Assessment of Asian energy security index in the context of global CO_2 mitigation

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Asian countries are facing rapid growth in energy demand and consequently energy security issues. Under the circumstance, they also try to address climate change mitigation. This paper analyzes interactions between energy security and CO_2 mitigations using results of energy systems model, which we call DNE21+. The results reveal that the interactions vary by region. The US and Western Europe reduce their CO_2 emissions with keeping the level of energy security. In contract, Asian countries confront trade-off between energy security and mitigations. In global carbon constraint case (at 450 ppm CO_2-eq), Asian countries will concentrate their energy supplies on gas imports from the Middle East and the Former Soviet Union (FSU). This is due to i) their smaller reserves of oil and gas, ii) their smaller capacity of carbon storage, and iii) geographical locations that are close to the Middle East and FSU.

INTRODUCTION

Asian countries are currently facing rapid growth in energy demand and energy security issues along with their economic growth. In the international negotiations on climate change, long-term objectives including 2 degrees Celsius target have been referred. Asian countries also try to address climate change mitigation. The objective of this paper is to answer the following questions;

- How will "energy security index" change in the future in Base case compared to current levels?
- What is the impact of CO_2 emission constraints on the energy security index?
- What is the relationship between energy security and CO_2 mitigations? Is it a synergy or trade-off?
- Are there any regional differences in the relationship?
- If any, what are the factors for the regional differences?

For this objective, this paper introduces "energy security index" for the first step.

Then, we calculate "energy security index" by region up to 2050 using analysis results of world energy systems model, which we call DNE21+. This paper focuses on a workable illustration of energy security rather than theoretical discussion or methodology development. The illustration enables better communications on a world-wide level.

1. Introducing Energy Security Index

The framework of energy security depends on context, such as time and geographical factors. Each specialist focuses on different risks and end points. Suzuki et al., (1998) and von Hippel et al., (2011) clarified two types of energy security framework: i) conventional one, and ii) comprehensive one. The conventional one is mostly focusing on securing access to oil and other fossil fuels. The comprehensive one is focusing on very wide range of dimensions, i.e., energy supply, economic, technological, environmental, social-cultural, and military-security dimensions. They emphasized the importance of these dimensions, which are the criteria of risk and uncertainties associated with energy security as a workable framework for analysis of future energy paths.

This paper focuses on energy supply and climate change mitigation (as an environmental dimension) in order to conduct a numerical representation. Referring to Neff (1997) and the IEA (2007), this paper simply formulates "energy security index (ESI)" to represent the degree of energy insecurity situations as follows:

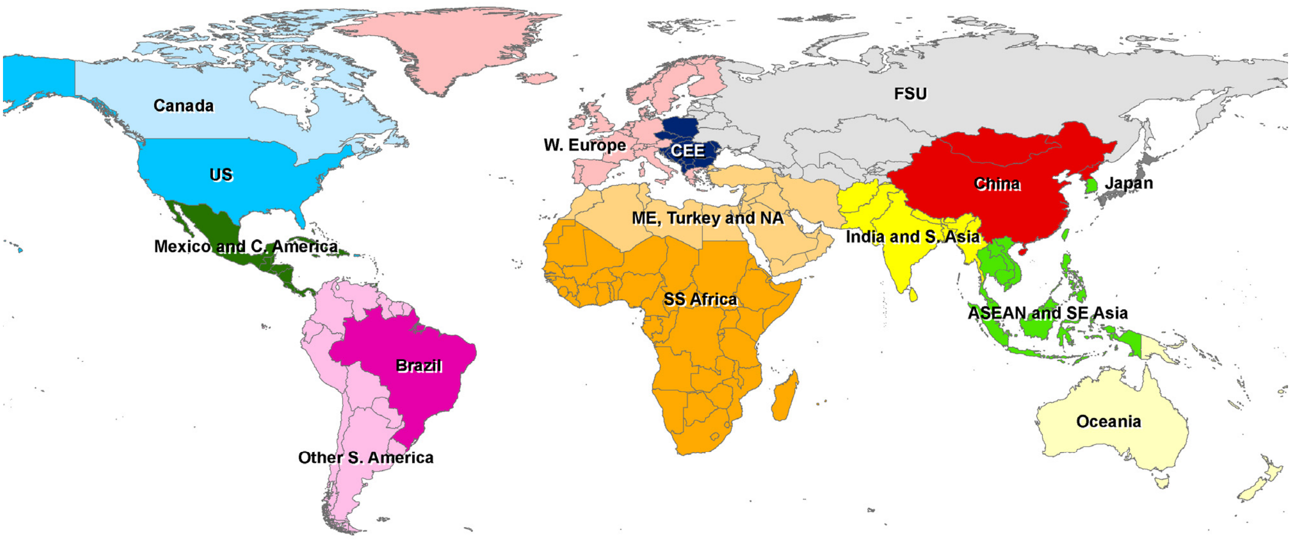
$$\text{Energy Security Index} = \sum_i \left(r_i \cdot {S_{i,oil}}^2\right) \cdot c_{oil}/TPES + \sum_i \left(r_i \cdot {S_{i,gas}}^2\right) \cdot c_{gas}/TPES \quad (1)$$

where $S_{i,oil}$ is the share of each supplier (region) i in the market of oil, r_i is the political risk rating of region i, and $C_{oil}/TPES$ is the oil share of TPES (total primary energy supply). The ESI is reflecting insecurity degree of oil and gas imports for the region. We assumed that domestic fuel supplies within region are risk free for the region. The ESI is reflecting i) oil and gas shares of TPES, ii) market concentrations of oil and gas, and iii) political risk of supply country. For simplicity "oil" means "crude oil" in this paper (See Appendix A for the details of fuel categorization for the ESI analysis).

For a value of political risk, we refer to the World Bank's Worldwide Governance Indicators (World Bank, 2008). In the study we assume that the value of governance indicator remains constant over the 2006-2050 (See Appendix B).

Figure 1 illustrates regional division for the ESI analysis. The DNE21+ has more detail regional resolution; however, we aggregate into 15 regions in order to avoid an unnecessary complexity of trade matrix for oil and gas. This paper uses the short label shown in Figure 1 only for descriptive purposes. See Appendix B for the details of regional division for the ESI analysis.

Figure 1　Regional division for the energy security index analysis



Note: We aggregate the 77 regions inside the DNE21+ into the above 15 regions. See Appendix B for the detail regional division for the ESI analysis.

2. DNE21+ Model and CO_2 Emission Constraint

2.1 DNE21+ Model

The world energy systems model, which we call DNE21+, minimizes the net present value of the world energy systems costs up to 2050. The model divides the world into 77 regions and solves the cost-effective energy trade between the regions. As for oil and gas transportations, the DNE21+ calculates trajectories of capacities and trade volumes by tanker and pipeline. Regional reserves of fossil fuels, potentials of renewables and capacities of carbon storage are exogenously determined.

See also Akimoto et al., (2004, 2010), Oda et al., (2007), and Sano et al., (2012) for a detailed description of the energy supply, CCS technologies and demand sectors in the DNE21+.

2.2 Case Descriptions of CO_2 Emission Mitigations

In this study, we conducted three simulation cases; i) Base case. ii) 650 case, and iii) 450 case. The 650 and 450 cases are given as a global carbon constraint inside the DNE21+. The details are as follows:

i) Base case…No additional mitigation policies. (For reference, based on the DNE21+ results, the volume of global energy-related CO_2 emissions in 2050 is 56.2 $GtCO_2$/yr.)

ii) 650 case…Stabilizing the atmospheric GHG at 650ppm CO_2-eq in the long-term. This is equivalent to Representative concentration pathways (RCP) 4.5. The volume of global energy-related CO_2 emissions in 2050 is limited at 36.6 $GtCO_2$/yr.

iii) 450 case…Stabilizing the atmospheric GHG at 450ppm CO_2-eq in the long-term, or halving global GHG emissions by 2050. This is equivalent to RCP3PD (peak and decline). The volume of global energy-related CO_2 emissions in 2050 is limited at 13.1 $GtCO_2$/yr.

The volume of global energy-related CO_2 emissions is 26.2 $GtCO_2$/yr in 2005. The volume in 2008 is 28.4 $GtCO_2$/yr (IEA, 2011a). These volumes exclude CO_2 emissions from international aviation/marine bunkers.

3. Results

3.1 Results in Base case

Time trend of the ESI (energy security index) depends on several factors. If one country takes a policy for promoting the domestic fuel development in order to improve the current insecurity situation, the country would lose the potential for future expansion of domestic fuel supply and future improvement of energy security. If China's industry increases the volume of oil imports, it would affect other Asian countries' market concentrations of oil import.

Figure 2 shows the results of ESI in the selected major regions for 2001 and 2030 in Base case. The ESI in 2001 is calculated based on TPES (IEA, 2011b) and trade matrix (GTAP, 2006). Compared to the ESI in 2001, all of these regions increase their vulnerability in 2030. This is mainly due to i) decrease of domestic oil productions, and ii) increase of oil and gas demands.

Figure 2 Results of ESI in Base case for 2030

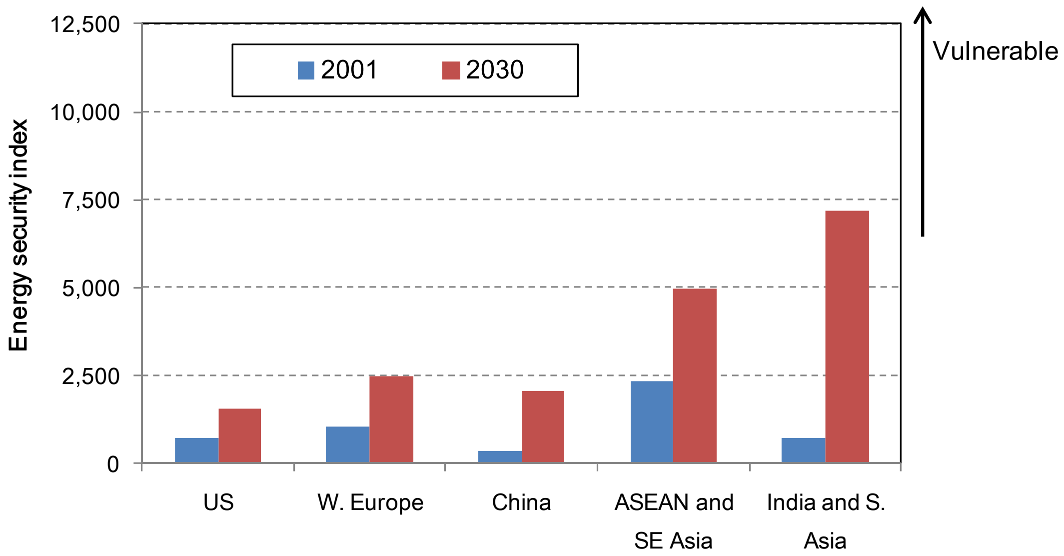


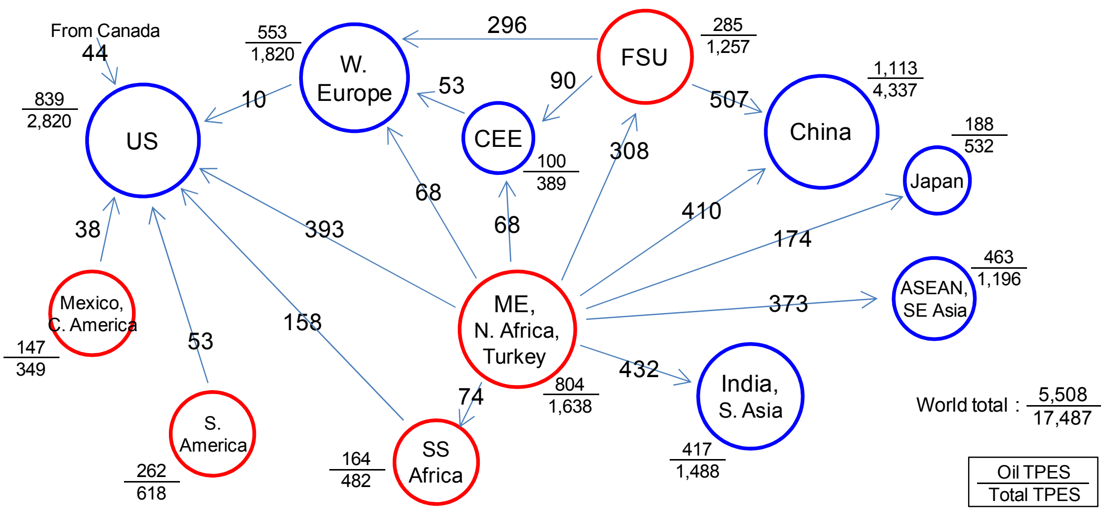
Figure 2 also indicates that Asian countries (except China) are more vulnerable than the US and Western Europe in 2030. This is due to Asian countries' characteristics, i.e., i) relatively small resource reserve of oil and gas, ii) relatively high demand of oil and gas, and iii) geographical locations.

Figure 3 illustrates the DNE21+ results of trade and TPES in 2030. The TPES of oil in Asian countries including Japan is 2,180 Mtoe/yr in 2030. The volume of oil import is 1,923 Mtoe/yr. The volume of interregional oil production is 257 Mtoe/yr. Asian countries import 3.6 times as much oil as the US, i.e., 536 Mtoe/yr in 2010 (IEA, 2011b). The Middle East, i.e., the (potentially) largest oil exporter, is geographically close to these Asian countries. The FSU is also close to Asian countries; however, China, the largest oil importer, consumes the FSU oil. As a result, Asian countries (except China) concentrate their oil supply on the Middle East oil. In the contrast, the US and W. Europe are surround by several (potentially) oil exporters, such as Canada, Mexico, Central America, South America, Sub-Sahara Africa and the Middle East.

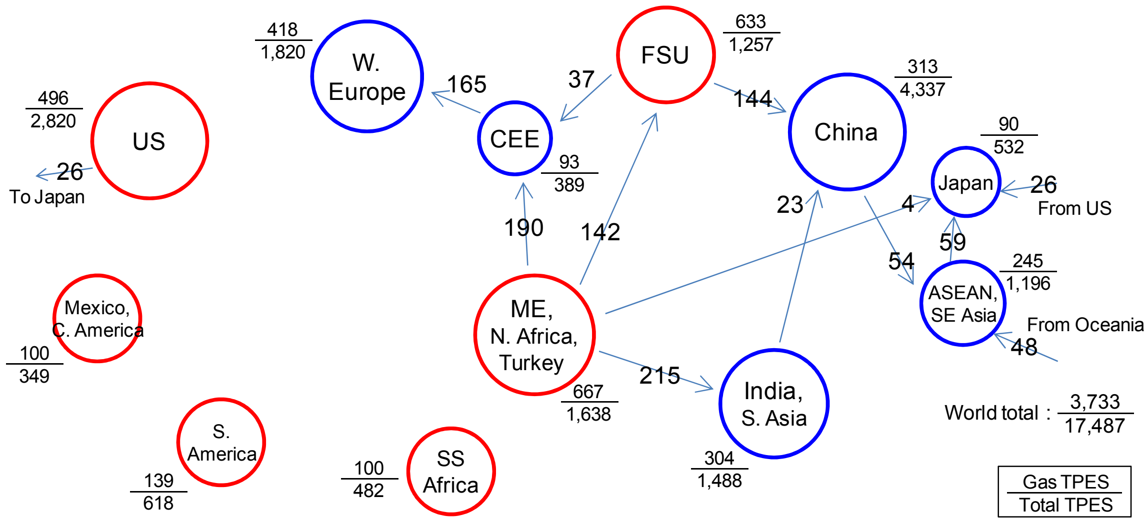
In terms of gas import, Asian countries rely on the Middle East, the FSU, Oceania and the US. Compared to the oil, the importing regions of gas are relatively diversified. However, the volume of gas import is substantial in Asian countries. In W. Europe, interregional gas production is dominant in the TPES while the remainder relies on Central and Eastern Europe (CEE) gas import. The US is a gas exporter in 2030.

Figure 3 Results of trade and TPES in 2030 (selected regions and paths)

(a) Oil



(b) Gas



Note: The red circle means a net fuel exporter. The blue circle means a net fuel importer.

3.2 Results in 650 and 450 cases

Figures 4 and 5 show the results of ESI by case in selected major regions for 2030 and 2050, respectively. The results are a bit complex and the trends of ESI vary by case and region. For comparison, we aggregated these regions into two mega regions; i) US and W. Europe, and ii) Asia total including Japan. We calculated the weighted average ESI for these two mega regions using population (Figure 6).

Figure 4 Results of ESI by case for 2030

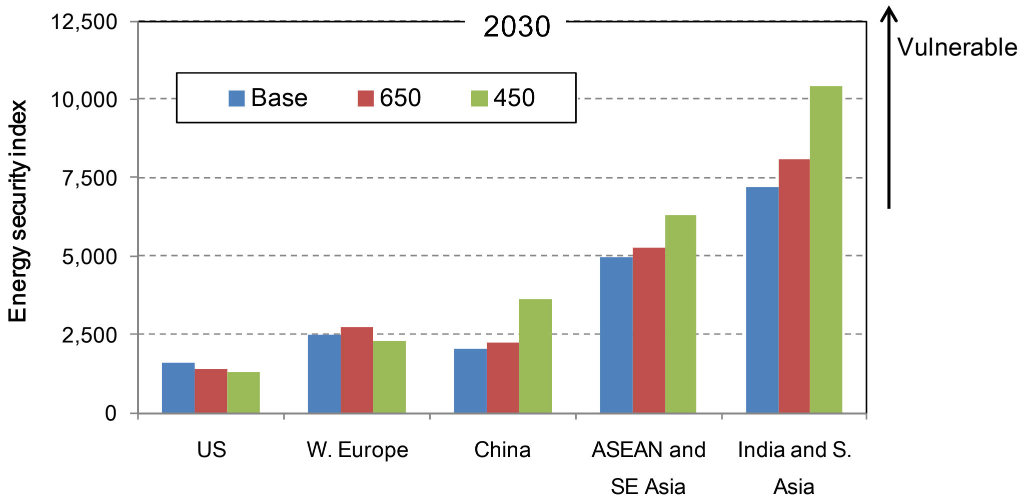


Figure 5 Results of ESI by case for 2050

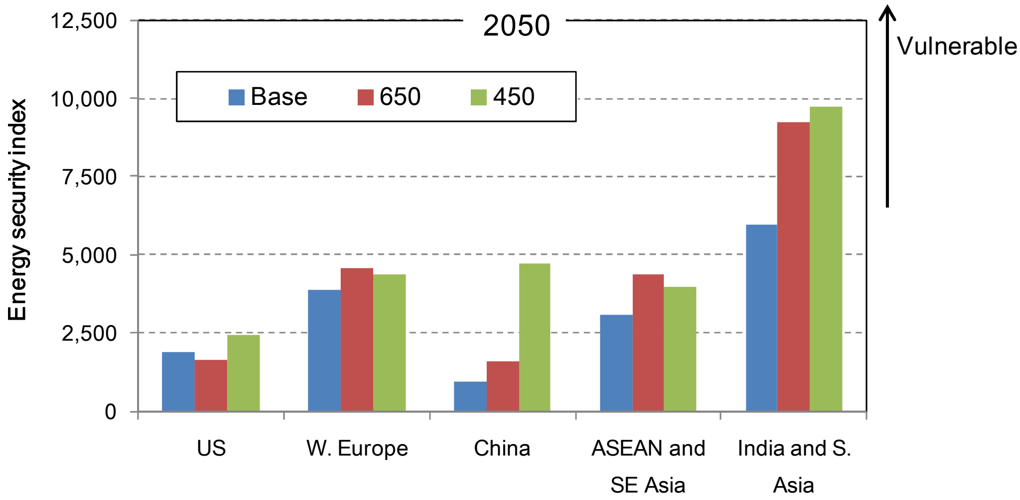


Figure 6 indicates that carbon constraints do not have a clear impact on ESI in the US and W. Europe. In the results in 2030, it seems that the US and W. Europe slightly receive co-benefit both for energy security and CO_2 emission reductions. In the contrast, Asian countries clearly become more vulnerable as a group in the carbon constraint cases. Figure 7 illustrates the reasons why Asian countries clearly become more vulnerable in the carbon constraint cases.

In terms of carbon storage capacity in Figure 7, total capacity in Asia is assumed to be 390 $GtCO_2$ which accounts for 11 % of that of world total (Sano et al., 2012). Asian TPES in Base case accounts for 45 % in 2050. In terms of pig iron in Figure 7, assumed Asian pig iron production accounts for about 70 % in 2050. Pig iron production consumes a certain amount of coke (and coal/gas injection) for blast furnace and requires CCS deployments for substantial CO_2 emission reductions. Compared to the potential volume of energy demand and CO_2 emissions, Asian carbon storage capacity is relatively small.

Figure 6 Regional trend of ESI by case for 2030 and 2050

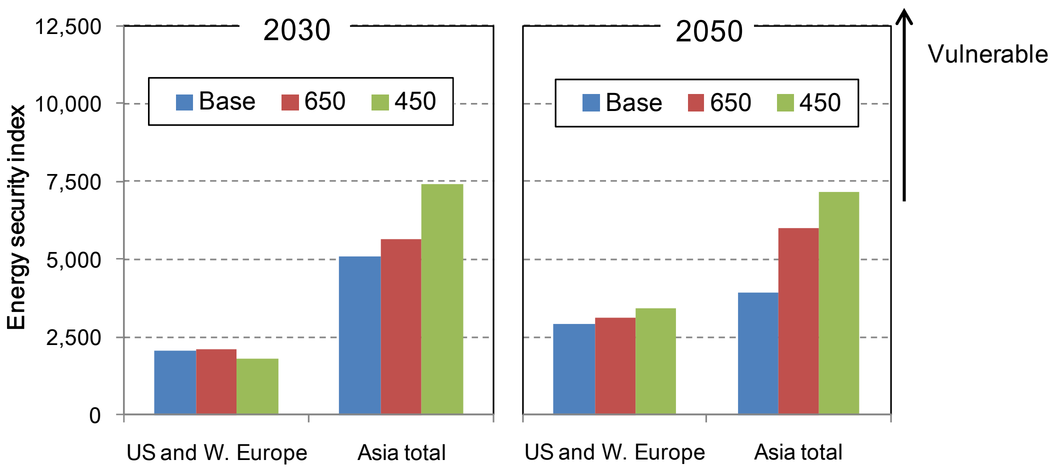
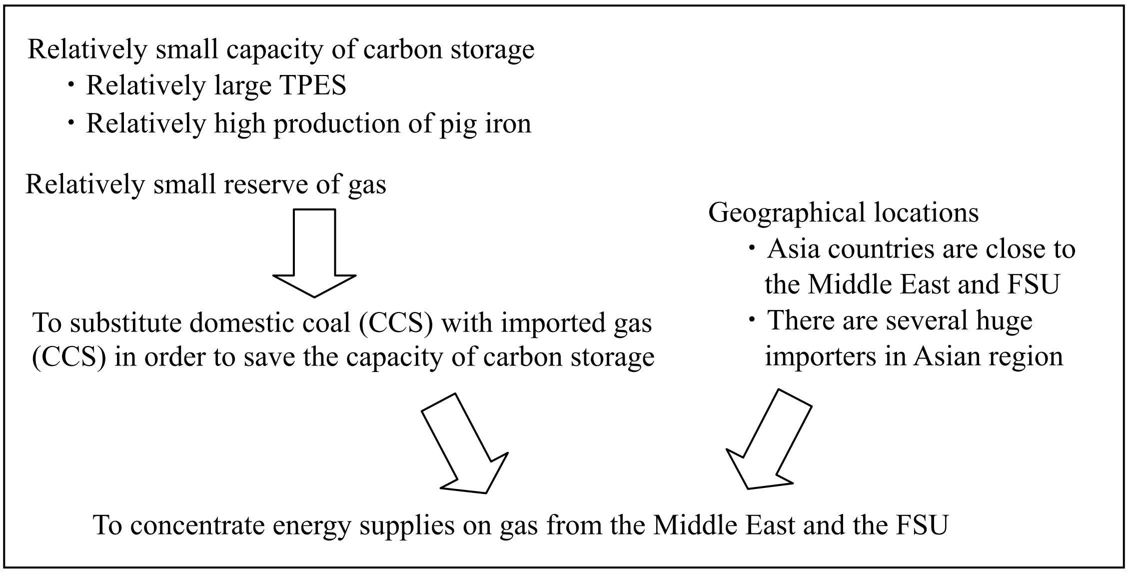


Figure 7　Summary for factors of Asian countries' vulnerability in carbon constraint cases

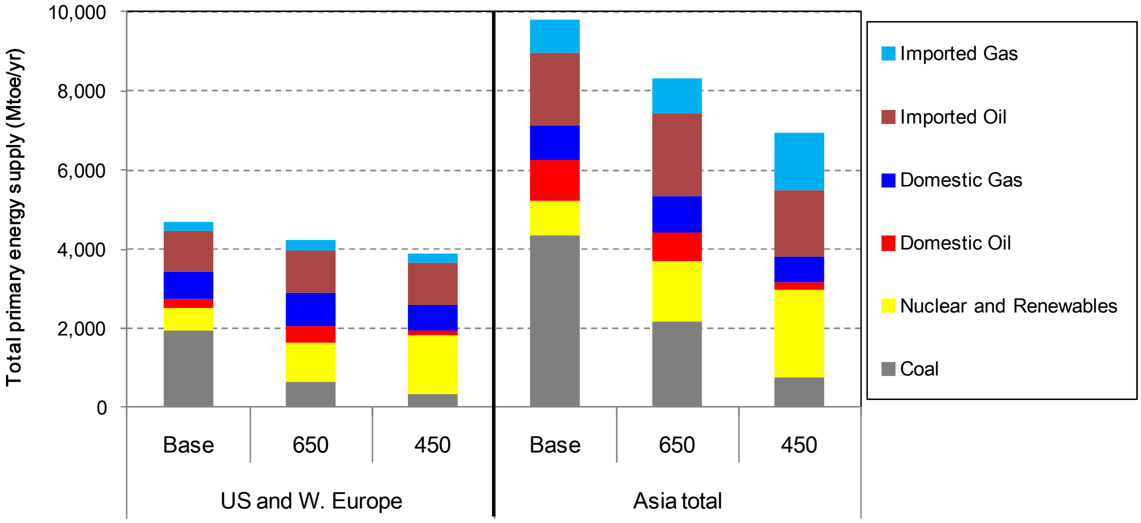


In terms of fuel substitution in Figure 7, Figure 8 shows the results of TPES in the two mega regions for 2050. In both regions coal consumptions substantially decrease in 650 and 450 cases; however, Asian countries substitute domestic coal with imported gas. This is due to small capacity of carbon storage in Asia, and small reserves of gas.

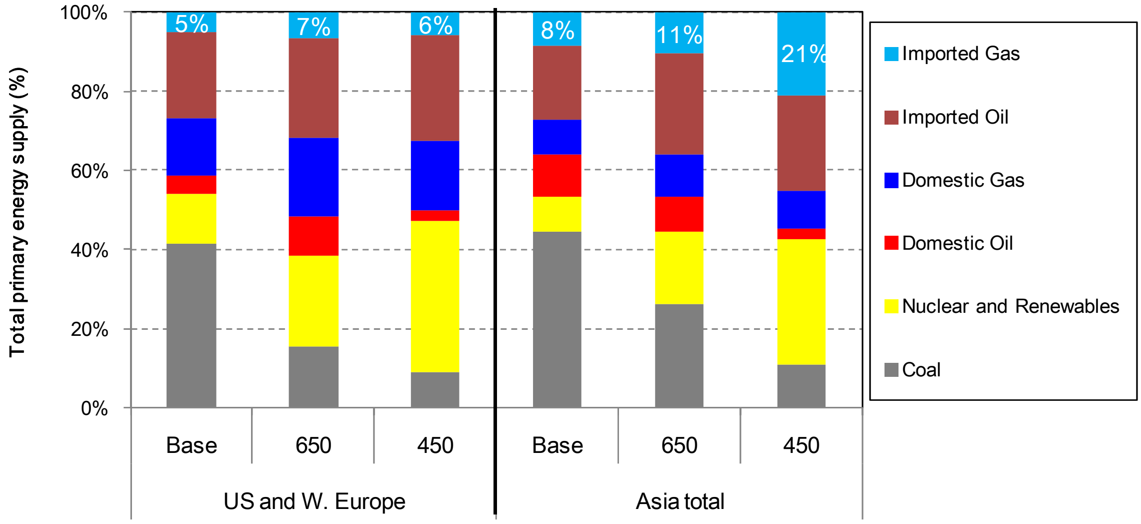
In terms of geographical locations in Figure 7, China also relies on the FSU oil and gas, and Asian countries concentrate their increased gas demand and supply on the Middle East gas (Figure 9). As a result, carbon constraints make Asian energy security more vulnerable.

Figure 8　Results of TPES by case in 2050

(a) Volume (Mtoe/yr)



(b) Share (%)



CONCLUSION

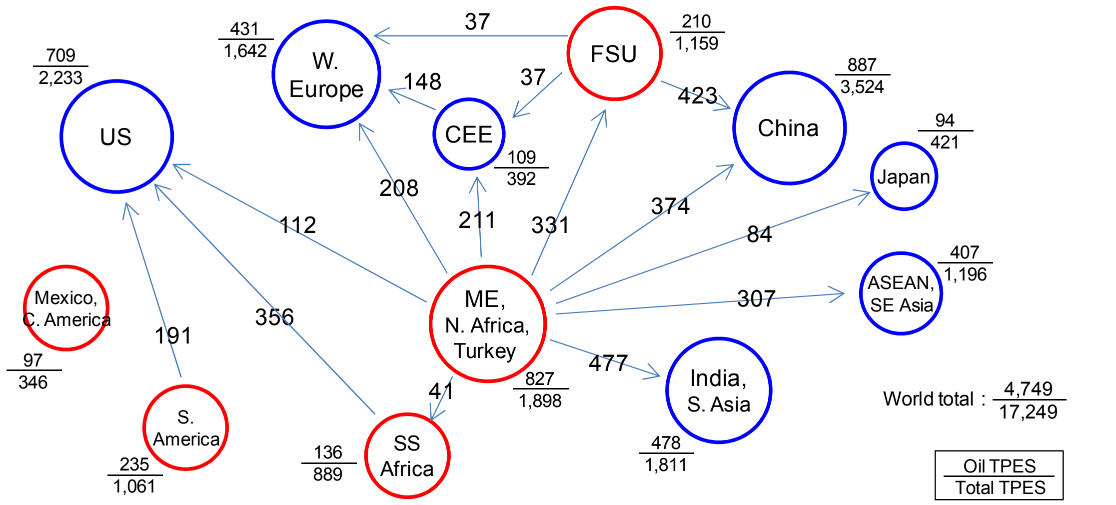
In this paper we calculated energy security index by region up to 2050 using analysis results of world energy systems model, DNE21+. In addition to Base case, two global carbon constraint cases are simulated. The results are summarized as follows.

1) In Base case, energy security of Asian countries become more vulnerable in 2030 compared to current levels. This is because they concentrate their increased oil and gas demands on fuel imports from a small number of regions (the Middle East and FSU).
2) The relationship between energy security and CO_2 mitigations varies by region.
   - Carbon constraints make energy security of Asian countries more vulnerable compared to Base case.
   - In contrast, the energy security index for the US and Western Europe is stable even in the carbon constraint cases.
3) The reasons of the regional difference are i) resource reserve of gas, ii) capacity of carbon storage, and iii) geographical locations.
   - Asian countries have smaller reserves of gas and smaller capacity of carbon storage compared to expected large energy demands. They are geographically close to the Middle East.
   - In the US and Western Europe, geographical locations enable them to diversify their oil imports. The US expands domestic gas production and does not import gas.

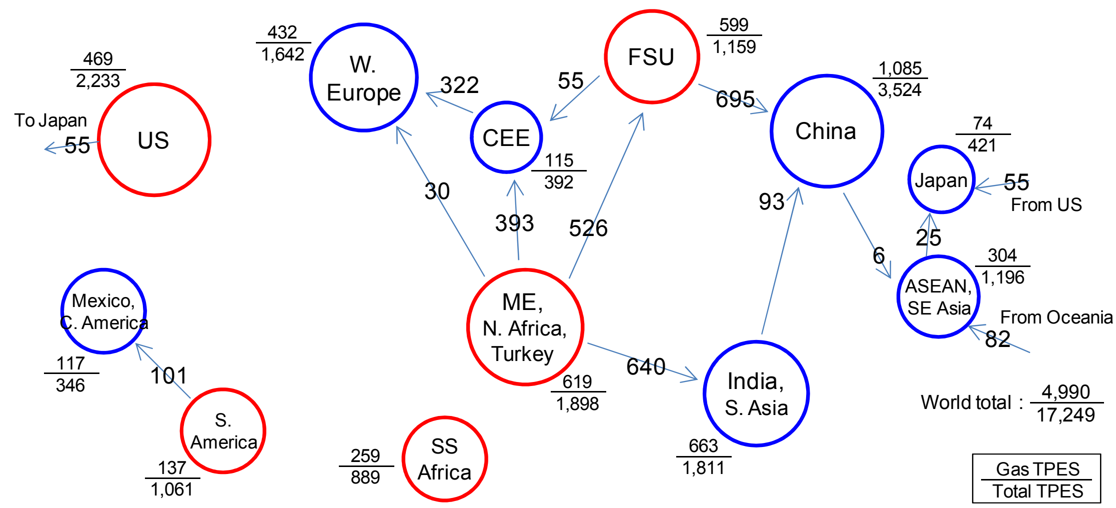
A simple story of synergy between CO_2 mitigation and energy security is widely mentioned. It states, “CO_2 mitigation consequently improves the energy insecurity situation through acceleration of energy saving and diffusion of renewables”. The results in this paper indicated that the simple story could be applied for some regions but not for all the regions in a global scale.

Figure 9 Results of trade and TPES in 450 case for 2050 (selected regions and paths)

(a) Oil



(b) Gas



Note: The red circle means a net fuel exporter. The blue circle means a net fuel importer.

Appendix A

In terms of fuel categorization, for simplicity, "oil" represents "crude oil" in this paper. The introduced ESI (energy security index) is focusing on vulnerability derived from crude oil and gas imports. The index doesn't reflect vulnerability from petroleum products imports. From a historical viewpoint, the US had been a net importer of petroleum products before 2009. Net import of petroleum products corresponded to 10.8% of crude oil import in 2005. In 2009 and 2010 the US was a net exporter of petroleum products (IEA, 2011b).

Appendix B

Table B1 List of regional division for the ESI (energy security index) analysis

	Short label	**Region**/representative countries	Political risk
1	US	United States, Guam, Puerto Rico, etc	1.64
2	Canada	Canada	1.51
3	W. Europe	**Western Europe**/UK, France, Germany, Italy, Spain, Portugal, Belgium, Netherlands, Luxembourg, Denmark, Sweden, Finland, Austria, Ireland, Greece, Norway, Iceland, Greenland, Switzerland, etc	1.60
4	Japan	Japan	1.52
5	Oceania	Australia, New Zealand, Papua New Guinea, Fiji, French Polynesia, Kiribati, Nauru, New Caledonia, Solomon Islands, Tonga, American Samoa, Vanuatu, etc	1.50
6	China	China, Mongolia, Democratic People's Republic of Korea	2.11
7	ASEAN and SE Asia	**ASEAN and Southeast Asia**/Korea, Taiwan, Viet Nam, Cambodia, Laos, Malaysia, Singapore, Indonesia, Thailand, Philippines, Brunei, etc	2.29
8	India and S. Asia	**India and South Asia**/Pakistan, Afghanistan, Myanmar, Bangladesh, Nepal, Bhutan, Sri Lanka, Maldives	2.20
9	ME, Turkey and NA	**Middle East, Turkey and North Africa**/Saudi Arabia, Bahrain, Oman, Qatar, UAE, Yemen, Iran, Iraq, Kuwait, Jordan, Israel, Lebanon, Syria, Cyprus, Turkey, Egypt, Libya, Tunisia, Algeria and Morocco	1.92
10	SS Africa	**Sub-Saharan Africa**/South Africa, Sudan, Ethiopia, Somalia, Kenya, Uganda, Tanzania, Mozambique, Swaziland, Lesotho, Madagascar, Angola, Benin, Botswana, Burkina Faso, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Republic of the Congo, Democratic Republic of the Congo, Guinea, Gabon, Gambia, Ghana, Guinea, Liberia, Mali, Mauritania, Namibia, Niger, Nigeria, Senegal, Sierra Leone, Togo, Zaire, Zambia, Zimbabwe, Western Sahara, etc	2.58
11	Mexico and C. America	**Mexico and Central America**/Cuba, Jamaica, Haiti, El Salvador, Dominican Republic, Trinidad and Tobago, Guatemala, Honduras, Nicaragua, Costa Rica, Panama, etc	2.26
12	Brazil	Brazil	2.02
13	Other S. America	**South America except Brazil**/Venezuela, Guyana, Paraguay, Uruguay, Argentina, Colombia, Ecuador, Peru, Bolivia, Chile, etc	2.07
14	FSU	**Former Soviet Union**/Russia, Ukraine, Estonia, Latvia, Lithuania, Belarus, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaijan, etc	2.24

15	CEE	**Central and Eastern Europe**/Hungary, Poland, Czech, Bulgaria, Romania, Slovakia, Croatia, Slovenia, Bosnia And Herzegovina, Serbia, etc	1.88

Note: The values of political risk are assumed base on World Bank (2008). Small values mean relatively political stable countries.

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