# The Energy Perspective and Nuclear Role under Global Warming

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## 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 [1].

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.

## TOWARD A NEW CLIMATE CHANGE REGIME ESTABLISHMENT

### 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.

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 [2]. 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 (Fig. 1). The scenario was designed based on two assumptions, one is that the amount of cumulative $CO_2$ emissions in the 21[st] century would be 650GtC equivalent, the other is that the zero-emission would be achieved in 2160. Some recent researches [3] also employed the concept of zero emission or near zero emission for seeking best options of climate change mitigation. It is suggested, 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.

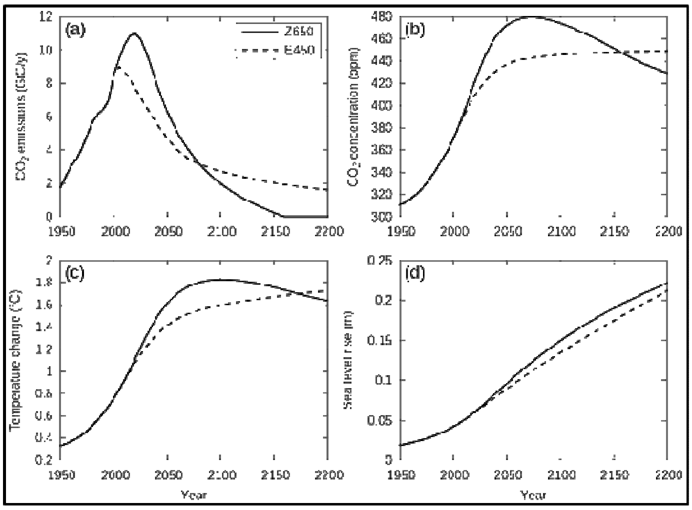


Fig. 1. Comparison between Z650 and E450.

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 1 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 21[st] 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.

**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 [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. 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. Z650, which is the mitigation scenario, assumed a global CO2 emission cap based on scientific Z650 scenario described above.

*Long-term Energy Vision*

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

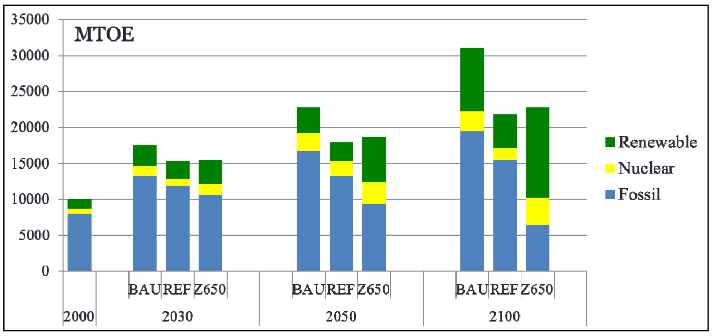


Fig. 2. Global total primary energy supplies for the three scenarios.

*Energy Related CO2 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 16GtCO2 in 2010 and emissions in 2050 will be reduced to 7G compared to 2005 levels of 15G. On the other hand, emissions by developing countries will peak in 2030 of 17G, 1.6 times 2005 emissions and decline to12G, 1.1 times in 2050 to 2005 emissions of 11G. CO2 reduction to 19G in the World is 20% in 2050 compared to 2005 levels of 26G.

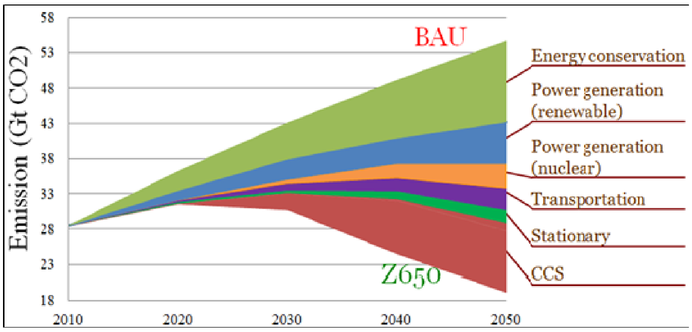


Fig. 3. Contributions of each sector to $CO_2$ emission reduction based on simulations.

Compared with BAU, emission reductions by region and till 2050 in Z650 are investigated (Fig. 3). Energy conservation contributes the most during the whole period, 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, and contribute 27% of all reduction in 2050.

*Economic Assessment*

An economic assessment was conducted based on 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 323 trillion USD (in 2005 value) in the world with almost the same portions of 154 and 169 trillion USD in industrialized and developing countries.

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 (114) in industrialized countries and two thirds (248) 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.

## ROLE OF NUCLEAR ENERGY

As shown in Fig. 2, 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, as 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 from 2050.

**Impact to TPES and Power Generation**

The global TPES of the Z650, NuPO and NoFBR are shown in Fig. 4.

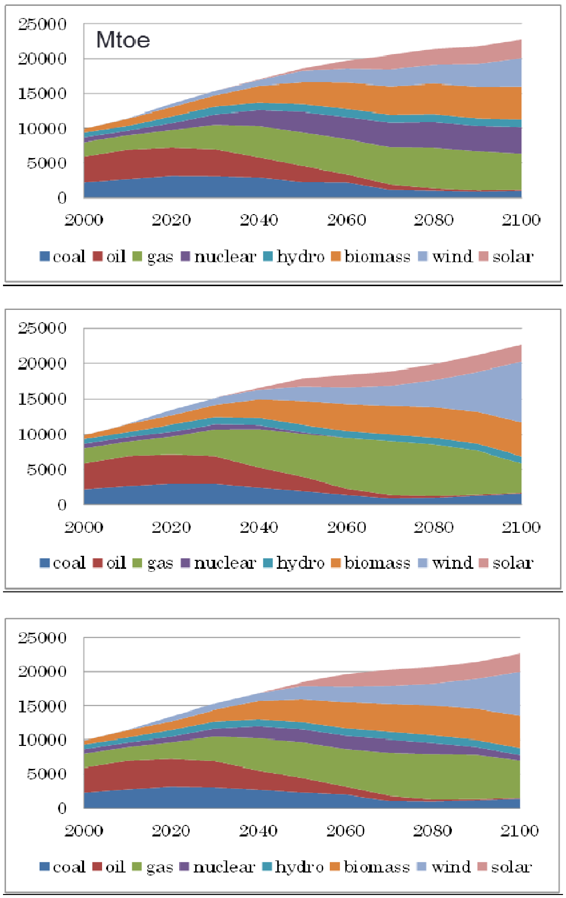


Fig. 4. Projected TPES (upper: Z650; middle: NuPO; lower: NoFBR) (unit: Mtoe).

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.

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. 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.

**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.

## 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.

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