Energy Perspective, Security Problems and Nuclear Role Under Global Warming

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Additional information is available at the end of the chapter

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1. Introduction

It is the critical issues of the 21st century to achieve global scale 3E problems, which are keeping Environmental preservation, Energy security, and Economic growth. Recently there are several recommendations to affect national energy policy. Climate change due to carbon dioxide in atmosphere has not been fully proved, but Precautionary Principle to reduce carbon emission has been adopted internationally because it will be too late to cope with disaster after a century. It is a time to take much longer time span for energy planning to cope with future energy crisis, which seems inevitable due to apparent limit of resources.

Role and potentials of nuclear energy system in the energy options are discussed from the viewpoint of sustainable development with protecting from global warming. They are affected dramatically by different sets of energy characteristics, nuclear behavior and energy policy even under the moderate set of presumptions. Introduction of thousands of reactors in the end of the century seems inevitable for better life and cleaner earth, but it will not come without efforts and cost. The analysis suggests the need of long term planning and R&D efforts under the wisdom.

New regime establishment has been discussed toward climate change in Section II. The feasible target for new emission scenario called Z650 (Overshoot & Zero-Emission) instead of traditional concept and energy mix against global warming has been proposed. Taking the effort for energy-saving as major premise, carbon capture and storage for fossil fuel, renewable energy and nuclear energy should be altogether developed, which means energy best mix should be achieved, under the constraint of keeping CO2 concentration in the atmosphere around 450ppm.

Energy security problems and nuclear role have been also discussed in Section III. The basic overview of energy security and method of evaluation are reorganized. Energy security which had wide conception is indicated by method that compares the energy security level in each country. The role and potential of nuclear power from the viewpoint of the energy security is an important point to examine the direction and the role of the nuclear power industry in the future. It is understood that the energy security is severely affected by the case without nuclear energy.

Energy issue and nuclear energy role after the Fukushima Daiichi Accident has been further examined in Section IV. The root causes and countermeasures of the Fukushima Daiichi Accident are described and the direction for energy and nuclear power after the accident is discussed.

The path and key issues for "Sustainable development" has been summarized in Section V. Nuclear power and renewable energy should be two wheels towards low carbon societies against global warming with economic growth and with avoiding energy security problem.

2. Toward a new climate change regime establishment

2.1. Climate change history

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.

2.2. 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 reexamine 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 (Matsuno et al., in [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 (e.g., UKCCC, 2008 [2]; Allen et al., 2009 [3]) 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. Figure 2 shows the emission pathways (a), the CO_2 concentrations (b), the global temperature rises from the pre-industrial period (c), and the sea level rises due to thermal expansion (d) of the two scenarios. 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 CO2 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.

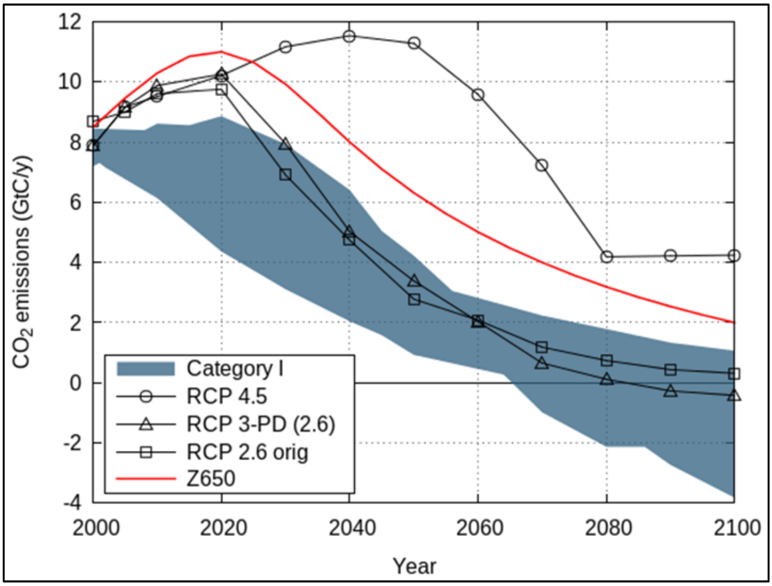


Figure 1. CO$_2$ emission pathways: RCPs and Z650 (Matsuno et al., in [1])

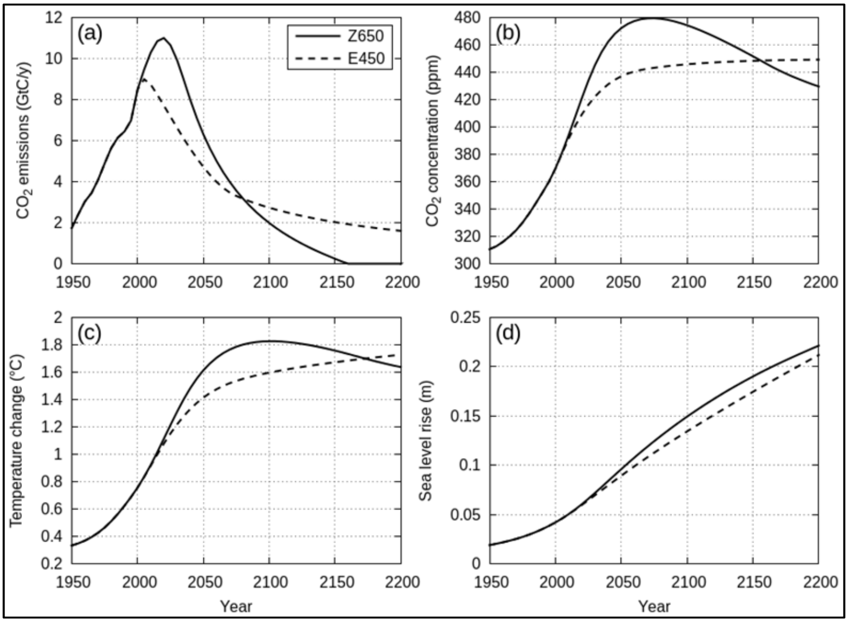


Figure 2. Comparison between Z650 and E450 during short to midterm (Matsuno et al., in [1])

2.3. Optimal way toward the global vision

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 (Kurosawa et al., 1999 in [4]) 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 CO2 emissions, assumed no changes of current the energy and environmental policies in the future. It is very similar with the Reference Scenario of IEA (IEA, 2010 in [5]) (Figure.3). 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 CO2 reduction policy. It has a similar performance with the New Policy Scenario of IEA (IEA, 2011 in [6]) (Figure.4). Z650, which is the mitigation scenario, assumed a global CO2 emission cap based on scientific Z650 scenario described above (Figure. 2(a)).

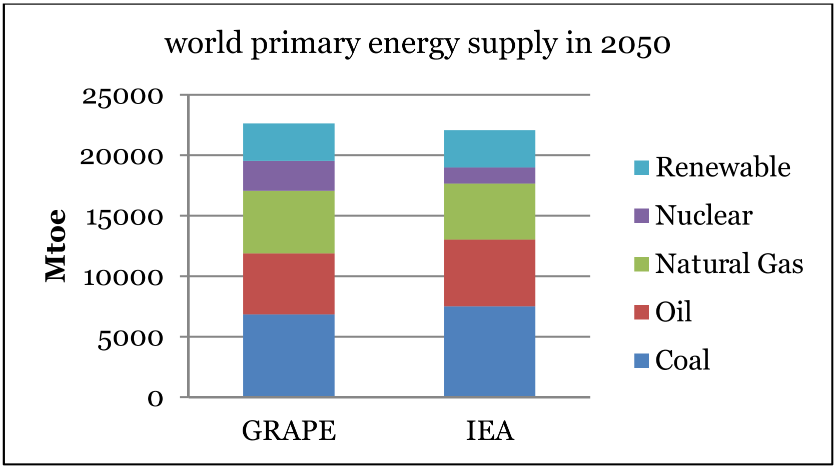


Figure 3. Comparison between BAU in this study with the Reference Scenario of IEA

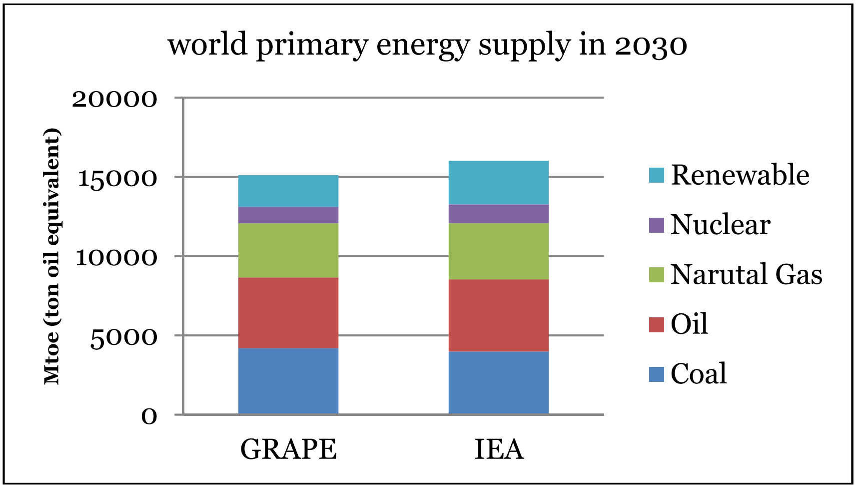


Figure 4. Comparison between REF in this study with the New Policy Scenario of IEA

2.3.1. Long-term energy vision

The simulated global total primary energy supply (TPES) for the three scenarios is shown in Figure 5. 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 6. 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.

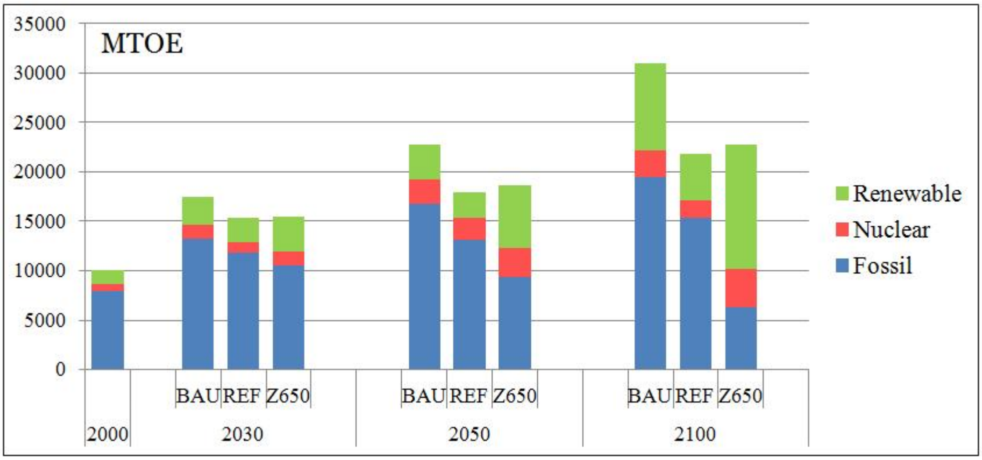


Figure 5. Global total primary energy supplies for the three scenarios

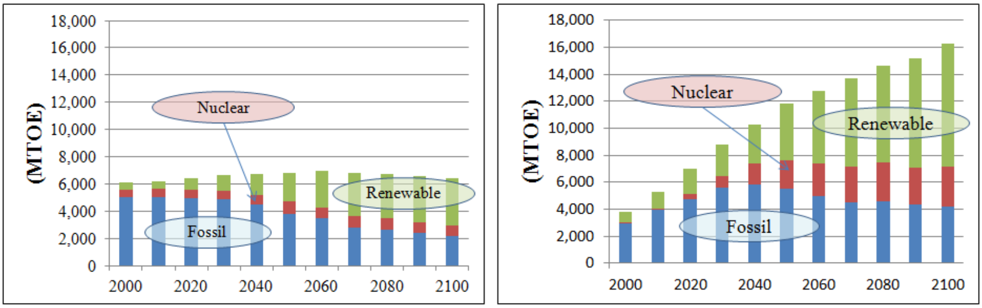


Figure 6. Regional total primary energy supply for Z650 (left: industrialized countries; right: developing countries)

The results for global power generation trends for Z650 are shown in Figure 7. In general, decarbonization and pluralization processes will be improved together. The fossil fuel will play essential role during early stage, but will decrease after the peak in 2040. During the second half of the century, it will cover less than 15% of the total power generation. The nuclear energy will increase constantly during the first half, and provide approximate 30% of the global power. As to renewable energies, large scale utilization of the wind power will start from 2020, while that of the solar photovoltaic power will start from 2050. Both of them increase steadily till the end of the century. Together with the stable hydro power and increasing biomass power generation, the renewable energies will cover almost 40% of global power generation in 2050, and a portion of about 60% in 2100.

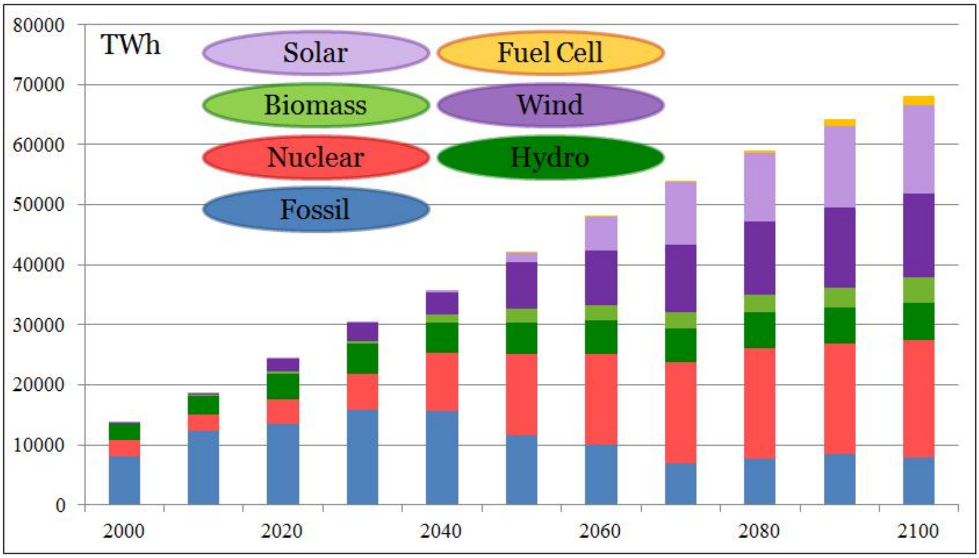


Figure 7. Global power generation for Z650

2.3.2. *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 (Figure. 8). 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.

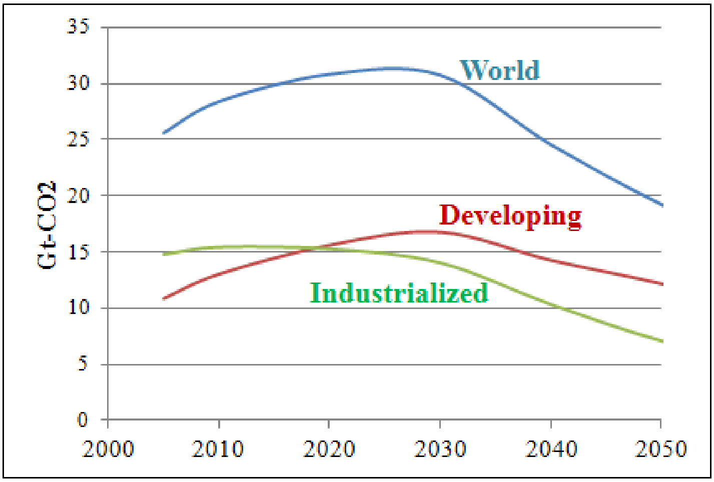


Figure 8. Global and regional CO2 emissions of Z650

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 (Figure. 9). 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 (Table 1). 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.

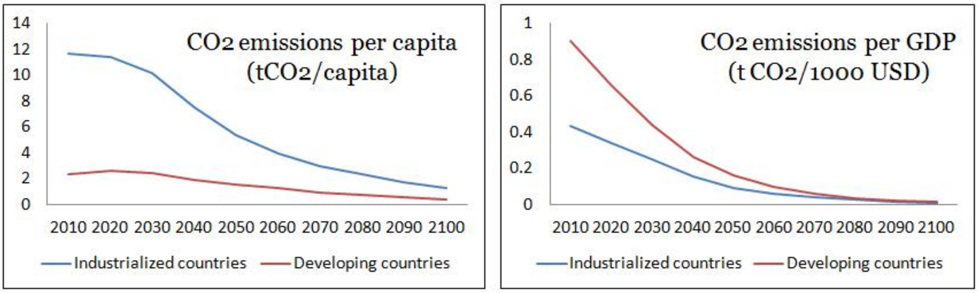


Figure 9. Two CO_2 emission index based on simulation of Z650

Region	CO_2 emissions					
	2030			2050		
	Ratio to 1990 levels	Ratio to 2005 levels	Ratio to REF of 2030	Ratio to 1990 levels	Ratio to 2005 levels	Ratio to REF of 2050
World	1.60	1.20	0.82	1.00	0.75	0.46
Industrialized countries	1.05	0.95	0.89	0.53	0.48	0.48
USA	1.16	0.96	0.90	0.57	0.47	0.47
EU15	0.89	0.86	0.91	0.46	0.45	0.53
Japan	0.93	0.79	0.90	0.55	0.47	0.66
Developing countries	2.82	1.54	0.77	2.05	1.12	0.45
China	2.77	1.48	0.74	1.53	0.82	0.37
India	3.42	1.91	0.72	2.83	1.57	0.37
ASEAN	3.74	1.64	0.80	3.41	1.50	0.57

Table 1. Global and regional emissions in major industrialized and developing countries

Compared with BAU, emission reductions by region and sector 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 (Figure. 10). 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.

The results of analysis of CO_2 reductions by sector show that energy conservation contributes the most during the whole period (Figure. 11), occupies 42% and 32% of all reduction in 2030 and 2050 respectively. The second contributive sector is the power generation. It will contribute 25% and 27% of all reduction in 2030 and 2050 respectively. The carbon capture and storage (CCS) will play an increasing role in later stage, contribute 27% of all reduction in 2050.

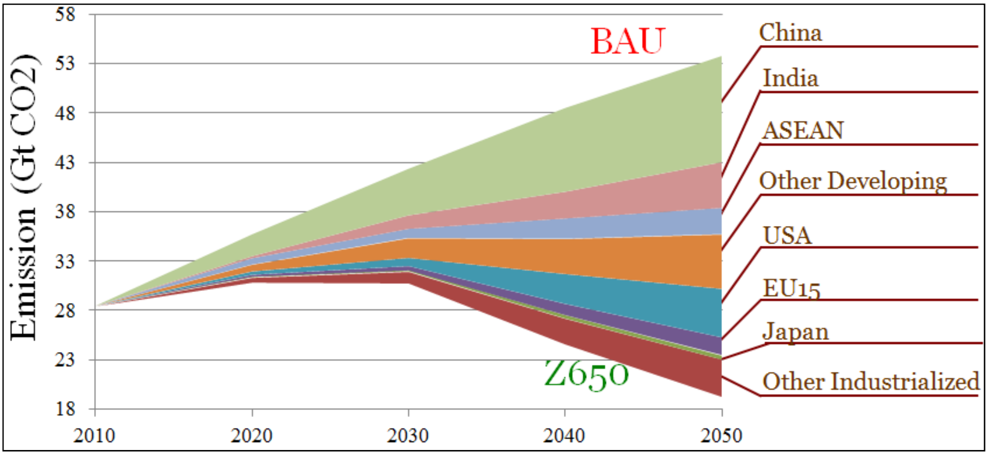


Figure 10. Simulated regional emission reductions in Z650 compared with BAU

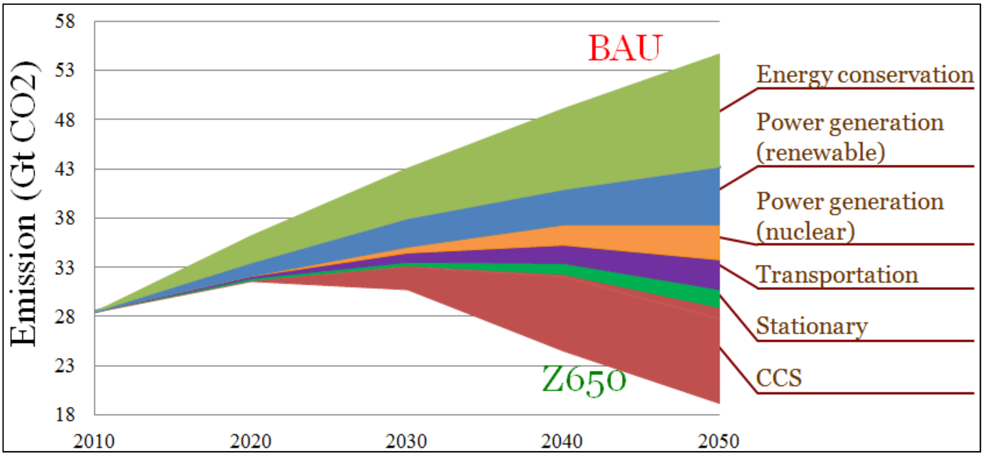


Figure 11. Contributions of each sector to CO_2 emission reduction based on simulations

2.3.3. *Economic assessment*

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 Gt CO2 during the 40 years, in which 622 Gt generated in industrialized countries while 840 Gt 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 (Table 2).

<table>
<tr><td rowspan="2">REF</td><td colspan="2">CO2 Emissions (ratios to 2005 levels)</td><td rowspan="2">Acc. Emissions GtCO2 (2010-2050)</td><td colspan="2" rowspan="2">Acc. Costs T$ (2010-2050)</td></tr>
<tr><td>2030</td><td>2050</td></tr>
<tr><td>World</td><td>1.5</td><td>1.6</td><td>1462</td><td colspan="2">323</td></tr>
<tr><td>Industrialized countries</td><td>1.1</td><td>1.0</td><td>622</td><td colspan="2">154</td></tr>
<tr><td>Developing countries</td><td>2.0</td><td>2.5</td><td>840</td><td colspan="2">169</td></tr>
<tr><td rowspan="2">Z650
(Z650+)</td><td colspan="2">CO2 Emissions (ratios to 2005 levels)</td><td rowspan="2">Acc. Reductions GtCO2 (2010-2050)</td><td rowspan="2">Additional Investments T$ (2010-2050)</td><td rowspan="2">Fuel Saving T$ (2010-2050)</td></tr>
<tr><td>2030</td><td>2050</td></tr>
<tr><td>World</td><td>1.2</td><td>0.75</td><td>362</td><td>11
(42)</td><td>14
(10)</td></tr>
<tr><td>Industrialized countries</td><td>1.0
(0.7)</td><td>0.5
(0.2)</td><td>114
(256)</td><td>4
(37)</td><td>5
(10)</td></tr>
<tr><td>Developing countries</td><td>1.5
(1.9)</td><td>1.1
(1.5)</td><td>248
(106)</td><td>7
(5)</td><td>9
(0)</td></tr>
</table>

Table 2. Global and regional economic analysis based on the simulations

In order to achieve the Z650 vision against global warming, an accumulative emission reduction of 362 Gt CO2 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.

In order to evaluate the economic performance further, an additional scenario analysis was conducted. In the new scenario, which is so called Z650+, the emission cap for industrialized countries is added to constraint conditions according to the G8 Summit Declaration. That is the industrialized countries will reduce their emission by 80% in 2050 compared with 2005 levels. The projection results are also shown in Table 2.

The accumulative emission reduction is the same, but one third will be carried out in developing countries and two thirds in industrialized countries. Due to the lower reduction potential of low cost in industrialized countries, the total necessary additional investments jump to 42 trillion USD, which is equivalent to 1.09% of the global accumulative GDP in the same period. The data for industrialized and developing countries change to 37 and 5 trillion USD, 1.66% and 0.31%, respectively. At the same time, the fuel savings will be less than Z650, and will mainly distribute in industrialized countries. As a result, the good balance between additional investments and fuel saving is destroyed. In addition, the high cost in industrialized countries would not bring benefits to developing countries.

2.4. Role of nuclear energy

As mentioned above, nuclear energy will play an important role to achieve the proposed vision against global warming. Its share in global TPES will increase steadily during the first half of the 21st century, from approximate 10% in 2030 to almost 20% in 2050, and will keep the level in the second half of the century. It will contribute more in power generation sector. Approximate 20% of global electricity in 2030 and more than 30% in and after 2050 will be generated by nuclear energy.

In order to evaluate the role of nuclear energy, the analysis on two sub-scenarios based on Z650 were carried out. One is NuPO, in which nuclear energy will be phased out with considering

Fukushima Daiichi Accident affect, that is no new plant will be built from 2020 and the current plants will be closed according to designed life time. The other is NoFBR, which means the technology of Fast Breeder Reactors (FBR) will not be utilized. In usual case such as Z650 scenario, we assumed that the FBR technology will be available and introduced from 2050.

2.4.1. *Impact to TPES*

The global TPES of the Z650, NuPO and NoFBR are shown in Figure 12. In the case of phasing out nuclear energy, natural gas including that from unconventional resources will be the main alternative during the first half of the period. However, large-scale introduction of renewable energies, especially the offshore wind energy, occurs during the second half of the period due to the limitation of natural gas resources. On the other hand, the absence of breeder technology does not cause significant influence to TPES during the early stage. But the increase of nuclear energy utilization will be limited by the uranium resources thereby more natural gas will be introduced during the middle stage. Within the end stage of the period, similar to the characteristics in NuPO, large-scale of renewable energy will be introduced.

Anyway, Z650 scenario shows Light Water Reactor (LWR) will play important role in the first half century, while FBR, latter half.

2.4.2. *Impact to power generation*

Figure 13 illustrates the projection results of the global power generation for the Z650, NuPO and NoFBR. In general, similar portfolio is necessary for both NuPO and NoFBR compared with Z650. The natural gas, biomass and wind energy will be the main alternatives to nuclear energy during the early stage. While natural gas with CCS, solar energy and fuel cell will be the main alternatives during the late stage. However, the scales of introducing these technologies are smaller in NoFBR compared with NuPO due to the availability of LWR. And the more coal can be used through the technology of IGCC with CCS during the middle stage. According to the technology portfolio, the global average costs for power generation in NuPO are much higher than in Z650 during the whole period and will be almost twice in 2100 (Figure. 14). On the other hand, the global average costs for power generation in NoFBR are not significantly different with those in Z650 till around 2060. However, it will increase rapidly during the end stage in the case of NoFBR, and will be approximately 50% higher than in Z650 (Figure. 14).

2.4.3. *Economic impact*

The same economic assessments as for Z650 are performed for NuPO. Compared to the Z650 scenario, global total additional investment through 2050 would increase from 11 trillion USD to 17 trillion USD while benefits from fuel saving would decline from 14 trillion USD to 9 trillion USD. The additional investment and fuel savings are 6 trillion USD and 5 trillion USD for industrialized countries, 11 trillion USD and 4 trillion USD for developing countries. These results indicate that the more negative impacts will happen in developing countries. There is no significant difference between the economic performance of NoFBR and Z650 till 2050.

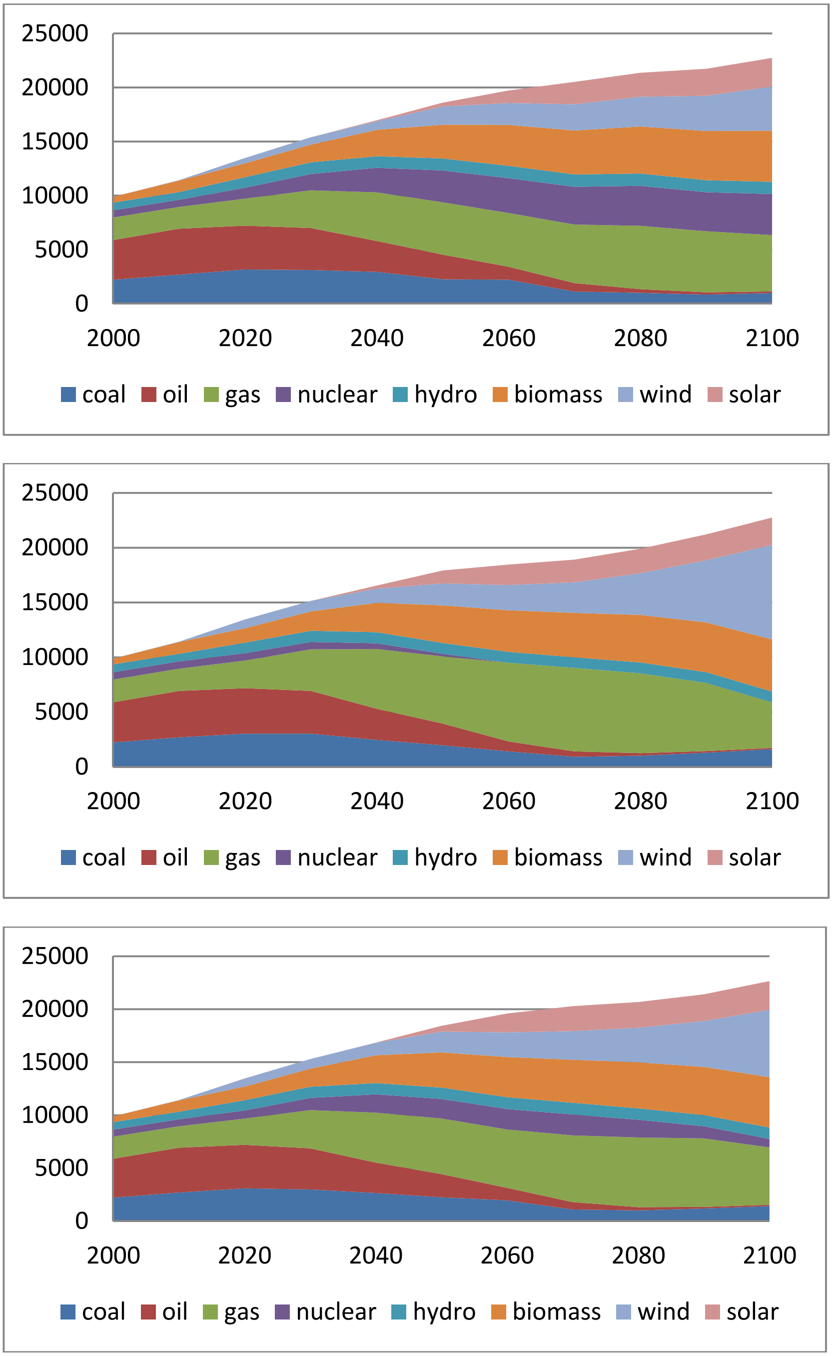


Figure 12. Projected TPES (upper: Z650; middle: NuPO; lower: NoFBR) (unit: Mtoe)

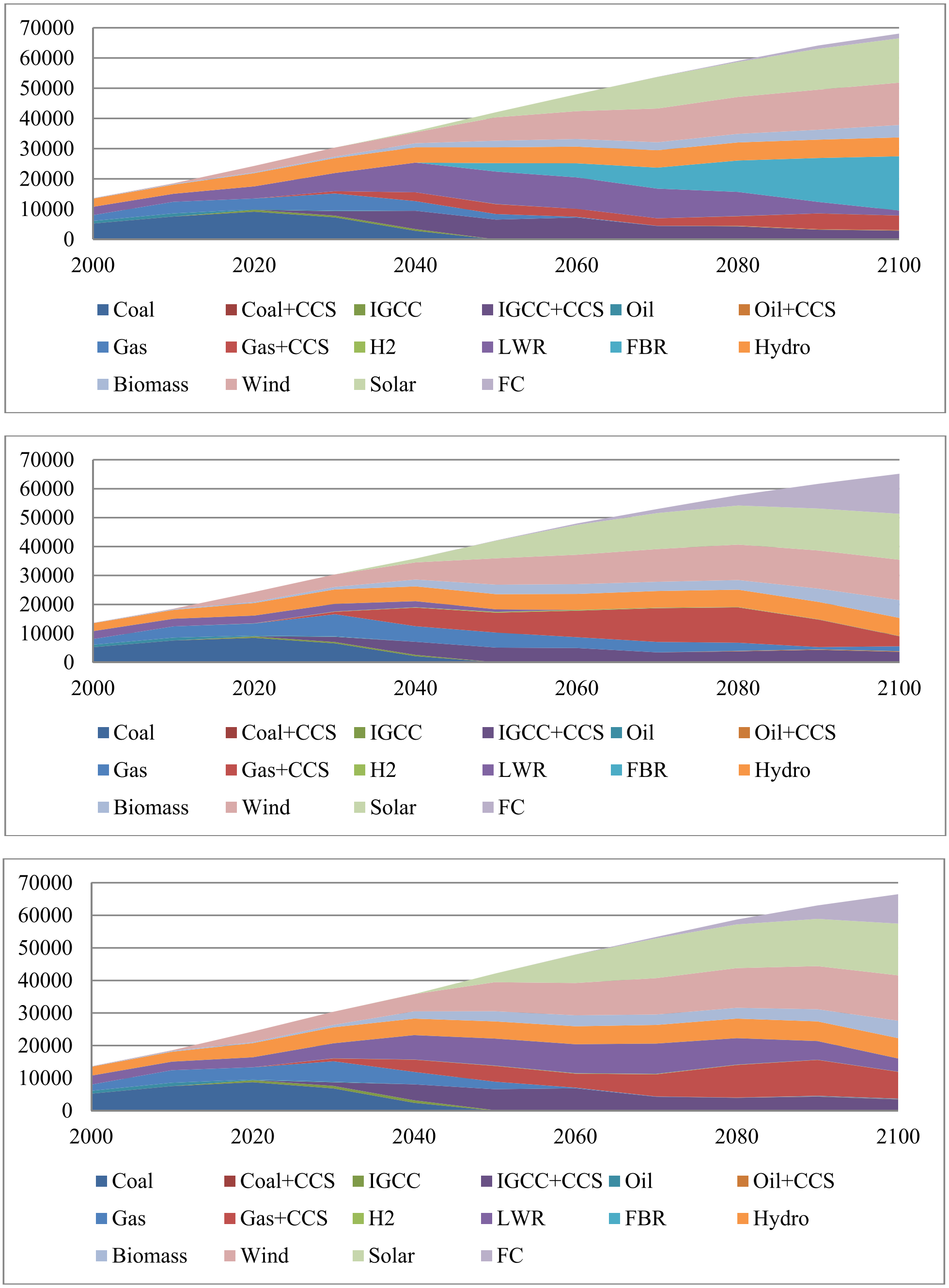


Figure 13. Figure 13 Projected global power generation (upper: Z650; middle: NuPO; lower: NoFBR) (unit: TWh)

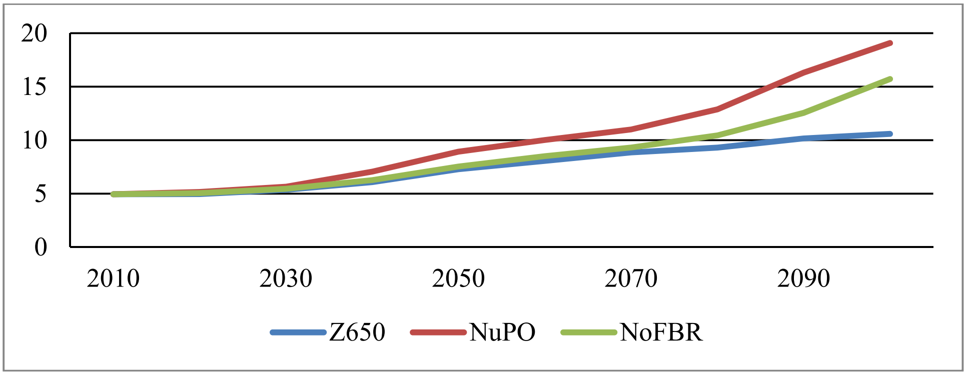


Figure 14. Projected global power generation costs (unit: cents/kWh)

3. Energy security problems

3.1. Energy security history

It is the biggest problem of the 21st century to achieve global scale 3E problems, which are keeping Environmental preservation, Economic growth, and Energy security. Recently there are several recommendations to affect national energy policy. For instance in Japan, the role and progress of nuclear is expected to solve the global warming up, by Council for Science and Technology Policy, the Atomic Energy Commission and the Agency of Natural Resources and Energy, and etc.

Expert meeting on "Nuclear Energy and Security of Supply" was held for OECD/NEA/NDC, during Dec. 2007- Dec. 2008, in Paris. One of the authors has attended the meeting for Japanese Expert. The explanation, examples, and proposals are based on the meeting discussion [7].

In fact, there are multiple concepts for energy security, due to the differences of the quantity of resources, density of energy network, or the needs of the times [7-9]. As broad definitions, under time axis or spatial axis, two approaches, divided to the long term on global problem and short term on each area problem, are advocated in the paper. The problem of short term on each area is recognized as definition of energy security of narrow meaning in general, which are further categorized into incidental (temporal) problem and structural problem.

The model is popular for poor resource countries to evaluate security risk based on the imported energy resources portfolio methodology which targets to energy best mix. Several evaluations of energy securities such in Europe and Japan are discussed [7-9]. As specific example of evaluation, the evaluation process is shown how to evaluate the security risk from the five points of view, energy efficiency, diversification index of energy resource portfolio, energy resource dependency from Middle East and Russia, self-sufficiency ratio in the primary energy supply, and CO2 emission index. The comparison results are also indicated in seven developed countries belong to OECD. Furthermore, the study of nuclear role from the viewpoint of different results of nuclear existence or not is discussed [8]. The Scenario Planning analysis of "Two China in 2015" is also introduced [10].

3.2. Concept of energy security

3.2.1. Energy resources

Figure 15 shows evolution of primary energy structure, shares of oil and gas, coal, and non-fossil sources, in percent, historical development from 1850 to 1990 (triangles) and in scenarios to 2020 (open circles), 2050 (diamonds), and 2100 (closed circles) [11]. Three cases as follows are indicated in the figure;

Case A includes three high-growth scenarios,

Case B has a single middle-course scenario, and

Case C is the most challenging.

The primary energy had changed to coal of fossil fuels from firewood which is originated by solar energy since the Industrial Revolution, shift to oil occurred in the 20th century, and then it has come to nuclear power and fossil fuels in general in 2000. In the future, to meet the challenges of energy resource depletion and global warming, it will be migrated to renewable energy and nuclear energy in any scenario.

Table 3 shows energy intensity (electric power generation) for each electric power source in [12]. Looking at the energy density of various types of power, nuclear and coal-fired power plants are large and overwhelmingly 1 GWh/m2/year, while renewable energy is very small about 10kWh/m2/year, renewable energy significant expansion in the primary energy ratio would be difficult to expect. It is expected to have the division of roles and complement each other, nuclear power as a backbone power source, and renewable energy as distributed one.

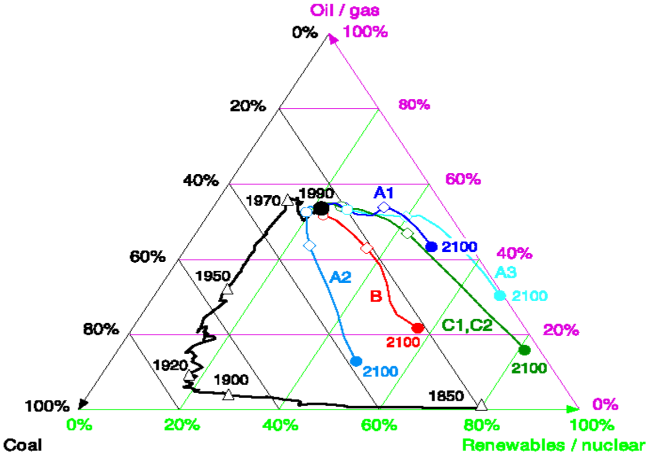


Figure 15. Evolution of primary energy structure.

Candidate	Power density per square meters [kWh/m^2・year]	Remarks
Electrical needs in house	**35**	Detached home（160sq.m. 40A）
Electric needs in office	**400**	Eight-story（architectural area 3,000sq.m.）
Biomass power	**2**	Poplar plantation（6years-cycle） Generating efficiency 34%
Wind power	**21**	Tehachapi (U.S.A.) C.F.20%
Solar power	**24**	Roof of detached house（160sq.m. 3kW, equipment availability15%）
Hydro power	**100**	Average of 100 hydro power plants in Japan
Coal-fired power	**9,560**	Hekinan coal-fired power plant (2.1million kW）
Nuclear power	**12,400**	Kashiwazaki-Kariha（8.212million kW）

Table 3. Energy intensity (electric power generation) for each electric power source.

Discovery, production, and projection of oil and gas with CO2 emission is shown in Figure 16 [13]. Looking at the fossil fuel resources, whereas the amount of discovery peaked in 2000 on the border, as shown in the figure, because the peak in demand is still ahead, it is expected to accelerate the decrease in supply.

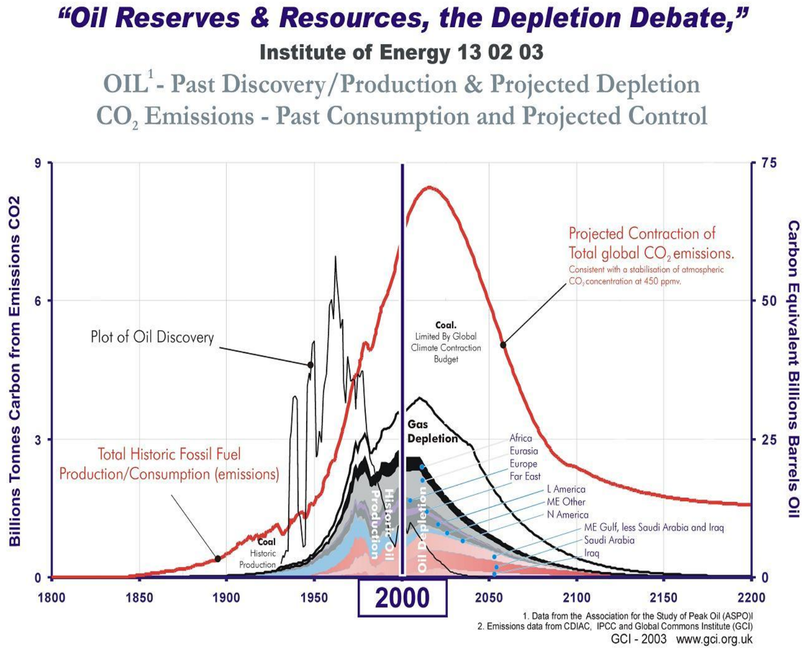
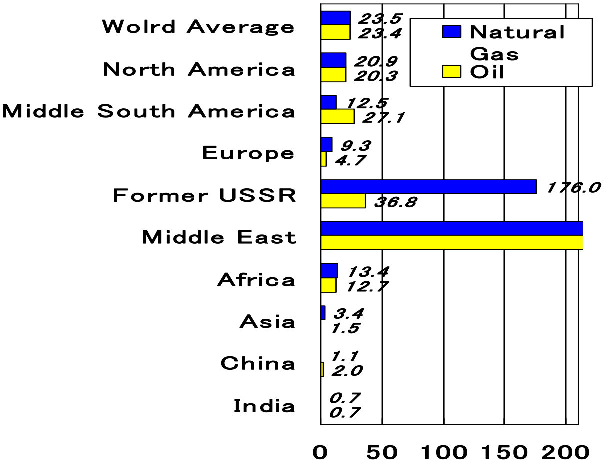
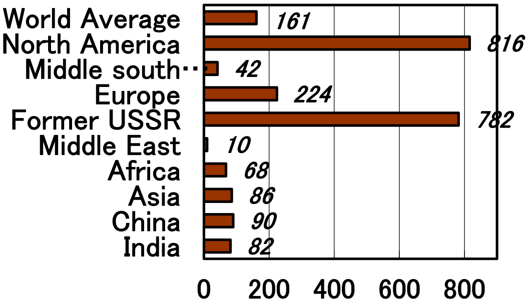


Figure 16. Discovery, production, and projection of oil and gas with CO2 emission.

As understood from Figure 17 which shows fossil fuel resources per capita [14], the oil and natural gas unevenly distributed in the Middle East and Russia, on the other hand coal is a large amount of endowment in the world mainly in North America and Russia. The challenge is anticipated to be significant that there has less abundance of fossil fuels, while increase in demand in Asia. It is growing awareness of energy security in the countries of East Asia led by China is a matter of course.



(a) Proven oil and natural gas reserves (Ton per capita)



(b) Proven coal reserves (Ton per capita)

Figure 17. Fossil fuel resources per capita.

Uranium, on the other hand, look at the next 50 years, initially is large in consumption in developed countries, from 2020 consumption in developing countries will increase in the supply and estimated additional resources to the resource confirmation become severe by 2050 that also somehow with the addition of promising high-cost resources [15]. According to the simulation results of the authors shown in Figure 18, Uranium is consumed in industrialized countries first, while consumption in developing countries increased after

2020. The uranium resources are used significantly in nuclear power, by the time 2100 are also likely to depletion [8]. For this reason, the introduction of fast breeder reactors can be required as countermeasures as soon as possible, considering long Plutonium breeding time.

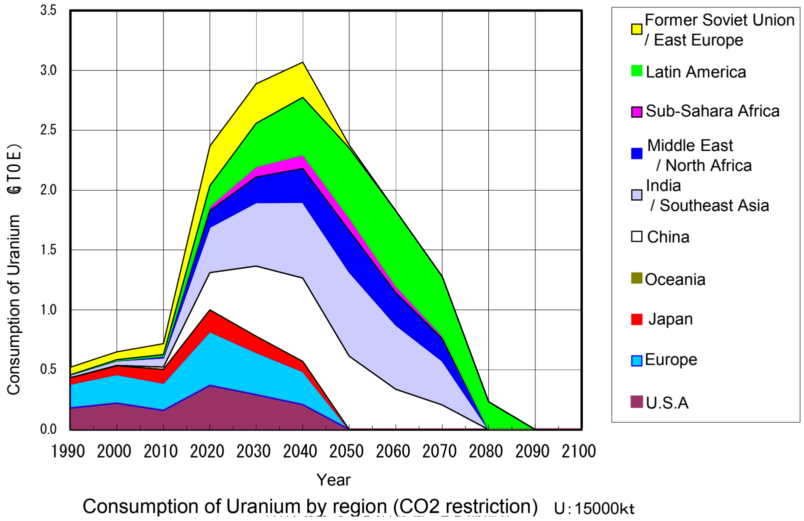


Figure 18. Uranium usages in the World.

3.2.2. *Major factors threatening energy security*

In a familiar concept, safety issue is a measure of the risk factors that occur in good faith in an organization act in basically. In contrast, security issue, as seen in the information security issue, is a measure to risk factors due to external attacks or malicious action in the organization.

As a broad concept, there is a national security. The underlying is to ensure the national interests for the people as a nation in power relations between nations. As they say, energy security and food security accounts for the foundation of national security. Apart from this, there are also domestic issues such as counterterrorism.

Energy security, in a situation no one knows what will happen (risk factors), is to ensure sufficient energy source as a nation. World War II was said to be a scramble for oil. Another example is that the population to be able to survive is determined by the amount of supplied energy. In this way, energy is the backbone of the nation, and energy policy is also considered as a measure of energy security.

In the OECD / NEA expert meeting, "security of energy supply and role of nuclear energy " held in 2008, the security of energy supply was discussed [7]. At the meeting, "the economics of imported energy, social, political and technical problems" were discussed. OECD / NEA has first announced Nuclear Outlook 2008 in 2009, in which the idea " nuclear power is alternative resource, and can be supplied by the countries that political stability is important for energy security" was also showed [16].

3.2.3. Definition of energy security

There are different energy security concepts in Europe and U.S.A. with Japan. The important issues in Europe are electric power network in the community (EU), and the prevention of large scale black out, and fuel supply (Gas and Uranium shortage etc.). On the other side, the important issues in Japan are the improvement of self-sufficiency rate for energy import and making good portfolio of energy resources to be caused by few natural resources.[9] They are not opposing concepts between the Europe concept (stability of supply network) and Japanese one (self-sufficiency and market power). The diversity of defined energy security is to be indicated by nation or entity, for instance of U.S.A. which has electric network vulnerability same as Europe. Another example, regardless China locates in the Continent of Asia, China is regarded to have similar concept to Japan of the island country. For these reasons, it is searched for various and hierarchical definition to approach accurate analysis of security risk, and that the risk is also examined on time and spatial axes. These multilateral considerations are the essence to measure security risk.

The broad sense definition of energy security risk is classified by time axis and spatial axis in Table 4 [8]. The short term energy security risk is narrow definition of the energy security as it is called. It means energy security risk happened in term around 10 years, and can be categorize in nation, area or global under spatial axis. The problem of energy resource supply from other countries, especially the approach to energy resources best mix, is one of the most important problem for isolated and few natural resources country, like Japan,. Expanding for use of energy by developing countries like BRICs is serious matter not only it causes energy resources conflict for other countries but it also brings out strong demand for keeping energy resources for themselves.

The other hand, on long term around 100 year problem, it is the global energy problem which are shortage of fossil fuel energy and global warming. They are the most important issues in recent energy environment problems.

Range	Area	Content
Narrow meaning SoS **Short Term ~10y Energy Crisis**	**❁Country** **❁Region** **❁World**	**❁Energy supply- Best mix** **❁Fuel supply- U problem** **❁Electricity supply- Network** **❁Developing countries usage (China, India, etc.)- Best mix**
Long Term ~100y Energy Problem	**❁Global**	**❁Fossil Fuel Exhaustion** **❁Global Warming**

Table 4. Wide meaning energy security - short term regional crisis vs. long term global problem.

In short term energy crisis can classify into incidental (temporal) crisis like accident or terrorism and structural crisis like Middle East instability or expanding of energy demand in Asia, as shown Table 5 [8]. The measures are different in these crises, immediate action as typified by oil reserve and long term political solution as typified by resource development.

	Cause	Consequence	Countermeasure
Contingent Crisis	● **Conflict,** ● **Accident,** ● **Terrorism**	● **Energy supply chain (Sea-lane) interruption**	● **Petroleum reserve** ● **International and Regional Corporation** ● **Anti-Accident** ● **Anti-Terrorism**
Structural Crisis	● **Middle East instability,** ● **Energy demand increase in Asia,** ● **Technology development stagnation,** ● **Environmental problem**	● **Price fluctuations,** ● **Supply shortage,** ● **Resource straggle,** ● **Weak consumer**	● **Energy Technology Development** ● **Energy Policy** ● **Foreign policy** ● **Defense policy**

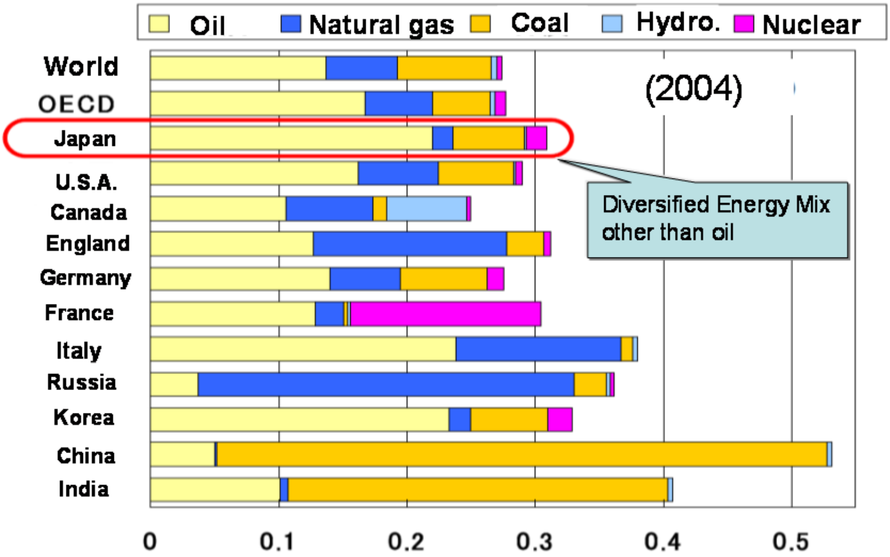
Table 5. Short term regional energy crisis.

3.3. Evaluation method for energy security

3.3.1. Indexes for energy security

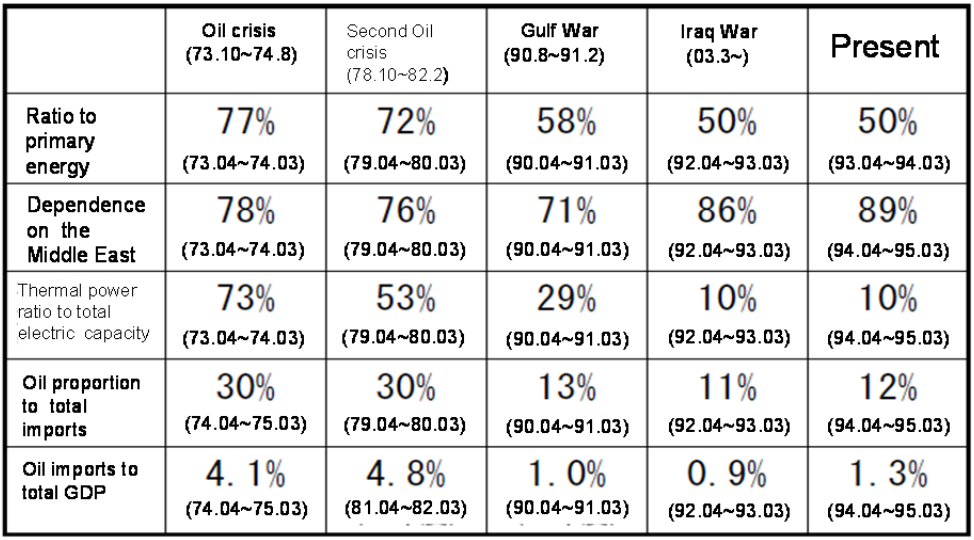
The most basic index of energy security in island country is self-sufficiency ratio in the primary energy supply. The self-sufficiency ratio is 96% in England and 140% in Canada, while 50% with nuclear, 8% without nuclear in France. In Japan, it is 14% with nuclear power, without nuclear power, only 8%. Diversified index of primary energy is indicated in Figure 19 [17]. Balanced energy supply country can get low number, which means that they have achieved Best-Mix in energy resource. Canada has the most balanced energy portfolio. While China is indicated the highest number 0.55, because of China relied heavily on coal-fired thermal power. Japan is also indicate higher number 0.31 than the average of OECD or World (0.27), because Japan largely relies on oil.

The Basic Act on Energy Policy in Japan points out the necessary of energy resources diversification, that is one of the course to keep the steady supply of energy. Table 6 shows that oil dependency in Japan on primary energy supply placed in high level as 77% when it is at oil crisis in 1970's. It takes still in higher level index (50%) compere with the global average (40%), now. On the other hand, Japan continues to make effort to reduce oil dependency. It is understood that the rest three items on the table become low level, such as the ratio of oil proportion to total imports [18].



Diversified Energy Mix other than oil

Figure 19. Diversified index of primary energy.



	Oil crisis (73.10~74.8)	Second Oil crisis (78.10~82.2)	Gulf War (90.8~91.2)	Iraq War (03.3~)	Present
Ratio to primary energy	77% (73.04~74.03)	72% (79.04~80.03)	58% (90.04~91.03)	50% (92.04~93.03)	50% (93.04~94.03)
Dependence on the Middle East	78% (73.04~74.03)	76% (79.04~80.03)	71% (90.04~91.03)	86% (92.04~93.03)	89% (94.04~95.03)
Thermal power ratio to total electric capacity	73% (73.04~74.03)	53% (79.04~80.03)	29% (90.04~91.03)	10% (92.04~93.03)	10% (94.04~95.03)
Oil proportion to total imports	30% (74.04~75.03)	30% (79.04~80.03)	13% (90.04~91.03)	11% (92.04~93.03)	12% (94.04~95.03)
Oil imports to total GDP	4. 1% (74.04~75.03)	4. 8% (81.04~82.03)	1. 0% (90.04~91.03)	0. 9% (92.04~93.03)	1. 3% (94.04~95.03)

Table 6. Energy security index of oil dependency in Japan.

On diversified index of region of crude oil import, Japan and East Asia dependent on Middle East heavily (0.7-0.9), while the index is 0.2 in U.S.A., 0.3 in Europe and China. It means that these nation import from multi region and keep good balanced portfolio [18]. Basic Act on Energy Policy said, "As reducing excessive dependence on specific geographic regions for the import of primary energy sources". But 90% of oil has imported from Middle

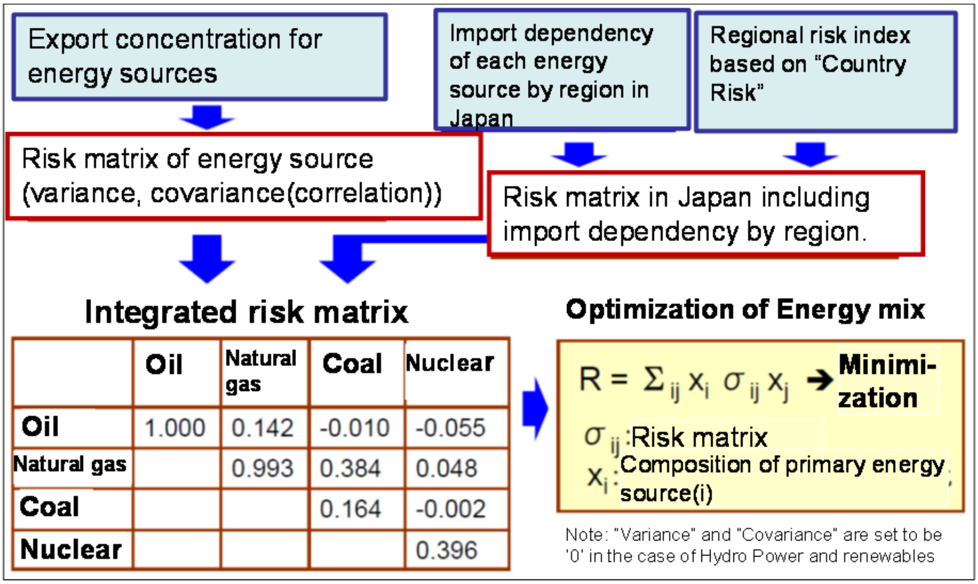
East as shown the table which is the energy security index concerning oil, in Japan. In U.S.A. it is also to become big problem which the diversified index to Middle East is rising 20% today. On the other hand, it is the problem that Europe depend 30% supply of crude oil and 20% supply of natural gas on Russia.

3.3.2. Share index models to prove procurement stability of energy sources

According to the Kainou, energy security consists of structural risk and individual risk of the conversion, production, and transportation for each phase. Structural risk can be evaluated by the variance of its configuration [18]. Herfindahl Index of the formula (1) is a typical evaluation formula and is also referred to as stable supply risk.

$$H = \sum W_i^2 \,\text{(Wi: Share of each risk factor)} \qquad (1)$$

The method is shown in Figure 20 to evaluate a comprehensive risk matrix which reflects importing region is unevenly distributed or where energy source is supplied and so on. It is thought that this evaluation index is the most comprehensive energy security. According to this evaluation, "whereas the highest risk of oil energy sources, coal has the least variance and risk, and nuclear power is an energy source that has the next least risk and has minus co-variance (small connection to other energy sources)" [19]. Judging from the energy security (without taking into account the environmental issues), it is the best mix for Japan to reduce greatly the dependence on oil imports, to increase the ratio of coal drastically, and then to increase the ratio of nuclear power on the structure of primary energy, which can lead to minimization of risk.



	Oil	Natural gas	Coal	Nuclear
Oil	1.000	0.142	-0.010	-0.055
Natural gas		0.993	0.384	0.048
Coal			0.164	-0.002
Nuclear				0.396

$R = \Sigma_{ij} x_i \sigma_{ij} x_j \rightarrow$ Minimi-zation

σ_{ij} :Risk matrix

x_i :Composition of primary energy source(i)

Note: "Variance" and "Covariance" are set to be '0' in the case of Hydro Power and renewables

Figure 20. Risk based best energy composition. (METI, 2001)

Since uranium resources are distributed over countries that are socio-politically stable and adequate diversity of supply is maintained (absence of apparent over-concentration of market power to specific countries/ regions), nuclear fuel is understood as less risky in terms of procurement than a number of fossil fuels (specifically gas and oil). This can be measured primarily by calculating share indices. The method is shown in IEA (2007) which is based on Herfindahl-Hirschman Index (HHI), which is defined as the sum of square of share of all supply options with certain modification to reflect different socio-political risks. Putting domestic fuel supply as risk-free, HHI is modified as ESMC (which stands for energy security market concentration), with:

$$\mathrm{ESMC} = \sum S_{if}{}^{2}, \text{ where Sif: share of import of fuel f from country/region i}.$$

Since there are different degrees of socio-political stableness across countries/regions, ESMC is expanded to:

$$\mathrm{ESMCpol} = \sum (r_i * S_{if}{}^{2}), \text{where } \mathrm{r_i}\text{: political risk associated with exporting country/region i}$$

CRIEPI applied a similar methodology using HHI and risk premium [19]. Under the Japanese context, inter-temporal evaluation of Japan's primary energy mix was conducted, whose result is shown in Figure 21. The Risk Index in the figure is a procurement stability index that reflects instability of energy mix induced from global resource distribution, global trade share, Japan import structure of each energy resource, as well as socio-political risks of countries with resource deposits or exports. It has its maximum value 1 when all the primary energy needs are met solely by imported oil (in the same composition in the reference year, which in this case was set at 2005), while its minimum value 0 when the energy supply is preoccupied by domestic risk-free sources, such as hydro and other renewables. It revealed that the primary energy structure has evolved with remarkable improvements in its robustness since the period of oil crises in 1970s, through efforts to substitute oil with alternatives such as nuclear energy and natural gas, also shown in the background of figure.

3.3.3. Multiple indexes model to evaluate energy security level

3.3.3.1. Method

In this section, the method is explained which was used in a comparison study of security of supply using five parameters among seven OECD countries using OECD 2005 year data [20]. Japan energy policies have stressed three targets: energy security, lower energy prices, and environmental protection. In response to the recent structural imbalance of oil supply and demand, Japan has placed energy security at the top agenda of its energy policies. Review of the energy security level has importance in formulating and steering the energy policies. Although energy security meant basically national energy security that puts the main priority on a stable energy supply, it is required to consider energy security from wider viewpoints of global energy security, which includes environment, nuclear concerns, international relations and others as its priority aspects.

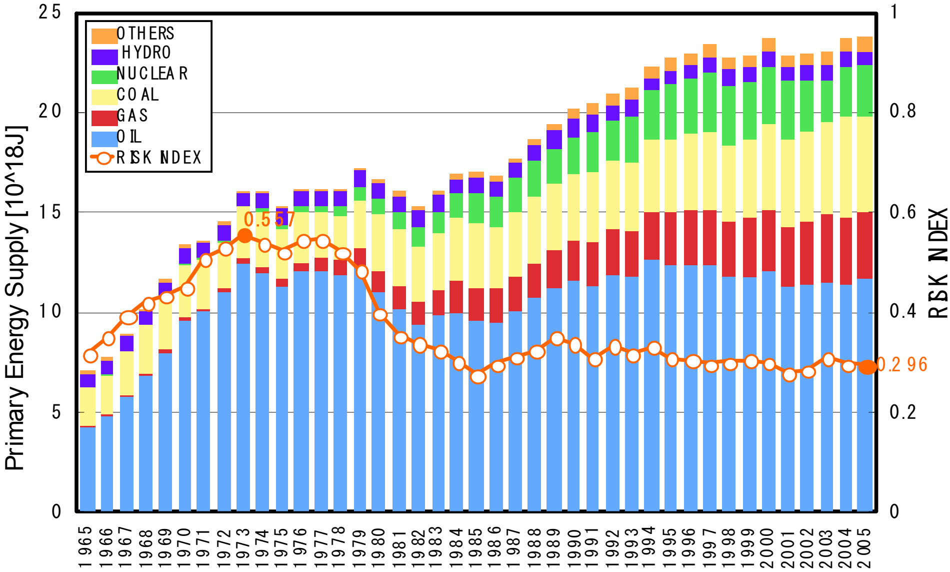


Figure 21. Historical evolution of primary energy mix and its procurement stability index in Japan.

The estimation is shown on energy security levels of OECD's G7 Summit member countries, which are Canada, France, Germany, Italy, Japan, UK and US. These nations occupy 81% of GDP, and 76% of primary energy supply in OECD member countries. The energy security levels are shown by the scores of standard deviation of the following factors, that is, are compared relatively for each country. Those scores of energy security levels for each country are estimated by the following process:

1st step: Select factors and indexes concerned on energy security.

The factors include as follows:

1. Ratio of self-sufficiency of energy supply, for index of energy supply independence, or resource amount rich or not.
2. Share of energy imported from specified areas, such as the Middle East and Russia, for index of stable energy supply, or of import risk by two big threats of political condition instability and marketing power.
3. Diversity of energy supply, for index of energy best mix, which is calculated by $\sum_i Wij^2$,

   Wij: Share of respective energy i (Coal, Oil, Gas, Nuclear, and Renewable) in energy supply for each country j.

4. Energy consumption per unit GDP, for index of energy usage efficiency.
5. CO_2 emission ratio, for index of global environmental problem measure, which is calculated by $\sum_i Wij \times Ci$,

   Ci: CO_2 emission per unit energy consumption of respective energy for each country.

2nd step: Estimate the deviation of data of each nation on each factor

A normal distribution of data is assumed. The lower point for each factor indicates the better performance, that is the higher score of Yij, from the viewpoint of energy security.

$$\mathrm{Yij} = 50 + 10 \times \mathrm{Xij} - \mathrm{Ave\ Xi} / \mathrm{Std\ Xi}$$

Ave Xi: Average of Xij for each factor
Std Xi: Standard deflection of Xij for each factor
Xij: Data on each factor i of each nation j
Yij: Deviation of data on each factor i of each nation j

3rd step: Sum up the above estimated scores of the adopted factors

Average score of Zj indicates the relative energy security level of seven countries.

$$\mathrm{Zj} = \mathrm{Ave\ Yij}$$

Ave Yij: Average of Yij for each nation j

The estimation is made by the data of OECD/IEA energy statistics [8,11,14].

3.3.3.2. Results

The scores on energy security levels of seven OECD nations for 2005 were calculated. The scores of Canada, US, and UK, resource-supplying countries, are relatively higher scores, compared with other nations, poor resource countries. Among the poor resource countries, Germany shows good diversification and France has good self-sufficient rate due to its high nuclear production capability, while Japan has low scores for factors except energy usage efficiency.

Figure 22 shows the trend of the scores on energy security levels of seven OECD nations for about 30 years (presented by five points) [8]. The method estimates energy security levels based on relative comparison. With a view on energy security levels of seven OECD member countries, the scores estimated by this method show that Japan is now placed at a lower level than most major OECD member countries.

3.3.3.3. Survey of nuclear contribution on security of energy supply

Nuclear energy has a great potential to improve energy security. Here, to clarify the nuclear contribution on energy security, a virtual world of 'without nuclear energy' is considered. Nuclear energy contribution on energy security is identified by comparing the levels between two cases, one is with nuclear energy and the other is without nuclear energy.

This study excludes energy usage efficiency as an index for the comparison which is equal in both cases. Nuclear energy contribution is considered to be zero and then nuclear energy is allotted to fossil energy sources in proportion to their respective portions in energy supply of the 2005 year data, for other indexes, diversity of energy supply, self-sufficiency ratio, share of energy imported from the Middle East and Russia, and CO_2 emission ratio.

As the method mentioned in the previous section is used for comparison purpose among countries, only order is meaningful. To evaluate the nuclear energy contribution, relative value is used. Each index except energy usage efficiency, which is not affected existence of nuclear, is normalized, where best one is unity while worst one is zero in two cases.

The comparison results are shown in Figure 23 [8]. Normalized scores of France with a great nuclear portion in energy supply become worse drastically, and those of Japan with scare energy resource and having nuclear energy promotion program, becomes worse also. Italy is not apparently affected by with or without nuclear. Other nations possessing nuclear energy with rich energy resources would not be affected seriously.

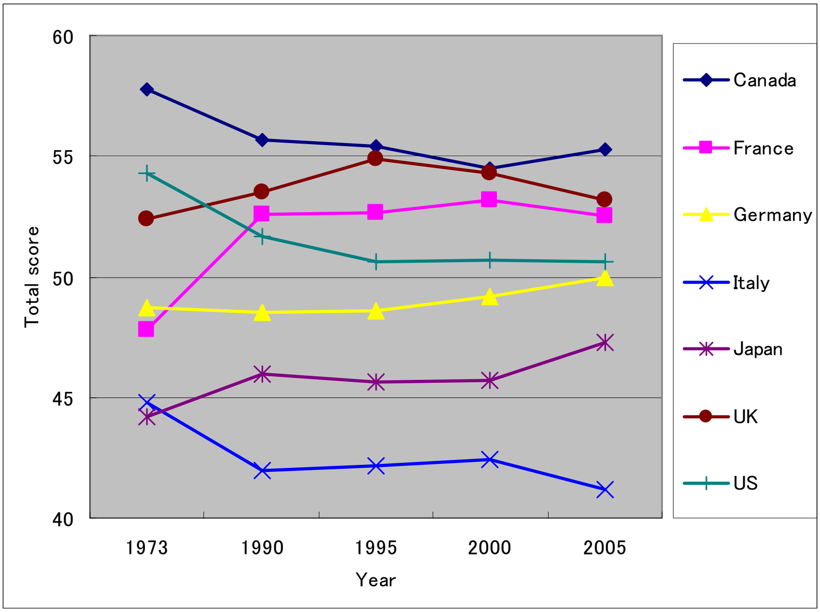


Figure 22. Trend of total scores of energy security levels of seven OECD countries.

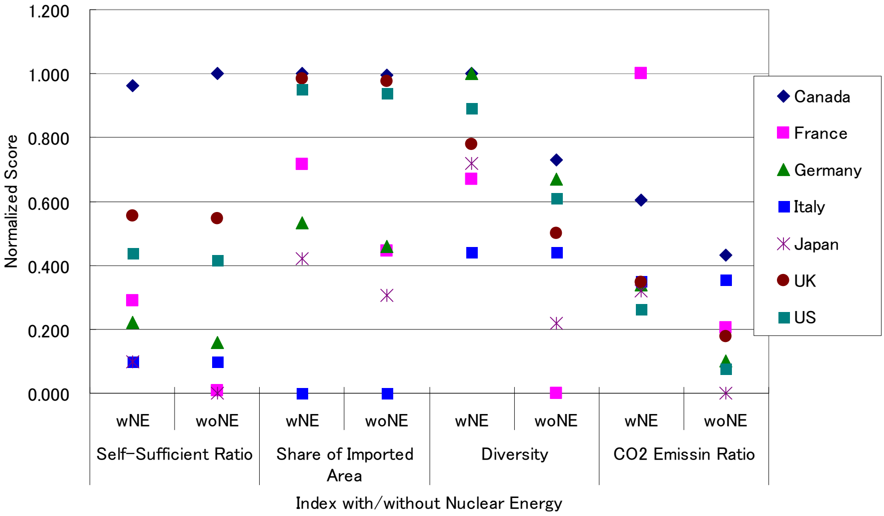


Figure 23. Comparison results of four normalized indexes with (wNE) and without(woNE) nuclear energy.

3.3.4. Emergent scenario of two China by scenario planning in 2015

The scenario-planning-based-approach has been proposed for the development of science and technology strategy through the analysis of energy crises in East Asia [10]. The method, with the discussion of experts of various fields, enables the comprehensive understanding of the problem to be considered, the development of a robust science and technology strategy for uncertain future, and the evaluation of individual research and development theme from various aspects. This is an example of a structural crisis in Table 5.

3.3.4.1. Master plan: Shared awareness of the issues

The research team conducts comprehensive analysis of risk factors, development of two scenarios with emphasis on 'China's future'. Investigation of strategic viewpoints needed on science and technology and evaluation of individual research and development theme for each of the scenarios are also performed.

3.3.4.2. Extraction of risk factors and determination of the scenario structure

The fragility of the energy system of East Asia, with aggravating further from now on, has a large possibility to bring national power decline and resource protectionism in the countries in East Asia. Such situation is a threat onto security of Japan, while it can also serve as an opportunity to growth national power and international presence of Japan, by advanced technology development and its technology transfer.

The two China images of 'Sovereign Right China' and 'Open China' were built and the 'Resource scramble scenario' and the 'Japan isolation scenario' were created from each in this research. As foresight which China image becomes dominant from now on is difficult, Japan needs to build a technology strategy with consideration of both possibilities.

In extracting risk elements as the components of the crisis scenario, eight risk categories are set as follows:

1. China resource protectionism,
2. China science and technology organization,
3. geopolitics and international relations,
4. energy infrastructure,
5. motorization,
6. electricity crisis,
7. nuclear accident and nuclear proliferation, and
8. environmental problem.

Although the elements mentioned in this stage was 30 items or more, as a result of scrutinizing these further, to realization of a master plan, and 18 items were listed for an element with an uncertain prospect in this time as shown in Table 7. It classifies into four categories for convenience.

China	・Market Mechanism in Energy Sector? ・Foreign Resources required ? ・Technology and Political System ? ・Prosperity and Political Stability? ・Electricity Generation increase? ・GHGs Control ?
Geographical features	・Korean Peninsula? ・Russian Resources? ・US-China Trading Friction ? ・Sea Lane?
Infrastructure, Terrorism	・Oil shipment corporation? ・Nuclear Accident? ・South –East Asia Terrorism ? ・Nuclear Safeguard in South Asia?
Technology, Environment	・Japanese Technology Superiority ? ・Automobile Efficiency? ・Energy Saving Mind? ・Post Kyoto Protocol?

Table 7. Asia crisis- scenario planning uncertainty factors to 2015. (MEXT, 2005)

3.3.4.3. Two China - "Open China" and "Sovereign Right China"

Based on the work described until now, examination intensive about the future image of China used as the base of each scenario was performed. Consequently, the two China images were formed as shown in Figure 24. Although it will probably be common but still hypothesis that it is shifting to "Open China" from "National power China" as a trend, and it cannot predict which "China" becomes dominant till around 2020. Japan is required to construct strategy based on both possibilities. In any case, nuclear power is dominant for energy technology.

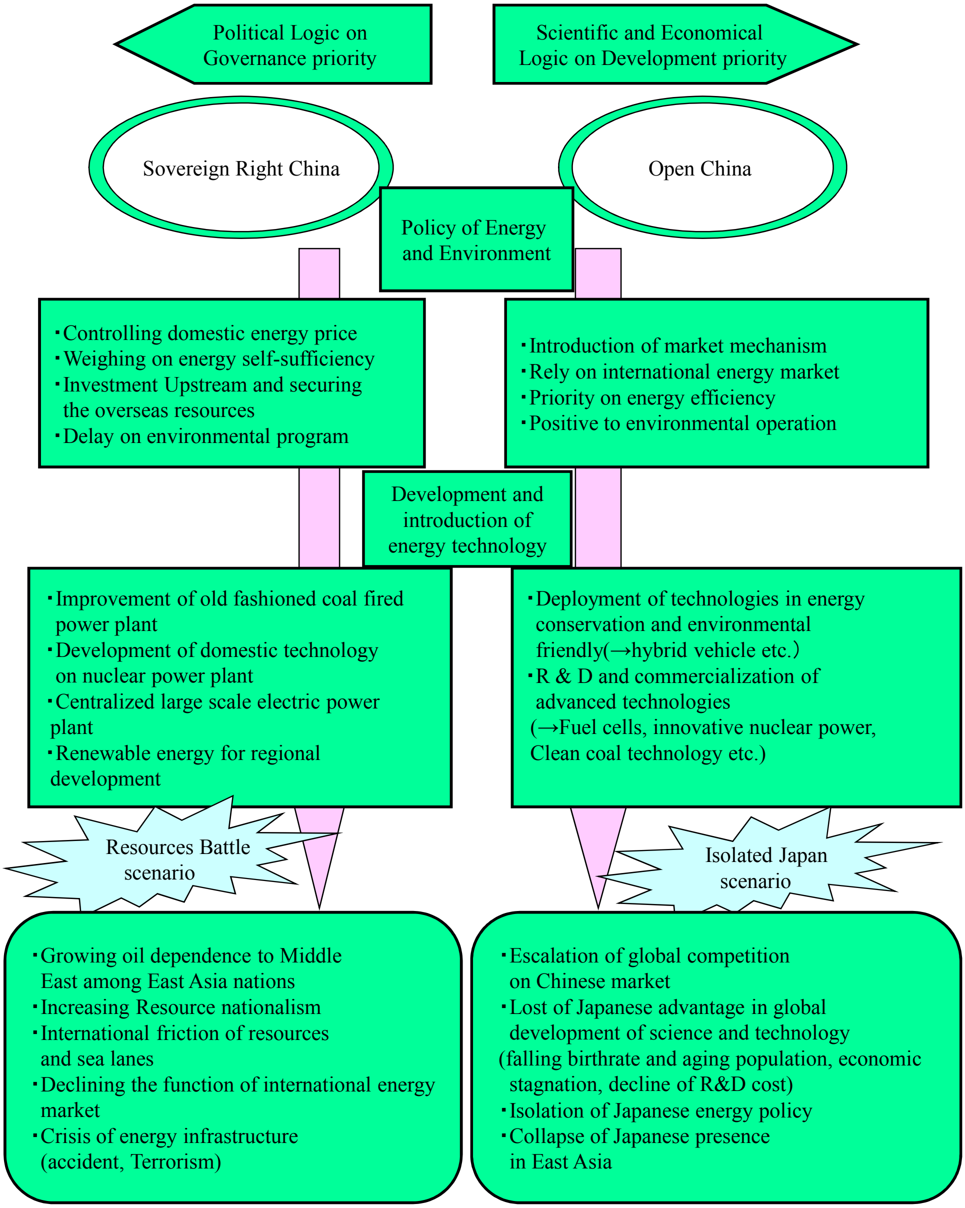


Figure 24. Emergent scenario of two China by scenario planning.

4. Energy issue and nuclear energy role after the Fukushima Daiichi accident

The Fukushima Daiichi Accident raised a new challenge of securing the safety of utilization. National nuclear policies of many countries are being reexamined along with the safety evaluation.

Safety design principle is "Defense in Depth" concept, which should be further reconsidered reflecting the accident causes. Usual systems focus on the forefront function, such as preventing damage, expansion mitigation, or incident prevention, while safety critical systems increases attention to back-up functions such as incident expansion mitigation or environmental effects mitigation, if it has a large enough impact on the environment. Common Mode Failure of External Initiating Event such as Earthquake or Tsunami, which is usually Rare Event, or auxiliary systems failure such as Off-site Power, EDG, Buttery, or Sea Water Cooling loss is difficult to install to Defense in Depth design.

According to the "Defense in Depth" concept reflecting Fukushima accident, we should consider three level safety functions; usual normal system, usual safety system, and newly installed emergency system including external support function. Anyway the diversity is significantly required for not only future reactor concept but also existing plant back-fit activities.

Swiss Cheese Model proposed by Reason, J indicates operational problem other than design problem [21]. Fallacy of the defense in depth has frequently occurred recently because plant system is safe enough as operators becomes easily not to consider system safety. And then safety culture degradation would be happened, whose incident will easily become organizational accident. Such situation requires final barrier that is Crisis Management.

Concept of "Soft Barrier" has been proposed here [22]. There are two types of safety barriers, one is Hard Barrier that is simply represented by Defense in Depth. The other is Soft Barrier, which maintains the hard barrier as expected condition, makes it perform as expected function. Even when the Hard Barrier does not perform its function, human activity to prevent hazardous effect and its support functions, such as manuals, rules, laws, organization, social system, etc. Soft Barrier can be further divided to two measures; one is "Software for design", such as Common mode failure treatment, Safety logic, Usability, etc. The other is "Humanware for operation", such as operator or maintenance personnel actions, Emergency Procedure, organization, management, Safety Culture, etc.

Premise here is that "Global warming and energy security are the invariant problems". The long-term energy demand and supply simulation to minimize the total energy system cost was conducted for energy prediction during the 21st Century in the world [22-23]. Taking the effort for energy-saving as major premise, carbon capture and sequestration for fossil fuel, renewable energy and nuclear energy should be altogether developed, which means energy best mix should be achieved, under the CO2 constraint around 450ppm atmosphere [24]. Nuclear phase-out scenario, in which new nuclear plant construction is prohibited, is possible from the simulation even considering the issue of global warming, with the following problems; increasing energy costs, little room for countermeasure, and large uncertainties of technology. The role of nuclear is also examined to understand energy security is severely affected by the case without nuclear energy. Therefore, rational use of nuclear power is requested, that is each country should make decision, Japan and several European countries will be also phase out, while China, India and ASEAN countries will continue to be introduced. If the accident happens again anywhere in, it will become the global phase-out. Therefore, rational unified safety standards (organizational structure, design and operation, regulations) should be reviewed based on the Fukushima Daiichi Problem world-wide analysis and established in the world.

5. The path and key issues for "sustainable development"

Figure 25 shows the path and key issues for "Sustainable development" [8], which is the target of the 21st century.

- Stabilization of world population.
- Reduction of the south and north economic difference.
- Preservation of global environment.
- Preservation and effective use for rare resources.

It is necessary to improve economic development and the living standard in the developing countries, as a fundamental solution for the population growth in the world and for the reduction of "Income gap between North and South" also. It is necessary to secure energy that is low-cost and resource restriction free, to support economic in the developing countries. Moreover, great control of carbon-dioxide emissions is necessary to mitigate the climate change influence. It is necessary to achieve a worldwide spread of technical improvement/ recycling society system that aims at the efficiency improvement of the resource use.

- The hydrocarbon resources such as oil and natural gases are to use for the recycling as the raw material.
- Drastically conversion into non-fossil energy is indispensable.
- Expansion of nuclear power energy use: It is precondition to secure the durability by constructing the fuel cycle with the viewpoint of the resource and waste.
- Use of renewable energy source: It is important to improvement the technology that aims at cost reduction.

Because Japan has the feature as the following energy systems, it is considered to be possible to deal with the energy crisis enough if the policy is correctly set.

- Development and usage of highly effective energy conversion technology.
- Usage of nuclear power generation.
- Renewable energy technology development; especially, the world is led in the Photovoltaic technology.

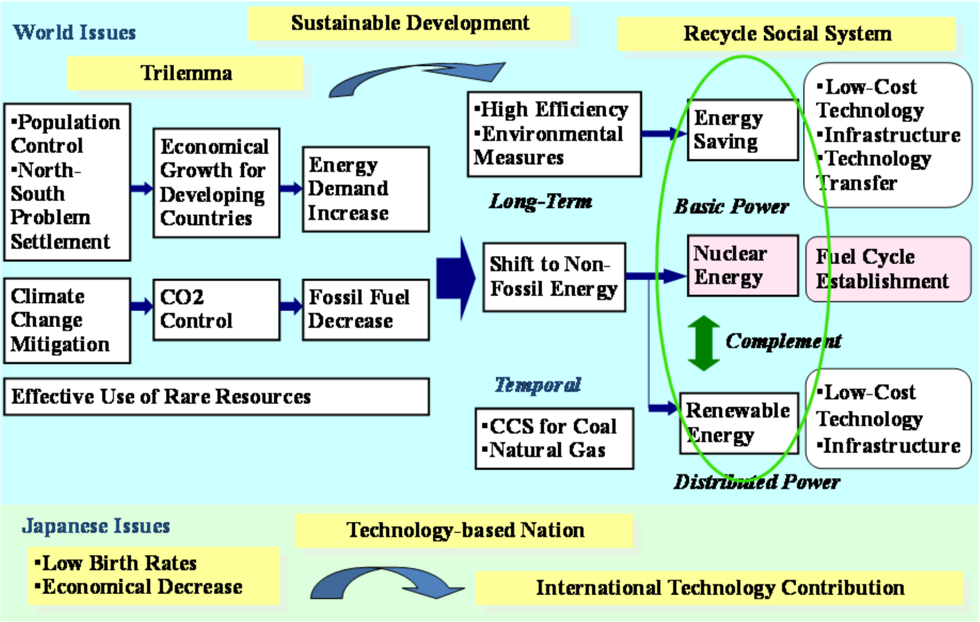


Figure 25. Global Environmental and Energy Resource Problems, and Energy Perspectives

6. Conclusions

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. The key findings are as the following.

1. Instead of the traditional 450ppm equilibrium stabilization of IPCC, a new 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 so called Z650 scenario could avoid long-term risks. At the meanwhile it could meet short term need of relatively large emissions. The proposal improves the possibility of international agreement compared with the G8 Summit proposal, which argued that the worldwide greenhouse gas emissions must be reduced by at least 50% in 2050 compared to the 1990 or recent year levels.
2. 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 results of individual industrialized countries fit with the national targets well.
3. The cost-effective analysis 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.
4. Nuclear energy will play an important role for achieving the vision against global warming. Large-scale introductions of the more expensive renewable energies during early stage are necessary without nuclear energy or next generation nuclear technology. As a result, the power generation cost will increase rapidly thereby the negative economic impact will be significant especially in developing countries. Therefore, rational use of nuclear power is requested to combat global warming.

Compared with the threat from global warming, energy security is the more traditional key issue for global and regional sustainable development. Based on the overview of energy security concepts and existing evaluation methods, we proposed a new integrated index to evaluate national energy security from the wide conception. Case studies employing the index for OECD countries and China were conducted to evaluate the role of nuclear energy. The key findings are the following.

1. From the viewpoint of self-sufficient ratio, nuclear energy affects security index largely in the energy importing nations but slightly in the resources nations.
2. From the viewpoint of energy diversity and CO2 emissions, the absence of nuclear energy decreases the security index significantly by which influences the sustainability of national economic growth.
3. The nuclear policies of China will influence not only the domestic economic growth but also the energy situations in the world, especially the surrounding nations.

Nuclear energy will play an important role from the necessity of mitigating climate change, as well as improve energy security. However, the Fukushima Daiichi Accident raised a new challenge of securing the safety of utilization. Following the safety design principle of "Defense in Depth", three level safety functions should be considered for the hardware. Those are, the usual normal system, usual safety system, and emergency system including external support function. On the other hand, software for design including common mode failure treatment, safety logic, and usability should be improved together with the human-ware for operation including personnel actions, emergency procedure, organization, management, and safety culture.

Sustainable development is the final target for human society. The energy related environmental issues and energy issue are the main challenges during the 21st century. Although the energy conservation is the most important issue in the energy policy, the utilization of nuclear energy is also essential to maintain the global environment and energy security together with the improvement of the renewable energy and the development of the carbon dioxide isolation technology for the fossil fuel. Therefore, it is necessary to continue technological development so as to demonstrate each potential as for the basic energy in 21st century.

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