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How to find a reasonable energy transition strategy in Korea?: Quantitative analysis based on power market simulation

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ABSTRACT

The Korean government announced a new energy transition policy that emphasizes phasing out nuclear and coal energy and increasing renewable energy sources. However, a lack of quantitative research has resulted in disagreements about the most suitable energy transition strategy for Korea. To evaluate the policy, we designed a quantitative analysis that simulates generation scheduling and settlement processes in the Korean power market. We then analyze the economic impacts, conflicts of interest, greenhouse gas (GHG) emissions, and the power system's market price sensitivity to the price of imported liquefied natural gas (LNG) in four energy transition scenarios: i) the government's new energy transition policy, ii) phase-out of nuclear energy, iii) phase-out of coal energy, and iv) simultaneous phase-out of nuclear and coal energy. Additionally, we evaluated the effects of coal taxation. Based on the power market simulation results, we conclude that phasing out nuclear energy with increasing taxation of coal, or only phasing out coal energy are two reasonable scenarios for energy transition in Korea. The simultaneous phase-out of nuclear and coal energy, which was originally pursued by the government, is inferior to the recommended scenarios in the aspects evaluated. Policymakers should consider these results when developing feasible energy transition scenarios.

1. Introduction

Owing to the unexpected impeachment of former President Park in March 2017, a new government was established in Korea. The newly elected president, Moon Jae-In, signed an executive order to permanently cease operations of Nuclear Power Plant Gori I, which had been in operation for approximately 40 years. At the retirement commemoration for Gori I, President Moon stated that Korea should begin its energy transition, emphasizing the need to evolve to an energy system with clean and sustainable energy sources.

Korea's energy policy has previously focused on subsidizing the energy-intensive heavy and chemical industries with low retail electricity rates. These low retail rates were achieved by maintaining low generation costs through state-led investment in baseload units such as nuclear and coal-fired power stations. However, Korean people have become increasingly concerned about the environmental hazards associated with power generation, including nuclear accidents, climate change, and fine dust emissions. Against this background, people in Korea have disagreed about which is the most suitable energy transition strategy for Korea, because they set different weighting factors on evaluation factors for energy mix policy, such as energy security, cheap price, air pollution, safety, etc.

Increasing concerns about environmental and safety issues and the corresponding attempts by governments to handle them are found in many countries worldwide. The literature that examines foreign energy transition cases has identified factors that should be considered when evaluating energy transitions.

In France, the recent energy mix strategy has been changed from emphasizing energy security with nuclear power generation to actively responding to climate change issues (Andriosopoulos and Silvestre, 2017). Considering the trend in France, Andriosopoulos and Silvestre (2017) focused on the impacts on greenhouse gas (GHG) emissions through an energy transition scenario that attempts to replace nuclear power with other resources. Fischer et al. (2016) stated that, over the past 25 years, the German government has been implementing energy transition policies (*Energiewende*) that include limiting the lifetime of the last nuclear reactor to 2022, and by 2020, increasing the share of renewable energy in gross energy consumption to 18% and reducing GHG emissions by 40% compared to 1990. The authors discussed the energy transition in Germany in terms of four factors: the security of

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electricity supply, rising electricity prices (which can be a financial burden for private households, particularly poor ones (Frondel et al., 2015)), the impact on employment, and its practical implementation. In East-Asia, Japan began to address its energy transition to increase the utilization of renewable energy and decrease dependency on nuclear power after the Fukushima nuclear disaster. Hong et al. (2013) assessed possible energy mix scenarios after the Fukushima nuclear crisis in terms of the levelized cost of electricity, energy security, GHG emissions, land transformation, water consumption, heated water discharge, air pollution, radioactive waste, and solid waste. This study suggested that it would be necessary to have more than 35% of electricity supplied by nuclear power generation to reduce GHG emissions to 70% of the 1990 rate by 2030. In other words, the use of nuclear power helped Japan increase the sustainability of its energy system. Indeed, The CNN (2016) reported that Japan decided to restart nuclear power generation in August 2015 given the rise in retail household electricity rates of 19% from 2011 to 2015 and the spike in carbon dioxide emissions because of fuel imports necessitated by the brief, but complete, suspension of nuclear power generation. Sun et al. (2016) found that rather than nuclear disaster, Chinese energy transition policies have focused on reducing carbon dioxide emissions caused by coal per unit of gross domestic product from 2005 levels by 60–65% by 2030. The authors compared various Chinese energy transition scenarios with a 2030 business-as-usual scenario based on total costs, total installed capacity, GHG emissions, and direct job creation, suggesting the most suitable energy transition scenario for China based on the results of evaluating certain comparison factors. In the United States, energy security has been regarded as the most important factor in energy policy since the international oil shocks of 1973 and 1978. However, establishing social agreement on the correct balance between climate change mitigation strategies and energy security guarantees has been challenging (Bang, 2009). Ross et al. (2016) highlighted two significant trends in the US energy mix: an increase in renewable energy generation and a decrease in coal usage. Because gas can be produced cheaply in United States, these two outcomes are possible without increasing dependency on gas. Further, Comello and Reichelstein (2016) established that the solar industry in the United States would become uncompetitive following a radical reduction in federal investment tax credits from 30% to 10% in 2017. This change would decrease price competitiveness for investors by increasing levelized cost, which represents break-even value, resulting in lower investor profits. Hence, we can infer that a radical transition can threaten the viability of certain stakeholders, suggesting that a moderate transition policy is necessary. To choose a suitable and balanced energy transition scenario for Korea, an evaluation will be performed based on the factors considered in the studies mentioned above.

In studies dealing with Korea's energy, Park et al. (2013) only analyzed changes in the cost of electricity generation and GHG emissions from 2009 to 2050 among three energy mix scenarios for the Korean power system: the current energy mix plan, the newly established plan, and the plan with ambitious targets for renewable energy integration. This study employed LEAP model that predicts changes in unspecified energy systems using statistical data such as energy balance statistics, GDP, and population. Hong and Brook (2018) pointed out that it is hard in the Korean case to simultaneously achieve a reduction in usage of coal and nuclear power, while also cutting back on GHG emissions. The authors arrived at their conclusion by estimating future GHG emissions, generation cost, safety from nuclear accidents, and renewable energy penetration, and then comparing Korea with other countries. The comparison indexes used in the study were generation mix, population density, geographical features, and volume of primary energy imports. The statistical estimation approaches used in these studies would be valid for identifying rough trends in a future energy system but are limited in their ability to provide the exact predicted values required for practical policy making.

Fortunately, the Korean power system can easily obtain precise forecasts of the various impacts of the state-led energy mix plan, called the basic plan for long-term electricity supply and demand[1] (hereafter the ESDP). This is because the ESDP describes the confirmed yearly generation construction roadmap and provides credible long-term electricity demand forecasting. Moreover, the Korean power market can be quite precisely mimicked with the data in the ESDP and the characteristics of a cost-based pool (CBP) mechanism. As the 8th ESDP was confirmed in December 2017, this study conducts evidence-based research by simulating the operation of the Korean power market instead of using statistical estimation approaches. By simulating the Korean power market, this study considers several factors used for evaluation and quantitatively analyzes the impacts of several energy transition scenarios.

The findings of this study can be used to support and supplement the most recent research in (Hong and Brook, 2018), which provided useful insight into reasonable directions for Korea's future energy transition. Furthermore, based on the results of this study, stakeholders with different priorities in energy mix evaluation can reach an agreement on the most practical and reasonable future energy transition strategy.

2. Background

2.1. Korean power market

In 2001, the Korean government separated power generation companies (GENCOs) from the Korea Electric Power Corporation (KEPCO), which was previously a vertically integrated utility company including generation, transmission, distribution, and retail. In addition, the Korea Power Exchange (KPX), an independent system operator, was established to ensure the transparency and fairness of market and system operations. Six public GENCOs operate as subsidiaries of KEPCO in addition to several private GENCOs. These GENCOs sell electric power in the wholesale market operated by KPX. KEPCO then buys the electric power via the market and resells it to consumers by using its own transmission and distribution network. KEPCO has the exclusive rights to sell electrical power, with the exception of community energy system companies in several districts. Community energy system companies are the local energy service providers with licenses to supply heat as well as electric power in specific districts instead of KEPCO. KPX conducts clearing generation bids, settlement, market surveillance, and market information release. As an independent system operator, KPX runs security-constrained economic dispatch considering accident prevention and reserve management to ensure stable operations. Fig. 1 presents the structure of the Korean power industry and the role of each entity.

2.2. Operating mechanism in Korean power market: cost-based pool

Before delivery day, KPX receives bids for generation quantities with cost functions from GENCOs. It then establishes the price-setting scheduling to determine the hourly system marginal price (hereafter SMP) and which generators should be operated for each hour by using forecasted hourly demand, submitted generation bids, and cost information through unit commitments technique. When establishing the price-setting scheduling, the participating generators are placed in order of the lowest marginal cost. The most expensive generator, located at the top of the generation stack meeting forecast demand, is appointed as the marginal generator. The marginal cost of the marginal generator is set as the SMP for that hour. After establishing the price-setting scheduling, KPX sets the operation scheduling through economic dispatch technique by considering the reserve requirements, system

[1] The basic plan for long-term electricity supply and demand set up by the KPX and Ministry of trade, industry and energy is a guideline for the introduction of new generation facilities and the abolishment of older facilities to meet the expected load.