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Energy security in East Asia under climate mitigation scenarios in the 21st century ☆

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ABSTRACT

Japan, China, and South Korea depend heavily on imports for most of their energy. This study aims to investigate how energy security in these three East Asian countries will change in the future under climate mitigation policy scenarios. The study will help researchers and policy makers to better understand the relationship between climate and energy issues that will arise in relevant policy discussions. The analysis was conducted using a computable general equilibrium model. A reference scenario and two policy scenarios based on the Representative Concentration Pathways adopted by the Intergovernmental Panel on Climate Change are analyzed and compared between primary energy, fossil fuels imports, and diversification of energy sources.

The findings suggest that to reduce greenhouse gas emissions, the three East Asian countries need to shift their energy structures from currently dominant fossil fuels to renewables and nuclear power. The lower the target of allowable emissions, the larger the required shifts will have to be. Among fossil fuels, coal use in particular must significantly decrease. Such structural shifts improve energy self-sufficiency, thus enhancing energy security. However, the impact of diversification of energy sources (measured by the Herfindahl index) under climate mitigation scenarios differs by country and scenario. Until 2050, diversity improves in all three countries relative to the base year. After that, in some countries the diversity should decline because of high dependence on a specific energy source. Overall, it is revealed that energy security improves along with climate mitigation. This improvement will also contribute to the economy by reducing energy procurement risks.

1. Introduction

Climate change is currently the most significant global environmental issue and policy discussions with mid- to long-term perspectives are ongoing worldwide. A critical negotiated treaty is the United Nations Framework Convention on Climate Change (UNFCCC). The Copenhagen Accord, agreed in December 2009, was an important step along the global path to climate change, and the Annex I parties and some major non-Annex I parties, such as China and India, submitted their pledges on greenhouse gas (GHG) emission reduction by the end of January 2010. The Kyoto Protocol expired at the end of 2012, but at the 2012 UN Climate Change Conference there was agreement to extend it until 2020 and to develop a successor to it by 2015. However, important developed countries such as Canada, Japan, and Russia did not participate in the post-Kyoto Protocol.

In recent years, energy demand has dramatically increased in large emerging countries such as China and India. This demand is driven by economic and population growth, and is expected to increase further [1,2], raising concerns about energy supplies in the future. In addition, because production and reserves of fossil fuels such as crude oil and natural gas are predominately located in a limited number of countries [1], other countries, including those in East Asia, that are poor in energy resources and dependent on imported fossil fuels will face potential price-fluctuations and geopolitical risks.

Climate change measures[1] are aimed at reducing GHG emissions, in particular CO_2. To emit less GHGs, promotion of energy efficiency and shifts to low-carbon energy, namely shifts from coal to natural gas and from fossil fuels to renewables and nuclear

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[1] In this study, only mitigation measures are considered under climate change policies. Adaptation measures are not considered.

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energy, are critical. If energy savings and low-carbon energy use are both adopted as climate change measures, the volume of and the dependence on imported energy will decrease[2]. This in turn will help to improve energy security [5,6].

To achieve energy security—that is, sufficient energy to support economic activity and social welfare—in countries that rely on foreign energy sources, risk diversification is essential. The methods include diversifying supply (importing fuels from many countries and not relying only on a small number of suppliers), diversifying fuel types, and industrial globalization [7]. It is also important to reduce energy imports and to increase energy self-sufficiency. The latter highlights the fact that business analytics research is nowadays essential in identifying and mapping the potential needs and strategies that energy firms and governments need to take in order to tackle the energy security issue that is higher in their agenda than ever before. In that respect, this is where our paper contributes in the existing literature.

In this context, East Asian countries have a significant energy security issue. Japan and South Korea (hereafter Korea) produce little or no fossil fuels [1,2]. China produces fossil fuels, but its demand exceeds its production [1,2]. In addition, it is expected that China will continue to enjoy high economic growth in the future, meaning energy demand and energy imports will both increase significantly [2].

Research on energy security in Asian countries is part of the Asian Energy Security Project [8–22], coordinated by the Nautilus Institute [23]. The research includes Japan, Korea (North and South), China, and Vietnam, and uses both a narrow definition (energy security only in terms of energy supply), and a more broadly defined energy security that is not only based on energy supply, but also includes economic, technological, environmental, social and cultural, and military perspectives, applying the Long-range Energy Alternatives Planning (LEAP) software system [20,21]. The LEAP system is a scenario/energy pathway-based energy-environment modeling tool to create models of different energy systems. Energy pathways or scenarios are internally consistent storylines of how an energy system might evolve over time (often between 20 and 50 years) in a particular socioeconomic setting and under a particular set of policy conditions [20,24]. Multiple energy pathways within a country or a region are compared to indicate which pathway is preferable using various energy security criteria such as cost, energy output, fuel imports and exports, and technological development. Other external methods such as diversification indices, multiple-attribute analysis and matrices, and qualitative analysis can be applied using the results from the LEAP system for further analysis on energy security [20].

There are some studies investigating the subject of energy security. Vivoda [25], for example, develops an energy security assessment instrument, which allows to analyze broadly defined energy security by considering 11 energy security dimensions. However, although the concept is shown, energy security is not analyzed in the paper. Löschel et al. [26] propose ex-post (e.g., energy prices) and ex-ante (e.g., concentration of energy supplies) indicators to evaluate energy security of countries. Using the illustrative indicators, they analyze energy security in Germany, the Netherlands, Spain, and the USA. However, their analysis on future energy security by the ex-ante indicators is only in short term (year 2030) and is based on one of the International Energy Agency (IEA)'s scenario. Kruyt et al. [27] implement more comprehensive analysis on energy security applying a scenario approach using a global energy system model, similar to the abovementioned LEAP system. They use a climate mitigation scenario and apply several energy security indicators, including energy prices and supply/demand, and fuel shares, to Western Europe as a whole in the mid-term perspective (year 2050). Although the approach is similar to our study, they employ an energy system model like the LEAP system and do not analyze Asian countries for which the energy security issue is of enormous concern.

In the operations research (OR) area, research on energy, especially energy system management and decision making on energy-related issues, has been extensively conducted, while that on energy security is fairly limited. The following are two examples on energy security in this area. Lia et al. [28] focus on oil-importing optimal decision using a multi-objective programming approach connecting with emergency (risk) scenarios. Gülpınar et al. [29] tackle with the issue on investment decision in petroleum markets under the supply disruption risk. Although these studies approach important aspects of the energy security issue, they do not consider other energy sources and the wider economic system, important elements that need to be addressed since oil markets are not independent.

Some studies such as Boland et al. [30], Marufuzzaman et al. [31], Matos and Hall [32], and Relvas et al. [33] address the trade (or supply chain) issue of different energy types, which relate to the energy security issue, and are treated in this paper to some extent. Other examples related to energy in OR are as follows. Arora and Taylor [34] generate probability density estimates for electricity consumption using the data of individual smart meters, which can be used for minimizing consumers' excess electricity use and devising time-of-use pricing for suppliers. Similarly, Zhao et al. [35] forecast electricity consumption using the high-order Markov chain based time-varying weighted average method, which will contribute for avoiding wastes of scarce energy resource or electricity shortages. In addition, Li et al. [36] apply the grey theory for forecasting electricity consumption in Asian countries using limited (short-term) data, which is valuable for policy making in developing countries showing high and unstable growth. On the other hand, Papadopoulos and Karagiannidis [37] apply a multi-criteria analysis method for optimizing the penetration of renewables for power generation into an insular system. These studies do not directly approach the energy security issue, but such energy management and decision making are closely related to it by reducing or optimizing energy use. Considering the above aspects, this paper contributes in the area of business analytics with an application on the energy sector, more specifically examining the energy security issue focusing on East Asia.

In this paper, we analyze the energy security issue in three East Asian countries, Japan, China, and Korea. Energy security is an important issue for these countries because their economic activities are highly dependent on fossil fuels and they are among the world's largest fossil fuel importing countries [1,2]; with the majority of imports, particularly oil, coming from the Middle East.

We examine climate mitigation policies (or emission pathways) using a computable general equilibrium (CGE) model. By using a CGE model, an inclusive assessment of economic activities (markets), including energy sectors and non-energy sectors, and the whole activities of countries are kept in the analysis; an approach that differs from the abovementioned studies. In addition, multiple climate mitigation scenarios are considered simultaneously for comparison. Since the climate change and broader energy issues are now both related to global business more than ever before, this study contributes to business analytics literature that focus on energy-related research. We analyze energy security in terms of primary energy structure, net imports of fossil fuels, and diversity of energy type. Furthermore, we analyze the entire 21st century, in contrast to previous studies that focus on the short to medium term. The long-term consequences are important, because the world will be highly dependent on fossil fuels for many years to come (e.g., Masui et al. [38]; Riahi et al. [39]; Thomason et al. [40];

[2] Renewables are basically domestic energy and nuclear energy is considered semi-domestic energy [3,4].