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This paper is one of a series published by FEEM on the theme of innovation modeling in the context of the challenge of stabilising atmospheric concentrations of greenhouse gases, as part of the Innovation Modeling Comparison Project. This is an international project launched and overseen by the Steering Committee of the informal International Programme on the Economics of Atmospheric Stabilisation. The broad aim of the collaboration is to advance understanding of the economic issues surrounding atmospheric stabilisation, and the specific aims of the IMCP are to provide insights into the "state of the art" and implications of endogenous modeling of technical change in global energy-environment models when applied to various levels of atmospheric stabilisation.

Members of the Steering Committee provided review comments on earlier drafts and the paper has been forwarded to external review, the final results will be published as a Special Issue of the Energy Journal. The papers have all been encouraged to draw on a common baseline (the "Common Poles-Image baseline") and to report results in comparable formats, so as to facilitate intercomparison of the different modeling results. All the results and judgements expressed here remain the responsibility of the authors.

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Analysis of Technological Portfolios for CO_2 Stabilizations and Effects of Technological Changes

Summary

In this study, cost-effective technological options to stabilize CO_2 concentrations at 550, 500, and 450 ppmv are evaluated using a world energy systems model of linear programming with a high regional resolution. This model treats technological change endogenously for wind power, photovoltaics, and fuel-cell vehicles, which are technologies of mass production and are considered to follow the “learning by doing” process. Technological changes induced by climate policies are evaluated by maintaining the technological changes at the levels of the base case wherein there is no climate policy. The results achieved through model analyses include 1) cost-effective technological portfolios, including carbon capture and storage, marginal CO_2 reduction costs, and increases in energy system cost for three levels of stabilization and 2) the effect of the induced technological change on the above mentioned factors. A sensitivity analysis is conducted with respect to the learning rate.

Keywords: Energy systems model, Global warming, Technological portfolios, Technological changes

JEL Classification: C61, O33, Q41, Q42

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1. Introduction

It is important to consider technological change endogenously in evaluating strategies for global warming mitigation over the long term. This is because it is often observed that new technologies are usually too expensive to be practical during the initial stages; however, for some reasons, their adoption is accelerated once their costs decrease below certain thresholds. However, endogenous technological changes cannot be easily solved using optimization models because of their intrinsic nonconvex character. (Messner, 1997; Kypreous et al., 2000).

We developed a world energy systems model—DNE21+ (Akimoto et al., 2004 and 2005)—that considers the technological change endogenously for three technologies, namely, wind power, photovoltaics (PV), and fuel-cell vehicles (FCVs). These are technologies of mass production and are considered to follow the typical learning curve at a constant learning rate; they should thus be treated endogenously. On the other hand, it is not currently clear what laws quantitatively govern the technological changes in other large-scale technologies such as nuclear and carbon capture and storage (CCS); their technological changes are treated exogenously in this model. The DNE21+ is a linear programming model that employs a bottom–up approach for the technologies at the energy supply side and minimizes the total cost of world energy systems. Its high regional resolution enables a detailed analysis of the relatively high cost of energy transportation, regional differences in energy systems, and technology level. The cost minimization with endogenous technological changes can be solved by the model-run iteration.

Model analyses were conducted for the base case (no climate policy) and three levels of CO_2 concentration stabilization. For each stabilization level, two cases—one with and the other without the induced technological change (ITC)—were studied in order to quantitatively analyze the effect of ITC. In addition, a sensitivity study was conducted with respect to the learning rate.

2. Model

2.1 Model Framework

The DNE21+ model was originally developed for the analysis of the post-Kyoto regime, which requires that major countries be treated separately, and it was extended to be used for the study of the ITC effect as well. It considers a time range that covers the entire 21st century with representative time points of 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2075, and 2100. The model disaggregates the whole world into 77 regions, such as the U.S., Canada, the U.K., France, Japan, Australia, China, India, and Russia. For obtaining a detailed account of the transportations of energy and CO_2, large countries such as the U.S., China, and Russia are further disaggregated into several regions. The model represents the energy supply sectors in a bottom-up fashion and the end-use energy sectors in a top-down fashion similar to the DNE21 (Fujii and Yamaji, 1998) and LDNE21 (Yamaji et al., 2000) models, which are the precursors of this model. The total cost of energy systems between 2000 and 2100 is minimized.

2.2 Energy System Modeling

Primary energy sources of eight types are explicitly modeled: natural gas, oil, coal, biomass, hydro and geo-thermal, PV, wind, and nuclear power. Coal, oil, natural gas, methanol, hydrogen and biomass fired power plants, hydro & geo-thermal, wind, PV, and nuclear power plants are explicitly taken into account for electricity generation. The integrated coal gasification combined cycle (IGCC) with CO_2 recovery is also formulated. In addition, various types of energy conversion technologies such as oil refining, liquefaction of natural gas, and coal gasification are explicitly modeled as technological options. The model also has the historical vintages of these technology facilities. Regarding CO_2 recovery, both the chemical absorption from the flue gas of thermal power plants and physical absorption from the outlet gas of fossil fuel gasification plants are explicitly modeled. In connection with CO_2 recovery, two major CO_2 sequestration measures—ocean sequestration and underground sequestration—are explicitly formulated. Underground CO_2 sequestration is further divided into four types: injection into oil wells for EOR operation, storage in depleted natural-gas wells, injection into coal beds for ECBM operations, and sequestration in aquifers.

The end-use energy sector of the model is disaggregated into four types of secondary energy carriers: solid fuel, liquid fuel, gaseous fuel, and electricity. The liquid fuel demand is further segregated into three types of oil products: gasoline, light fuel oil, and heavy fuel oil. Electricity demand is expressed by load duration curves having four types of time periods: instantaneous peak, peak, intermediate, and off-peak periods. The future energy demand when a no climate policy exists is exogenously provided by the energy type, region, and year. Energy savings in the end-use sectors are modeled in a top-down fashion by using the long-term price elasticity; the transportation technologies in end-use sectors, for example, are not explicitly formulated. However, the hydrogen energy economy has recently attracted considerable attention. In this regard, we attempted a simplified modeling of FCVs as one of the greatest hydrogen consumers. For this evaluation, it is assumed that the gasoline demand is partly substituted by hydrogen that is to be used in FCVs. While the production costs of both gasoline and hydrogen are endogenously determined by the model, a direct comparison of their costs does not provide the solution because of the cost difference between the two types of vehicles; we impose a cost penalty on hydrogen due to the higher cost of FCVs.

In the model, the disaggregated regions of the world are linked to each other by the interregional trading of eight items: coal, crude oil, synthetic oil, methane, methanol, hydrogen, electricity, and CO_2. The method of transportation, e.g., tanker or pipeline, is selected under the least cost criteria in the model.

3. Model Assumptions

3.1 Primary Energy

The potentials and costs of the eight types of primary energy are assumed as follows: Most of the assumed potentials are based on GIS data, which can be easily processed to obtain the corresponding potential of each region.

Fossil Fuel

The assumed potentials of conventional oil and natural gas are derived from USGS GIS data (USGS, 2000) and those of unconventional oil and gas are estimated countrywise using the data of Rogner (1997). The potential of coal is assumed using the country data provided by the WEC (World Energy Council, 2001). **Errore. L'origine riferimento non è stata trovata.** summarizes the assumed world fossil fuel potentials. The production costs of the fossil fuels are estimated based on the study by Rogner and other studies.

Table 1 Assumed fossil fuel potentials in the world

	Anthracite and bituminous	Sub-bituminous	Lignite
Coal [Gtoe]	424	208	253

	Conventional			Unconventional
	Remaining reserves	Undiscovered (Onshore)	Undiscovered (Offshore)	
Oil [Gtoe]	137	60	44	2,342
Natural gas [Gtoe]	132	59	52	19,594

Renewable Energy

The world hydropower potential is obtained from the WEC (2001) and is assumed to be 14,400 TWh/yr. The world potential of wind power, PV, and biomass are assumed to be approximately 12,000 TWh/yr, 1,271,000 TWh/yr, and 3,960 Mtoe/yr, respectively. These three types of energy potentials are estimated by combining some elements in the GIS data such as the wind speed, solar radiation power, and land use. The potentials of all the four types of renewables are classified into five cost grades. The costs by grade for the year 2000 are summarized in Table 2.

Table 2 Cost of renewables by grade for the year 2000

Grade	Hydropower [$/MWh]	Wind power [$/MWh]	PV [$/MWh]	Biomass [$/toe]
1	20	56	209	171
2	30 / 60	60	272	185
3	120	71	352	227
4	150	87	487	454
5	180	118	720	1000

Nuclear Energy

In this study, only fission has been considered to model nuclear power. The facility cost in 2000 is assumed to be 1,900 $/kW for the U.S., while the costs for other regions and time points are adjusted by using a certain location factor, which is a function of GDP per capita. The facility usage rate of nuclear power is assumed to be 85%. The variable cost of fuel and operation is assumed to be 10 \$/MWh.

3.2 CO_2 Capture and Storage

Table 3 lists the assumed facility costs and the energy requirements for CO_2 capture technologies. The cost reduction and energy efficiency improvement of CO_2 capture technologies are exogenously assumed to proceed with time; this is based on several sources (David et al., 2000; Fujii et al., 1998). In this model, the cost of electricity generation is endogenously determined by the region, time point, and type of time period in the model, and therefore, costs per ton of avoided CO_2 emissions are also determined within the model, although the energy requirements are exogenous. Table 4 summarizes the assumptions of the potentials and costs of CO_2 sequestration. These data are estimated based on several reports, papers, etc. The details are provided by Akimoto et al., (2004).

Table 3 Assumed facility costs and energy required for CO_2 capture

	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 in 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

Note: Cost reduction and energy efficiency improvement are assumed to proceed with time.
Source: David et al. (2000); Fujii et al. (1998)

Table 4 Assumed CO_2 sequestration potentials and sequestration costs in the world

	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 of CO_2 capture is excluded.
‡ The proceeds from recovered oil are excluded.
†† 40.2 is the initial value in 2000, and the capacity increases with natural gas production.
‡‡ The proceeds from recovered gas are excluded.
* The potential is the "practical" one, i.e., 10% and 20% of the "ideal" potentials for onshore and offshore, respectively.
** The cost includes the cost of CO_2 liquefaction.

3.3 Population, GDP, and Final Energy Demands

Future scenarios of population, reference GDP, and reference final energy demands are derived from the B2 Marker Scenario of IPCC SRES (Nakicenovic et al., 2000; TGCIA, 2000). However, we made some modifications to the original scenario data for consistency with the historical data (IEA, 2002; World Bank, 2002; OECD/IEA, 2000) and region division of this model. Energy savings in end-use sectors are modeled using the long-term price elasticity. The elasticities of electricity and non-electricity are assumed to be –0.3 and –0.4, respectively. The model determines the least cost energy systems that meet the final energy demands in the reference case as well as in emission reduction cases, assuming that energy saving occurs based on the price elasticity.

3.4 Endogenous Technology Learning

The technological change is treated endogenously for wind power, PV, and FCVs, as described before. In this paper, the typical learning curve expressed by equation (1) is assumed for these technologies. C_y, FC, LR, and CI_y denote cost at year y, floor cost, learning rate, and cumulative installation at year y, respectively. The learning rate denotes the cost reduction ratio for doubling the cumulative installation. FC and LR are exogenously provided, while C_y and CI_y are endogenously determined by Eq. (1).

$$C_y = (C_{2000} - FC)(1 - LR)^{\log(CI_y / CI_{2000}) / \log 2} + FC \qquad (1)$$

The determination of C_y and CI_y is carried out through iterative model runs. For the first model run, the time series values of initial guess are used for C_y, while those of CI_y are determined through the model run. New time series values of C_y are determined by Eq. (1) using the obtained time series values of CI_y. These values of C_y are used for the second model run. This operation is iterated until the variations in the time series values of C_y and CI_y between two successive model runs become acceptably small for all the three technologies.

In order to obtain an approximate solution of the nonconvex problem, which is attributed to endogenous technology learning, Messner (1997) used a mixed integer programming model (MIP). However, the MIP is not practical in our case because of the huge model size. The assumed crucial parameters, such as learning rates, are described in the following paragraphs.

Wind Power and PV

Wind power and PV comprise mature technology components whose cost portions are regarded as fixed, and only the remaining portions undergo cost reduction according to learning rates. The assumed parameters are shown in Table 5.

The initial values of time series costs for the first model run were assigned based on the costs for the year 2000 that were listed in Table 2, along with the annual cost reduction rates. The annual reduction rates were assumed as 1.0 %/yr for wind power and 3.4 %/yr for PV, which were determined based on EPRI/DOE (1997). Figure 1 shows the convergence of the time series cost for the base case. Although the times required for the model run iterations vary depending on the circumstances, a good convergence is achieved by repeating the iterations several times.

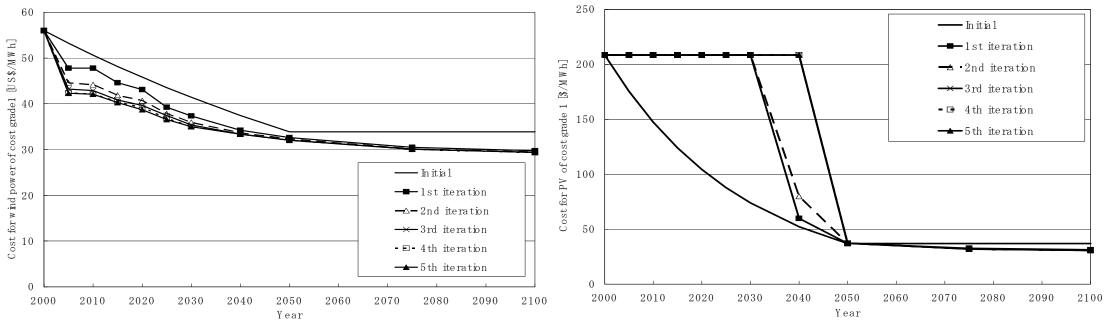
Table 5 Assumed cost reduction for wind power and PV

	Floor cost ratio in 2000 [%]	Ratio of cost for learning in 2000 [%]	Learning rate*** [% for doubling]
Wind power	36*	64	15
PV	13**	87	25

* Costs of construction, electric facilities, road for access, etc.
** Cost of power conditioner. Source: Yamada and Komiyama (2002).
*** Source: A. Grubler et al. (2002).

Figure 1 Convergence of time series cost for the base case

Wind power PV



FCVs

The assumed cost reduction for FCVs is shown in Table 6. FCV technology was divided into four components. The initial values of cost for the first model run were assigned based on the study of Tsuchiya (IAE/NEDO, 2003). The cost difference between FCV and gasoline vehicles is imposed as a cost penalty on hydrogen, which substitutes for gasoline.

Table 6 Assumed cost reduction for FCVs

	Cost in the year 2000 [US$/vehicle]	Floor cost [US$/vehicle]	Learning rate [% for doubling]
Fuel cell	149,000	2,500	20
Hydrogen tank	3,300	420	10
Motor, battery controller	8,750	1,250	10

Note: Costs of gasoline vehicle and common components are 12,500 and 8,400 US$/vehicle, respectively.
The energy efficiency of FCVs at wheel is 3.1 times that of gasoline vehicles.

4. Model Analysis Results

4.1 Simulation Cases

In this work, three CO_2 stabilization cases were studied with and without the ITC, besides the base case that has no CO_2 constraint. The CO_2 emissions paths for stabilization were determined based on diagrams in TAR WGIII Chapter 2. However, the DNE21+ model is an energy system model and does not explicitly treat the land use change or CO_2-emitting industries like cement. Therefore, the emissions from land use and cement production were determined exogenously based on SRES B2, and they were subtracted from the above determined CO_2 emissions paths to obtain the path of CO_2 emissions exclusively from energy systems. For the cases with the ITC, the technological changes of wind power, PV, and FCVs were treated endogenously in the same manner as in the base case using the same parameters, as shown in Tables 5 and 6. However, we obtain different time series costs, i.e., different cost reduction rates among the three constraint cases and the base case because the constraint cases demand more low-carbon technologies. Consequently, they accelerate their cost reductions according to the learning curves—the more stringent the constraint, the faster is the rate of the cost reduction. Thus, the ITC is considered as the acceleration of the "learning by doing" process in this study. On the other hand, for cases without the ITC, the time series costs that were obtained for the base case were retained as fixed values even for the emission constraint cases. A discount rate of 5% was adopted throughout the study.

4.2 Model Results and Discussions

Figure 2 shows the world primary energy productions for the base case and ITC cases. Nuclear and renewables are expressed in primary equivalent by using a conversion factor of 0.33. The utilization of non-fossil fuels, such as nuclear power, wind power, PV, and biomass, increases in the CO_2-concentration stabilization cases. Figure 3 shows the CO_2 emission and sequestration. Sequestration in aquifers and ocean sequestration play an important role in the stabilization of CO_2 concentration; the lower stabilizations require the CO_2 sequestration to be utilized earlier. Figure 4 shows the world final energy consumption. Gasoline is substituted by hydrogen for FCV use; the trend is especially clear in the 450-ppmv ITC case.

Figure 2 World primary energy production for the base case and ITC cases

Base case Comparison

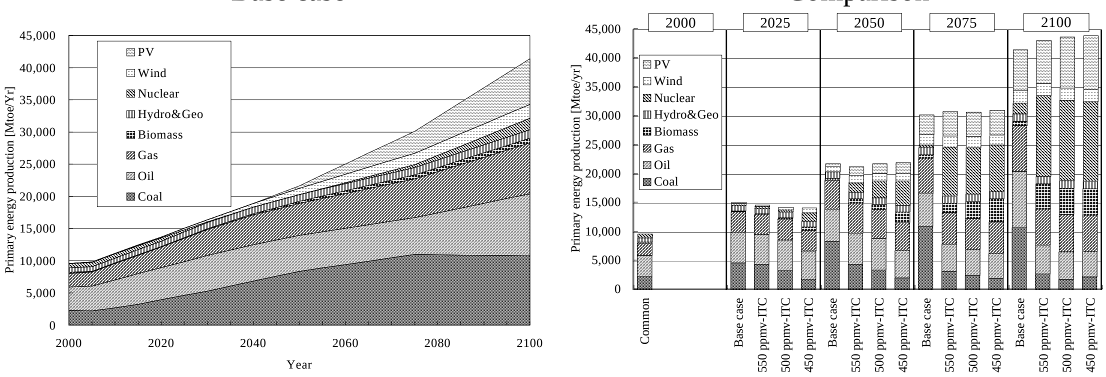


Figure 3 World CO_2 emission and sequestration for the base case and ITC cases

Base case Comparison

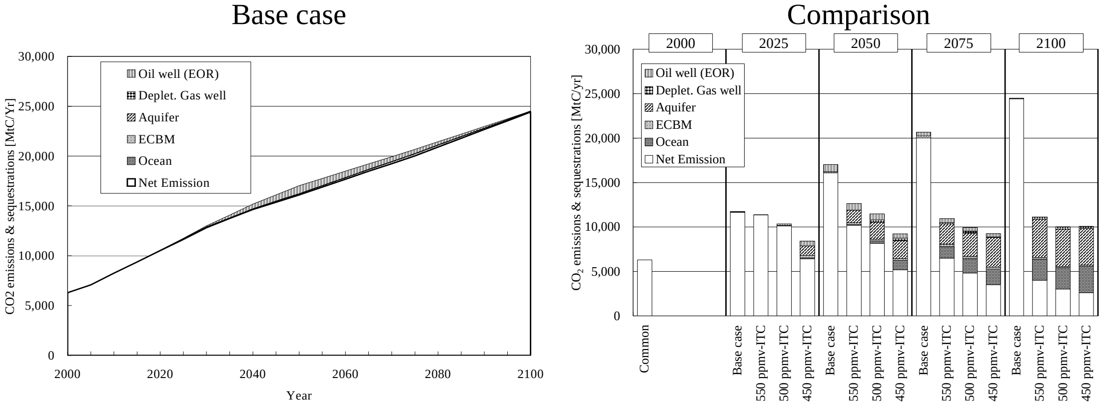
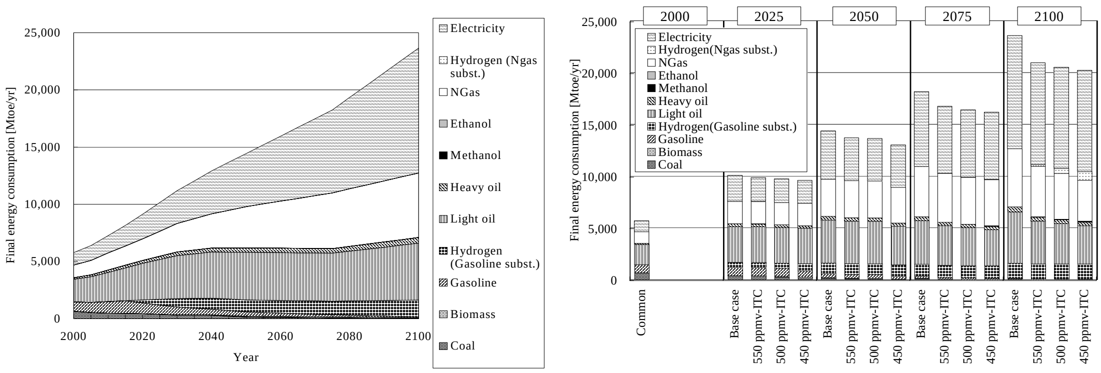


Figure 4 World final energy consumption for the base case and ITC cases

Base case Comparison



The following is a discussion of the effects of the ITC by a comparison of the results of all the cases. Figure 5 shows the achieved time series costs for the three technologies assuming endogenous learning for the base case and ITC cases. For wind power and PV, only the costs of grade 1 are shown. Although the cost for wind power in the base case is lower than that for the 550- and 500-ppmv ITC cases at some time points because of the competition among the technologies for the mitigation of global warming, the lower stabilization cases induce the early introduction of the three technologies. As a result, cost reductions are observed in the early time period. The cost differences between the base case and ITC cases are mainly observed during the short time period when substantial technology introduction occurs, while they are small after a certain number of installations; this means that the effect of the ITC manifests during a time period of a substantial initial introduction. For example, the largest difference in the cost of PV between the base case and the 450-ppmv ITC case is observed in 2040. The costs in 2040 and the averaged annual cost reduction rates between 2000 and 2040 are 208 US$/MWh and 0 %/yr for the base case and 34 US$/MWh and 4.4 %/yr for the 450-ppmv ITC case, respectively.

Figure 6 shows the changes in power generation by wind power and PV, in terms of hydrogen consumption (which substitutes for gasoline), in nuclear energy production and in CO_2 sequestration that are caused by suspending the ITC. As seen in the figure, positive values indicate increases for non-ITC cases as compared to ITC cases and negative values indicate decreases for non-ITC cases. CO_2 sequestration and nuclear energy production are presented as examples to indicate the effects of the ITC suspension on other technologies based on exogenous learning. The CO_2 sequestration is the sum of the five types shown in Figure 3. Power generation by wind power and PV decreases due to the ITC suspension, especially around the middle of the 21st century. The highest decreases are approximately 400, 900, and 1400 Mtoe/yr for 550, 500, and 450 ppmv, respectively. These ratios are approximately 15%, 50%, and 60% relative to the cases with the ITC. The effect of the ITC suspension on wind power and PV production increases for lower stabilization. With regard to the hydrogen that substitutes for gasoline, the decreases in consumption due to the ITC suspension are small for the 550- and 500-ppmv stabilizations because hydrogen consumption in the base case is almost identical to that in the 550- and 500-ppmv ITC cases, as shown in Figure 4. For the 450-ppmv stabilization, the decrease in the hydrogen consumption and the ratio of the decrease are largest in 2015 and they become smaller with time.

Contrary to the decrease in the utilization of these three technologies, increased amounts of CO_2 sequestration and nuclear power are utilized around the middle of the century for stabilizing the CO_2 concentration. The largest increases and their ratios to those in the corresponding ITC cases are approximately 160 MtC/yr (6%) and 150 Mtoe/yr (10%) in 2050 for 550 ppmv, 200 MtC/yr (11%) and 440 Mtoe/yr (48%) in 2040 for 500 ppmv, 500 MtC/yr (14%) and 540 Mtoe/yr (20%) in 2040 for 450 ppmv, respectively.

Figure 7 shows the marginal CO_2 reduction costs and the increases in the discounted total system cost relative to those in the base case. The marginal reduction costs increase with decreasing concentration level. On the other hand, the increases in the marginal CO_2 reduction cost due to the ITC suspension are considerably smaller than those caused by the CO_2 stabilization level difference. The increase in the total system cost acquires an increasingly nonlinear characteristic as the stabilization level lowers, and the increase resulting from lowering the stabilization level is larger than that caused by the ITC suspension, as shown in the figure on the right.

Figure 5 Time series costs for three technologies with endogenous technology learning

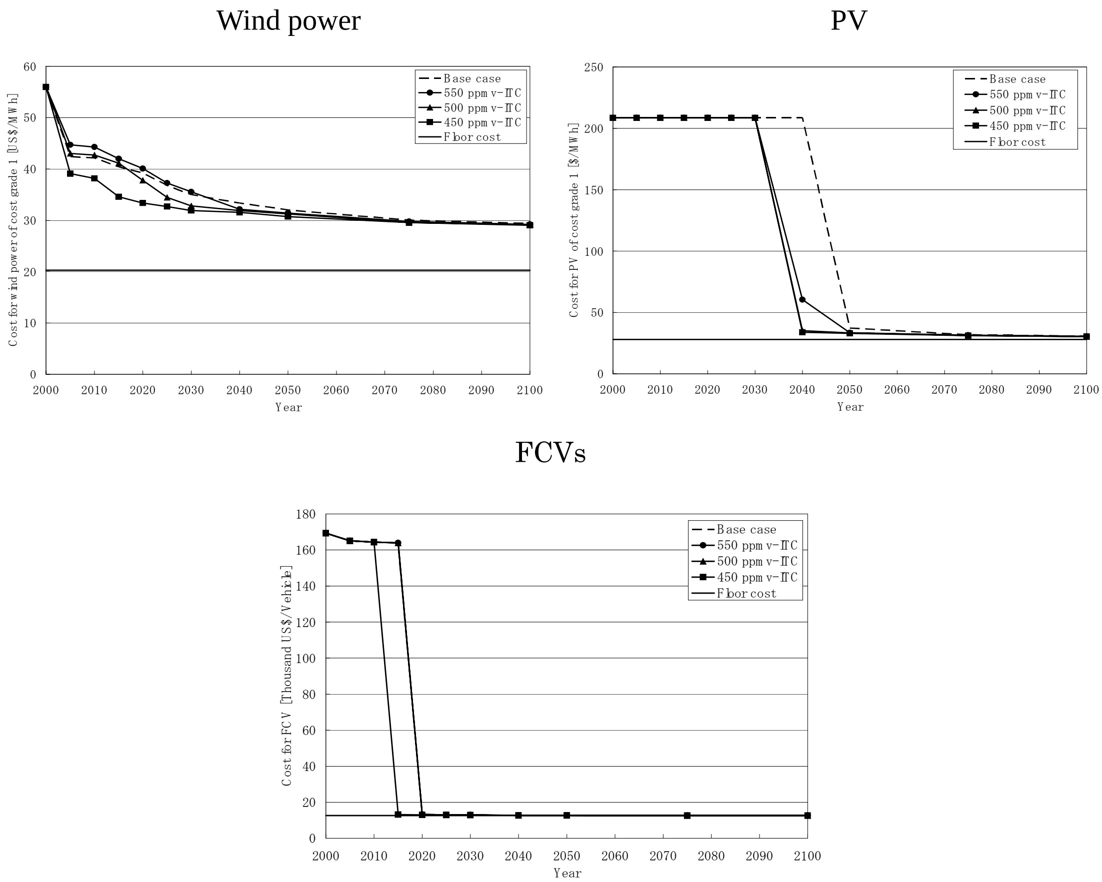
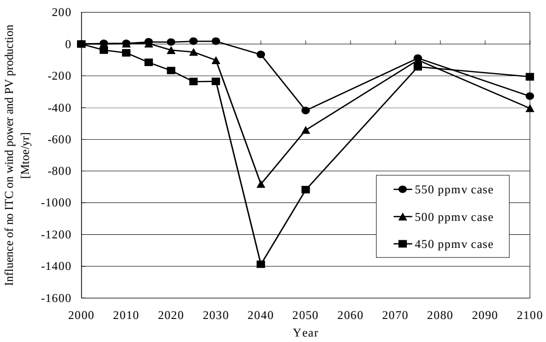
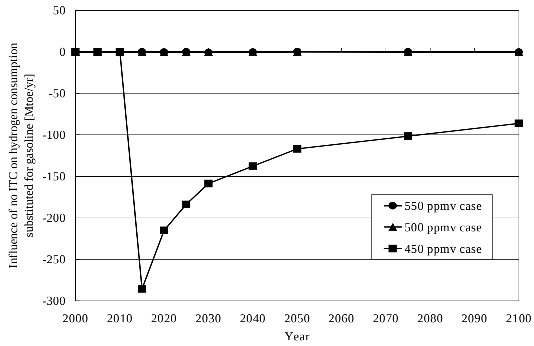


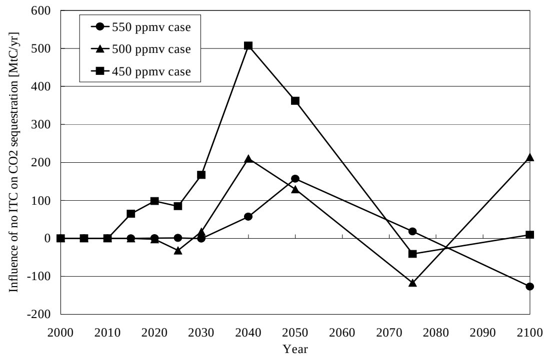
Figure 6 Effects of ITC suspension

Power generation by wind power and PV Hydrogen consumption subst. for gasoline





CO_2 sequestration Nuclear



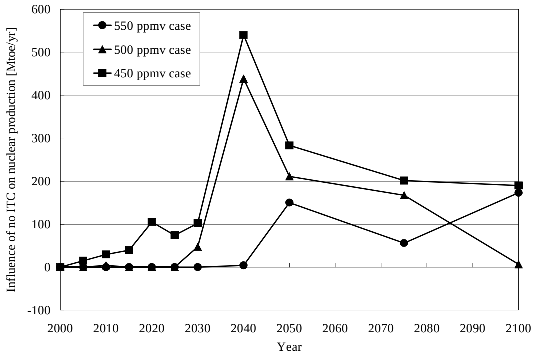
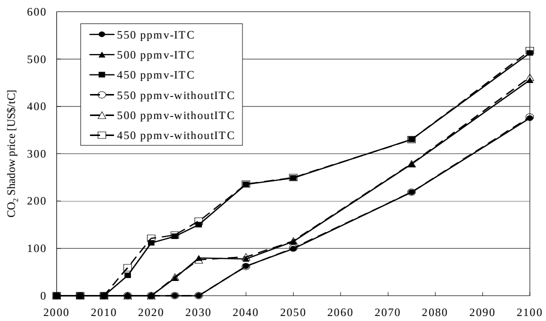
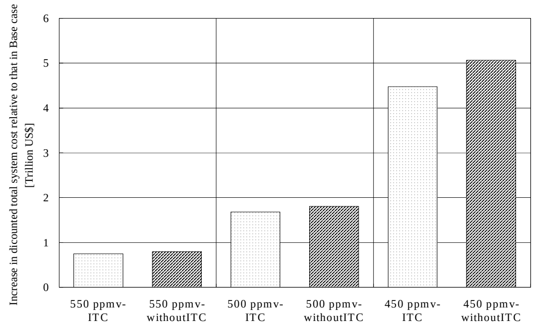


Figure 7 Marginal CO_2 reduction costs and increase in discounted total system cost relative to those in the base case

Marginal CO_2 reduction costs Increase in discounted total system cost





The above mentioned minor effects of the ITC suspension on the marginal CO_2 reduction costs and total system cost are considered to be caused by the small portion of endogenously treated technologies among the technologies considered in the model. If the technological change in new technologies such as CO_2 capture can be treated endogenously, the effect of ITC will become more conspicuous even in the marginal cost and the total system cost.

Sensitivity Analysis

A sensitivity analysis was conducted with respect to the learning rate; the learning rates of the three technologies were changed by 5 percentage points simultaneously for the three CO_2 stabilization cases. Figure 8 shows the obtained time series costs for the two sets of learning rates and the three stabilization cases.

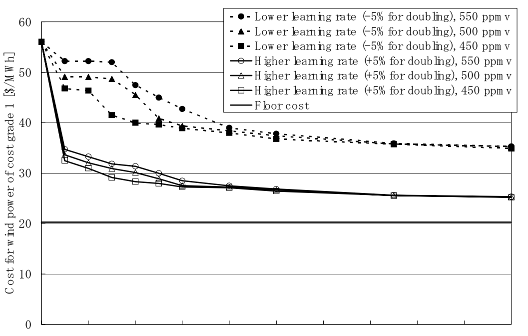
For wind power, the effects of the change in the learning rate are conspicuous throughout the time span. The differences in cost due to the CO_2 stabilization level are observed mainly between 2000 and 2040, which is identical to the results of the original learning rate shown in Figure 5.

On the other hand, the differences in the cost of PV due to the CO_2 stabilization level are very small and almost indiscernible. Only the changes caused by the learning rate are observed. This implies that the timing of the initial introduction of PV depends principally on the learning rate and not on the stabilization level. The initial cost of PV in 2000 is considerably higher than that of wind power, and the utilization in 2000 is very small. In general, the cost reduction, which takes place according to the learning curve in the initial period, is relatively large for the same ratio of increase in cumulative production.

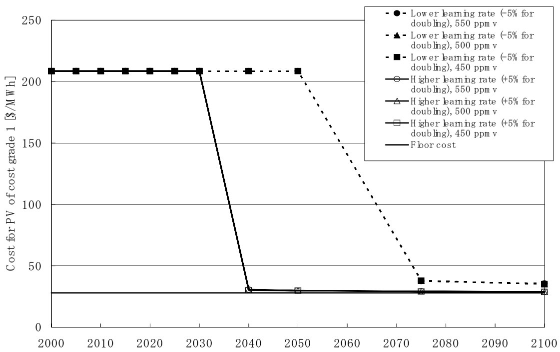
For FCVs, a higher learning rate does not lead to a significant change in the utilization as compared to the original learning rate. The original learning rate seems to be so high that the higher learning rate does not accelerate the utilization of FCVs further. For cases involving a lower learning rate, a delayed cost reduction in FCVs is observed for the higher CO_2 stabilization levels.

Figure 8 Sensitivity to the learning rate

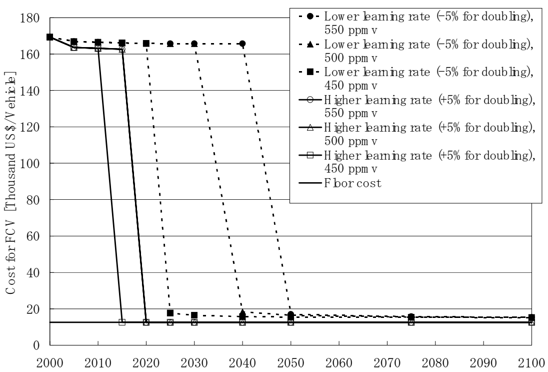
Wind power



PV



FCVs



The impact of the learning rate is relatively large, especially for immature technologies that have high cost and small utilization at the initial time point.

5. CONCLUSION

A world energy systems model was developed to explore cost-effective measures for different levels of CO_2 stabilization and the effects of induced technological changes on them. This model treats technological changes endogenously only for wind power, PV, and FCVs, which are technologies of mass production and are expected to follow the typical learning curve at a constant learning rate; all other technologies are treated exogenously. Owing to its high regional resolution, the model is able to consider in detail the transportation cost of energies, regional differences in energy systems, and technology level in the exploration of cost-effective energy systems for both the no-policy case and stabilization cases of 550, 500, and 450 ppmv. The conclusions are as follows:

1) Endogenous technology learning is successfully resolved through iterative model runs.

2) More nuclear and renewables, less fossil fuels, and more CCS technologies are to be used for lower levels of stabilization. The total system cost increases in a non-linear fashion as the stabilization level becomes lower.

3) The effect of the induced technological change is significant in terms of the amount of technology utilization only during the time period of the initial substantial introduction of the technology.

4) The marginal CO_2 reduction costs and the total system cost are not influenced substantially by the ITC because the portion of endogenously treated technologies is not large in this study.

5) The values of the learning rate should be carefully determined because their impact may be relatively large.

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(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003

(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003

(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003

(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003

(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

(lxxi) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by Fondazione Eni Enrico Mattei and Consip and sponsored by the EU, Rome, September 23-25, 2004

(lxxii) This paper was presented at the 10th Coalition Theory Network Workshop held in Paris, France on 28-29 January 2005 and organised by EUREQua.

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(lxxiv) This paper was presented at the ENGIME Workshop on “Trust and social capital in multicultural cities” Athens, January 19-20, 2004

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(lxxvi) This paper was presented at the 3rd Workshop on Spatial-Dynamic Models of Economics and Ecosystems held in Trieste on 11-13 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics

(lxxvii) This paper was presented at the Workshop on Infectious Diseases: Ecological and Economic Approaches held in Trieste on 13-15 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics.

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