Analysis of Asian Long-Term Climate Change Mitigation in Power Generation Sector

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Recent share of total primary energy supply of Asian countries in the world reaches about one third and it will be larger in the future due to great economic growth of Asia including China and India. On the other hand, climate change is one of the important global issues and deep CO_2 emission reduction will be required. From this perspective, energy efficiency improvement and low carbonization in Asia will be a key factor for tackling climate change issues. Nuclear power generation, carbon dioxide capture and storage (CCS), and renewables such as wind power and PV are expected to be keen technologies for CO_2 emission reduction. However, future cost, social acceptance, etc. of these technologies are very uncertain. In this paper, long-term climate change mitigations in power sector in Asian countries were analyzed by using a world energy systems model. In this analysis, four technology scenarios and four CO_2 emission reduction cases were assumed. The achieved results through model analyses include 1) drastic reforming of power generation structure and large costs are needed for deep CO_2 emission reduction, 2) The above-mentioned technologies have large impacts on CO_2 emission reduction cost.

INTRODUCTION

The great economic growth of Asia, including China and India, is expected to continue in the foreseeable future. As the economy grows, energy supply and CO_2 emission become considerably larger. According to the IEA statistics, shares of total primary energy supply and CO_2 emission of Asian countries in the world reach about one third and forty percent. These shares are expected to be larger in the future according with economic growth of Asia. Therefore, CO_2 emission reduction for climate change mitigation in Asia has large impacts on global CO_2 emission reduction. Energy efficiency improvements are important and fundamental measures for CO_2 emission reduction. Furthermore, technologies for low-carbonization are expected to be keen technologies for deep CO_2 emission reduction. In power sector, nuclear power generation, carbon dioxide capture and storage (CCS), and renewables such as wind power and PV are the technologies for low-carbonization. However, future cost, social acceptance, etc. of these technologies are very uncertain and it is difficult to estimate the contribution of these technologies to the future CO_2 emission reduction.

In this paper, CO_2 emission reductions for climate change mitigation in Asian countries were quantitatively analyzed by using a world energy systems model, which the authors call DNE21+[1]. The DNE21+ model is an inter-temporal linear programming model that minimizes the world total energy system costs. In DNE21+ model, Asia is divided into 15 countries and regions. This regional segregation enables to analyze with regional differences in consideration. For the analyses, four technology scenarios are assumed. One is the base scenario and the other three scenarios are the scenarios for considering uncertainty of three technologies of nuclear power generation, CCS, and wind power & PV. Four cases for different levels of CO_2 emission reduction are also assumed. Climate change mitigations in power sector in Asian countries are discussed through quantitative analyses of the comparison among combinations of the four technology scenarios and the four reduction cases.

1. Assessment Model

1.1 Overview

The DNE21+[1] is an inter-temporal linear programming model for assessing global energy systems and global warming mitigation, in which the sum of the discounted world total energy systems costs are to be minimized. The model covers the time range up to the middle of the 21st century with the representative time points of 2000, 2005, 2010, 2015, 2020, 2025 2030, 2040 and 2050. The model consistently represents energy systems (e.g., energy flows, capacities of energy-related facilities, and performances and costs of various technologies) with the amounts of production activity (e.g., the production amount of crude steel), the amount of service activity (e.g., the traffic amount in the transportation sector), and the final energy demands in other top-down sectors being met by the best combination of technologies. When any emission restriction (e.g., an upper limit of emissions, targets of energy or emission-specific unit improvements, or carbon taxes) is applied, the model specifies the energy systems whose costs are minimized and still meet all the assumed requirements. The salient features of the model include (1) analysis of regional differences with fine regional segregation, (2) a detailed evaluation of global warming measures by modeling around 300 specific technologies that can be used to counter global warming.

About the regional segregation, the DNE21+ model disaggregates the whole world into 54 regions: US, UK, France, Germany, Japan, Australia, China, India, Brazil, Russia, etc. The Asia is divided into 15 regions as summarized in Table 1. This regional segregation enables to analyze with regional differences in Asia considering with global consistency.

The assumed technologies in power generation sector are listed in Table 2. Both widely used technologies and novel technologies, which are expected to change within the time period of evaluation, are considered. Facility vintages are considered for the technologies in the model. For other sectors, technologies in other energy supply sector (e.g., oil refinery, biomass fermentation), industrial sector (iron and steel, cement, pulp and paper, aluminum, ethylene/propylene, and ammonia), transportation sector (passenger car, bus and truck), and residential and commercial sector (e.g., refrigerator and lighting) are also explicitly modeled.

Table 1 Regional definition of Asia in DNE21+

Region name in model	Countries
Japan	Japan
China	China, Hong Kong
North Korea, Mongolia	Democratic People's Republic of Korea, Mongolia
Viet Nam, Cambodia, Laos	Viet Nam, Cambodia, Lao People's Democratic Republic
Korea	Korea
Malaysia, Singapore	Malaysia, Singapore
Indonesia	Indonesia
Thailand	Thailand
Philippines	Philippines
Brunei	Brunei Darussalam
Chinese Taipei	Taiwan Province of China
India	India
Pakistan, Afghanistan	Pakistan, Afghanistan
Myanmar	Myanmar
Other Asia	Bangladesh, Nepal, Bhutan, Sri Lanka, Maldives

Table 2 Assumed technologies in Power generation sector in DNE21+

		Capital cost ($/kW in 2007 price)	Generation efficiency (LHV %)
Coal power	Low efficiency (e.g., sub-critical)	1250	22.0–27.0
	Middle efficiency (e.g., critical in the present; super-critical (SC) in the future)	1875	36.0–45.0
	High efficiency (e.g., SC, ultra SC in the present; IGCC and IGFC are included in the future)	2125	42.0–55.0
Oil power	Low efficiency (e.g., diesel)	313	22.0–27.0
	Middle efficiency (sub-critical)	813	37.0–45.0
	High efficiency (critical)	1375	50.0–60.0
	Combined heat and power (CHP)	875	37.0–47.0*
Gas power	Low efficiency (steam turbine)	375	26.0–32.0
	Middle efficiency (combined cycle)	813	38.0–47.0
	High efficiency (combined cycle with high temperature)	1375	52.0–62.0
	Combined heat and power (CHP)	875	38.0–48.0*
Biomass power	Low efficiency (steam turbine)	1500–1125	18.0–28.0
	High efficiency (combined cycle)	2750–2000	36.0–46.0
Nuclear power	Conventional	3000	–
	Advanced	2625	–
IGCC/IGFC with CO_2 capture		3500–2625	33.0–51.0
Natural gas oxyfuel power		2375–1750	40.7–50.7
Hydrogen power (FC/GT)		1375	52.0–64.5
Electricity storage (e.g., pumping-up)		1250	–

* Generated heat excluded.
Note: The ranges in the table depend on the year.

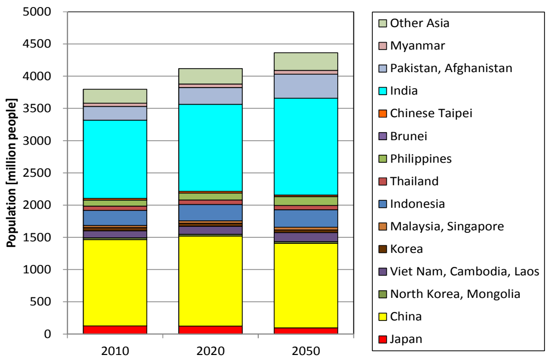
1.2 Population and GDP Assumptions

Socioeconomic scenario is one of the key assumptions for analysis of future climate change mitigation. We have developed a set of socioeconomic scenario[2]. Figure 1 shows the assumed population and GDP scenario for Asia. Currently, the population of Asia is 3,800 million and the share in the world is 55 %. The population reaches 4,100 million in 2020 and 4,400 million in 2050, but the share in the world is decreased to about half because of the large population growth in Asia. About GDP, the rapid economic growth of Asia, including China and India, is expected to continue in the foreseeable future. The assumed GDP of Asia in 2050 is 52,000 billion US2000$/yr (MER) and the average annual growth rate of GDP from 2010 to 2050 is 3.7 %/yr. The share in the world is about 40 % and this economy growth implies that Asia will have large impact on the global CO_2 emission.

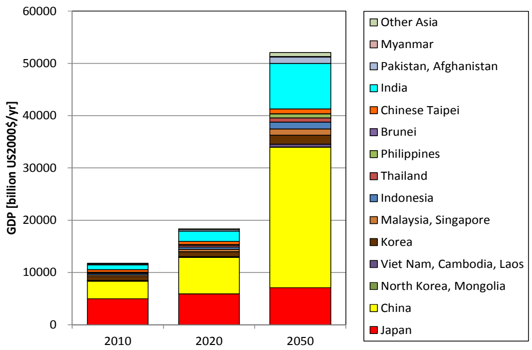
The assumed population and GDP are not directly used to assume conditions for the DNE21+ model but to assume the amount of production or extent of service activity in individual sectors. The amount of production or extent of service activity is consistently satisfied by the optimal combination of various technologies for individual sectors that are explicitly modeled. For other sectors, baseline scenarios of final energy demands are assumed together with their long-term price elasticities using top-down modeling.

Figure 1 Assumed population and GDP scenario for Asia

Population



GDP



1.3 Technology Scenarios

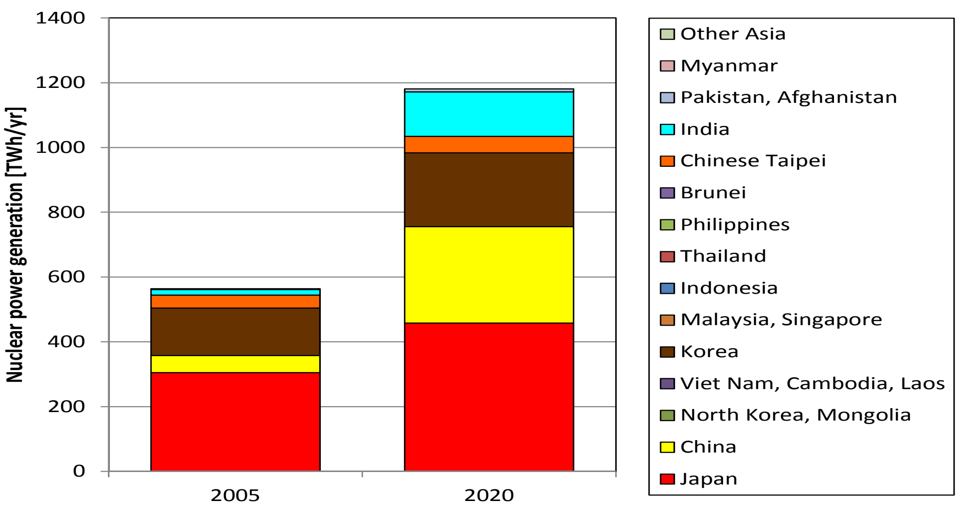
In this paper, we focus attention on three technologies; nuclear power generation, CCS and renewable energies (wind power and PV). A base technology scenario and three technology scenarios are assumed for analyzing the impact of the above three technologies on climate change mitigation.

Nuclear Power Generation

Nuclear power is a key technology for CO_2 emission reductions, but there are key factors other than cost that need to be considered, including the lead time and the public acceptance of the use of nuclear power. Therefore, exogenous scenarios are assumed for nuclear power generation until 2020 for the base technology scenario, as presented in Figure 2. The generation is estimated from national plans of nuclear power plant construction[3]. Within the timeframe until 2050, there are greater flexibilities in nuclear power construction than there are for 2020, because of the longer remaining time. Nuclear power generation after 2020 are therefore determined on the basis of cost-effectiveness criteria of the model with maximum growth rate constraints (0.7%/yr relative to regional total electricity demand). Japanese nuclear power generation in Figure 2 is assumed based on the strategic energy plan of Japan. The plan will be reviewed in near future considering Fukushima-Daiichi nuclear power accident resulting from the earthquake and tsunami of March 11, 2011. The accident will have strong negative effects on the deployment of nuclear power not only in Japan, but also in other countries of the world. However, this study follows cost-effectiveness criteria with maximum growth rate constraints for the base technology scenario, regardless of the high level of uncertainty in the global outlook.

No new nuclear scenario is also assumed as technology scenario for nuclear power generation. In this scenario, new installation of nuclear power plant after 2010 is not allowed, but operations of existing nuclear power plants are allowed until their life time (50 years).

Figure 2 Scenarios for nuclear power generation for Asia



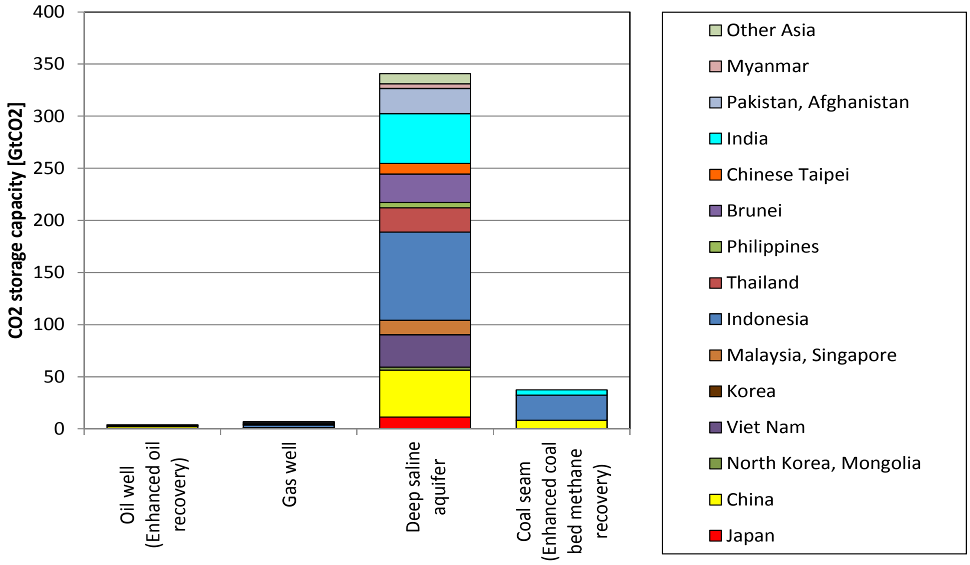
Carbon dioxide Capture and Storage (CCS)

CCS is recognized as one of the key technologies for large emission reductions. However, the technology is still in the incubation stage preceding commercial use, and there is large uncertainty of wide deployment of CCS in current condition. For example, the IEA roadmap for CCS shows that 100 projects (around 300 $MtCO_2$/yr) are to be implemented by 2020[4]. This is not so substantial in comparison with the potential global emissions expected for 2020. Therefore, deployment of CCS in 2020 is not allowed, but deployment of CCS after 2020 is taken into account, depending on the CO_2 storage capacity of the respective region for the base technology scenario. Figure 3 shows the assumed CO_2 storage capacity of Asia. The capacity was assumed based on GIS (Geographic Information System) data of USGS, etc[5]. The largest source of CO_2 storage in Asia is aquifer, and the capacity is 340 $GtCO_2$. The total CO_2 storage capacity of Asia is 390 $GtCO_2$, and the capacity correspond to 11 % of that of the world total.

No CCS scenario is also assumed as technology scenario for CCS. In this scenario, deployment of CCS is not allowed within the time frame until 2050.

Figure 3 CO_2 storage capacity of Asia

Note: Gas well capacity is endogenously increased according with gas production in the model (Maximum: 55$GtCO_2$)



Wind power and PV

Wind power and PV are expected to be keen technologies for CO_2 emission reduction. However, their cost, potential, and intermittent generation which is the negative features of these technologies will affect their diffusion. In this paper, two scenarios are assumed for the analysis as shown in Table 3. Continuous cost reductions are assumed for the base technology scenario. On the other hand, slower cost reductions after 2030 are assumed as conservative renewable cost scenario considering the cost for construction, electric facilities, road for access, etc. that cannot be achieved large cost reduction through learning by doing.

Potential of wind power and PV of Asia is assumed as shown in Figure 4. Wind power is cheaper than PV, but the potential is limited (760TWh/yr). Same potential is assumed for the base technology scenario and the conservative renewable cost scenario.

Table 4 summarizes the assumed four technology scenarios.

Table 3 Assumed cost for wind power and PV

Scenario	Technology	Cost in 2000 [$/MWh]	Annual cost reduction [%/yr]	
			2030/2000	2050/2030
Base technology scenario	Wind power	56 – 118	1.0	1.0
	PV	209 – 720	3.5	3.5
Conservative renewable cost scenario	Wind power	56 – 118	1.0	0.5
	PV	209 - 720	3.5	1.7

Note: The ranges in the table depend on cost grade. Five cost grades and potential are assumed based on some GIS data, such as wind-speed, solar radiation power, etc.

Figure 4 Potential of wind power and PV of Asia

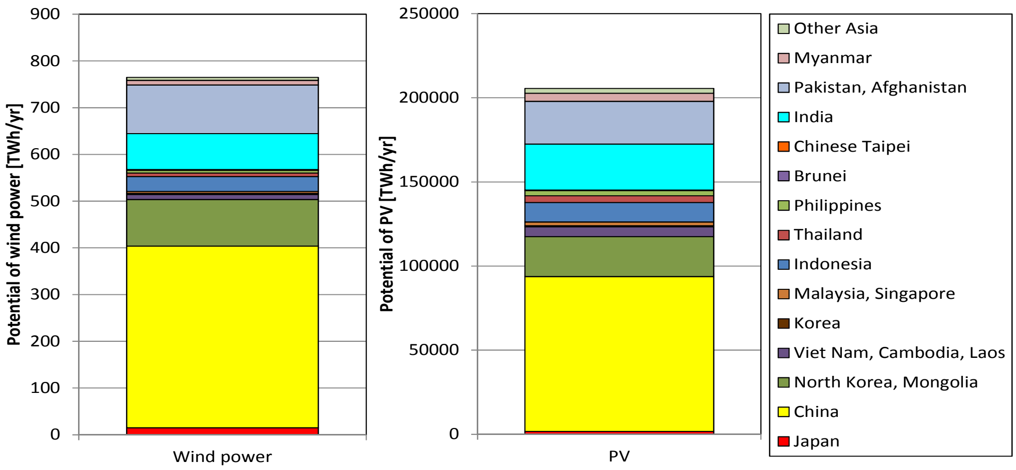


Table 4 Assumed technology scenarios

Technology scenario	Technology assumption		
	Nuclear power	CCS	Wind power and PV
Baseline technology scenario	Model original assumption		
No new nuclear power scenario	No new installation	Model original assumption	Model original assumption
No CCS scenario	Model original assumption	No CCS deployment	Model original assumption
Conservative renewable cost scenario	Model original assumption	Model original assumption	Slower annual cost reduction

2. Model Results

2.1 Simulation Cases for emission reduction levels

In this study, four simulation cases were conducted as shown in Table 5. A baseline case is a scenario without CO_2 mitigation policy. 650ppm CO_2eq case, 550ppm CO_2eq case and 450ppm CO_2eq case adopt the global energy-related CO_2 emission cap in Table 4. Equalizing marginal CO_2 abatement cost across countries was assumed in this study. This means that the least cost measures in the world are assumed.

2.2 Model Results and Discussions

Figure 5 shows net CO_2 emission and CO_2 storage of Asia for the four cases with the base technology scenario. In the baseline case, CO_2 emission reaches double relative to that in 2005 between 2020 and 2030, and CO_2 emission in 2050 is 26 $GtCO_2$/yr which corresponds

Table 5　Assumed simulation cases

Case	Global energy-related CO_2 emission cap			
	2020	2030	2040	2050
Baseline case	No constraints on CO_2 emission			
650ppm CO_2eq case	38	40	40	37
550ppm CO_2eq case	33	35	30	23
450ppm CO_2eq case	32	30	22	13

to 47 % of the global CO_2 emission in 2050 (55 $GtCO_2$/yr). CO_2 emissions in 2050 are 17 $GtCO_2$/yr for the 650ppm CO_2 case, 11 $GtCO_2$/yr for the 550ppm CO_2 case and 7 $GtCO_2$/yr for the 450ppm CO_2 case. These emissions correspond to +86%, +14%, and -25% relative to the emission in 2005, respectively. The CO_2 constraint of the 450ppm CO_2 case corresponds to halve the global CO_2 emission relative to 2005. Although large growth of CO_2 emission of Asia according to economic growth is prospected as shown in the baseline case, emission reduction from current level is needed under the 450ppm CO_2 case.

Total electricity generations by technology of Asian countries are shown in Figure 6. Coal power generation is the largest supplier until 2050 in the baseline case. For CO_2 emission reduction, fuel switching from coal to gas and expansion of nuclear power are deployed in 2030. CCS is also deployed in 2030, but the volume is relatively limited in comparison with the CO_2 emission reduction as shown in Figure 5. Power generation by wind power and PV is smaller than that by fossil fuel plant with CCS due to their high cost. In 2050, nuclear power, CCS, wind power and PV are widely diffused for CO_2 emission reduction. In the 650ppm CO_2eq case, nuclear power generation is largely expanded relative to the baseline case, under the cost-effectiveness criteria. In the 550ppm CO_2eq and the 450ppm CO_2eq case, CCS and PV are also diffused as the cost-efficient technologies for CO_2 emission reduction. Electricity generation in Figure 6 includes the electricity for CCS and it becomes larger according with CO_2 emission reduction level.

Figure 5　Energy-related CO_2 emission and storage of Asia (Base technology scenario)

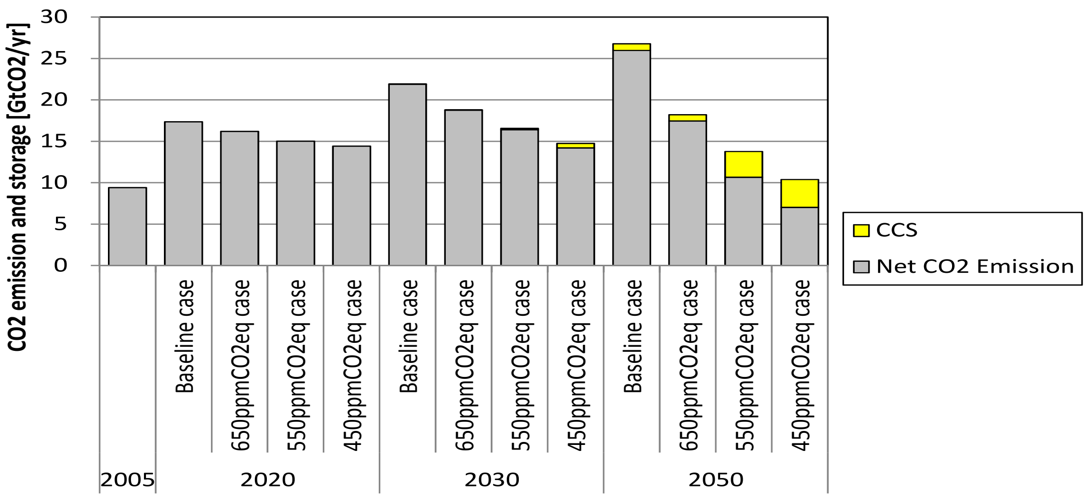


Figure 6 Electricity generation by technology of Asia (Base technology scenario)

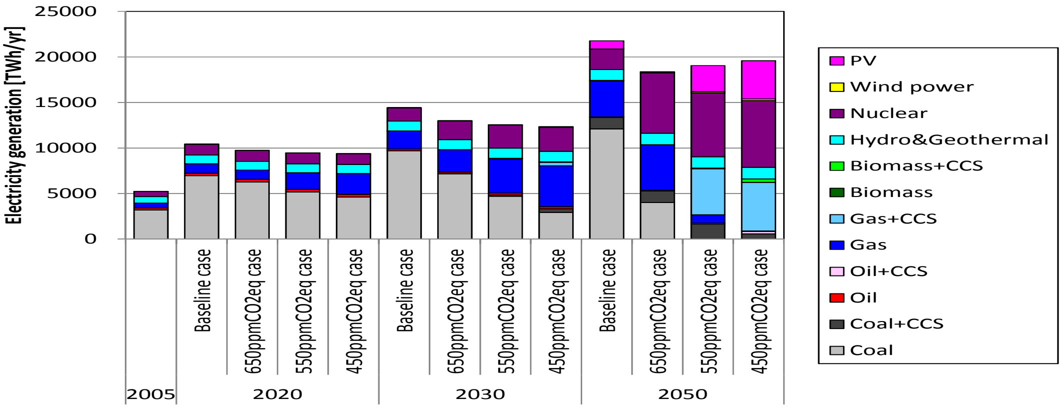


Figure 7 and Figure 8 show comparison of electricity generation and CO_2 emission reductions relative to the baseline case with the base technology scenario for Asian countries. In 2030, electricity generation structures in the no CCS scenario and the conservative renewable scenario are similar to that in the base technology scenario. In the no new nuclear power scenario, gas power generation substitutes for new nuclear power generation which is installed in the baseline technology scenario. CO_2 emission reduction by "Power generation: Others" is larger than that by the three technologies in 2030. This reduction is mainly achieved by fuel switching from coal to gas and efficiency improvements of coal and gas power plants. These measures are important to achieve steady mid-term CO_2 emission reduction. In 2050, weakened technology in each case is substituted by the rest two technologies. In the 450ppm CO_2eq case, the share of the rest two technologies is pushed up for achieving the required huge CO_2 emission reduction.

Figure 9 and Figure 10 show marginal CO_2 abatement cost and increase in total energy system cost relative to the baseline case with base technology scenario. In the base technology scenario, marginal CO_2 abatement costs in 2050 are \$30/tCO_2 for the 650ppm CO_2eq case, \$130/tCO_2 for the 550ppm CO_2eq case, and \$470/tCO_2 for the 450ppm CO_2eq case. The CO_2 marginal abatement cost of the 450ppm CO_2eq case is very high even in the base technology scenario. The increase in total energy system cost of this case in 2050 is 1,140 billion US2000\$/yr which corresponds to 2.2% of the assumed GDP. In the other three technology scenarios, marginal CO_2 abatement cost and total energy system cost rise up relative to that in the base technology scenario. The no CCS scenario has the largest impact on marginal CO_2 abatement cost. The marginal CO_2 abatement costs in 2050 are \$40/tCO_2 for the 650ppm CO_2eq case, \$250/tCO_2 for the 550ppm CO_2eq case, and \$2470/tCO_2 for the 450ppm CO_2eq case. Impact of the no new nuclear power scenario on total energy system cost is relatively large than that on marginal CO_2 abatement cost. This is because base load which is supplied by nuclear power generation in the other cases are substituted by other higher cost generations. The increases in total energy system cost in 2050 are 190 billion US2000$/yr for the 650ppm CO_2eq case, 620 billion US2000$/yr for the 550ppm CO_2eq case, and 1,300 billion US2000$/yr for the 450ppm CO_2eq case. The difference of the total energy system cost of the 450ppm CO_2eq case in 2050 between the base technology scenario and the no new nuclear power scenario is 160 billion US2000$/yr. This additional cost is larger than the cost for the 650ppm CO_2eq case. The impact of the conservative renewable cost scenario on these economic indicators was smaller relative to the other two scenarios, because wind power and PV are substituted by nuclear power and CCS and their costs are lower in average.

Figure 7 Comparison of electricity generation of Asia among the technology scenarios

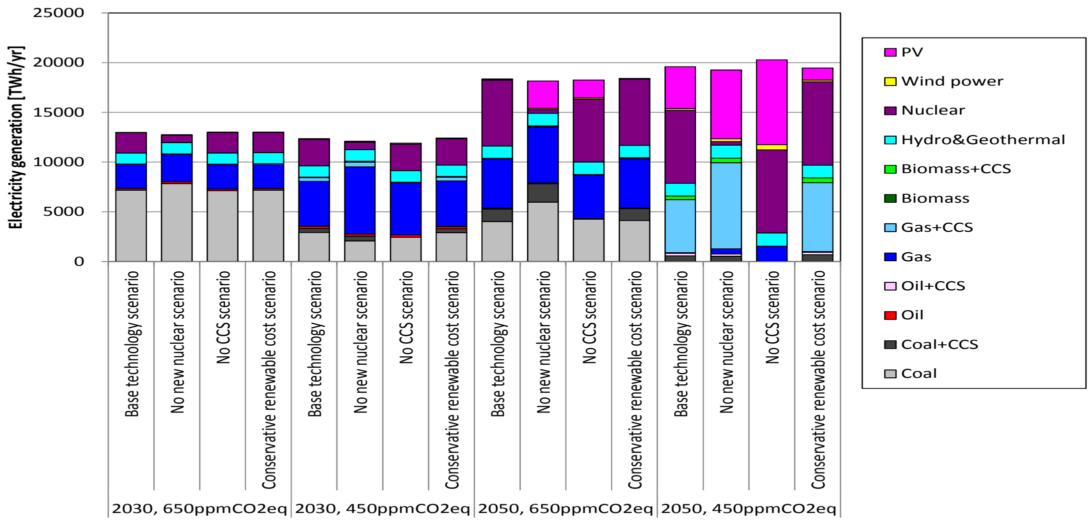


Figure 8 Energy-related CO_2 emission reductions relative to the baseline case with the base technology scenario (Asia)

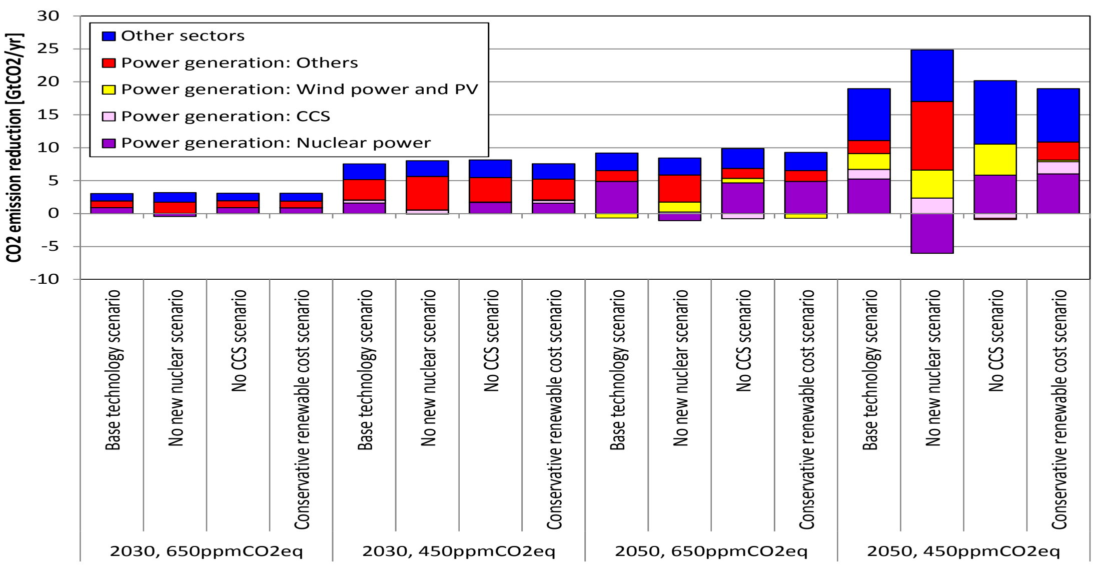


Figure 9 Marginal CO_2 abatement cost

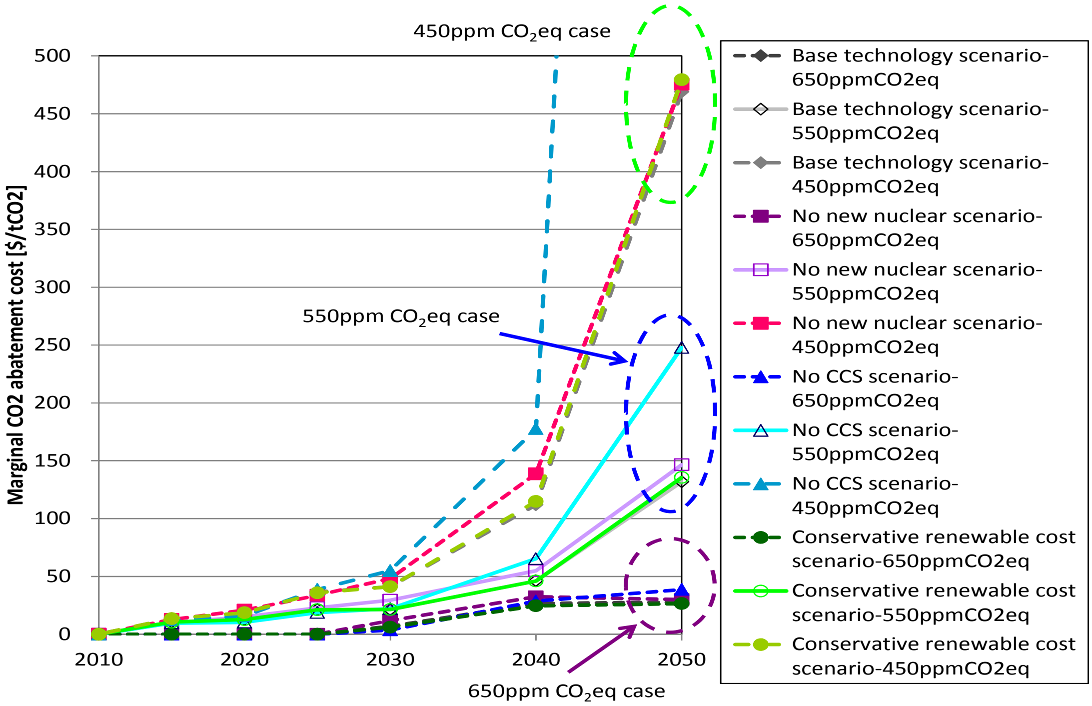
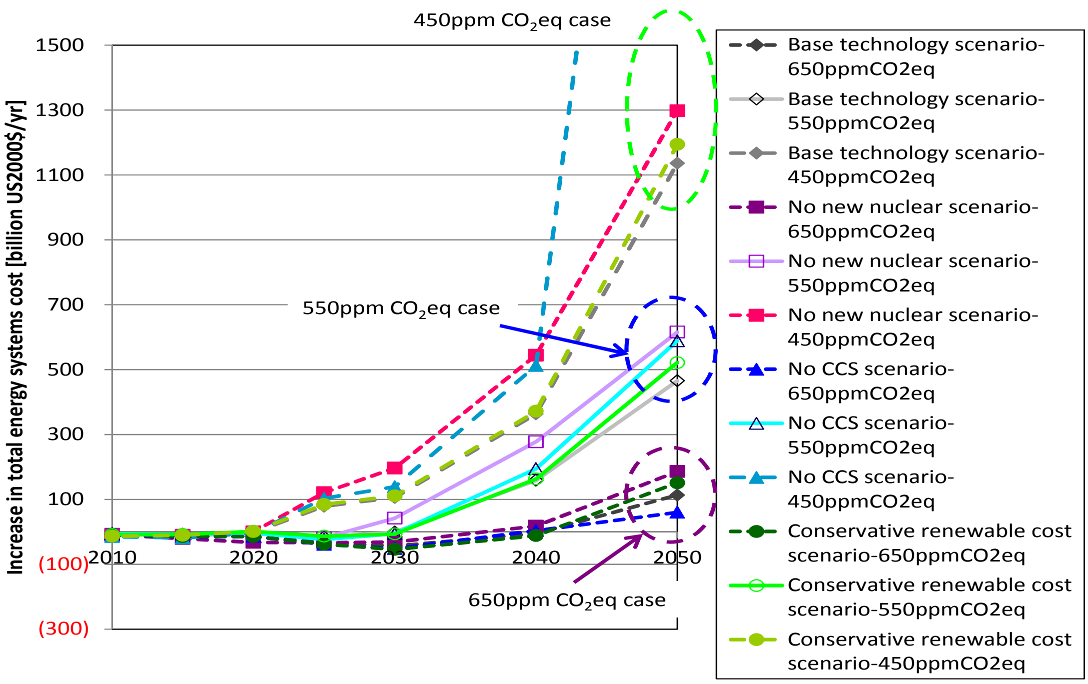


Figure 10 Increase in total energy system cost relative to the baseline case with the base technology scenario (Asia)



CONCLUSION

The climate change mitigations of Asian countries in power generation sector considering uncertainty of nuclear power generation, CCS and renewables (wind power and PV) were quantitatively analyzed by using DNE21+ model. The results are summarized as follows.

1) Even in the base technology scenario, drastic reforming of power generation and large costs are needed for deep CO_2 emission reduction, especially for the 450ppm CO_2 case.
2) In the three technologies scenario for nuclear power generation, CCS and renewables, the weakened technology is substituted by the rest two technologies and the assumed CO_2 emission reductions are potentially achievable. However, the required additional costs from the base technology scenario are large, especially for the no new nuclear power case and the no CCS case. CO_2 emission reduction without these technologies will become more difficult due to the increase in economic burden.
3) Mitigation measures of fossil fuel power plants (efficiency improvement and fuel switching among fossil fuels) have large impacts on mid-term climate change mitigation and they are important to achieve steady CO_2 emission reduction.

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