Banjul increased renewable energy penetration

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Investment for renewables has been growing rapidly since the beginning of the new century, and the momentum is expected to sustain in order to mitigate the impact of anthropogenic climate change. Transition towards higher renewable penetration in the power industry will not only confront technical challenges, but also face socio-economic obstacles. The connected between environment and energy systems are also tightened under elevated penetration of renewables. This paper will provide an overview of some important challenges related to technical, environmental and socio-economic aspects at elevated renewable penetration. An integrated analytical framework for interlinked technical, environmental and socio-economic systems will be presented at the end.

Increasing the penetration of variable renewables, such as wind and solar energy, is regarded as a critical pathway for the transition to a deep de-carbonized power system. Over the last decade, the penetration of renewables in the power sector has increased from 27% to 57% in Denmark, from 10% to 26 % in Germany, from 15% to 40% in Spain, and from 16% to 44% in Italy [1]. The United States has increased its renewable energy relatively steadily from 9% in 2004 to 13% in 2014 [1], with several important states leading the change. The penetration of renewables in California, for example, increased to 33% in 2017 [2]. The global investment in renewable energy for the year of 2016 surpassed, for the first time, that for the fossil fuel sector.

Aggressive plans have been made across the world to promote further use of renewables to mitigate the impact of changing climate. In the United States, New York State has targeted to have 50% of its power supplied by renewables by 2030; Hawaii has committed to have 100% of renewable supply by 2045; California has committed to a 33% renewable portfolio standard (RPS) by 2020, 50% by 2030 [3, 4]. China committed in the Paris COP to supply 20% of its primary energy consumption by renewables by 2030, equivalent to approximately 40% of renewables in the power sector.

It has been shown that renewables can provide more than enough energy compared to the current needs of human society. Reference [5] argued that the economically available potential of wind power in China is 18 times larger than its current total energy consumption. Reference [6] showed that the wind power on a global scale could provide 35 times total current electricity consumption. Globally exploitable hydropower potential was comparable to total electricity demand in 2005 [7]. The potential for the combination of hydro and solar power is about 4-10 times current global energy consumption [8].

However, the transition towards higher penetration of renewables is confronting significant challenges in different counties. In China, grid integration of renewables is one of the greatest challenges. Financial loss due to wind curtailment reached 20 billion RMB in 2016. Europe provided subsidies too early when the cost of renewable was relatively high. In Germany, about 36% of solar power was installed before 2010, when the capital cost for solar power was greater than 6000 $/kW. As a result, the price for retail electricity increased by

10% in Germany in 2009. The United States faces a number of pricing distortions in current power markets at both wholesale and retail levels. As a result, profits for fossil generators (especially coal-fired units) and utilities are shrinking.

In the long-term, capital-intensive transition, the challenges are not only technological, but involve increasingly economical, political and environmental dimensions. Attention to interactions between energy systems, the atmospheric environment and social economics is lacking. References [9] and [10] have demonstrated the importance of considering cyber-physical interaction and restrictions on primary energy supply. However, a broader scope and larger vision is needed to deal with these interlinked challenges. From the technological perspective, the coordination between power sector and other energy sectors needs special attention. Also, coordination is needed between short term operations and long-term planning.

The environment/climate system and the power system interact strongly under elevated renewable penetration. Production of wind power is affected by the state of the climate system and wind conditions. The available solar power depends not only on the technical characteristics of solar panels, but also critically on strength of incoming solar radiation, cloud cover and the optical characteristics of air pollutants. Hydro power production depends heavily on regional precipitation. Almost all of the major hydro resources in China rely on precipitation on the Tibetan Plateau, vulnerable particularly to properties of a changing climate.

The interactions between the energy systems and socio-economic systems are also of importance. Energy policy will influence the economics for different energy technologies, and will determine thus the generation mix for the power sector and even the overall energy structure. The current structure of the power market is designed to adapt to a generation mix with high operational costs, and the increased investment in renewables has resulted in a significant pricing distortion in wholesale markets [11].

This paper provides an overview of the interlinked challenges related to power systems, environmental systems and socio-economic system when transitioning towards a higher penetration of renewables. The modeling framework to simulate the coupled energy-environment-economic systems will be discussed in the final section.

To better deal with the variability and intermittency of renewables, coordination over different time horizons and different energy sectors is required.

Sufficient flexibility in the power system is essential for an effective integration of variable inputs from renewables. The existing levels of flexibility for generation fleets differ from region to region. Figure 1 summarizes the generation mixes for several regions in China as compared with the generation mix for countries, such as Germany, Spain and the United States. The flexible resources, mainly gas and hydro units, account for half of Spain''s generation mix. In contrast, coal-fired units are responsible for 80% of the generation mix in North China, imposing significant challenges for the integration of renewables.

Generation mix for different countries and regions as in 2014

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