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GREEN AMMONIA TO ADVANCE THE ENERGY TRANSITION IN CHINA: AN ANALYSIS FROM A COMPLEX SYSTEM ENGINEERING PERSPECTIVE

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ABSTRACT

This paper discusses the development of future green ammonia supply chains in China with the theory of complex system engineering, taking account of technical system, actors and institutions in future energy systems featured socio-technical systems as a whole. The energy condition in China identified features a spatial imbalance between renewable energy supply and demand, which cannot be fully addressed by the current power system-centric solution. This calls for hydrogen to make a concerted effort in the energy transition. By comparing major hydrogen delivery options, we argue that green ammonia can play a feasible role for large-scale energy distribution and long-term energy storage. The development of green ammonia supply chains and direct use of ammonia are proposed to avoid large uncertainties and initial investment in the early stage. The market creation will be key in the supply chain development. A long-term bilateral contract between buyer and seller and a joint investment in an integrated supply chain by several stakeholders are advised to share risks and ensure capital recovery. In addition, government participation is crucial in the early development phase by setting regulatory and financial institutions to support the market creation and supply chain development.

Keywords: Hydrogen Economy, Green Ammonia, Supply Chain, China, Complex System Engineering

INTRODUCTION

China pushes towards peaking emission by 2030 and reaching neutrality by 2060 [1]. Investments in wind and solar energy grew significantly and accounts for one-third of the world's total capacity [2]. However, the divergence between installed capacity and renewable power generation grows due to the gird inflexibility and insufficient transmission [3]. Lately, China step a move to green hydrogen produced from renewable energy. Mid and long-term targets was set for achieving carbon reduction goals and supporting the energy transition [4]. In the upcoming hydrogen economy, green ammonia increasingly draws attention as a reliable and efficient means to storing and transporting hydrogen [5, 6]. Therefore, an assessment of the development of future green ammonia supply chains is necessary.

A review of current literature reveals that recent studies have paid attention to assessments of green ammonia supply chains. Most of them have discussed cases beyond China (e.g. see [7-9]), and a limited number of studies are in the scope of China (e.g. see [10]). Moreover, these studies concentrate on the techno-economic evaluation. However, modern supply chains comprise of technical infrastructure, actors, interactions, etc. [11]. No research has discussed socio-technical supply chains. This paper aims to analyze the development of green ammonia supply chains in China with the theory of complex system engineering.

The remainder of this paper is arranged as follows: the methodology of complex system engineering is introduced in Section 2. Section 3 discusses green ammonia to advance the energy transition in China, while Section 4 presents our conclusions.

METHODOLOGY

Energy transitions are defined as long-term structural changes in energy systems [12]. Today's energy system is essentially a supply chain, known as a socio-technical system, as it is not only a technical matter, values of individual actors, policies, regulations and markets also shape the system [11, 13]. Complex system engineering addresses not only challenges in technical dimension, but also multi-actor complexity of socio-technical systems [14]. The framework proposed in works [14, 15], which is improved from previous works [16, 17], identifies three key pillars in handling complex socio-technical systems, including: technical system, actors and institutions, as shown in Fig. 1. In general, technical system refers to technical components in energy systems; institutions are the devised rules, while actors are the entities making decisions and participating in the process; the connections emphasizes the interactions between each other that should be considered simultaneously. Actors build and operate technical systems, which in turn influence actors' decisions. Institutions such as: norms, strategies influence actor behaviours, which in turn reshape institutions. The theory is used to view system behaviours as a results of interactions between social and technical components of energy systems.

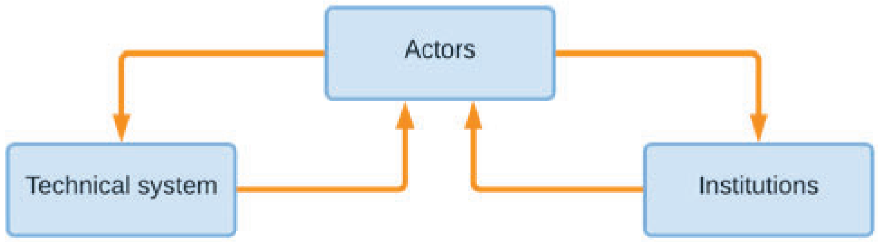

Fig. 1. Framework for analysing socio-technical systems

GREEN AMMONIA TO ADVANCE THE ENERGY TRANSITION IN CHINA

This section is discussed separately from the aspects of the energy condition in China, the current power system centered solution, and the development of green ammonia supply chains as follows.

The energy condition in China

China's economy still relies heavily on coal. The coal-dominant primary energy supply has made China the world's largest coal consumer and CO2 emitter [18]. The government targeted to phase out fossil fuel use by increasing the share of non-fossil energy in total energy consumption, in which, renewable energy is expected to play a key part [19]. China outpaces the rest of the world in wind and solar energy. The aggregate wind and solar generation capacity reached over 500 GW by 2020, and a massive renewable energy projects are in planning [20]. However, the energy condition in China presents an obvious spatial mismatch between renewable energy supply and potential demand, as shown in the Fig. 2. The aggregate wind and solar energy generation capacity in the north, northwest and northeast of China accounts for around 60% of the total capacity in China by 2020, thanks to the abundant renewable resources in these regions [20]. In contrast, economic clusters are generally located in the east and south of China. Therefore, large-scale and long-distance renewable energy distribution is fundamental to facilitating the energy transition in China.

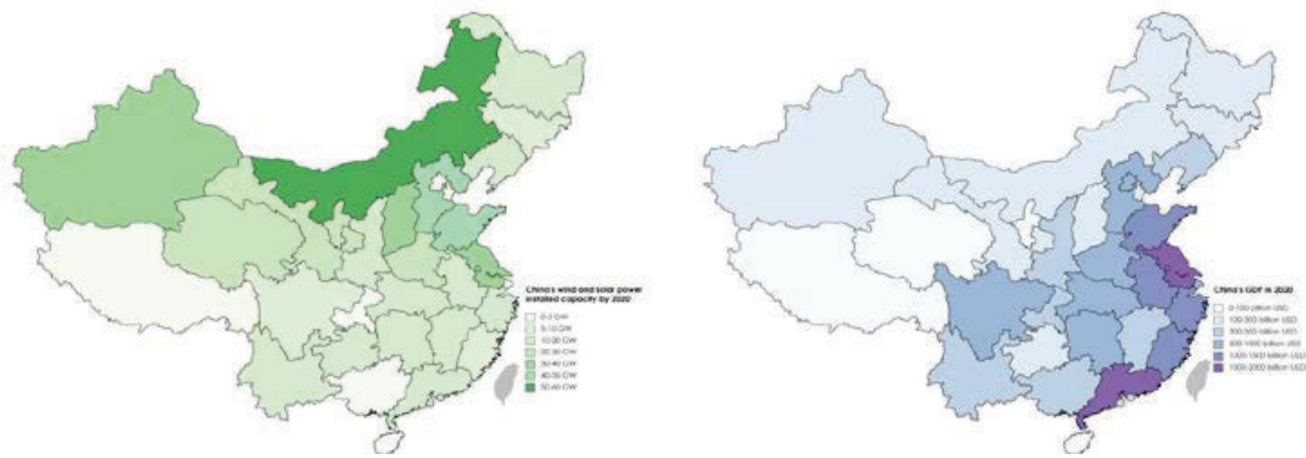

Fig. 2. Spatial mismatch between renewable energy supply and economic development

The power system centered solution

The spatial imbalance has led to serious renewable power curtailment, which declines the use of renewable energy. The further development of power system has been the focal point to address energy distribution and facilitate the energy transition declared in the 14th Renewable Energy Development Five Year Plan [21]. By 2020, China's national grid companies: China State Grid and China Southern Power Gird have built 20 ultra-high voltage lines to transmit renewable energy to load centers accounting for around 30% of total installed capacity of wind and solar energy, which is still not sufficient considering the fast expansion of renewable power bases in recent years [22]. Meanwhile, the intermittent power aroused challenges for grid integration that the overall operating rate of these lines was lower than 40% in 2019 [23]. Therefore, smarter power system is urgently needed by incorporating energy storage technologies. In addition, introducing market-based solutions is encouraged to eliminate institutional barriers.

The development of green ammonia supply chains

Meanwhile, these challenges also call for a concert effort. Revealed from the latest published 2021-2035 Hydrogen Development Plan of China, green hydrogen is expected to play a leading role for large-scale energy storage and long-distance energy distribution [4].

Fig. 3 shows hydrogen distribution costs we estimated for the most promising options. Although pipeline transportation appears to be the ultimate solution, distribution cost is influenced dramatically by volume and distance due to the high capital and operating expenses required. In contrast, liquid hydrogen and ammonia are more flexible options which have similar costs and limited influences by distance and volume. Ammonia defeats liquid hydrogen in terms of safe transportation and long-term storage due to much lower flammability and mild storage conditions [5, 6]. In addition, the transportation will be more efficient if ammonia can be directly used. Therefore, these advantages enable transporting hydrogen as ammonia a flexible, economical and safe option. Since infrastructure for ammonia is already in place due to a century of use in agriculture, the development of green ammonia supply chains and direct use of ammonia are proposed to avoid large uncertainties and significant initial investment in the early stage.

A supply chain comprises upstream production, midstream transportation and downstream wholesale and retail markets. The creation of green ammonia markets is essential in the development of future supply chains, given that green ammonia costs double that of grey ammonia [10]. Considering the large capital investments required in the infancy stage, the upstream and midstream with the participation of hydrogen producers, ammonia producers and ammonia transport operators can be operated with a joint investment to optimize the supply chain and reduce risks. Similar to the practices in renewable power generation [24], the creation of a long-term bilateral contracts between producer and consumer is proposed to share risks between both sides and guarantee investment recovery. Besides, government participation in the early stage is essential to support market creation and development of supply chains, e.g. incentivizing supply and demand, designing a clear and consistent regulatory framework, achieving ancillary policies, etc.

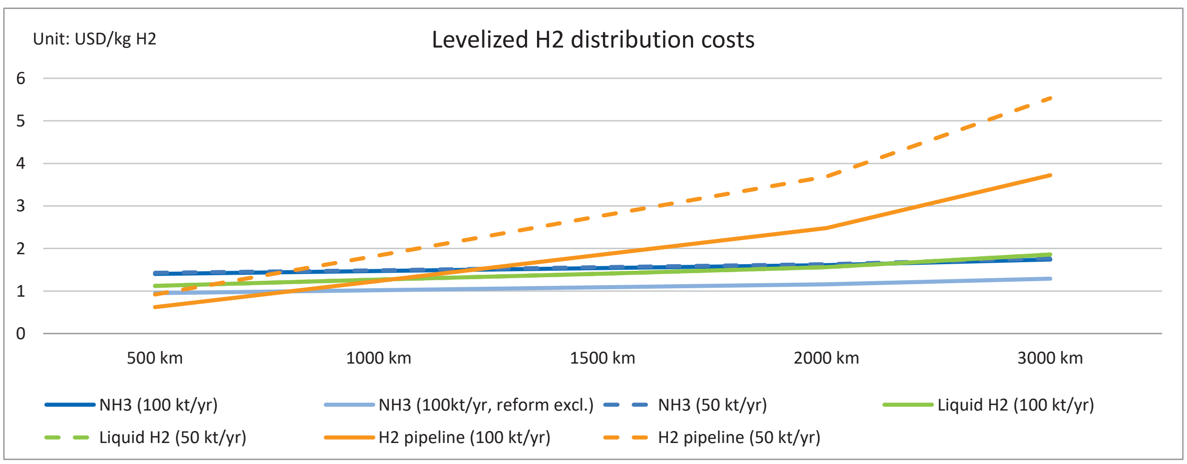

Fig. 3. Hydrogen distribution costs by distance and volume

CONCLUSIONS

Green ammonia is expected to play a key role in the transition to a hydrogen economy. The development of green ammonia supply chains to advance the energy transition in China was analyzed with the theory of complex system engineering. We considered the components of technical system, actors and institutions in the analysis of future energy systems featured socio-technical systems. We identified the spatial imbalance between future energy supply and consumption in China which cannot be fully addressed by the development of power systems. As a prospective hydrogen carrier, we argued that green ammonia can play a feasible role for large-scale energy distribution and long-term energy storage. The development of green ammonia supply chains and direct use of ammonia were proposed to avoid large uncertainties and significant initial investment in the early stage. Market creation will be key to the supply chain development. A joint investment in an integrated supply chain by several stakeholders and the creation of long-term bilateral contract between buyer and seller were also proposed to share risks and ensure capital recovery in the early phase. In addition, regulatory and financial institutions are essential to support supply chain development, which well requires government participation.

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