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Energy Procedia 37 (2013) 7502 – 7511

Energy Procedia

GHGT-11

Role of CCS in a New International Climate Regime

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Abstract

This paper examines the role of CCS in a new post-2012 international climate regime. Instead of the traditional 450ppm equilibrium stabilization of IPCC, a new scenario based on zero-emission and overshoot schemes was proposed recently. The scientific examinations demonstrated that the so called Z650 scenario could avoid long-term risks while meeting short term need of relatively large emissions. A numerical experiment of global energy system optimization shows the technical feasibility of the Z650 scenario not only globally but also regionally. The obtained time series total primary energy mixes suggest that the consumption of fossil energy will peak at 2030, and the clean energies, especially the renewable energy will play an essential role during the second half of the century. The resulted regional emission curves reflect the differences of financial and technical capability among areas. The industrialized countries will reduce their emissions by 50% in 2050 compared with 2005 levels, while the emissions of developing countries will increase by 10% at the same time. The cost-effective analysis based on the simulation results of the energy model shows that the Z650 scenario is economically rational. Compared with the reference case, the additional investments in Z650 scenario could be covered by the fuel savings during the following 40 years (2010-50) both globally and regionally. However, the comparison between the projection results and the national initiatives of major countries indicates that the policy measurements should be considered to promote the low carbon technology deployment and transfer. For this purpose, the existing CDM system should be enhanced on one hand, and a simpler and more efficient international scheme should be developed on the other hand.

The emission reductions by sector in Z650 scenario compared with business as usual scenario indicates that CCS will be essential technology from 2030 on. It becomes the second contributing sector following the efficiency improvement both in demand and supply sides in 2050 by realizing approximate 27% of the total reduction. However, the limitation of geological sequestration capacity prevents CCS to contribute more during the second half of 21[st] century. Further evaluation of CCS is conducted through an additional scenario analysis in which CCS technology is not available. As a result in power sector, the share of fire power generation plant decreases remarkably. To cover the shortage, the photovoltaic plays the main alternative role up to 2050, and fuel cell becomes the key solution from then on. Less reduction contribution of power sector requests more reduction in transportation sector. As the result, more electric vehicles and fuel cell vehicles are necessary from earlier stages. Utilization of these expensive technologies destroys the cost-benefit balance that is obtained in Z650 scenario. Regional analysis

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Selection and/or peer-review under responsibility of GHGT
doi:10.1016/j.egypro.2013.06.694

suggests that the additional cost in developing countries is much more than that in industrialized countries. This experiment indicates the technological priority of CCS from economic viewpoint.

Keywords: climate regime; CCS; energy model; cost-benefit analysis

1. Introduction

In order to address climate change, most countries joined the United Nations Framework Convention on Climate Change (UNFCCC) in early 1990s to examine how to reduce global warming. The Third Conference of Parties (COP3) took place in 1997, and adopted the principle update to the treaty, the Kyoto Protocol. In the protocol, industrialized countries and economies in transition (Annex I countries) committed to reduce their aggregate greenhouse gas emissions by about 5.2% during the period of 2008-2012 (so called the first commitment period) compared to 1990 emission levels. With the coming up of the expiration date of the first commitment period, the post-2012 climate regime has been examined during recent years. According to the Bali Action Plan adopted at the COP13 in 2007, intensive negotiations aimed at urgently enhancing the implementation of the Convention up to and beyond 2012 have been conducted during 2008 and 2009. However, the COP15 taking place in Copenhagen in December 2009 failed to produce an international agreement involving binding greenhouse gas emissions reduction targets. From then on, the international negotiation on climate change fell into a chaotic state. The COP16 held in Cancun in the end of 2010 and the COP17 held in Durban in the end of 2011 adopted the Cancun Agreements and the Durban Agreements that consist of significant decisions by the international community. The agreements represent key steps forward in capturing plans to reduce GHG emissions and to help developing countries protect themselves from climate impacts. However, the framework of the climate regime has not been clarified.

Fruitless negotiations on international binding scheme of GHG emissions reduction illustrate that the absence of a common vision become the biggest obstacle of combating global warming. It is time for us to go back to the beginning of the issue to consider what kind of world we can share.

2. New Climate Regime

In order to benefit the new international consensus against global warming, a post-2012 climate regime was examined through climate science investigation, energy system analysis, and international cooperation scheme discussion [1] [2] [3].

2.1. Global emission pathway

In general, the base of the climate regime combating global warming is that it is necessary to limit the global surface temperature to 2°C compared to pre-industrial levels (so called "2°C target"). In the Copenhagen Accord and following COP Agreements, this target was reconfirmed. Based on the target and the fourth assessment report of IPCC, the G8 Summit (Declaration 2007, 2008 and 2009) argued that the worldwide greenhouse gas emissions must be reduced by at least 50% in 2050 compared to the levels of 1990 or recent years. However, the ambitious argument failed to get global consensus due to the strong opposition by most developing countries who claimed that the reduction plan did not have sufficient scientific background and did not leave enough space for their economic growth. Therefore, it is necessary to re-examine the scientific analyses of the climate change for developing a reliable emission pathway which can be accepted worldwide.

Employing the schemes of zero emission and overshoot, a research group developed a new stabilization concept named “Zero-emission Stabilization (Z-Stabilization)” instead of the traditional equilibrium stabilization. Their researches [1] documented that the Z-Stabilization could avoid long-term risks while meeting short term need of relatively large emissions. Based on the new concept of stabilization and the 2°C target, a global GHG emission scenario named Z650 was proposed (Figure 1). The scenario was designed based on two assumptions, one is that the amount of cumulative CO_2 emissions in the 21st century would be 650GtC equivalent, the other is that the zero-emission would be achieved in 2160. Some recent researches [4] [5] [6] also employed the concept of zero emission or near zero emission for seeking best options of climate change mitigation. These researches suggest, from practical viewpoint, that a functional form with a peak within several decades following by monotonic decrease to approach to zero is necessary for a reliable emission pathway.

The performance of the designed Z650 scenario was examined, along with a typical 450ppm equilibrium stabilization scenario (E450), though projection experiment by using a simplified climate system model. The CO_2 concentration under the Z650 scenario increases more rapidly, exceeds 450ppm in about 2030, and goes to its peak of about 480ppm around 2070 due to the lager amount of emissions during the early period of 21st century. It declines thereafter because the emission will be less than the natural absorption, crosses the 450ppm line around 2160, and goes down steadily. In contrast the concentration under E450 scenario stays below 450ppm, and increases steadily to approach the final equilibrium state. As a result, the maximum temperature rise under Z650 scenario is 1.8°C at around 2100 (if all GHG was taken into account, the peak value would be 2.3°C). The peak will last only several decades, and then the temperature will decrease to a stable state (1.7°C higher than the pre-industrial level). At meanwhile, almost no significant difference of sea level rise occurs between the two scenarios. These results obtained through the projection experiment indicate that the proposed Z650 scenario could be a new solution on combating climate change given by science. According to the Z650 scenario, the global CO_2 emissions will peak between 2020 and 2030 with a ratio of approximate 1.3 and decrease to around 0.75 in 2050 compared to 2005 level.

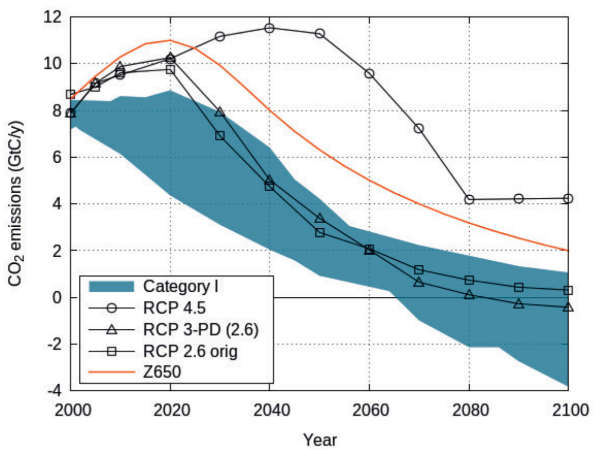

Figure 1 CO_2 emission pathways: RCPs and Z650 [1]

2.2. Energy model and scenarios

In order to examine the technical feasibility of the Z650 scenario and investigate the optimal way to realize it, numerical experiments of global energy system optimization using GRAPE (Global Relationship Assessment to Protect the Environment) model [7] were conducted. Fifteen regions were set in the model to cover the global aggregate, those are: United States, Western Europe, Japan, Canada, Oceania, Russia, Central Europe, East Europe, China, India, ASEAN countries, Middle East and Northern Africa, Southern Africa, Brazil, and Latin America. The former 8 regions were defined as industrialized countries, and the rest regions were defined as developing countries. The final energy demands for every region were assumed based on population and economic growth, while the technology assumptions were examined based on previous researches. The cost minimization of global energy system was carried out to optimize the global and regional energy supply.

Three main scenarios were analyzed for the period of 2000 to 2150. BAU (Business as Usual), which is the baseline scenario of CO_2 emissions, assumed no changes of the current energy and environmental policies in the future. REF (Reference), which is the reference scenario of economic assessment, assumed that energy conservation would be promoted according to regional capacities and conditions but no CO_2 reduction policy. Z650, which is the mitigation scenario, assumed a global CO_2 emission cap based on scientific Z650 scenario described above.

2.3. Long-term energy vision

The simulated global total primary energy supply (TPES) for the three scenarios is shown in Figure 2. Under BAU, the TPES with a large portion of fossil fuel increases substantially, triples in 2100 compared with the 2000 level. The TPES of REF increases slightly during the later stage, almost doubles in 2100 compared with the 2000 level, due to the influence of the regional energy conservation measures. However, the main component is still the fossil fuel.

On the other hand, the resulted TPES of Z650 is the cleaner in combination despite the same amount with REF. In order to prevent global warming, the consumption of fossil energy will peak at 2030, and the clean energies, especially the renewable energy will play an essential role during the second half of the century. As the results, portion of Fossil: Nuclear: Renewable is 5: 2: 3 in 2050, while 3: 2: 5, in 2100. Regional TPES for Z650 is also examined as shown in Figure 3. In industrialized countries, total primary energy is almost constant up to 2100, where share of fossil fuel gradually decreases and share of renewable energy mainly increases alternatively. In developing countries, total primary energy continuously increases up to 2100, where peak of fossil fuel consumption is around 2040, and both nuclear and renewable energy increase remarkably.

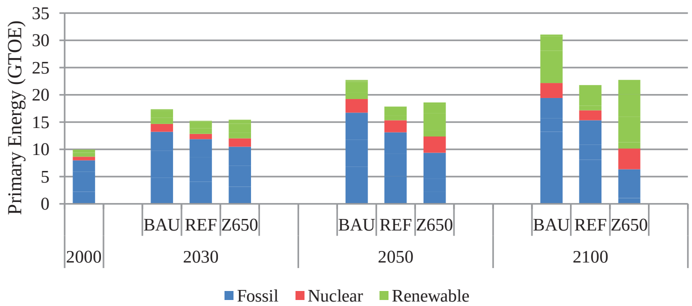

Figure 2 Global total primary energy supplies for the three scenarios

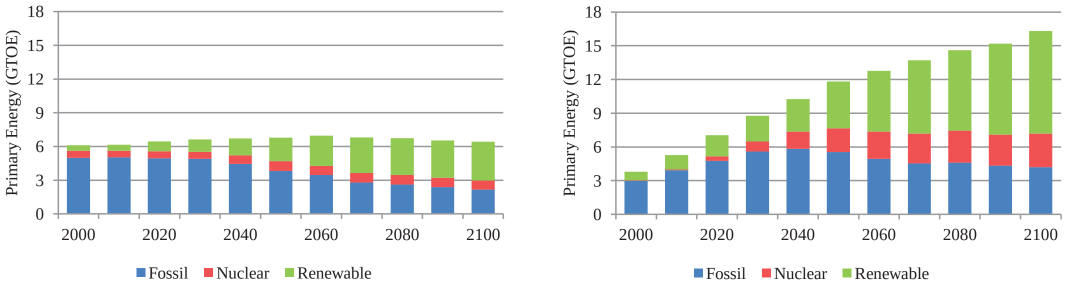

Figure 3 Regional total primary energy supplies for Z650
(left: industrialized countries; right: developing countries)

2.4. Cost-benefit analysis

An economic assessment was conducted based the analysis of necessary additional investments and the fossil fuel saving. The analysis is based on the accumulative statistics during 2010-2050. In REF, the world will emit 1,462 $GtCO_2$ during the 40 years, in which 622 $GtCO_2$ generated in industrialized countries while 840 $GtCO_2$ generated in developing countries. At the meanwhile, total energy system costs will be 232 trillion USD (in 2005 value) in the world with almost the same portions in industrialized and developing countries.

In order to achieve the Z650 vision against global warming, an accumulative emission reduction of 362 $GtCO_2$ is to be carried out, one third in industrialized countries and two thirds in developing countries. For the purpose, total additional investments of 11 trillion USD are necessary worldwide, which is equivalent to 0.28% of the global accumulative GDP in the same period. The data for industrialized and developing countries are 4 and 7 trillion USD, 0.18% and 0.43%, respectively. Most of the investments are distributed in transportation and power sectors.

At meanwhile, the additional investment will yield significant savings in fossil fuel consumption. The total fuel savings in the Z650 compared to the REF are 57 GTOE of coal and 32 GTOE of oil. However, additional 26 GTOE of natural gas will be consumed. Calculated using current prices of the fossil fuels, the undiscounted value of these fuel saving is 14 trillion USD, 5 in industrialized countries and 9 in developing countries. Thus, in this case the additional investments could be covered by the fuel savings during the following 40 years both globally and regionally. There would be a good balance between benefit and investment from the optimal energy mix. This assumes the technologies to be used by 2050 are those technologies that currently appear to be feasible and are expected to be widely deployed by 2030.

2.5. Energy related CO_2 emissions

Based on the global CO_2 emission cap of Z650, the global energy system optimization projected regional CO_2 emissions. Emissions of industrialized countries peak in 2010 and emissions in 2050 will be reduced by 50% compared to 2005 levels. On the other hand, emissions by developing countries will peak in 2030 at 1.6 times 2005 emissions and decline to 1.1 times 2005 emissions in 2050.

From the standpoint of regional equitability, per capita emissions in the industrialized nations will approach that of the developing nations by 2100 and the CO_2 emissions per GDP of the developing nations will approach that of the industrialized nations. The results for industrialized nations show that CO_2 emissions per capita and CO_2 emissions per GDP will converge around 2050. Global emissions in 2030 will be 1.6 times that of 1990 (1.2 times that of 2005) and will be about 1990 levels. Compared to the REF scenario without CO_2 constraint, the ratio for global emissions in 2030 for Z650 is 0.82. For industrialized nation the ratio is similar at 0.89. For 2050, the ratio to the REF scenario for industrialized nations of 0.48 is similar to the global ratio of 0.46. As the reduction potential is higher for developing nations, the effect is larger. In general, the resulted regional emission curves reflect the differences of financial and technical capability among areas. These results provide useful information for global harmony.

Compared with BAU, emission reductions by region till 2050 in Z650 are investigated. Among the regional emission reductions, that of the developing countries with substantial economic growth in the future occupies more than two thirds in the following 40 years. Especially the reductions in China, India and ASEAN countries contribute 31%, 13% and 8% of the total reduction in 2050 respectively. It means that the decarbonization in the regions with substantially increasing energy demands will hold the key to combat global warming. Among the industrialized countries, the United States will contribute the most. Its reduction occupies 14% of global reduction in 2050. While reduction in Japan only contributes approximate 1% of global reduction until 2050.

2.6. Practical approach to the global vision

To achieve the global low carbon vision in the real world is still a challenge even though the numerical experiments suggest that it is technological achievable and economical affordable. Table 3 summarizes the projected CO_2 emissions in 2030 and 2050 under REF and Z650, together with the domestic initiatives of the major industrialized (American Power Act; EC Commitment 2009.2.4; Japan's Basic Plan of Energy) and developing countries [8] [9]. It indicates that the domestic initiatives of the major industrialized counties agree with the projected emissions under Z650, while those of the developing countries agree with the projected emissions under REF. It can be predicted that the result of the bottom up approach, so called nationally appropriate mitigation actions (NAMA), will be a low carbon society in industrialized countries and an energy efficient society in developing countries. Therefore, further measures are necessary for developing countries through an international cooperation approach.

Table 1 Projected emissions and domestic initiatives of major industrialized and developing countries

Ratio to 2005	REF		Z650		Domestic Targets	
	2030	2050	2030	2050	2030	2050
World	1.5	1.6	1.2	0.75		
Industrialized countries	1.1	1.0	1.0	0.5		
USA	1.1	1.0	1.0	0.5	0.8	0.4
EU15	0.9	0.8	0.9	0.4		0.5
Japan	0.9	0.7	0.8	0.5	0.6	0.2
Developing countries	2.0	2.5	1.5	1.1		
China	2.0	2.2	1.5	0.8	2.1	2.3
India	2.6	4.3	1.9	1.6	2.7	4.1

The picture is clear that the key issue towards a global low carbon vision is how to fill in the significant gap between REF that can be addressed through domestic effort and the Z650 for developing countries. The cumulative reductions during the following 40 years (2010-2050) are 248 $GtCO_2$ which require additional investments of \$7 trillion with benefits from fuel saving of \$9 trillion. To eliminate this gap, low carbon technology deployment is essential according to the described analysis results (Fig. 8). The necessary reduction is an order of magnitude larger than the current Kyoto Protocol CDM (360 $MtCO_2$/year) and it would be difficult for the current CDM mechanism to address it. An enhanced international mechanism that meets these requirements will have to be developed that incorporates the Z650 target in the framework to promote low carbon technology deployment. The key principles of the mechanism are, a)to be low carbon technology oriented; b)to promote the engagement of developing countries; c)to be based on bilateral offset mechanism; d)to utilize the existing bilateral financial mechanism; e)to remove financial additionality; and f)to conduct with a simple management system.

3. Role of CCS in the Climate Regime

In order to examine the role of CCS in the new climate regime, the CO_2 reduction contributions by sector in Z650 scenario was investigated (Figure 4). It is clear that the energy conservation contributes the most during the whole period, which occupies 42% and 32% of all reduction in 2030 and 2050 respectively. The fuel conversion from fossil to nuclear and renewable energy will also play important role, and will contribute 25% and 27% of all reduction in 2030 and 2050 respectively. CCS, however, will be essential technology from 2030 on. It becomes the second contributing sector following the efficiency improvement both in demand and supply sides in 2050 by realizing approximate 27% of the total reduction. However, the limitation of geological sequestration capacity that was set to be 1000 Gtone CO_2 according to IPCC report prevents CCS to contribute more during the second half of 21st century.

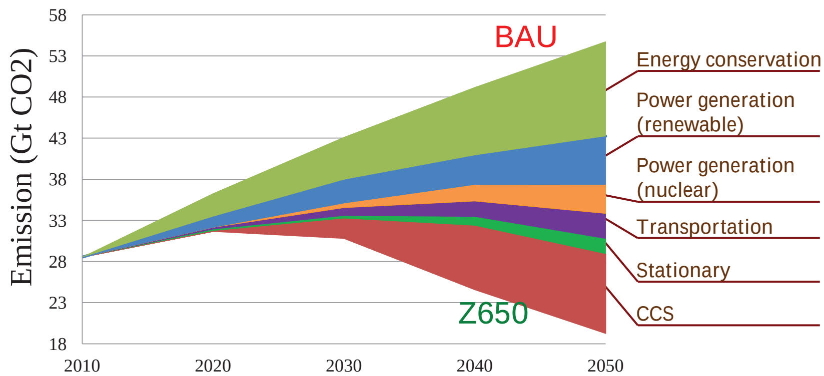

Figure 4 Contributions of each sector to CO_2 emission reduction based on simulations

Further evaluation was conducted through an additional scenario analysis in which CCS technology is not available (NoCCS). The projection results were investigated compared with the standard Z650 scenario.

3.1. Impact to power generation

The global power generation mix for the Z650 and NoCCS scenarios are shown in Figure 5. As a result, the share of fossil fire power generation plant decreases remarkably. To cover the shortage, the renewable energy especially the photovoltaic plays the main alternative role up to 2050, and fuel cell becomes the key solution from then on. Even though these alternatives keep the electricity supply to be possible, the contribution to CO_2 reduction by power sector will be limited, especially during middle stage (Table 2).

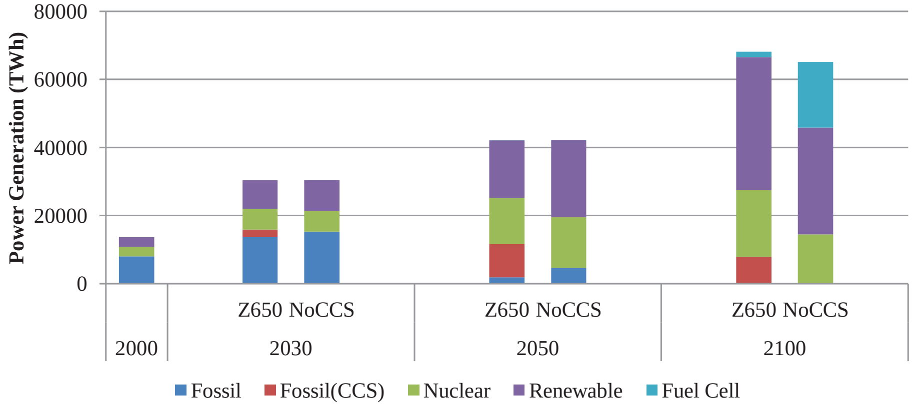

Figure 5 Power generation mix for Z650 and NoCCS scenarios

Table 2 CO2 emissions by sector in Z650 and NoCCS scenarios (Mtone CO_2)

	2030		2050		2100	
	Z650	NoCCS	Z650	NoCCS	Z650	NoCCS
Power generation	9495	9748	874	1761	51	11
Transportation	6995	6830	4954	3971	153	29
Stationary	14278	14247	13440	13537	4427	4590

3.2. Impact to other sectors

Less reduction contribution of power sector during the middle stage requests more reduction in transportation sector (Table 2). As the result, more electric vehicles and fuel cell vehicles are necessary from earlier stages, and plug-in hybrid vehicle will lost its future position.

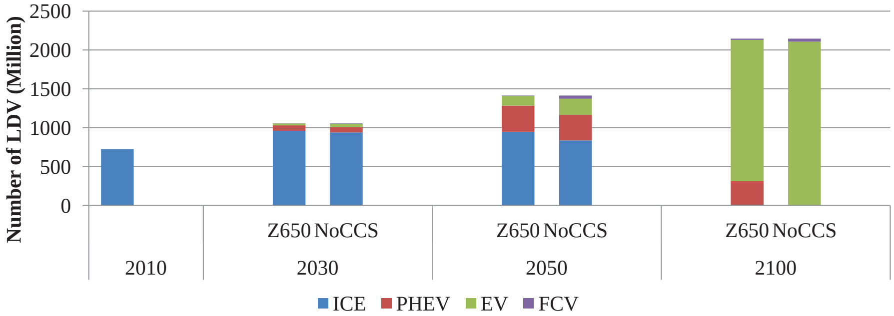

Figure 6 Numbers of LDV in Z650 and NoCCS scenarios

3.3. Economic impact

In general, expensive technologies become necessary due to the absence of CCS. The same cost-benefit analysis was conducted for the NoCCS scenario as mentioned above. The economic performance is compared with that of Z650 in Figure 7. Globally, the limitation of using fossil energy increases the fuel saving benefit by approximately 25%, but the additional investments will be 135% larger. As a result, the cost-benefit balance that is obtained in Z650 scenario will be destroyed. Regional analysis suggests that the additional cost in developing countries is much more than that in industrialized countries. This experiment indicates the importance of CCS from economic viewpoint.

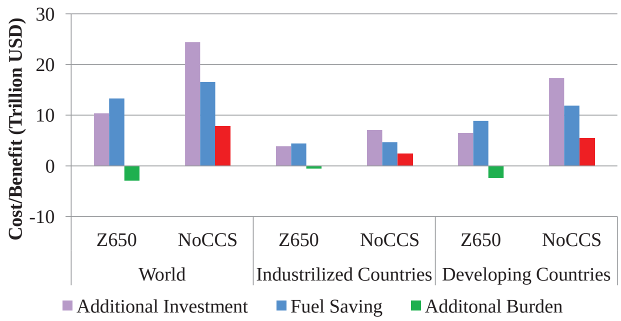

Figure 7 Economic performances of Z650 and NoCCS scenarios

4. Conclusion

In order to address the biggest challenge to global sustainable development caused be global warming, a new post-2012 climate regime was examined to be scientifically sound, economically and technologically rational.

Instead of the traditional 450ppm equilibrium stabilization of IPCC, Z650 scenario based on zero-emission and overshoot schemes was proposed recently. The essential limitation is that the total emission during the 21st century should be lower than 650GtC. The scientific examinations demonstrated that the scenario could avoid long-term risks. At the meanwhile it could meet short term need of relatively large emissions.

A numerical experiment of global energy system optimization shows the technical feasibility of the Z650 scenario not only globally but also regionally. The obtained time series total primary energy mixes suggest that the consumption of fossil energy will peak at 2030, and the clean energies, especially the renewable energy will play an essential role during the second half of the century.

The cost-effective analysis shows that the Z650 scenario is economically affordable. Compared with the reference case, the additional investments in Z650 scenario could be covered by the fuel savings during the following 40 years (2010-50) both globally and regionally.

The resulted regional emission curves reflect the equitability among areas. Both emissions per capita and emissions per unit GDP converge towards the end of the century. The industrialized countries will reduce their emissions by 50% in 2050 compared with 2005 levels, while the emissions of developing countries will increase by 10% at the same time.

The results of individual industrialized countries fit with their domestic initiatives well. However, there is a significant gap between domestic initiatives and global low carbon vision in developing countries. Therefore, an international cooperation approach is necessary based on domestic bottom up approach. Because that the deployment of low carbon technologies plays an essential role in the global optimization scenario, a technology oriented international cooperation mechanism is necessary for the approach besides the enhancement of the current CDM.

Investigation of the role of CCS on achieving Z650 scenario indicates the necessity of the option, especially during the middle stage.

Acknowledgements

This paper is based on a research project launched by the Canon Institute for Global Studies. We'd like to thank the project members, Mr. Masanori Tashimo, Dr, Takahisa Yokoyama, Ms Yuriko Aoyanagi, Mr. Kazuaki Matsui, Dr. Dr. Atsushi Kurosawa, Mr. Ken Oyama, Dr. Yasumasa Fujii, and Dr. Ryo Komiyama. We also thank Prof. Matsuno, Mr. Toshihiko Fukui, Mr. Ryozo Hayashi, Mr. Kazumasa Kusaka, and Mr. Akihiro Sawa for their kindly advices on the research.

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