



Hydropower curtailment in Yunnan Province, southwestern China: Constraint analysis and suggestions

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ABSTRACT

China has the richest hydropower resources in the world. Yunnan's exploitable hydropower resources rank third in China, second only to Tibet and Sichuan Province. Yunnan has experienced soaring growth in installed hydropower capacity in the past several decades. The fast development of hydropower makes the province one of the main producers and exporters of hydroelectricity. However, with inconsistencies between hydropower development and various related resources, more and more hydropower generation has been curtailed in recent years. The increasing curtailment of hydropower generation not only caused large-scale waste of sustainable energy, but also impaired the potential higher contribution of hydropower for GHG emission reduction. This paper provides an overview of the hydropower resources and their development in Yunnan and systematically analyzes the constraints causing the curtailment of hydropower generation. We argue that there are several constraining factors such as slowdown of economic growth, inadequate transmission capacity due to a weak grid structure, inconsistency between power grid companies and local government, and uneven distribution of precipitation seasonally and annually. Recommendations are made to alleviate or eliminate hydropower curtailment in Yunnan and other hydropower rich areas.

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1. Introduction

As the largest developing economy in the world, China is currently also the biggest energy consumer and carbon emitter [1–3]. China's huge population with rapid economic development in recent decades has inevitably been accompanied by a rapidly growing energy demand. Since coal is the major source of primary but not clean energy in China, this country is facing increasingly serious environmental pollution problems [4–6]. In recent years, the pollution haze in China has lasted for a prolonged time and widely affected the country [7–9]. China has promised to reduce CO₂ emissions intensity by 40–45% in 2020 relative to 2005, and over 15% of primary energy consumption from non-fossil energy sources by 2020 [10–12]. Therefore, it is inevitable for China to develop clean and renewable energy.

Hydropower is a clean, renewable and cost-effective source of energy, and it can respond quickly to rapidly varying load [13,14], hydropower has been developed in more than 150 countries and accounts for approximately 16% of the electricity generation in the world [15,16]. China has the largest potential hydropower resources, with economic exploitable capacity of 542 GW and corresponding average annual generation of 2470 trillion watt hours (TWh) [17]. Although the development of hydropower is controversial due to the adverse impact on the surrounding environment and ecosystem [18,19], taking some measures such as environmental impact assessment before construction of a hydropower plant and during operation can reduce the impact and make a hydropower plant more environmentally friendly [20–24]. Therefore, with the deterioration of the air quality due to heavy reliance on coal-based thermal power, developing hydropower is of great importance for China to satisfy its burgeoning energy demands and help it to transform to a lower carbon electricity system [25–27]. China places hydropower in a prominent role as one of the most important forms of renewable energy during the 12th and 13th Five Year Plan. Under the impetus of various supporting policies, hydropower has experienced an unparalleled development in recent decades [14,28,29]. As shown in Fig. 1, the installed hydropower capacity of China exceeded 100 GW in 2004, 200 GW in 2010, scaled up to more than 300 GW in 2014 and reached 332 GW in 2016, which is approximately the cumulative hydropower installed capacity of USA, Brazil, Canada and India [30]. By the end of 2016, hydropower accounted for approximately 20% of the nation's installed electricity generation capacity [31,32]. Furthermore, this strong growth will continue in the foreseeable future years since the goal of China's medium and long-term hydropower development plan presents a target of 380 GW by 2020 [33,34].

Yunnan Province, located in southwestern China, is endowed with plentiful hydropower resources [36,37]. The total exploitable hydropower capacity of Yunnan Province is estimated at 101,940 MW, ranking just behind Sichuan and Tibet in China, and concentrating approximately 20% of the total exploitable hydropower resources of the nation. As a power base for “West to East Power Transmission” (WEPT), the hydropower installed capacity of

Yunnan Province has surged from 9698 MW in 2006 to 60,960 MW by the end of 2016, so high that this capacity surpasses India's hydropower installed capacity in 2015 [30] (the world's 5th largest hydropower country, shown in Fig. 2).

However, with the rapid development and high penetration of hydropower, issues of consumption and export of generated hydropower in Yunnan become a problem [36]. The surplus power often faces binding transmission capacity constraints, and much hydroelectricity has been curtailed in recent years in Yunnan because of construction of transmission channels lagging behind or the inconsistencies between local government and power grid companies. The curtailed hydroelectricity was reported to be approximately 4.4 TWh in 2009, and this number was scaled up to 31.2 TWh in 2016, and expected to be more than 40 TWh in 2017. As shown in Fig. 3, the curtailed 31.2 TWh hydroelectricity in 2016 is approximately 11.6% of the total power generation of the province, approximately 13.7% of the hydropower generation, and more than 2 times the wind power generation of the province. Furthermore, the amount of curtailed hydroelectricity in 2016 is approximately 22.1% of the total electricity consumption of Yunnan in that year, and close to the sum of the residential and tertiary industry electricity consumption of the province. More seriously, it was predicted that even more hydroelectricity would be curtailed in Yunnan in the future years if no effective measures were taken. Such a huge amount of curtailment not only wastes much clean energy but also hinders the realization of the green house gas (GHG) emission reduction commitment and the environmental governance of the nation [38,39], even the economic and sustainability future of China. Hence, it is crucial to find feasible measures to reduce hydropower curtailment in Yunnan.

This paper presents a comprehensive review of the hydropower curtailment in Yunnan. An overview and characteristics of Yunnan's hydropower is presented in Section 2, the evolution of hydropower curtailment of Yunnan is presented in Section 3 and the reasons causing hydropower curtailment are summarized in Section 4. Then, some perspectives and recommendations that should helpful to reduce hydropower curtailment are presented in Section 5. Finally, conclusions are presented in Section 6.

2. Overview and characteristics of Yunnan's hydropower

Located in southwestern China, the Yunnan Province borders on Guizhou and Guangxi Provinces in the east, and Sichuan Province in the north. It also shares international borders with Myanmar on the west and Laos and Vietnam on the south. With these geographical advantages, Yunnan proves to be the core area for opening the southwest of China to South Asia.

2.1. Privileged with rich hydropower resources

Fig. 4 shows the distribution of exploitable hydropower resources in China. Most hydropower resources are concentrated in the southwest of China (Tibet, Sichuan, Chongqing, Yunnan and

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