Costs and Technology Role for Different Levels of CO_2 Concentration Stabilization

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Abstract

In order to evaluate costs and technological options by region for various targets of CO_2 emission reduction, we have developed a world energy systems model of 77 region division and 100 year time span. For the evaluation, we conducted three case studies: 1) no-climate-policy, 2) concentration stabilization at 550 ppmv, and 3) stabilization at 450 ppmv. In the stabilization cases, we presumed for Annex I countries except for US to comply with the Kyoto target in 2010, and after 2010 for all the Annex I countries to achieve the UK-proposal target, e.g., 61% and 77% reduction in 2050 and 2100, respectively. The analysis results include that the marginal cost of CO_2 emission reduction in 2100 is about 120 and 290 $/tC for 550 and 450 ppmv, respectively, and that CO_2 capture and storage is important to reduce the stabilization cost in both the stabilization cases.

1. Introduction

The official discussion on the Post Kyoto regimes starts in 2005. In this discussion, the reduction target should be carefully examined from the long-term viewpoint of stabilizing atmospheric CO_2 concentration "at a level that would prevent dangerous anthropogenic interference with the climate system". In addition, it is now widely acknowledged that even a modest level of stabilization can never be attained without emission reduction in developing countries. However, discussion on reduction costs and technological options for emission reduction is inevitable in order to determine the reduction targets for both developed and developing countries. To provide valuable information for the discussion, this paper investigates the costs and technological options for cost-effective measures of CO_2 concentration stabilization using a world energy systems model having a high regional resolution. A higher regional resolution, in general, is desirable even for the global analysis because relatively high transportation cost of energy and existing large regional differences in energy demand growth, natural resources, energy technology level etc. can be taken into account in more detail.

2. Energy Systems Model

The model to be used in this study is briefly described in this section. The model, which we call DNE21+[1], is a linear programming energy systems model of dynamic optimization type. The time span ranges up to the end of the 21st century with representative time points of 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2075 and 2100. To consider existing regional differences and evaluate regional effects, the model divides the whole world into 77 regions: US, Canada, UK, France, Germany, Japan, Australia, New Zealand, China, India, Brazil, Russia, etc. To consider transportation costs of energy and CO_2 in more detail, large area countries, such as US, Australia, China, Russia, are disaggregated into several regions. The total world cost of energy systems is minimized over the whole time period from 2000 to 2100.

The energy supply sectors are modeled in the bottom-up fashion and the end-use energy sectors in the top-down fashion. Primary energy sources of eight types are explicitly modeled: natural gas, oil, coal, biomass, hydro & geothermal, photovoltaics, wind and nuclear. As technological options, various kinds of energy conversion technologies are explicitly modeled besides electricity generation. Some of them are oil refinery, natural gas liquefaction, coal gasification, water electrolysis, methanol synthesis etc. The historical vintages of these technology facilities are taken into account. Five kinds of CCS (Carbon capture and storage) technologies are also considered; 1) injection into oil wells for EOR operation, 2) storage in depleted natural gas wells, 3) injection into coal-beds for ECBM operation 4) sequestration in aquifers and 5) sequestration in ocean.

The end-use sector of the model is disaggregated into the following four types of secondary energy carriers: 1) solid fuel, 2) liquid fuel, 3) gaseous fuel and 4) electricity. Electricity demand is expressed by load duration curves having four kinds of time periods, and the relationship between electricity supply and demand is formulated for each of the four periods. The future energy demand in case of no climate policy is exogenously provided by energy type, region and time point as the reference scenario.

The world divided regions are linked to each other by interregional trading of 8 items: coal, crude oil, synthetic oil, methane, methanol, hydrogen, electricity and CO_2. In addition, CO_2 emission permits are also modeled as an interregional trading item.

3. Input Data Assumptions

Most of the assumed potentials of primary energy and CO_2 storage are based on the GIS data, which are easily processed to generate the corresponding potential for any one of the regions. Table 1 summarizes the world fossil fuel potentials assumed in the model. The world potentials of hydropower, wind power and photovoltaics are assumed to be 14,400 TWh/yr[2], 12,000 TWh/yr and 1,271,000 TWh/yr, respectively. The cost of hydropower is 20–180 \$/MWh; the cost of wind power and photovoltaics is 56–118 and 209–720 \$/MWh in the year 2000, respectively. Table 2 shows the assumed facility costs and the required energy of CO_2 capture technologies and summarizes the assumptions of the potentials and costs of CO_2 sequestration. Technology progresses are considered. For example, the cost reduction of wind power and photovoltaics is assumed to be, respectively, 1.0 and 3.4 %[5] per year up to the year 2050.

Future scenarios of population, reference GDP and reference final energy demands are derived from B2 Marker Scenario of IPCC SRES [8, 9]. Energy savings in end-use sectors are modeled in the top-down fashion using the long-term price elasticity. The elasticity of electricity and non-electricity is assumed to be –0.3 and –0.4, respectively.

Table 1: Assumed fossil fuel potentials in the world

	Anthracite and Bituminous		Sub-bituminous		Lignite
Coal	424		208		253
	Conventional				Unconventional
	Remaining Reserves	Undiscovered (Onshore)	Undiscovered (Offshore)		
Oil	137	60	44		2,342
Natural gas	132	59	52		19,594

Unit: Gtoe (gigatons of oil equivalent); Source: [2,3,4]

Table 2: Assumed facility costs and required energy of CO_2 capture, and potentials and costs of CO_2 storage

	Facility cost (US$/(tC/day)) †	Energy requirement (MWh/tC) †
CO_2 chemical recovery from coal fueled power	59,100 – 52,000	0.792 – 0.350
CO_2 chemical recovery from gas fueled power	112,500 – 100,000	0.927 – 0.719
CO_2 physical recovery on gasification plants	14,500	0.902 – 0.496
	Facility cost (US$/kW) †	Generation efficiency (% LHV) †
IGCC with CO_2 capture (physical recovery)	1,700 – 1,470	34.0 – 49.0
	Sequestration potential (GtC)	Sequestration cost‡($/tC)
Oil well (EOR)	30.7	81 – 118††
Depleted gas well	40.2 – 241.5	34 – 215
Coal-bed (ECBM)	40.4	113 – 447††
Aquifer	856.4	18 – 143
Ocean	–	36‡‡

† Cost reduction and energy efficiency improvement are assumed to proceed with time; ‡ cost of CO_2 capture excluded; †† the proceeds from recovered oil or gas excluded; ‡‡ the cost includes that of CO_2 liquefaction; Source: e.g., [1,6,7]

4. Analysis Results and Discussion

To evaluate the costs and technological options for CO_2 concentration stabilizations, we adopted the two stabilization targets of IPCC WG I[10] 550 ppmv (S550) and 450 ppmv (S450). We assumed the Kyoto target for the Annex I countries except for US in 2010, and for US a target of 2%/yr reduction of CO_2 intensity until 2010; and thereafter assumed the UK-proposal target[11] for all the Annex I countries, which target is to reduce CO_2 emissions down to 39 % in 2050 and 23 % in 2100 relative to that of 1990. CO_2 emissions of the Non-Annex I countries is constrained not to exceed the difference between S550/S450 emissions and the allowable maximum emissions of the Annex I countries, and the target of each developing country is determined so that the allocation among the Non-Annex I countries is proportional to their 1990 emissions.

4.1 Costs for Different CO_2 Concentration Stabilization Targets

Figure 1 shows the marginal costs (CO_2 shadow prices) for atmospheric CO_2 concentration stabilization at 550 and at 450 ppmv with CO_2 emission trading, and also shows the regional costs for the 550 ppmv stabilization without emission trading. The marginal cost for the 550 and 450 ppmv stabilization is about 90 and 150 $/tC in 2050 and is 120 and 290 $/tC in 2100, respectively. On the other hand, the cost without emission trading varies wide over the regions, and the costs for EU, Japan, Canada and New Zealand, in 2010 are very high mainly by the effects of facility vintages. The low marginal cost for US in 2010 is caused by the less severe carbon intensity target of her own. As another kind of finding, it is notable that even 550 ppm stabilization can never be achieved without emissions reduction in developing countries.

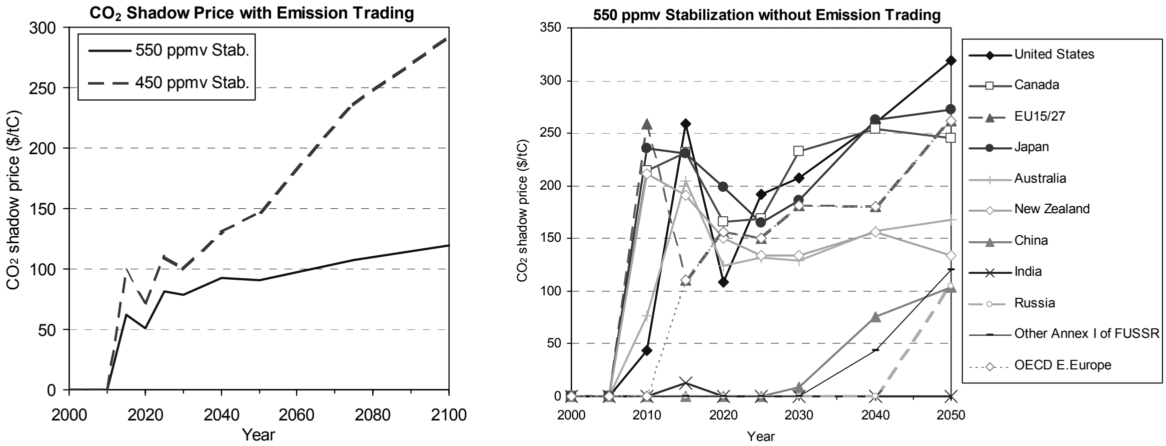

Figure 1: CO_2 shadow prices for CO_2 concentration stabilization at 550 and 450 ppmv with CO_2 emission trading, and the prices for the 550 ppmv stabilization without CO_2 emission trading

4.2 Technology Role for Stabilization

Figure 2 shows the world primary energy production for the 550 and 450 ppmv stabilizations with CO_2 emission trading, and Figure 3 shows the world CO_2 emissions and sequestration. The selection of the technologies is crucial for the least-cost emission reduction. Low-carbon fossil fuels, nuclear power and renewables increase their importance as compared in the no-climate-policy case and with lowering stabilization level, and energy savings are also important, particularly in developing countries. The cumulative amount of CO_2 sequestration from 2000 to 2050 is 48 and 75 GtC for the 550 and 450 ppmv, respectively; the amount from 2000 to 2100 is 270 and 360 GtC for the 550 and 450 ppmv, respectively. CCS is one of the key technologies for the least-cost stabilization. The similar figures for regions indicate that energy saving is more important in developing countries and CCS is more important in developed countries where the costs of energy savings are relatively high.

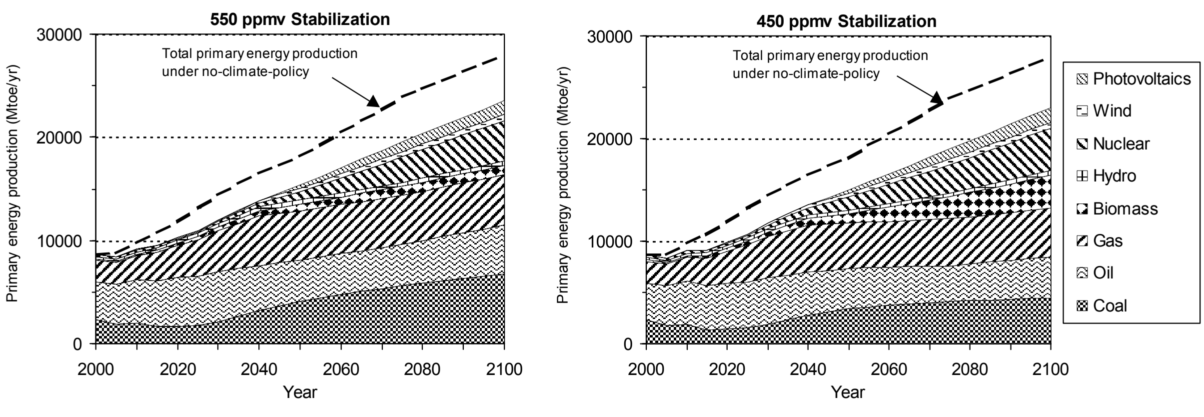

Figure 2: World primary energy production for CO_2 concentration stabilization at 550 and 450 ppmv

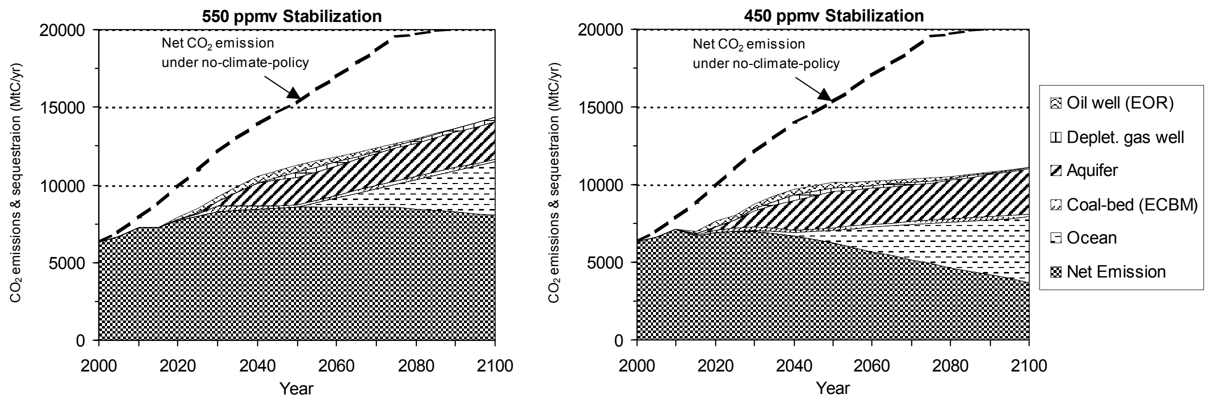

Figure 3: World CO_2 emission and sequestration for CO_2 concentration stabilization at 550 and 450 ppmv

5. Conclusion

An advantage of the model approach is that a variety of analysis results are self-consistent. In addition, the results of this study are consistent for the 77 regions because most of the assumed data are derived from the same databases. We conducted two case studies of concentration stabilization; the reduction targets for the regions are set reflecting the current world situations around the Kyoto Protocol and the long-term reduction targets of UK proposal for the Annex I countries. The emission reduction cost by region was obtained for the two stabilization cases without emission trading. For the cases with emission trading, the marginal cost of CO_2 emission reduction is 120 and 290 $/tC in 2100 for 550 and 450 ppmv stabilizations, respectively. To achieve these stabilization, a variety of technological options are required from the viewpoint of cost effectiveness; CO_2 capture and storage is indispensable, especially for developed countries. For exploring effective measures of global warming mitigation, the Post Kyoto regimes should be examined from the viewpoint of reduction costs and technology as well as warming impacts.

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