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Investment timing decisions in hydropower adaptation projects using climate scenarios: A case study of South Korea

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A B S T R A C T

Climate change alters the energy production of existing hydropower plants. Old-established facilities of hydropower are insufficient to handle changes in runoff under climate change. These facilities should be retrofitted and adapted to climate change. Adaptation of hydropower to climate change has two purposes: first, to fully utilize future water resources for maximizing electricity generation; and second, to generate profits in return of investment costs. Investment in the adaptation depends on issues such as climate scenarios, investment costs, and timing of implementation. Since future climate scenarios are intrinsically time-dependent, investment timing is the biggest issue. We propose the Adaptive Investment Model (AIM) to determine the timing of investment, using real options valuation. AIM comprises four steps: identification of hydropower adaptation to climate change (step 1), calculation of key variables (step 2), real options valuation (ROV) (step 3), and decision-making (step 4). This model allows investors to assess the economic feasibility and suggests optimal investment timing for adaptation to climate change. A case study involving the Chuncheon hydropower plant in South Korea demonstrated that AIM could generate an effective adaptation strategy.

1. Introduction

Hydropower contributed to 3,646 TWh (17%) of the world's electricity generation and had the largest share among renewable energy in the year 2012 (EIA, 2016). The potential capacity of hydropower generation is estimated to be more than 16,400 TWh per year, and the undeveloped potential is the highest in Africa, followed by Asia, Oceania, and Latin America (IEA, 2010, 2012). Because hydropower has been a stable electricity supplier during the past century, it plays a role of base load generation in some countries that have plentiful water resources. Hydropower accounts for more than 50 percent of the total electricity generation in Norway, Brazil, Venezuela, and Canada (IEA, 2015).

Global climate change (CC) has significant impact on the hydropower system and electricity demand (van Vliet et al., 2016). Precipitation and runoff will increase on a global scale, but regional changes may notably vary (Kumar et al., 2011). The hydrological uncertainties affecting hydropower plants include changes in precipitation and temperature, floods, droughts, and the melting of snow and ice. These climate-related risks alter the energy production and energy spill in hydropower plants by causing fluctuation in the volume and timing of runoff. Hydrological extremes such as floods and droughts prevent investors from forecasting precise energy production. The position of existing hydropower stands on a precipice due to the threat of CC. In regions with increasing precipitation, the capacities of old-established reservoirs and facilities are insufficient for handling the runoff under future CC, since they have been equipped according to a stable precipitation and runoff rate. In addition, water resources are insufficient in the dry season and energy spill peaks in the rainy season with the existing capacity. CC poses a threat to stable energy production and decreases returns of the existing hydropower plants. Thus, the existing hydropower plants must be adapted to CC to secure energy production and prevent energy spill.

Adaptation of infrastructure to CC is one method for dealing with the meteorological change. Because CC is unavoidable, adaptation to CC is an important factor of sustainable development

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(IPCC, 2011). The level of requirement and the level of difficulty in implementation control the decision-making process on adaptation. Adaptation investment must take into account sustainability and feasibility. However, it is not easy for investors to decide on an adaptation due to the difficulty of estimating investment timing and capacity in regard to highly volatile CC. Investments involve a suitable strategy and policy because change in climate will be extreme and unforeseeable (Adger et al., 2013).

Previous studies have discussed the impacts of CC on hydropower using different climate scenarios. Majone et al. (2016) showed significant differences in the CC impact on hydropower plants within a catchment in the period 2040–2070 under the SRES A1B emission scenario, based on a case study of hydropower in the southeastern Alpine region. Beniston and Stoffel (2014) investigated the impact of CC on natural and socio-economic systems, including agriculture and hydropower, using simulations from high-resolution regional climate models. Gaudard et al. (2014) developed a hydropower management model to predict energy production and reservoir capacity based on climate scenarios.

Financial analyses of hydropower under CC scenarios have also been conducted. Vicuna et al. (2008) investigated revenue changes of hydropower plants in Sierra, California under four different CC scenarios, and found that revenues differed according to the pattern of each climate scenario. Madani and Lund (2010) assessed that revenue and energy price were influenced by CC, and analyzed the benefits of expanding storage and generation capacity for high-elevation hydropower plants in California. Golombek et al. (2012) presented that CC affects the electricity market in Nordic countries, where hydropower has the largest share among electricity supplies and that supply and demand of the electricity market are affected by climate conditions.

Real options valuation (ROV) has been used to support investment decisions in infrastructure. The scope of ROV has been extended to not only valuation of projects, but also to strategies for investors. Trigeorgis (1996) set up applicable methods of ROV to projects with flexibility. Mun (2002) and Copeland and Antikarov (2003) improved upon this methodology and magnified the applicable range. Flexibility always affects precise valuation and decision making for an investment. ROV is different from traditional discounted cash flow (DCF) which involves the assumption of deterministic outcomes with no flexibility (Trigeorgis, 1996). In real business environments, uncertainties and variability continuously pose challenges for investors. Traditional DCF is fraught with problems that underestimate the flexibility value of a project (Mun, 2002). The application of ROV has increased in the economic assessment of renewable energy projects affected by climate conditions. Bøckman et al. (2008) utilized a real options model for small hydropower projects in Norway to determine an appropriate level of tariff and hydropower plant capacity under smooth CC. Gaudard (2015) applied the real options approach to assessing economic feasibility of a pumped-storage hydropower project considering glacier retreat in the Swiss Alps. Kumbaroğlu et al. (2008) presented a policy-planning model to evaluate investment of renewable energy technologies using ROV in a Turkish case. Martínez-Ceseña and Mutale (2011) showed that a ROV with features of flexible design and timing resulted in higher expected profits in a case study of hydropower plants. Wesseh Jr. and Lin (2015), using ROV, estimated the value of renewable energy technologies in Liberia, considering the uncertainty of fossil fuel price and learning-by-doing in renewable energy technologies. CC involves severe uncertainty and flexibility in water resource management (IPCC, 2014). ROV is a practical approach to accurately assess adaptation investments on existing power plants under CC (Park et al., 2014; Wang and Du, 2016). Uncertainties of existing hydropower arise from CC in the production phase because cash flow in a project tends to fluctuate. Furthermore, CC increases energy spill and affects energy production over time. It is very difficult to handle the flexibility of cash flow during a project period. If investors hold the timing option and choose the optimal investment schedule, investments clear uncertainties and produce maximum profit (Mun, 2002).

In this study, we propose the Adaptive Investment Model (AIM) to assist investors in developing strategies on the adaptation of existing hydropower plants under CC. The proposed model is the first attempt to explore the investment timing of existing hydropower plants' adaptation using ROV. Previous studies focused solely on the impact of future CC on energy production of hydropower from the perspective of risk management. However, our study facilitates precise estimation of maximum benefits and optimal investment timing corresponding with projected climate scenarios.

2. Case study site

CC alters patterns of temperature, precipitation, and sea level in regional scale. Frequent extreme weather events are likely to occur (IPCC, 2014). Improvement of climate scenario models facilitates simulations of precipitation to capture the pattern of uncertainty. Representative Concentration Pathways (RCPs) are used for making projections of future climate scenarios, which are more advanced methods than the previous ones (IPCC, 2014). In recent research, RCPs have been widely applied for estimating future climate. The Korea Meteorological Administration (KMA) reported that the annual precipitation of South Korea will rise by 16% under the projection of RCP 4.5 and 17.6% under RCP 8.5 from the early 21st century to the year 2100, which is three times higher than the global average increase (KMA, 2013). Fig. 1 shows the change rates of precipitation for 30 years between 2041 and 2070 and between 2071 and 2100, based on the 10-year average from 2001 to 2010. Results of the projected RCP 4.5 and RCP 8.5 demonstrate slight differences in each climate scenario. However, in all scenarios, precipitation will increase significantly from the past and will vary by location.

Hydropower plants in South Korea generated 7,820 GWh of electricity in 2014 (KEPCO, 2015). Hydropower, generated by various types such as reservoirs, run-of-rivers, and pumped-storage, has a capacity of 6,469 MW and a 6.7% share in the electricity market for the year 2015 (KEPCO, 2015). The case study site is the Chuncheon hydropower plant, located on the Bukhan (North Han) River in the city of Chuncheon in Gangwon province, South Korea (Fig. 2).

The hydropower plant has a catchment area of 4,736 km^2, reservoir storage of 15 km^3, and electricity generation capacity of 62.28 MW (MOLIT, 2016). This hydropower plant is owned and operated by Korea Hydro & Nuclear Power Corporation, the largest electric power company contributing to 30% of the power market in Korea. The characteristics of the case study are provided in Table 1.

The Chuncheon hydropower plant had been designed for an average annual generation of 145.0 GWh, however, the average annual generation has decreased to 123.2 GWh and average annual energy spill had been 56.1 GWh from 2010 to 2014. Fig. 3 shows the generated electricity production, energy spill, and runoff of the case study from 2000 to 2014, which are already affected by changing climatic patterns. Energy spill generally increased and energy production fluctuated over the previous 15 years. The increase in precipitation and runoff did not lead to an increase in hydropower production due to the insufficient capacity of the hydropower plant. Thus, adaptation of the plant through capacity upgrade is an effective solution to reduce energy spills and increase energy generation under CC. We will conduct the financial feasibility and

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