were added, replaced, or revised by the present author.

2. OUTLINE AND FEATURES OF THE MODEL

Fig. 1 shows the model framework used in this paper. It is made up of modules for the emission and the absorption of green-house gases, a module for atmospheric chemical reaction, a module for oceanic absorption of heat and carbon dioxide, a module for sea level rise and a module for effect of feedbacks. The emission module is divided into two parts, an anthropogenic part and a natural part.

The anthropogenic emissions depend greatly on scenarios of population changes, economic changes and resources. On which are implemented a wide range of models: a model on carbon dioxide emission from energy consumption, chlorofluorcarbon and halon emissions, cement CO_2 emissions, generation of methane from urban waste landfills, discharges from agricultural activities, discharge and absorption following land use changes. Calculations of the amount of green-house gases released and absorbed

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are input into the in-earth circulation model, and are used in estimates of their concentrations in the atmosphere, the amount absorbed into the oceans, or the rise in temperature and sea level as a result of atmospheric transport and chemical reactions of GHGs. As temperature and GHGs concentration rise, the demands for energy consumption, primary production of plants and many other GHGs emissions and absorption activities are altered. Such feedback effects are also built into the model.

The energy submodel, one of the most important part of the model, is different from the popularized version of ERM in the following respects. The period of calculation is from 1985 to 2100, and the initial values are the actual figures of the first year. The supply cost of conventional energy resources is calculated based on resource cost curves, which is an expansion of the 1989 version of ERM distributed by CDIAC(CMP-002/PC/R1). The consumption sectors in the developing countries are made up of three divisions, residential and commerce, industry, and transport as with the developed countries. A more rigid handling is made of the price differences between imported energy and domestically-produced energy. Energy efficiency (energy service/secondary energy input) or the emission rate for is computed on the basis of scenarios for energy consumption technology and those for the introduction of gas reduction technology, worked out by region, by consumption/conversion division, and by fuel. The green-house gases to be handled in the energy submodule are CO_2, CH_4, N_2O, CO, and NOx, whose discharges were computed.

3. MAIN ASSUMPTIONS OF SIMULATION

As for the standard scenario, I precluded measures to control the emissions of gases. Then, optional cases were concentrated on taxing a fossil fuel consumed according to the amount of carbon dioxide generated. The tax is added to the primary energy prices, assuming proportionality with the discharge of carbon dioxide, collected uniformly throughout the world from 1990 to 2100, with no tax recycling except in cases discussed later.

The population, a premise of the simulation, is assumed at 10.42 billion in 2100 as projected by the World Bank. As for labor productivity, the growth rate of GNP before modified with the energy prices is assumed to average 3.0%-3.5% annually for the developed countries by the end of this century and then dips by 0.5% every quarter century to 2.5%, 2.0%, 1.5%, and 1.0% during the next century. While the figure for the centrally planed economies and the developing countries, which is 4% to 5.5%, will drop to 2%-3.5% by the end of the next century.

As for energy efficiency, this model takes into account two factors. The first is innovation of combustion technology. The second is an autonomous improvement of combustion and service efficiency not included in the former factor. A using of stock capital approach for replacement of energy facilities coupling with prescribed energy conservation and innovation scenario was used in this part of the model. Fig. 2 is a schematized view of energy demand in this model.

The quantity of carbon dioxide derived from the consumption of energy is directly correlated with the amount of energy consumed. However, generations of methane and nitrous oxide depend greatly on the way fuels are consumed. Also, regarding nitrous oxides, the effect of control devices ought to be considered. Therefore, in calculating the discharge of GHGs, it is necessary to start from the end use structure of energy consumption similar to Fig. 2. Such calculations are made in the model. About renewable energy resources, up to 75% of the hydraulic energy resources are assumed to be tapped, while the cost of solar energy can be reduced to U.S.$0.06 per kwh by 2030 (solar option).

The taxes collected are assumed not to be refunded. What effect will be produced if all or part of the tax revenues is earmarked for environmental protection in other areas than the energy division? Trials of revenue investigations for land use are made in this paper, in particular for sustaining and increasing tropical forests. The effects are limited chiefly to cutbacks or to the absorption of GHGs with the control of clearing of forests and afforestation, without taking into account other environmental and economic effects. The standard scenario of forest clearing without any countermeasure is referred from the 1991 IPCC Reference Scenario (IRS 91) prepared by IPCC (Swart et al. 1991). This scenario envisages the forest clearing rate standing at 20 million ha in 1990, peaking at 25 million ha in 2035 and then beginning to fall due to the slowdown in population increase and a shortage of forest itself. The initial cost of forest improvement is put at US$400 per ha, and then for the following 30 years, it will be averaged at US$100 (present value) per ha per year. The same figures are used in order to avoid clearing of forests as well as new afforestation. The afforestable areas comprise 705.8 million ha (Grainger, 1988) of land that had recently been wooded or degraded, and also those forests that will be destroyed in the future.

The average yearly amount of absorbed carbon dioxide as a result of afforestation will be 1.7tC per ha for the following 100 years (IPCC, 1990) and most of this will be absorbed over scores of years after afforestation. This characteristic is dealt with in a dynamic forest growth model.

The discharge of gases from sectors other than the energy and land use is computed based on activity scenarios for each sector. For instance, the emissions of chlorofluorcarbon and halon are computed on the basis of regulations adopted by the Second Conference of the Montreal Protocol and that of methane gas from city wastes landfill is calculated with urban population variations and per-capita GNP changes. However, these emissions, as far as this paper is concerned, are identical for the standard scenario and optional scenarios.

4. STANDARD CASE

Fig. 3 refers to the standard case. It describes time-sequential changes in GHGs emissions from fossil fuels and other anthropogenic sectors, the concentration of GHGs in the atmosphere(converted into equivalent carbon dioxide concentration from the view point of solar radiation), the temperature increase and the rising of the sea level.

CO_2 emission derived from fossil fuels stood at 5.73 billion tons Carbon in 1990 and those from anthropogenic factors (inclusive of emissions from fossil fuels, land use, and cement production) were 7.47 billion tons C, and will soar respectively to 22.02 billion tons C and 22.66 billion tons in 2100. Their atmospheric concentration is 386.9 ppmv in terms of CO_2 equivalent (CO_2 level was 354.9 ppmv) in 1990 but will shoot to 1221.4 ppmv in 2100 (CO_2 level: 912.ppmv). The temperature rise will reach 4.5°C in 2100 (with 1830 as the base year and 4.1°C with 1985). The rise of the sea level will amount to 66.1 cm in 2100 as against 1985. These figures depend on the climate sensitivity that indicates the global temperature rise in case of CO_2 doubling. The case given in the figure is for 3°C.

5. UNDER MITIGATION SCENARIOS

Two groups of scenarios are dealt with. The first group envisages introducing a uniform carbon tax throughout the world, set at a fixed level constantly throughout the simulation period. Figs. 4-6 show decreases of primary energy consumption, fossil fuel consumption, fossil fuel-derived carbon dioxide emission, and GNP. The increase of

fossil fuel consumption will be slowed down, starting with a tax of US$10 per ton C(1975 value). With a tax of US$100 per ton C, the emissions of CO_2 at the outset of the next century will be kept at the present level. However, after that, the emissions will begin to grow again. Figs. 7-9 show rises in the GHGs concentrations, temperature and the sea level. The solid line shows figures in the absence of emission control measures in non-energy sectors, while the dotted line indicates figures with a tropical forest improvement, financed by carbon tax revenues. By the end of this century, about 800 million ha of forest, whose improvement envisaged in the scenario will begin with a low tax rate of US$5 per ton C emitted. But almost all uptake capability of carbon will be exhausted by the second half of the next century. By that time, about 2.5 billion tons of carbon per year will be absorbed. This effect combined with the reduction of fossil fuel consumption induced by carbon tax will lower the growth rate of the GHGs concentration. Even at this stage, a tax of at least US$100 will be needed in order to vanish the increase of CO_2 emission. If all the GHGs are the concerns, they will not be stabilized even with a tax of US$200 per ton of carbon. The higher increase rate of the CO_2 concentration will come back in the second half of the next century when the forests lose their capacity to assimilate carbon.

The second group of scenarios calls for limiting emissions of anthropogenic carbon dioxide and other green-house gases emissions. Several cases were projected, depending on whether the control is focused on carbon dioxide only or on all greenhouse gases (CO_2, CH_4, N_2O, CFC-11, CFC-12, HCFC-22, CFC-113, CFC-114, CFC-115, CCl_4, CH_3CCl_3, and CF_3Br). Or whether to cover the energy-consuming sector alone or to combine it with afforestation was also considered. Fig. 10 sets 1985 as the base year, and carbon tax rates were given for cases in which the permissible emission growth is limited to 1% per annum, or is frozen at the given level or minus 1%. Where fossil fuel-originated carbon dioxide emissions alone are limited and allowed to grow at 1% a year, the lowest tax rate will be applied. A tax of some US$50 per ton of carbon will keep the growth rate at 1% per annum. In the case where fossil fuel-derived emissions are reduced at an annual rate of 1%, the initial tax rate of about US$40 will have to swell to US$1,000 in 2070. With the emissions frozen at the initial level, the tax rate will rise from US$25 to US$300.

Tax rate changes will show an interesting pattern where all the greenhouse gases derived from human activities are considered as the controlled target. In this case, the tax rate will be seen a certain fall at the beginning of the next century mainly for two reasons. One is the effect placed on CFC by the Montreal Protocol. And the other is reforestation. It will prove most effective at the turn of the century and then become less effective. Fig. 11 traces the fall of GNP prompted by the imposition of taxes. The rate of decrease shows nearly the same pattern as the tax rate.

The targets described above for emission restrictions are very expensive from the viewpoint of tax payments, but are far from sufficient in terms of atmospheric stabilization effect. Fig. 12 shows changes in GHGs concentration in the atmosphere, which correspond to the scenario shown in Fig. 10. Even the scenario, which calls for reducing fossil fuel-derived carbon dioxide emissions at a rate of 1% a year, will fail to stabilize the CO_2 concentration level by the end of the next century. Fig. 13 and Fig. 14 show rises in temperature and the sea level. In the case discussed here, the temperature will rise 0.15°C, and in case of the sea level rise, 3.5 cm every ten years.

The carbon tax, as described above, will be effective to some degree in controlling the emission of greenhouse gases, but will fall short of stabilizing the atmosphere. It is essential to undertake comprehensive measures besides individual steps, not only carbon tax and so on.

6. COMMENTS

In this paper, I assessed the effectiveness of the carbon tax using coupling of global models related to the phenomena. The models used are simple ones with extensive parametrization and include many problems. But, they are useful enough to discuss the issue of global warming. I would like to improve the models, strengthen the integration of submodels, and enhance their characteristic features as an integrated model.

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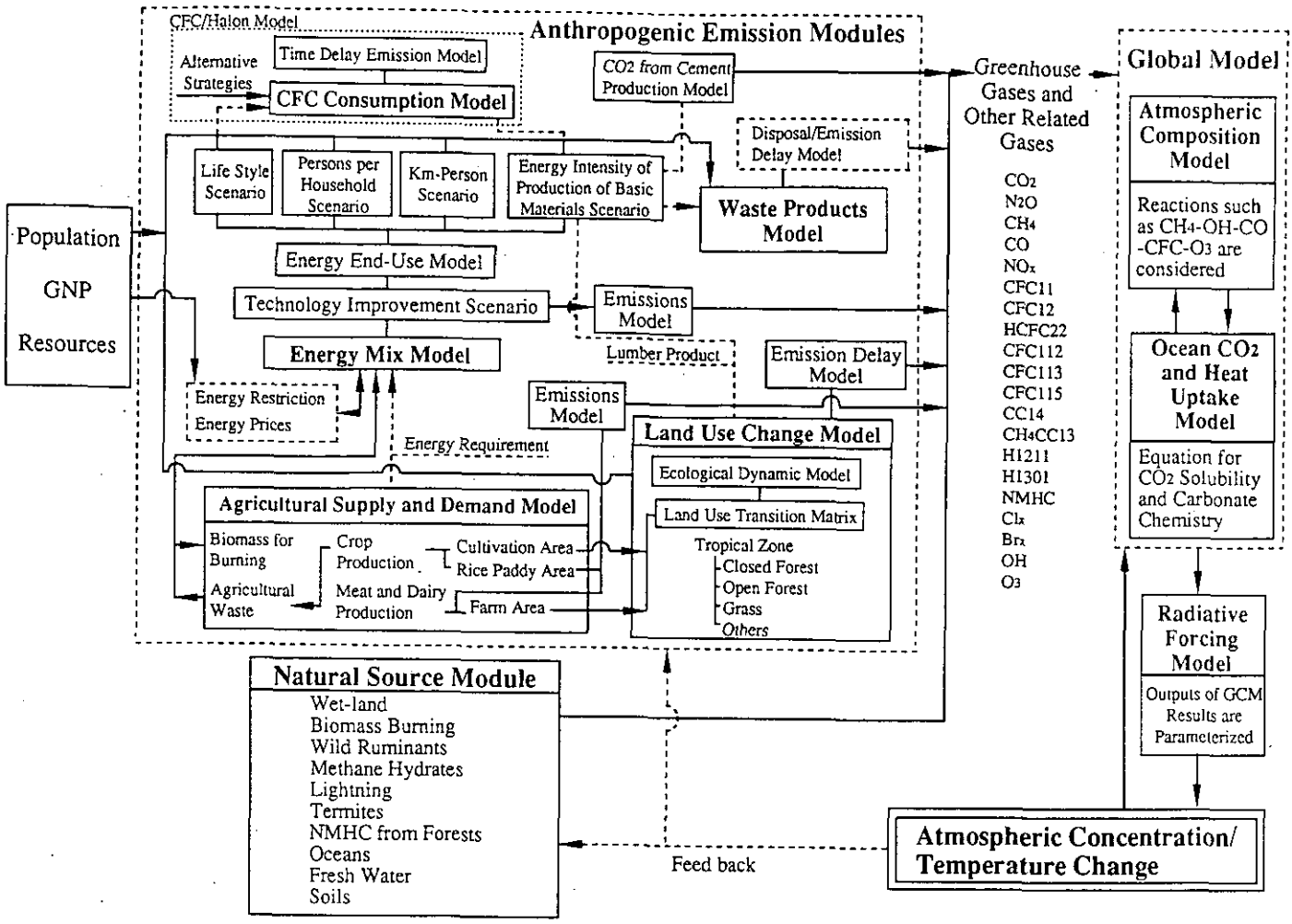

Figure 1 A model frame in this study

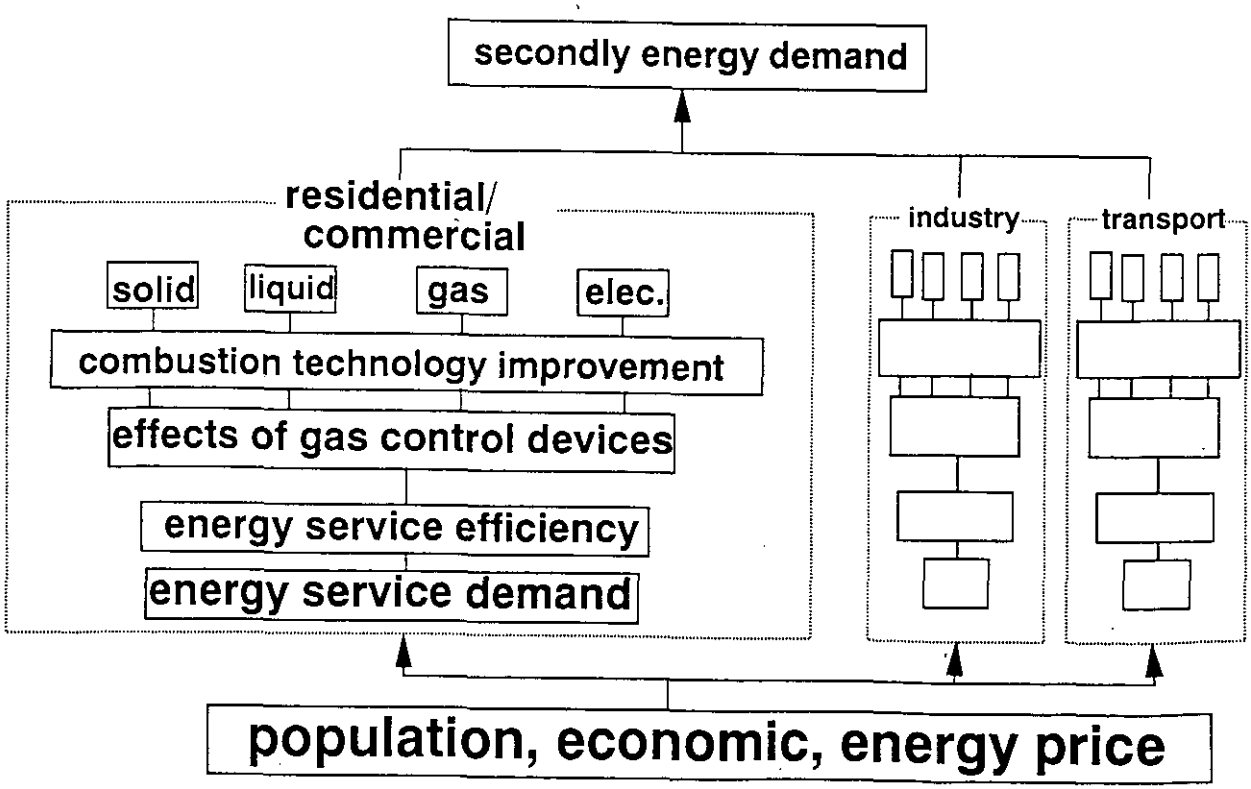

Figure 2 Scheme of calculating energy demands

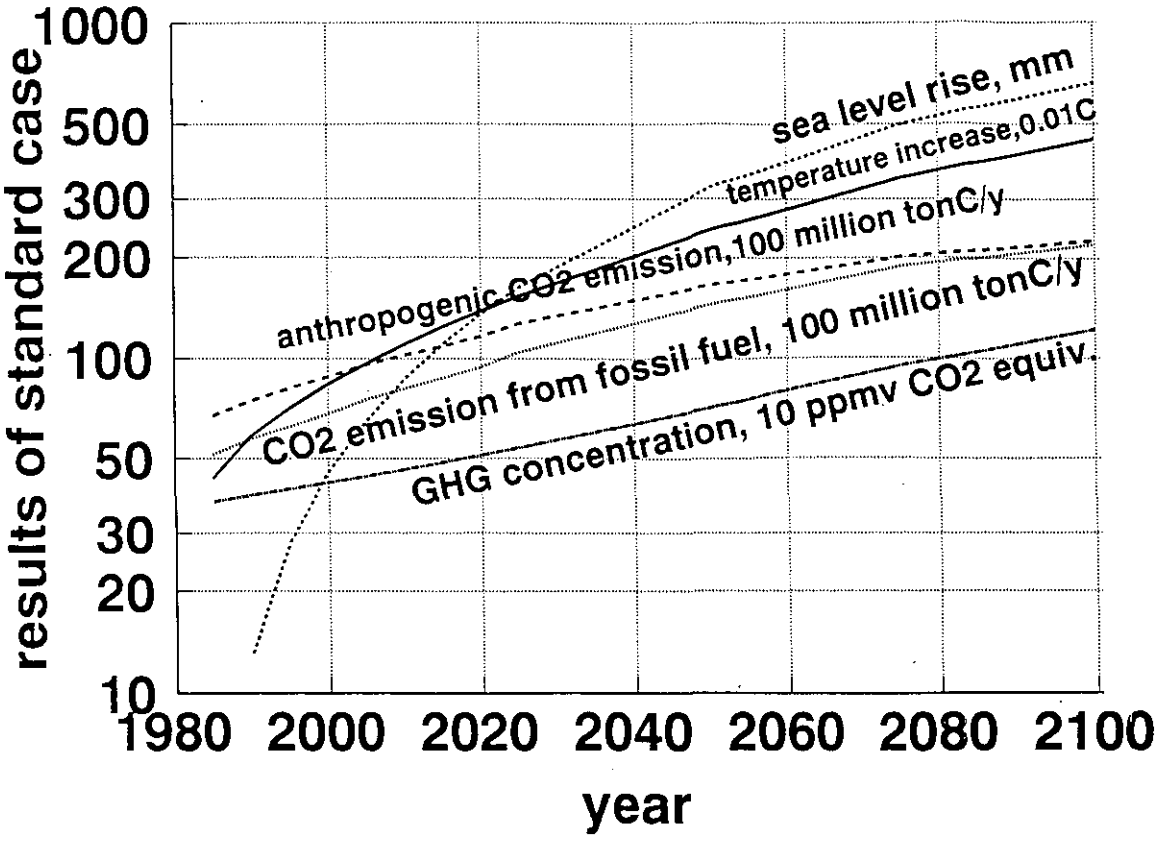

Figure 3 Major results of the standard case

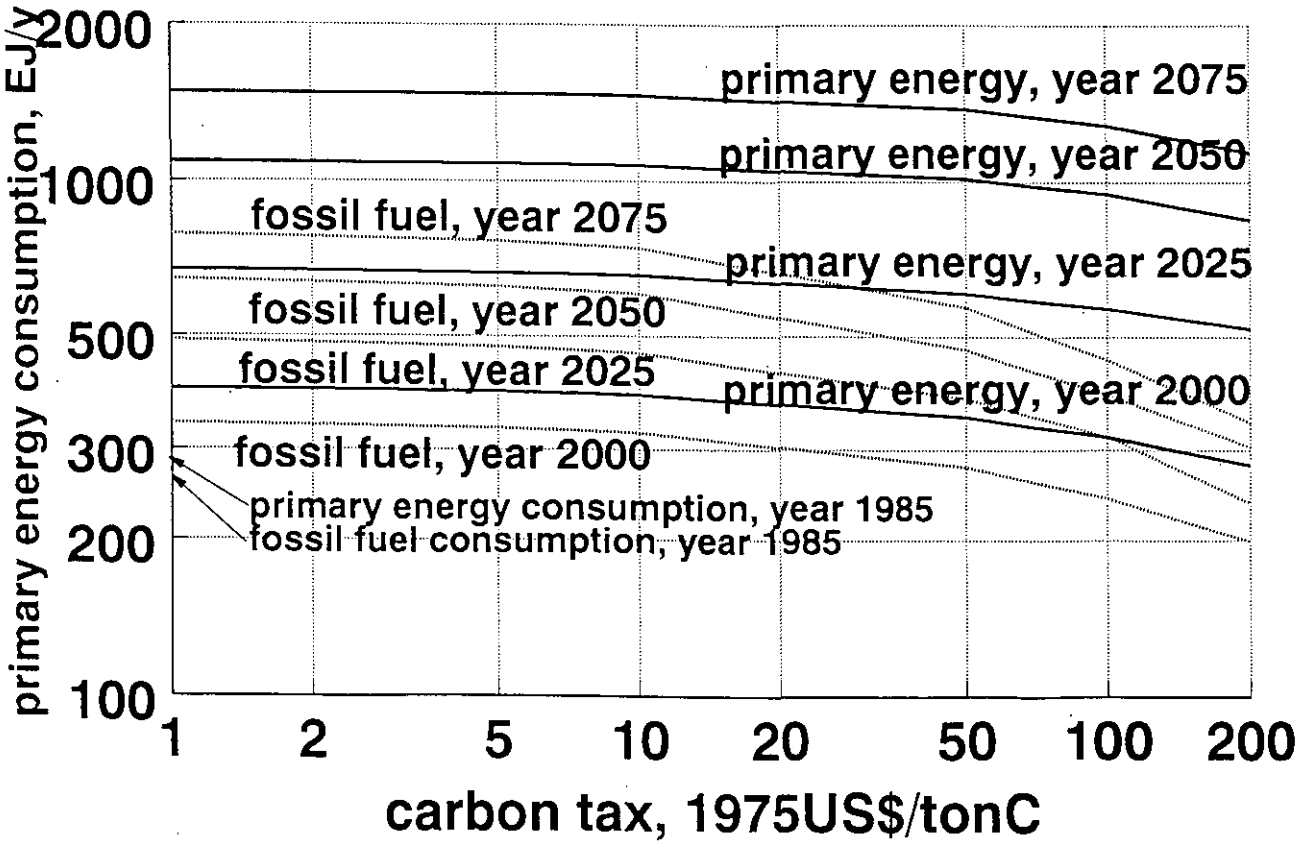

Figure 4 Energy consumption and carbon tax

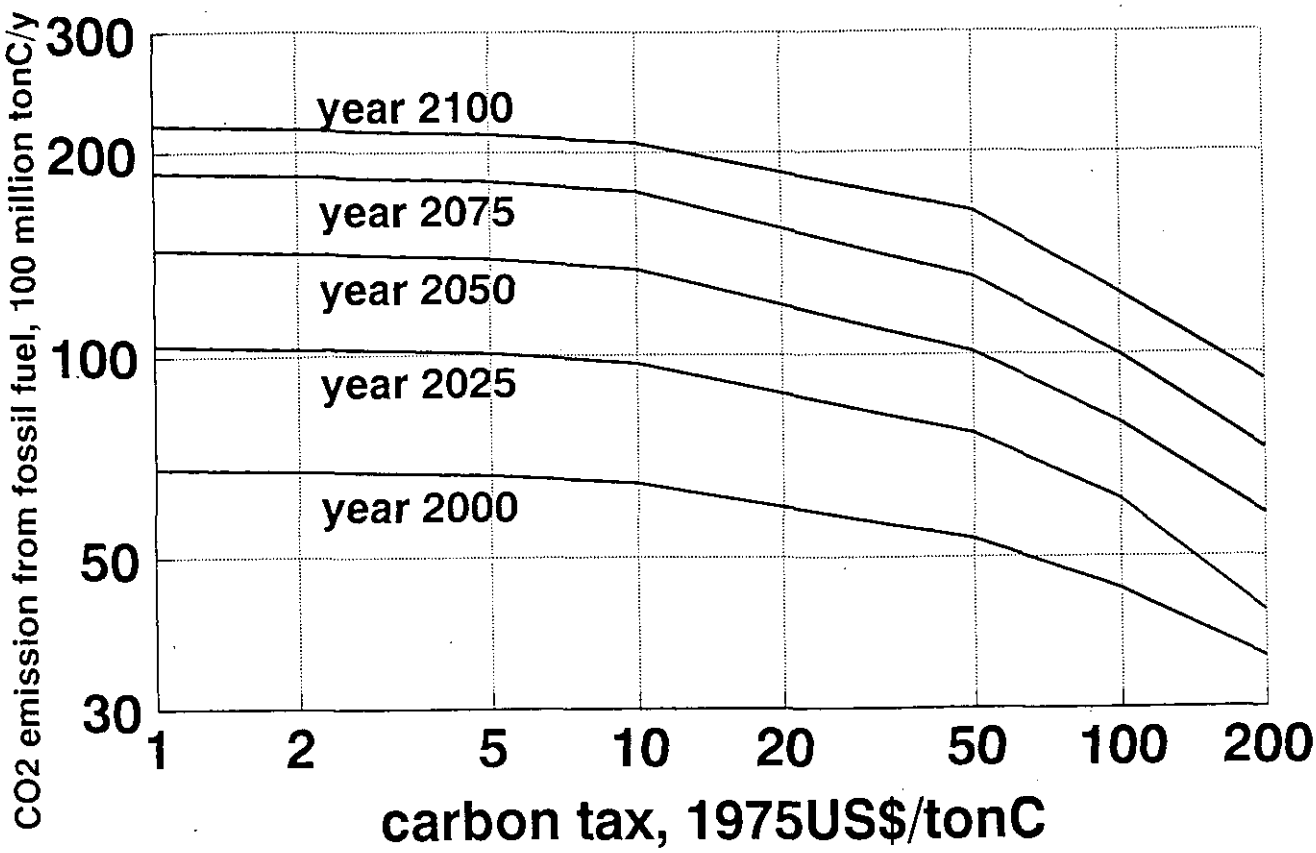

Figure 5 Carbon dioxide emission and carbon tax

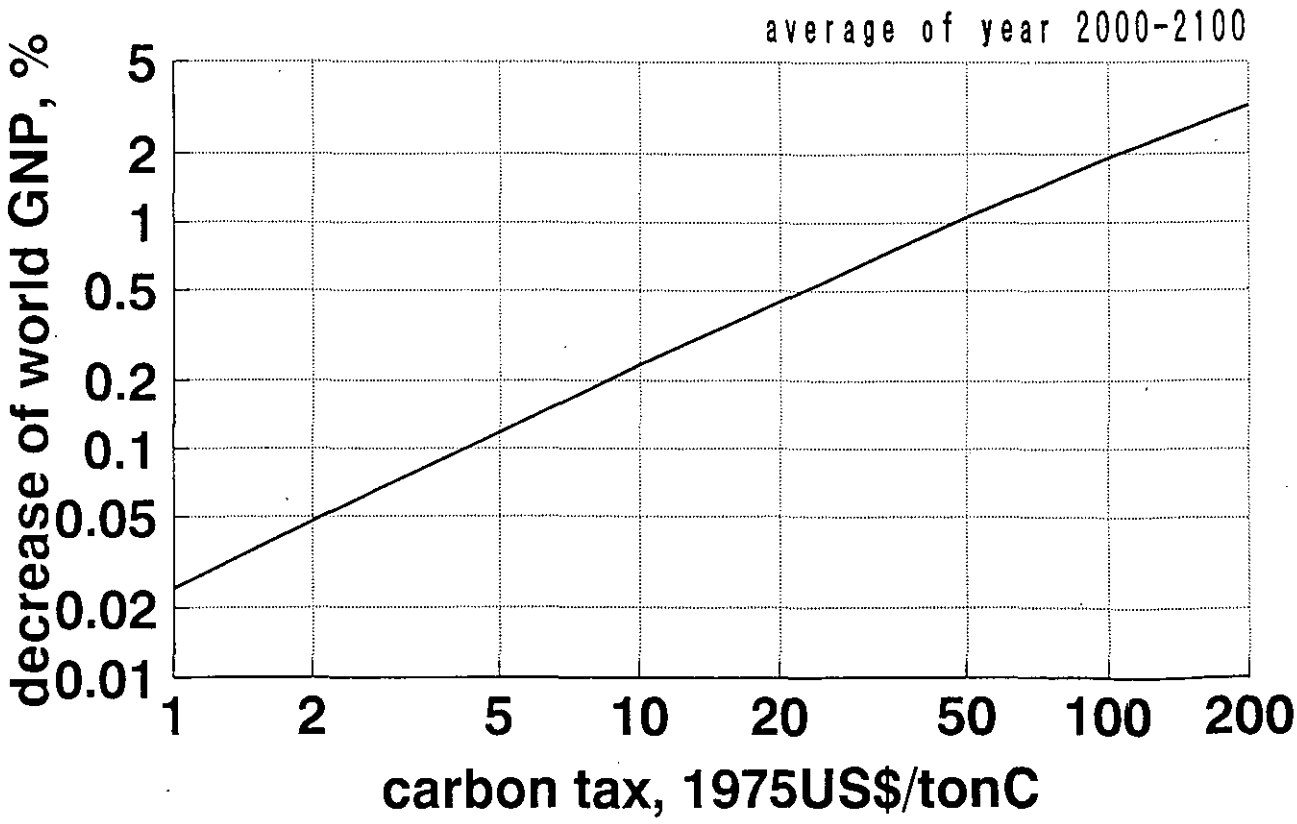

Figure 6 GNP loss and carbon tax

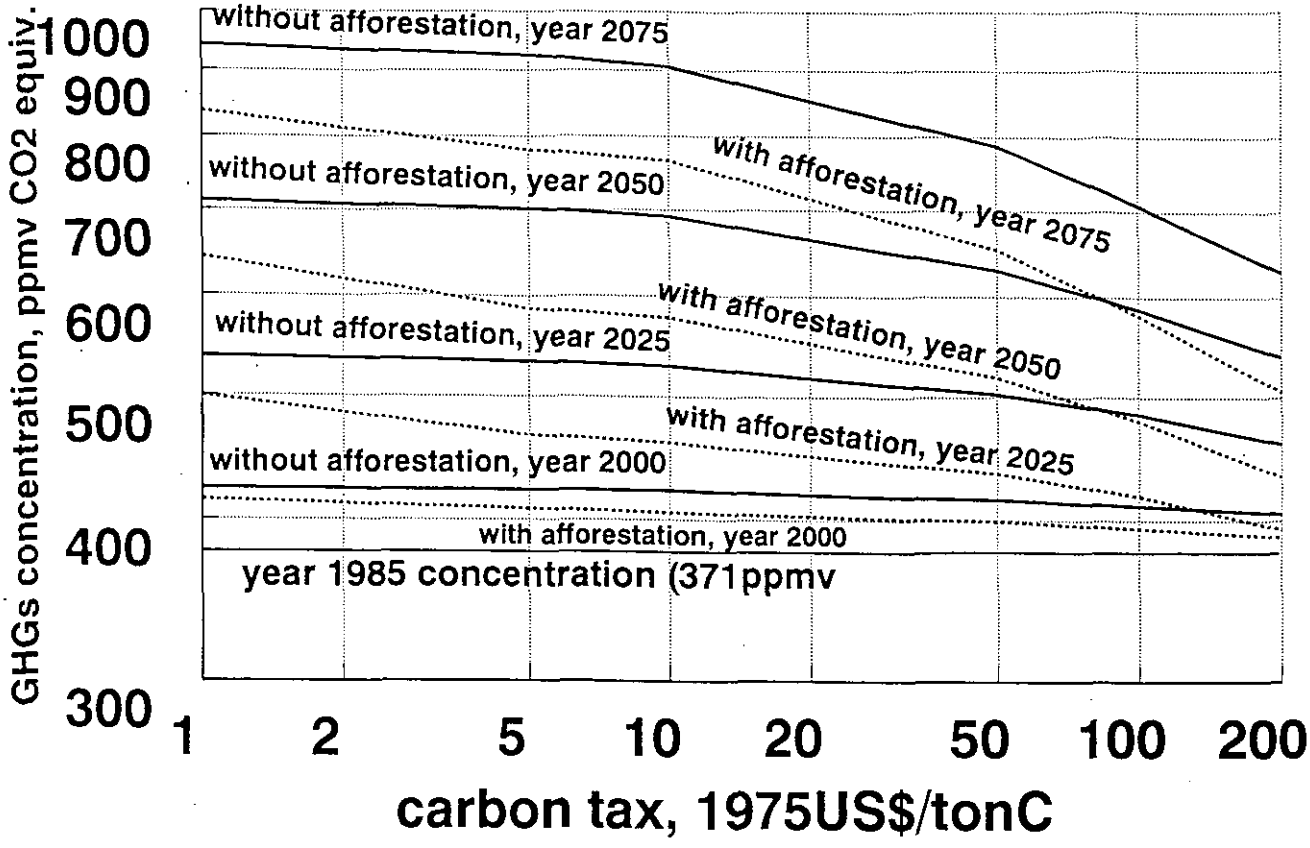

Figure 7 Emission of green-house gases and carbon tax

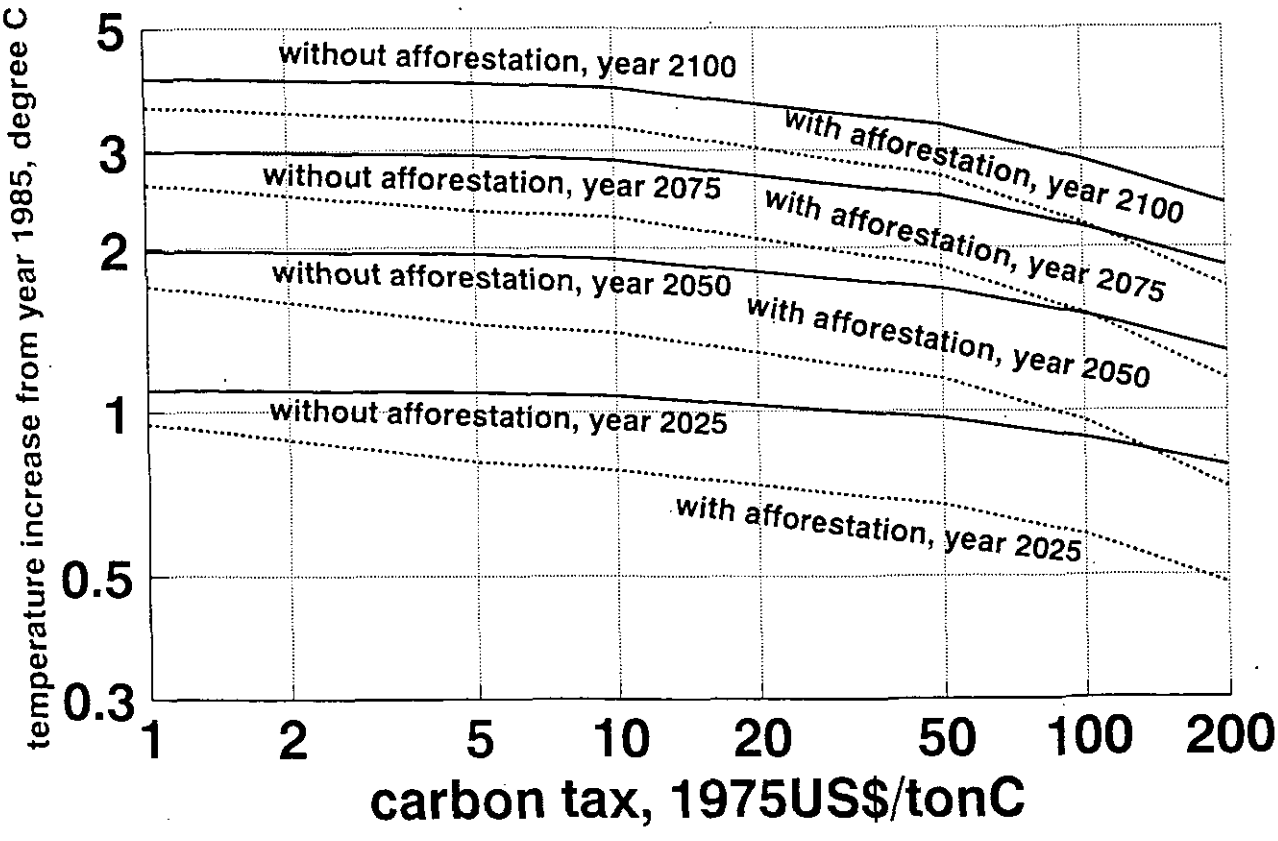

Figure 8 Temperature rise and carbon tax

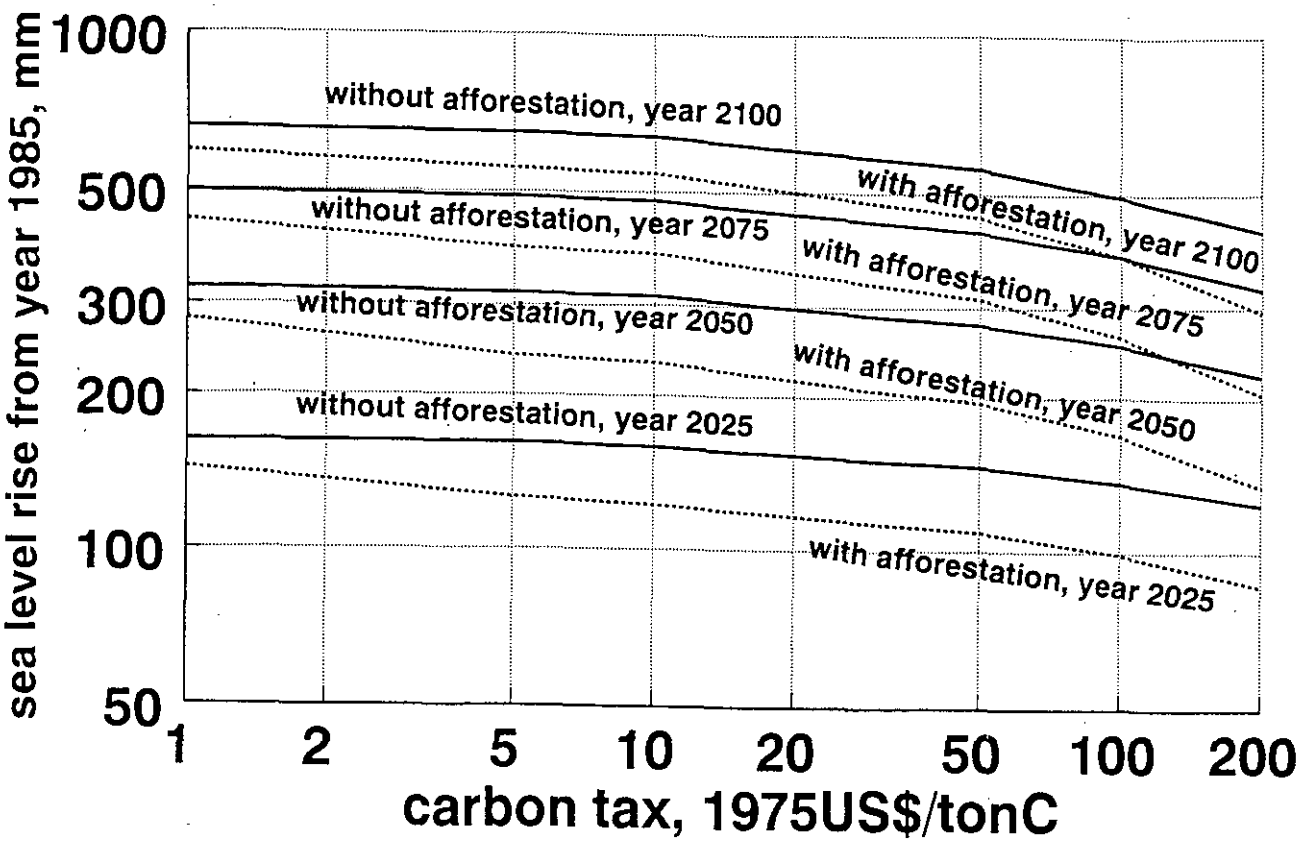

Figure 9 Sea level rise and carbon tax

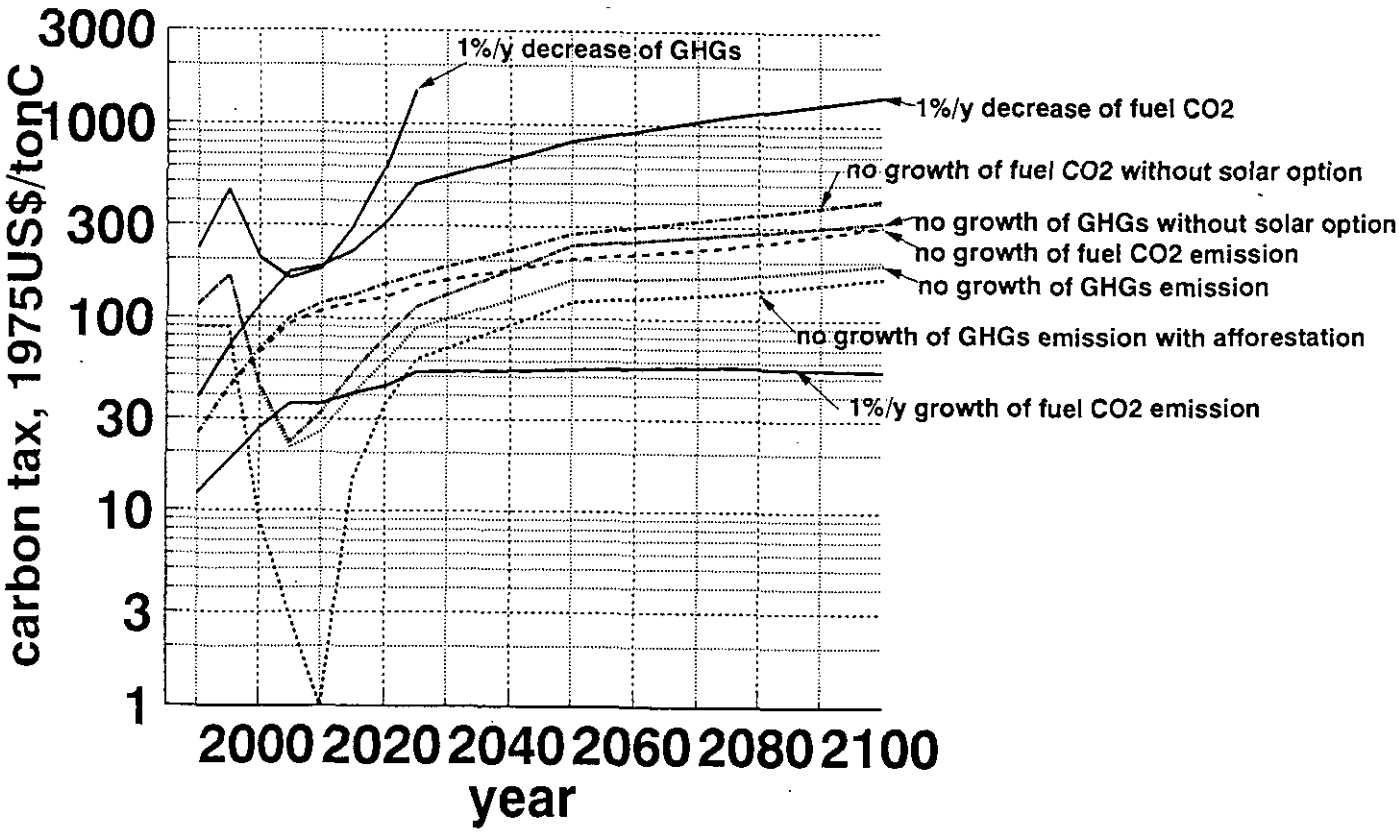

Figure 10 Regulation of GHGs emission and carbon tax

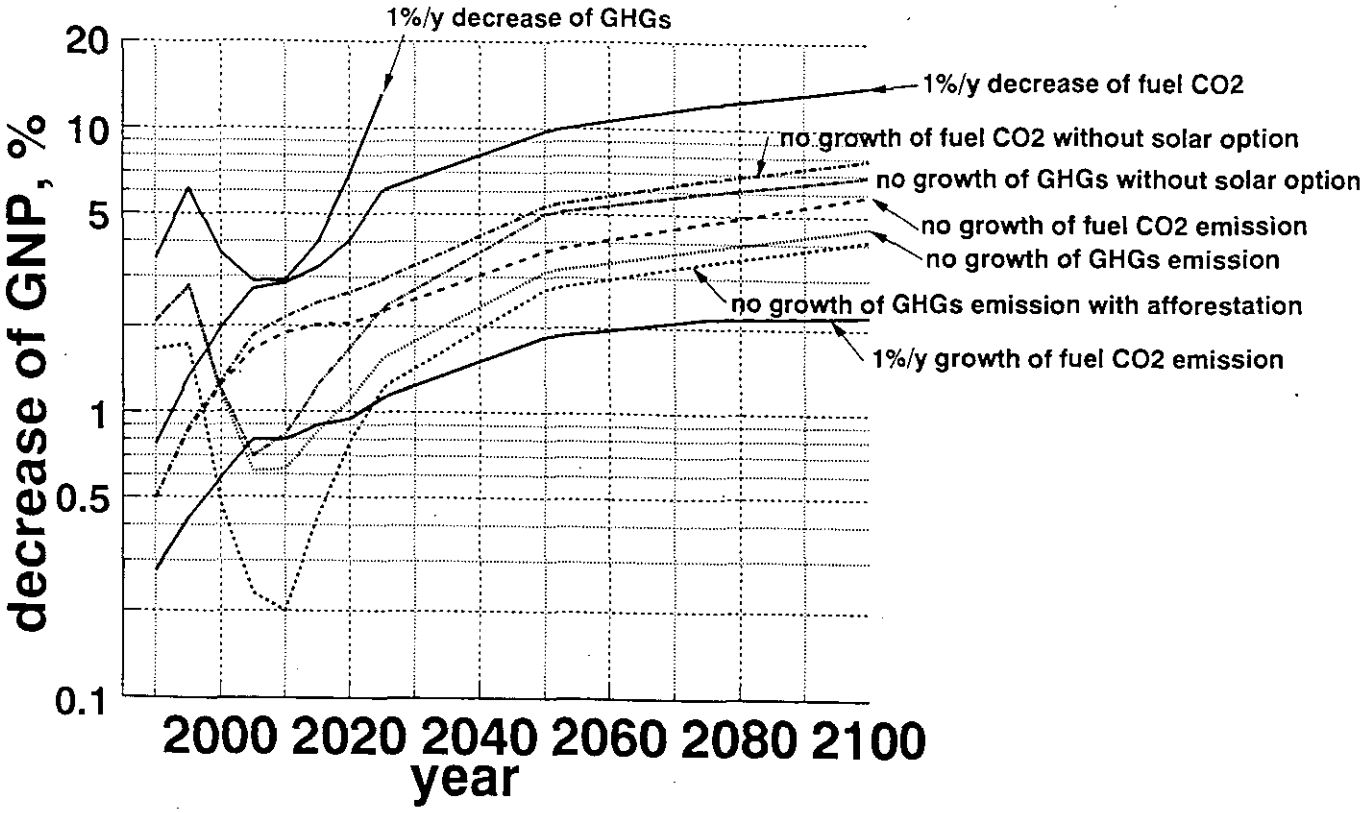

Figure 11 Regulation of GHGs emission and GNP loss

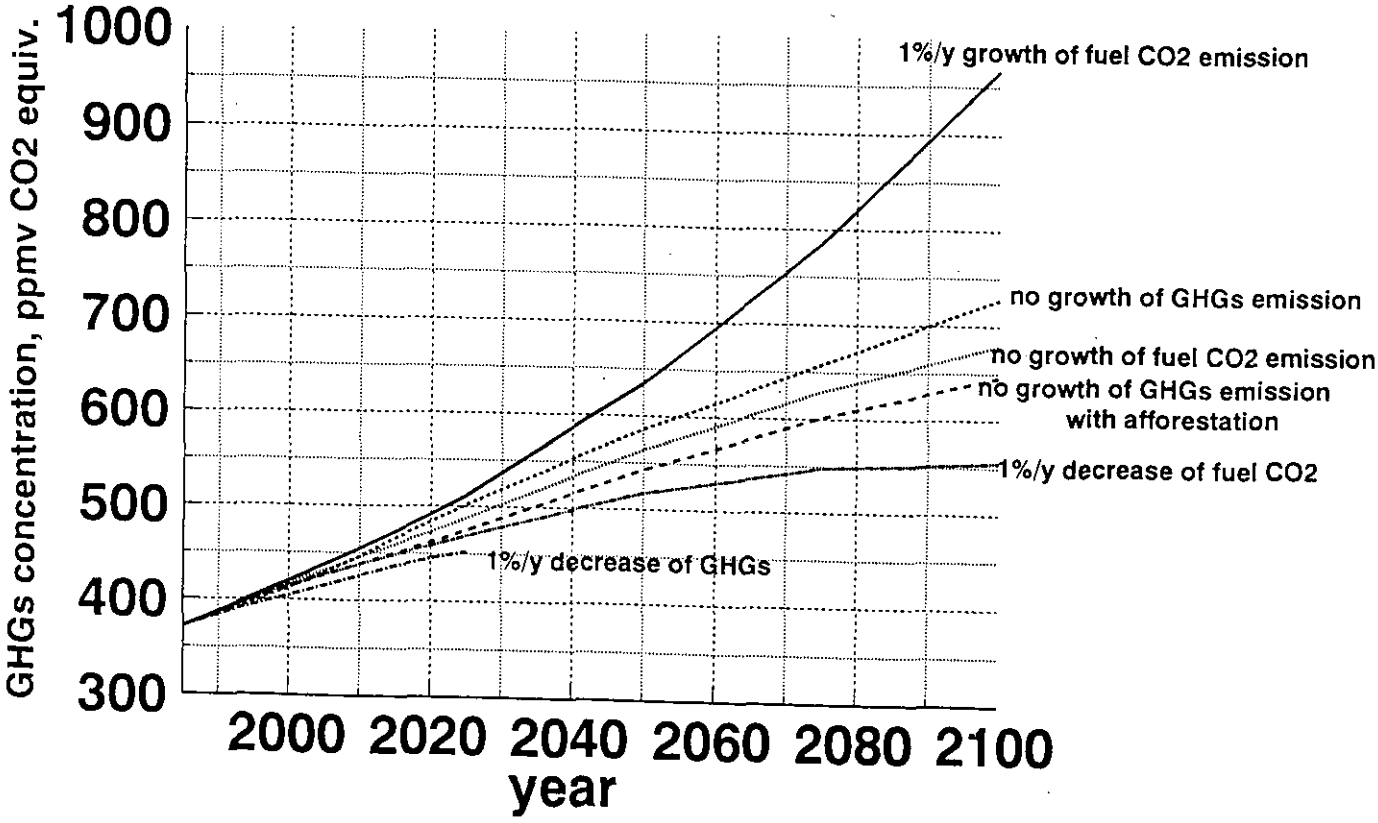

Figure 12 Regulation of GHGs emission and atmospheric concentration

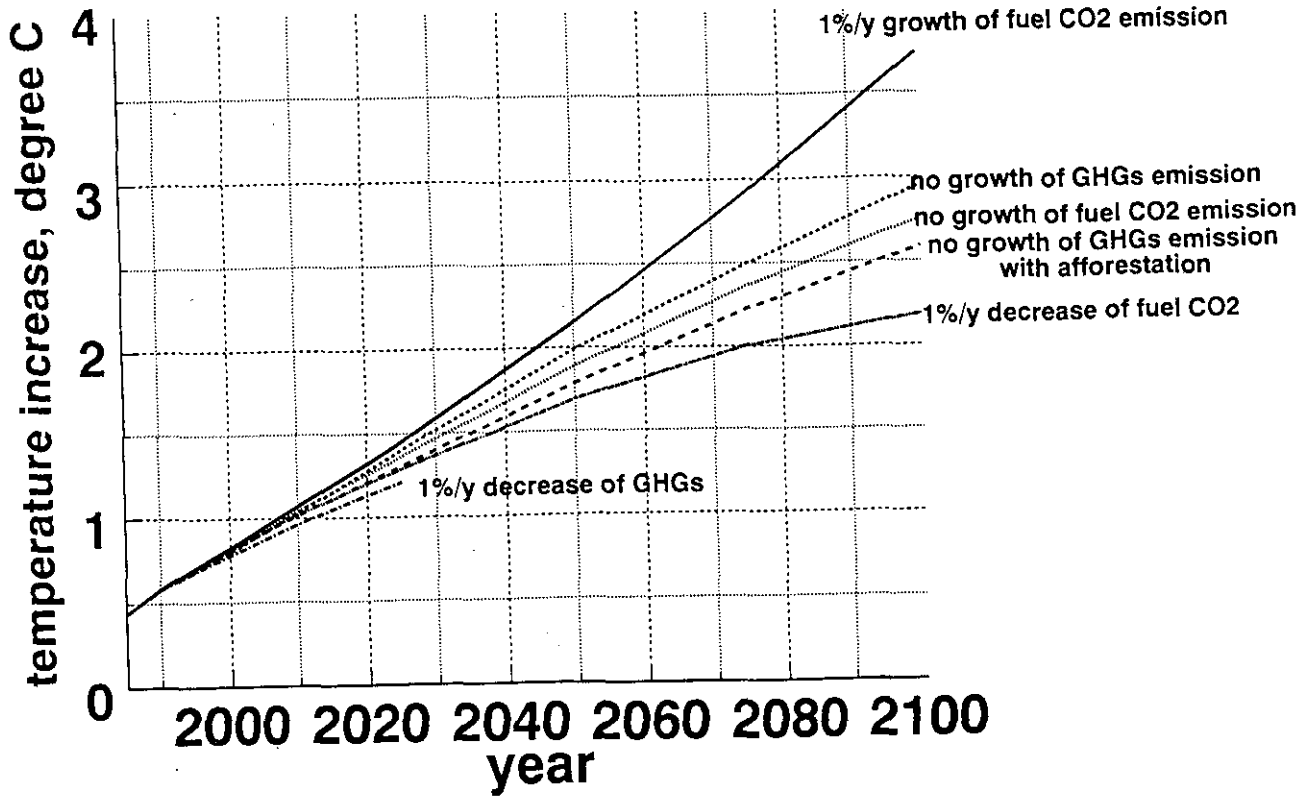

Figure 13 Regulation of GHGs emission and temperature rise

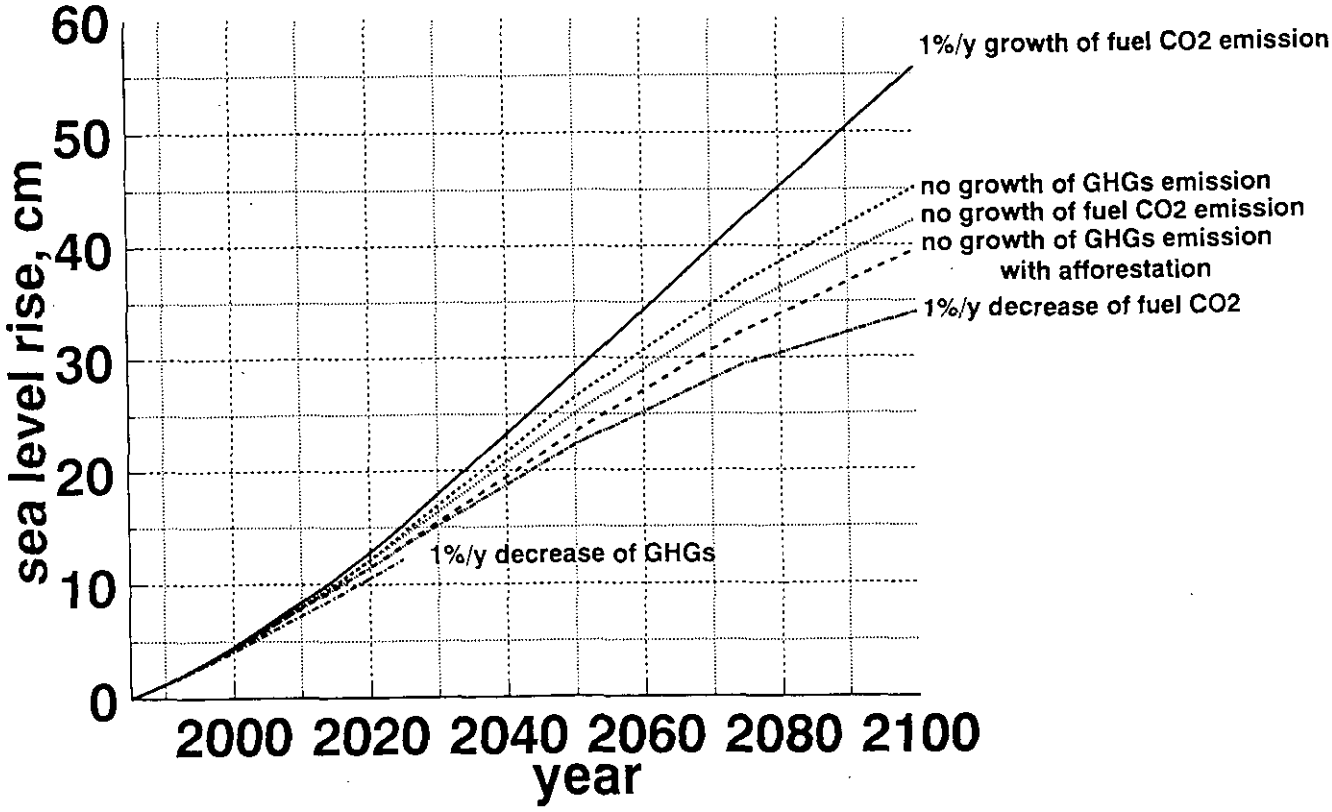

Figure 14 Regulation of GHGs emission and sea level rise