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A nuclear- to-gas transition in South Korea: Is it environmentally friendly or economically viable?

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Abstract: Given the limited potential for renewable energy and high population density of South Korea, nuclear has been an essential electricity generation option for supply of reliable power whilst reducing greenhouse-gas emissions and mitigating air pollution. However, the recently elected (2017) South Korean government has a policy committing them to a phase-out of nuclear and coal, offset by an increase in the share of variable renewables. However, the main component of the power transition is set to be liquefied natural gas (LNG), due to technical and economic barriers facing large-scale renewables. It is therefore critical for South Korea to develop an evidence-based perspective on the details of the transition, before any future energy policy is decided. Here we review: i) the national role of renewable sources given technical and economic limitations in South Korea; ii) potential environmental and economic issues with gas; and iii) potential barriers of and benefits to a nuclear pathway. Our conclusion is that, given the geographical and economic limitations facing South Korea, and the need to reduce carbon emissions cost effectively, a nuclear pathway coupled with a moderate renewable share offers the most viable policy, with a gas-focused energy future being neither environmentally friendly nor economic.

1. Introduction

The Fukushima Daiichi accident which followed the Great East Japan earthquake in 2011, along with the nuclear scandal surrounding bribery, faked safety tests and falsified components within the Korean Hydro and Nuclear Power (KHNP) company, which operates all nuclear power plants in South Korea (Choe, 2013), triggered a wave of anti-nuclear sentiment in South Korea. Therefore, despite the economic and environmental benefits of nuclear power (Alonso et al., 2015; Brook et al., 2015; Hong et al., 2014; Kharecha and Hansen, 2013), a future reliance on nuclear power is becoming highly uncertain in this economically prosperous East Asian nation.

Just as nuclear power is subject to severe social stigma, coal power is now facing a range of serious environmental challenges. Coal burning is the main source of greenhouse-gas emissions in South Korea (KOSIS, 2017). To meet the greenhouse-gas reduction plan agreed to by South Korea (i.e., 37% below the business-as-usual by 2030), the decarbonization of the electricity sector is essential. Integrated-coal-gasification combined-cycle plants linked with carbon-capture-and-storage technologies offer the potential to reduce greenhouse-gas emissions by 85% compared with a traditional coal power plant (Hoya and Fushimi, 2017). However, although carbon-capture-and-storage technologies might be commercialized over the long term, the present reality is that, given its inherent and ongoing technical and economic difficulties (Leung et al., 2014), closing down coal power is virtually the only answer to rapid greenhouse-gas emission reduction. Moreover, together with inflow from China, coal power is one of major pollution sources in South Korea (Donald, 2016; Kharecha and Hansen, 2013). Due to the worsening air quality in South Korea, public hostility to coal power is intensifying (Park, 2017).

In response to public pressure, especially from vocal special interest groups, the newly elected South Korean government has announced plans to replace coal and nuclear power with renewables (Cho, 2017; Democratic Party of Korea, 2017; Normile, 2017). However, the major component of the energy-replacement plan does not in fact depend on renewable sources, but on natural gas. The president of South Korea, Jaein Moon, affirmed the plan to replace the current nuclear-centered electricity policy to a new plan on 19 June 2017 (Kim, 2017).

As a first step, the government plans to cancel construction proposals for any new nuclear plant. Indeed, the government suspended the construction of two nuclear reactors (Shin Kori no. 5 and Shin Kori no. 6) (Chung and Jin, 2017). Existing nuclear power stations will not be permitted to apply to extend their generation license beyond the original licensed lifespan of 30–40 years. Recently, KHNP decided to close

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the oldest nuclear power plant in South Korea (Kori-1 which was commissioned in 1978), with decommissioning expected to take 15 years and cost $887 million USD (KHNP, 2017). If the operation license is not renewed for the other currently operating nuclear power plants, 12 reactors with the capacity of 9.7 GW will need to be decommissioned between 2023 and 2029. A similar approach is intended to be applied to coal power. All new construction plan of coal power plants will be cancelled, and any coal power plants under construction whose progress is $<$ 10% will be cancelled.

In the long term, to fill the reduced generation capacity left by the exit from nuclear and coal, natural gas will need to increase its generation capacity factor up to 60%. The total gas capacity was 33.7 GW (December in 2016) and its capacity factor was 41% in 2016. By 2030, the generation share of wind and photovoltaics is intended to increase to 20% (Oh, 2017). To drive expansion of renewable supply, a mandatory renewable target for a large generation plant and feed-in-tariff for small-scale generators will be introduced (Democratic Party of Korea, 2017). However, considering geographical limitations and high population density ($>$ 500 people km^{-2}) of South Korea, modelling has demonstrated that it is highly unlikely that South Korea can achieve 100% renewables, even in the longer term, while avoiding negative economic and environmental impacts (Hong et al., 2013). Given national geographical and economic constraints, renewable sources would be able to provide around 150 TWh, which is $<$ 30% of the total electricity demand in 2016.

The new South Korean government is planning to include a nuclear phase-out pathway in the 8th Electricity Generation Plan (MOTIE, 2017), which will project through to 2031. Although there are, as yet, few details announced by the new government, it is very important to analyze the potential negative environmental and economic impacts of the suggested non-nuclear pathway and provide evidence-based perspectives, before the plan is set. For the purpose, we sought to identify the likely features of the transition pathway, based on the current government's announcements, in the context of South Korea's geographical and socio-economic situation.

2. Electricity generation mix

South Korea consumed a total of 8631 PJ of final energy and 543 TWh of electricity in 2016 (KESIS, 2017) (Fig. 1) Coal generated 40% and nuclear 30%. Thus, to replace nuclear and coal power completely, about 70% of electricity generation needs to be provided by other sources. Even without further demand growth, this would require total generation of natural gas to be increased three-fold, or renewables to be expanded 17-fold. Even more starkly, non-hydroelectric renewable sources, including solar photovoltaic, wind, marine power and biomass, need to increase the total generation about 24 times, if hydroelectric power remains at the current level. Hydroelectric power delivered 30.1% of the total renewable electricity generation in 2016, with burning waste and biomass generating a further 39.5%. The sum of all other renewables including wind, solar photovoltaic and marine power generated $<$ 30.3% of the total renewable electricity generation.

3. Energy efficiency and renewable energy

As stated in the governmental plan, energy efficiency will be a crucial component in achieving a sustainable energy future. However, it can only be part of the solution, not the ultimate answer to emissions reduction, for two technical reasons. First, even should electricity demand reduce, an electricity sector will rely on carbon-based electricity if the generation side is not decarbonized. Given the causal relationship between economic growth and electricity demand (Apergis et al., 2010; Isa et al., 2015), and the historical energy demand trajectory for South Korea, energy-efficiency technologies and energy-conservation measures might lower demand relative to business-as-usual in the future, but it is unlikely to decrease in absolute terms. Second, an improved generation efficiency of wind and solar photovoltaic by 20% by 2035 (Huber et al., 2017) would increase the maximum annual potential of renewable generation by 30 TWh (Hong et al., 2013). Yet even if total energy demand in 2035 remains at the current level (543 TWh in 2016) due to strong demand-side energy efficiency measures, and if renewables could concomitantly generate 200 TWh of electricity via technological innovation (i.e., a 33% generation-efficiency improvement), then 343 TWh of electricity would still need to be generated from gas, if both coal and nuclear are removed.

During the last decade, renewable energy sources indisputably achieved remarkable technological developments and cost reductions, and became a centerpiece of many national energy policies (Bigerna et al., 2016; Connolly et al., 2016; Kemfert, 2017). It is also realistic to assume that some countries (e.g., Australia, Iceland, and Norway) could achieve high renewable shares thanks to sufficient natural resources (wind, water or sunlight, and suitable sites for hydro), coupled with a low population density (Steinke et al., 2013). A large network, termed a 'super grid', might further enhance the possibility of higher renewable shares by geographically distributing renewables (Breyer et al., 2015; Connolly et al., 2016). However, none of these options are currently viable at sufficient scale for South Korea, due to severe geographical limitations. Although energy storage is a key component for increasing renewable shares (Hong and Radcliffe, 2016; Luo et al., 2015; Schwarz and Cai, 2017), energy storage does not generate electricity; it simply permits shifts between demand and generation. Further, due to inevitable conversion losses, energy storage actually consumes 5–40% of electricity inputs during the charging and discharging process (Luo et al., 2015).

Worldwide, the population density of a country has a strong negative relationship to its share of total renewable electricity generation (Fig. 2). South Korea has the highest population density (519 people km^{-2}) and lowest renewable-electricity share among IEA member

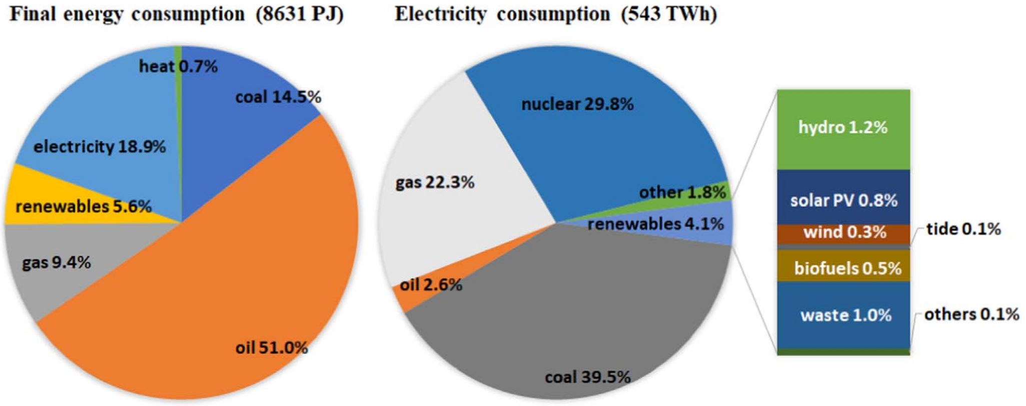

Fig. 1. The final energy consumption (left) and the electricity generation mix (right) in South Korea in 2016 (KESIS, 2017).