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Development and present situation of hydropower in China

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Abstract

As a clean and renewable energy, hydropower holds an important place in energy development for every country. China has the richest hydropower resources with 541 GW technical exportable installed capacity, a 17% global share. Hydropower is a key point of energy conservation and comprehensive utilization of resources to ensure the sustainable development strategy of China. This paper investigates the hydropower development of China and provides a summary of the current situation of the development. Over the past 100 years, China's hydropower developed tremendously. The total installed capacity of hydropower is 341.19 GW by the end of 2017 and the installed capacity of small hydropower is 79.27 GW. By the end of June 2018, 33 pumped-storage power stations had been constructed and 32 are under construction. The total installed capacity of pumped-storage power is 72.64 GW. More development will be achieved in the next decades according to China's development strategy.

Keywords: China; Development; Hydropower; Pumped-storage power; Small hydropower

Introduction

As a renewable clean energy, hydropower is an important component of China's energy, and occupies a significant place in energy balance and sustainable development of the energy industry. Energy conservation and comprehensive utilization of resources is a long-term policy of China's economic and social development. China puts sustainable development strategy in a prominent place, to save resources, protect the environment, maintain coordinated development of social economy, resources and environment. Preferential development of hydropower is one of China's energy source development strategies.

The total theoretical hydropower potential of China is 694 GW, about a 15% global share, and ranking first in the world. The technical exploitable installed capacity is 542 GW, a 17% global share, with a corresponding annual electricity generation of 2,474 TWh. The distribution of hydropower resources in China has three major characteristics including uneven spatial distribution, uneven temporal distribution, and high concentration. Southwest China has more hydropower resources, accounting for about

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two-thirds of total technically developable hydropower capacity. The annual distribution of runoff for most of the rivers in China is uneven. A positive aspect of China's hydropower resources, as described in the Summary on General Report of Investigation and Evaluation Results of Rural Hydropower Resources of P.R.C. (2008) Rural Hydropower Resources and Its Distribution, is the high concentration which may result in unified and efficient development.

Development of hydropower in China

Overall situation

The first hydropower station, Shilongba, was constructed in Yunnan Province in 1910. Two 240 kW hydraulic turbine generator units were installed and began generating electricity in 1912. The total installed capacity of Shilongba hydropower station was expanded to 6 MW in 1958 after seven times enlargement (Li, 2007). The station is still generating electricity today.

Before the establishment of PRC, the development of hydropower in China was quite slow due to wars. By 1949, China had a total installed hydropower capacity of 0.163 GW. The average installed hydropower capacity and electricity outputs per capita were 0.0007 kW and 3.3 kWh.

After the founding of PRC, the development of hydropower in China started a new page. In the early decades after the founding of the PRC, hydropower development was mainly concentrated in the eastern region due to the higher economic development and the rapid growth of electricity usage.

Xinanjiang hydropower station, the first large type hydropower station designed, equipped, and constructed by China, was constructed in April 1957 in Jiande, Zhejiang Province. Xinanjiang hydropower station is considered as a milestone of hydropower development in China since it provided the prologue to hydropower construction of China after the founding of the PRC.

In the same year, Sanmenxia hydropower project, the first large type comprehensive hydropower engineering project constructed on the main stream of the Yellow River, was launched. This project is located at the junction between Sanmenxia, Henan Province and Pinglu, Shanxi Province, and which is also the downstream of the middle Yellow River. In addition to electricity generation, the Sanmenxia hydropower project also functions as flooding control, ice prevention, and agriculture irrigation.

In September 1958, at the trunk stream of the Yellow River in Yongjing county of Gansu Province, Liujiaxia hydropower station, the first million-kilowatt level hydropower station of China, was begun. At the same time, two cascade hydropower stations downstream, Yanguoxia hydropower station and Bapanxia hydropower station started to be constructed. Subsequently, China continued to build up several large type hydropower projects at million-kilowatt scale.

By the end of 1978, the installed hydropower capacity in China had increased to 18.67 GW with annual electricity outputs of 50 GWh. The installed hydropower capacity and electricity outputs per capita increased to 0.02 kW and 51.5 kWh.

After the reforms and opening up of the PRC, the hydropower construction of China was accelerated. The development of hydraulic resources in the western region of China was put in an important position. After the 'West-to-East Electricity Transmission' strategy was put forward, the development and utilization of the abundant water resources in southwest China were gradually speeded up. In Yabi River, Dadu River, and Wu River, the main tributaries of the Yangtze River, a few large hydropower stations were completed and put into generation. On the upper reaches from Longyang gorge to Qingtong gorge

of the Yellow River, Lancang River, Nanpan River, and the Hongshui River, a number of hydropower stations with installed capacity over 1 GW were constructed and put into generation. As of the end of 1999, China's hydropower installed capacity had reached 77.39 GW and the annual electricity generation capacity had reached 221.9 GWh. The per capita installed capacity and generating capacity were 0.06 kW and 176.4 kWh, respectively.

In 1994, the landmark hydropower project of China, the Three Gorges hydropower station, started to be constructed. The Three Gorges hydropower station, located in Yichang City of Hubei Province, is the largest construction project in China and also the largest hydropower station in the world in terms of installed capacity (22.5 GW). The station has multiple functions, including power generation, flood control, transportation, etc. The station has 32 hydropower generating units, with 0.7 GW for each. On June 1, 2003, the Three Gorges hydropower station began to retain water and generate hydropower. On June 4, 2012, the last hydropower generating unit of the station was put into use.

From 1995 to 2000, the construction of Three Gorges hydropower station proceeded steadily, and 25 controlled hydropower stations, including Xiaolangdi, Wanjiazhai, Feilaixia, Jiangya, Wuluwati, Manla, Guanyinge, were successively completed and started running. The increased installed capacity of hydropower in this period was 11 GW, including 8 GW of medium and small size hydropower stations.

China's hydropower has become a strong component of China's power industry, and a strong foundation for the progress of social development.

From 2001 to 2005, the '10th Five-Year' planning of water resources development, hydropower stations, including Linhuaigang, Baise, Nierji, Zipingpu, Shapotou, Xixiayuan, Zaoshi, etc., proceeded successfully and functioned gradually. The increased installed capacity of hydropower was 16 GW in this period (Ministry of Water Resources, PR China, 2001).

For the '11th Five-Year' period of China, from 2006 to 2010, many large type hydropower stations were constructed, including Longtan, Jinghong, Goupitan, Laxiwa, Xiaowan, Pubugou, etc., and some large and extra-large type hydropower stations, including Xiangjiaba, Jinping II, etc., started construction (The National Development and Reform Committee, Ministry of Water Resources, Ministry of Construction, 2007). By the end of 2010, the total installed capacity of hydropower of China was over 200 GW.

During the '12th Five-Year' planning, 2011 to 2015, more large type hydropower stations, including Xiluodu, Xiangjiaba, Nuozhadu, Baihetan, Houziyan, Changheba, Dagangshan, Huangdeng, etc., were under construction (Renewable Energy Development Thrives During China's 12th Five-Year Plan, The National Development and Reform Committee, Ministry of Water Resources, Ministry of Housing and Urban-Rural Development, P. R. China, 2012; The National Development and Reform Committee, The People's Republic of China, 2012). The increased installed capacity of hydropower from 2011 to 2015 was 107.8 GW. More large hydropower stations are planned to be built in the next five-year plan, including Wudongde, Suwalong, Shuangjiangkou, Lianghekou, Liangjiaren, etc. (Han *et al.*, 2014)

According to the Bulletin of First National Census for Water of China, a total of 46,758 hydropower stations with a total installed capacity of 333 GW were constructed or under construction in China by 2011, among which, 22,190 stations have 500 kW or over installed capacity, including 20,866 stations that have been constructed with a total installed capacity of 217 GW, and 1,324 stations that were under construction with a total installed capacity of 110 GW (Ministry of Water Resources, P. R. China & National Bureau of Statistics, 2014). Table 1 shows the summary of hydropower stations in China.

According to the 2017 Statistical Bulletin for National Economic and Social Development, by the end of 2017, the total installed capacity of hydropower of China was 341.19 GW, and the electricity generation 1,189.84 TWh with the growth rate 2.7% and 0.5%, respectively. The installed capacity and

Table 1. Summary of hydropower stations constructed and under construction in China by the end of 2011.

Scales of hydropower stations		Amount	Installed capacity (GW)
Installed capacity ≥500 kW	Large type-I (≥1.2 GW)	56	154.86
	Large type-II (≥300 MW and <1.2 GW)	86	51.78
	Medium-size (≥50 MW and <300 MW)	477	52.42
	Small type-I (≥10 MW and <50 MW)	1,684	34.61
	Small type-II (<10 MW)	19,887	33.62
Installed capacity <500 kW)		24,568	5.59
Total		46,758	332.88

Table 2. Development of hydropower in China by the end of 2017.

Year	Total hydropower installed capacity (GW)	Share (%)	Energy generation (TWh)	Share (%)
1912	0.00048	–	–	–
1949	0.163	8.80	0.71	16.5
1957	1.02	22.00	4.82	24.9
1965	3.02	20.00	10.41	15.4
1970	6.24	26.20	20.46	17.7
1975	13.43	30.90	47.63	24.3
1980	20.32	30.80	58.21	19.4
1985	26.42	30.40	92.40	29.00
1990	36.05	26.10	126.70	20.4
1995	52.18	24.00	186.80	18.6
2000	79.35	24.87	243.10	17.8
2001	83.01	24.49	257.50	17.42
2002	84.56	23.95	271.00	16.50
2003	94.90	24.25	281.30	14.76
2004	108.13	24.54	327.70	14.99
2005	116.52	22.90	401.00	16.20
2006	128.47	20.65	416.70	14.70
2007	145.23	20.36	482.88	14.73
2008	170.90	21.63	585.19	16.88
2009	196.86	22.51	615.64	16.57
2010	211.57	21.90	721.02	17.14
2011	230.07	21.97	694.04	14.77
2012	248.81	21.70	860.85	17.43
2013	280.02	22.45	911.64	16.89
2014	301.83	22.19	1,064.34	18.84
2015	319.37	21.17	1,126.42	19.39
2016	332.11	20.18	1,193.37	19.43
2017	341.19	19.20	1,189.84	18.32

– Indicates no data were found.

energy generation are summarized in Table 2 (Ministry of Water Resources, People's Republic of China, 2008, 2011, 2015, 2017; National Bureau of Statistics of the People's Republic of China, 2018).

In the past 60 years, in addition to the huge economic benefits, China's hydropower development has also played an important role in new countryside construction, regional economic growth, atmospheric climate improvement, and economic and social development of the whole river basin. The construction of

Gezhouba hydropower station transformed Yichang from a small city to a medium-sized one, and then the construction of the Three Gorges hydropower station changed Yichang from a medium-sized to a large city.

Since the construction of the Three Gorges hydropower station project, the development of hydropower in China has changed from a simple technical engineering project to a social related integrated project, with more attention being paid to the interests of immigrants and ecological environment protection. Continuous exploration and progress have promoted the transformation of China's hydropower development model: from focusing on economic benefits only to the economic, social, and ecological comprehensive benefits; from focusing on the construction technique to independent innovation and ecological protection techniques; from a single hydropower development to enhancing the comprehensive development of the overall effectiveness of the whole basin.

Pumped-storage power stations

The pumped-storage power station is an important way to store energy in large quantities. It has the functions of peak regulation, frequency modulation, phase modulation, emergency reserve, etc. It is an economical and effective control method for the power system (Guo & Yu, 2011).

China is rich in hydropower resources, but the distribution is very uneven. The hydropower resources are mainly concentrated in the southwest and northwest whereas north China, east China, and northeast China are short of hydropower resources. In the 1960s, a pumped-storage power station was built for the Beijing–Tianjin–Tangshan power grid in north China. A 11 MW pumped-storage unit was installed in the Gangan reservoir in Hebei. In the 1970s, two 11 MW pumped-storage units were installed in Miyun reservoir of Beijing, and three 90 MW pumped-storage units were installed in Panjiakou reservoir of Hebei Province (Yan & Zhao, 2004).

From the middle of the 1970s to the middle of the 1980s, many coal-powered stations were built for the Beijing–Tianjin–Tangshan power grid and east China power grid, and the Dayawan nuclear power station was built in Guangzhou. Peak regulation became a problem. Therefore, in the 1990s, Guangzhou pumped-storage power station and Beijing Shisanling pumped-storage power station were built. Then, the construction of pumped-storage power stations was fully expanded in China. A batch of pumped-storage power stations were built in the mid 1990s, such as Xikou pumped-storage power station in Zhejiang, Xianghongdian pumped-storage power station in Anhui, and the Shahe pumped-storage power station in Jiangsu.

At the beginning of the 21st century, the construction of China's pumped-storage power stations entered a second period of rapid development, with 19 pumped-storage power stations starting construction in succession. With the development of electric power construction, the requirements for power supply reliability of the power grid are raised, and the demand for energy storage and adjustment for the large-scale development of new energy will also be higher. Therefore, more pumped-storage power stations will be constructed in China in the next several decades.

Since the first pumped-storage power station, Gangnan pumped-storage power station, was constructed in 1968, there has been tremendous development of the pumped-storage power station in China (List of Installed Capacity of Pumped-Storage Power Stations in China by the End of April 2016). By the end of June 2018, there was a total of 65 pumped-storage power stations in China, among which, 33 stations had been constructed and 32 were under construction. The installed capacity of constructed stations is 28.385 GW, and the installed capacity of the stations under construction is 44.250 GW. The total installed capacity of pumped-storage power stations is 72.635 GW. The constructed and under-construction pumped-storage stations are summarized in Tables 3 and 4.

Table 3. Pumped-storage power stations constructed in China by June 2018.

No.	Stations	Province	Installed capacity (GW)
Northeast China			
1	Baishan	Jilin	0.3
2	Pushihe	Liaoning	1.2
North China			
3	Miyun	Beijing	0.022
4	Shisanling	Beijing	0.8
5	Gangnan	Hebei	0.011
6	Panjiakou	Hebei	0.27
7	Zhanghewan	Hebei	1
8	Huhehaote	Neimenggu	1.2
9	Taishan	Shandong	1
10	Xilongchi	Shanxi	1.2
11	Baoquan	Henan	1.2
12	Huilong	Henan	0.12
Central China			
13	Heimifeng	Hunan	1.2
14	Bailianhe	Hubei	1.2
15	Tiantang	Hubei	0.07
East China			
16	Tianhuangping	Zhejiang	1.8
17	Tongbai	Zhejiang	1.2
18	Xianju	Zhejiang	1.5
19	Xikou	Zhejiang	0.08
20	Liyang	Jiangsu	1.5
21	Shahe	Jiangsu	0.1
22	Yixing	Jiangsu	1
23	Fomo	Anhui	0.16
24	Langyashan	Anhui	0.6
25	Xianghongdian	Anhui	0.08
26	Xiangshuijian	Anhui	1
27	Hongping I	Jiangxi	1.2
South China			
28	Guangxu	Guangdong	2.4
29	Huixu	Guangdong	2.4
30	Qingyuan	Guangdong	1.28
31	Xianyou	Fujian	1.2
Southwest China			
32	Cuntangkou	Sichuan	0.002
33	Yangzhuoyong	Xizang	0.09
Total			28.385

Small hydropower

Small hydropower, also known as rural hydropower, is defined as stations with installed capacity of less or equal to 50 MW. According to the Investigation and Evaluation Result of Rural Hydropower Resources of P.R.C. (2008), the total technical exploitable installed capacity of small hydropower in China is 128 GW, with an annual electricity generation of 535 TWh, ranking first in the world. Most

Table 4. Pumped-storage power stations under construction in China by June 2018.

No.	Stations	Province	Installed capacity (GW)
Northeast China			
1	Huanggou	Heilongjiang	1.2
2	Dunhua	Jilin	1.4
3	Qingyuan	Liaoning	1.8
North China			
4	Fengning I	Hebei	1.8
5	Fengning II	Hebei	1.8
6	Funing	Hebei	1.2
7	Yixian	Hebei	1.2
8	Zhirui	Neimenggu	1.2
9	Taishan II	Shandong	1.8
10	Wendeng	Shandong	1.8
11	Yimeng	Shandong	1.2
12	Luoning	Henan	1.4
13	Tianchi	Henan	1.2
Northwest China			
14	Fukang	Xinjiang	1.2
15	Zhenan	Shaanxi	1.4
Central China			
16	Pingjiang	Hunan	1.4
17	Damushan	Hubei	1.2
East China			
18	Changlongshan	Zhejiang	2.1
19	Jinyun	Zhejiang	1.8
20	Ninghai	Zhejiang	1.4
21	Jurong	Jiangsu	1.35
22	Jinzhai	Anhui	1.2
23	Jixi	Anhui	1.8
24	Hongping II	Jiangxi	1.2
South China			
25	Meizhou	Guangdong	1.2
26	Shenzhen	Guangdong	1.2
27	Yangjiang	Guangdong	1.2
28	Xiamen	Fujian	1.4
29	Yongtai	Fujian	1.2
30	Zhouning	Fujian	1.2
31	Qiongzhong	Hainan	0.6
Southwest China			
32	Panlong	Chongqing	1.2
Total			44.25

of the small hydropower resources are located at the upstream of the Yangtze River, the Zhu River and the Yellow River. Table 5 gives a summary of the technical exploitable installed capacity of small hydropower according to the rivers' potential capacity.

The development of small hydropower in China has gone through three periods since the foundation of PRC. The first period is from 1949 to 1979. The average annual increase of installed capacity was 0.21 GW

Table 5. Technical exploitable installed capacity of small hydropower in China.

Rivers exploitable capacity	Station installed capacity	Amount	Total capacity (MW)	Annual electricity generation (TWh)
≥ 10 MW	≥0.5 MW and ≤50 MW	22,935 + 8/2[a]	108,894	465.2
	≥0.1 MW and <0.5 MW	12,534	3,194	12.4
<10 MW	≥0.1 MW	19,787	15,944	57.4
Total		55,256 + 8/2[a]	128,032	535

[a]Indicates the transboundary rivers.

in this period. Around 90,000 small hydropower stations with installed capacity less than 12 GW were constructed, which brought about the total installed capacity to 6.33 GW and annual electricity 11.9 TWh. More than half of the counties in China have developed small hydropower stations, and 1,000 counties rely mainly on small hydropower stations for power supply, and 150 million people have electricity.

The second period is from 1980 to 2000. The average annual growth of installed capacity in this period was 0.88 GW. By the end of 2000, a total of 48,000 small hydropower stations with 50,000 kW and below had been built nationwide, which brought about 24.85 GW of installed capacity and 80 TWh of annual power generation. More than 1,500 counties have developed small hydropower. As the main method of electricity supply, the small hydropower stations cover half of the territory, one-third of the counties, and one-fourth of the population. Small hydropower has solved the problem of electricity consumption for more than 300 million of the population.

The third period is from the beginning of the 21st century. The average annual growth of installed capacity of small hydropower is 3.3 GW. By the end of 2017, 47,498 small hydropower stations were constructed in China. The total installed capacity of these stations is 79.27 GW, with annual electricity generation of 247.72 TWh. The installed capacity of the small hydropower is 23.2% of the total national hydropower installed capacity (301.83 GW) and 4.5% of the national total power installed capacity. The electricity generation of the small hydropower is 20.7% of the total hydropower electricity generation and 3.9% of the national total electricity generation. The exploited small hydropower is 62.0% of the total technical exploitable small hydropower resources, and the annual electricity generation of small hydropower is 46% of the technical exploitable annual electricity generation. Therefore, small hydropower becomes an important part of the hydropower industry. The installed capacity and annual electricity generation of small hydropower in China are summarized in Table 6 (Ministry of Water Resources, P. R. China, 2015).

China's hydropower exploration status

Overall hydropower exploration status in China

As previously mentioned, the water resources distribution is very unbalanced across China, as is the hydropower resources distribution. Southwest China is rich in hydropower resources, accounting for about two-thirds of total technically developable hydropower capacity. By the end of 2013, southwest China had built up 123.22 GW total installed hydropower capacity and an additional 35 GW

Table 6. The installed capacity and annual electricity generation of small hydropower in China.

Year	Installed capacity (GW)	Annual electricity generation (TWh)
2004	38.65	122.9
2005	43.09	135.7
2006	47.20	148.4
2007	53.86	163.5
2008	51.27	162.8
2009	55.12	156.7
2010	59.24	204.4
2011	62.12	175.7
2012	65.68	217.3
2013	71.19	223.3
2014	73.22	228.1
2015	75.83	235.1
2016	77.91	268.2
2017	79.27	247.7

hydropower capacity was under construction (excluding small hydropower constructions), accounting for 35% of total technically developable capacity. East China and central-south China have about 117.8 GW technically developable hydropower capacity in total, over 80% of which has been explored. Northwest China and northeast China where hydropower resources are limited have explored about one-third of their total technically developable capacity.

Most of the hydropower stations in China are located in areas with a lack of coal and that have better hydropower development conditions, such as Liaoning, Jilin, Zhejiang, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Chongqing, Sichuan, Yunnan, Guizhou, Shanxi, Gansu, Qinghai. The installed hydropower capacity for each of these provinces is not complete.

Spatial distribution of the hydropower stations

The former Ministry of Electric Power of China proposed the idea of constructing ten large hydropower bases based on the national census for hydropower resource before 1980. Then in 1989, the Water Resources and Hydropower Planning and Design General Institute of the former Department of Energy and Ministry of Water Resources proposed the idea of 12 hydropower bases, including an additional two bases, northeast China and north-mainstream of the Yellow River, based on hydropower development. In 2003, the Nu River hydropower planning was evaluated and approved. It was considered as the 13th hydropower base in China (Zhou & Qian, 2011).

The 13 national hydropower bases, as shown in Figure 1, are located on the Jinsha River, Yalong River, Dadu River, Wu River, the upstream of the Yangtze River, Nanpan River–Hongshui River, mainstream of Lancang River, upstream of the Yellow River, north-mainstream of the Yellow River, Western Hunan, Fujian–Zhejiang–Jiangxi area, northeast China, and Nu River. Estimates suggest the total potential installed hydropower capacities of these 13 hydropower bases are 278 GW, with annual electricity generation of 1,216 TWh, accounting for 51.4% and 49.1% of the total potential installed hydropower capacities and annual electricity generation in China. Detailed data about the 13 hydropower bases are shown in Table 7.

Fig. 1. Locations of 13 hydropower bases in China.

Pumped-storage power stations exploration status

The construction of pumped-storage power stations started in north China and east China, then developed from coast to inland, from east to west. The existing power stations are mainly distributed in southern China, east China and north China (Wang, 2008).

By the end of June 2018, the total installed capacity of pumped-storage power stations was 72.64 GW, among which, 28.39 GW has been constructed and 44.25 GW is under construction, and ranking first in the world. The share of installed capacity of pumped-storage power constructed and under construction for each part of China is shown in Table 8.

The installed capacity of pumped-storage power stations is about 21.29% of total hydropower installed capacity, and 3.90% of the total installed capacity of China.

Small hydropower exploration status

The small hydropower resources located across 1,715 counties or cities in China, are mainly distributed in central, west, and east China, around 70% of which are in the Great Western Development area, and

Table 7. Summary of China's 13 hydropower bases.

No.	Bases	Location (province)	Stations amount	Total installed capacity (GW)	Annual electricity generation (TWh)	Development status (%)[a] percentage based on the installed capacity		
						Constructed	Under construction	Planning
1	Jinsha River	Sichuan, Xizang, Yunnan	12	58.58	282.6	0	35	65
2	Upstream of the Yangtze River	Sichuan, Chongqing, Hubei	11	33.197	143.8	73	12	15
3	Yalong River	Sichuan	11	25.7	125	13	33	54
4	Main stream of the Lancang River	Yunnan	15	25.11	120.3	19	40	41
5	Dadu River	Sichuan	22	24.92	113.6	13	18	69
6	Nu River	Yunnan	13	21.99	103.7	0	0	100
7	Upstream of the Yellow River	Qinghai, Gansu, Ningxia	28	20.93	75	65	6	29
8	Nanpan River-Hongshui River	Yunnan, Guizhou, Guangxi	12	14.3	63.5	47	49	4
9	Northeast China	Heilongjiang, Jilin, Liaoning	62	13.26	35.5	43	4	53
10	Fujian-Zhejiang-Jiangxi Area	Fujian, Zhejiang, Jiangxi	65	12.2	31.5	68	3	29
11	Wu River	Guizhou, Chongqing	12	11.22	39.6	82	18	0
12	Western Hunan	Hunan	51	10.8155	37.8	68	9	23
13	North mainstream of the Yellow River	Shanxi	6	6.408	17.8	20	6	74

[a]Based on the data of 2010.

Table 8. The share of installed capacity of pumped-storage power for each part of China (including constructed and under construction).

Location	Installed capacity	Share
North China	12.103	24%
East China	16.360	33%
Middle China	6.190	12%
Northeast	4.100	8%
Southwest	1.292	3%
South	10.280	20%

among which Sichuan province has the most potential technical exploitable installed capacity of 20,699 MW. According to the Summary on General Report of Investigation and Evaluation Results of Rural Hydropower Resources of P.R.C. (2008) Rural Hydropower Resources and Its Distribution, the technical exploitable installed capacity and electricity generation of each province are shown in Table 9.

By the end of 2017, the installed capacity of small hydropower was 79.27 GW, accounting for 62% of the technical exploitable hydropower installed capacity, the annual electricity generation was

Table 9. The technical exploitable small hydropower resources for each province.

Province	Technical exploitable installed capacity (GW)	Annual electricity generation (TWh)
Northeast China		
Heilongjiang	3.221	7.724
Jilin	1.662	5.647
Liaoning	0.667	1.889
North China		
Beijing	0.186	0.421
Tianjin	0.005	0.02
Hebei	1.206	3.849
Neimenggu	0.658	2.129
Shanxi	0.853	3.381
Shandong	0.064	0.159
Henan	0.875	3.109
Northwest China		
Xinjiang	7.507	33.221
Shaanxi	3.116	12.432
Gansu	3.96	19.283
Qinghai	2.341	10.727
Ningxia	0.013	0.036
Central China		
Hunan	8.001	30.41
Hubei	5.455	19.681
East China		
Zhejiang	4.625	12.036
Jiangsu	0.058	0.173
Anhui	1.371	3.953
Jiangxi	4.229	14.716
South China		
Guangdong	6.901	23.715
Fujian	8.492	30.955
Hainan	0.632	2.269
Southwest China		
Sichuan	20.698	108.313
Guangxi	5.193	21.667
Yunnan	16.33	76.907
Guizhou	7.335	25.606
Chongqing	3.33	13.217
Xizang	9.047	47.401

247.72 TWh, accounting for 46% of the technical exploitable hydropower annual electricity generation. East and central China have higher development rates. For the installed capacity of small hydropower, the stations with installed capacity less than 0.01 GW are 15.5% of the total installed capacity, the stations with installed capacity more than 0.01 GW and less than 0.1 GW are 37.3% of the total, and the stations with installed capacity more than 0.1 GW are 47.2% of the total. The annual electricity generation of the small hydropower for 2017 was 20.7% of the total hydropower annual electricity generation. The installed capacity of small hydropower by the end of 2017 for each province is shown in Table 10.

Table 10. The installed capacity of small hydropower by the end of 2017 for each province.

Province	Installed capacity (GW)	Technical exploitable installed capacity (GW)	Percentage (%)
Xinjiang	1.64	7.507	21.85
Shaanxi	1.50	3.116	48.14
Gansu	2.63	3.960	66.41
Qinghai	1.10	2.341	46.99
Hunan	6.36	8.001	79.49
Hubei	3.81	5.455	69.84
Zhejiang	4.05	4.625	87.57
Anhui	1.11	1.371	80.96
Jiangxi	3.40	4.229	80.40
Guangdong	7.60	6.901	110.13[a]
Fujian	7.42	8.492	87.38
Sichuan	11.79	20.698	56.96
Guangxi	4.59	5.193	88.39
Yunnan	11.98	16.33	73.36
Guizhou	3.48	7.335	47.44
Chongqing	2.67	3.330	80.18
Others	4.14	19.148	21.62

[a]The data of technical exploitable installed capacity are based on the General Report of Investigation and Evaluation Results of Rural Hydropower Resources of PRC, which was finished in 2008, while the installed capacity for Sichuan province in 2017 is 7.6 GW, more than the technical exploitable installed capacity. The incomplete data of 2008 may lead to the conflict, while there is no renewed data of the technical exploitable installed capacity that can be obtained for now.

Global status of China's hydropower development

The total global hydropower installed capacity by the end of 2017 was 1,267 GW (including pumped storage) with an estimated 4,185 TWh electricity generated from hydropower in 2017 (International Hydropower Association, 2018). The five countries with the largest individual increases in 2017 were China (9.1 GW), Brazil (3.4 GW), India (1.9 GW), Portugal (1.1 GW), and Angola (1.0 GW). The total hydropower installed capacity of the top ten countries by the end of 2017 is shown in Figure 2.

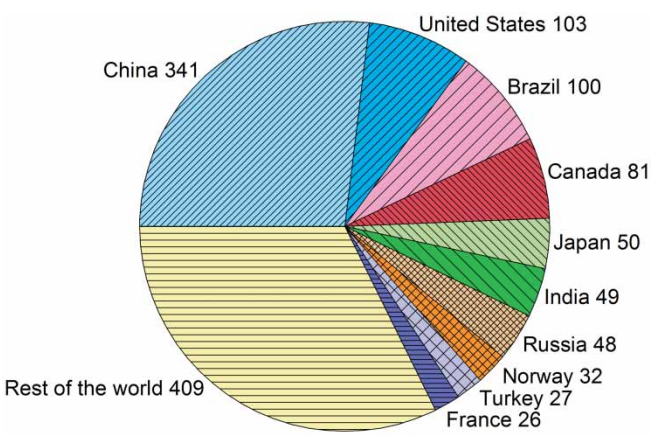

Fig. 2. Hydropower installed capacity (GW) of the top ten countries by the end of 2017.

Hydropower continues to be the foundation of China's energy transition since the government turns to renewable energy to reduce greenhouse emissions. By the end of 2017, the total hydropower installed capacity of China was 341.19 GW with 1,189.84 TWh electricity generation, accounting for 18% of the total, far more than wind (5%) and solar (2%).

Since the beginning of the 21st century, the development of China's hydropower has been remarkable. The country has quadrupled its installed capacity and undertaken over half of global hydropower growth during this period. Notable projects commissioned in 2017 included Changheba (2,600 MW), Houziyan (1,700 MW), and Miaowei (700 MW).

Prospect of hydropower development in China

After several decades' efforts, the installed capacity of hydropower in China changed from 163 MW at the foundation of PRC to 341.19 GW for 2017.

The National Energy Administration planned to increase the total conventional installed hydropower capacity to 350 GW by 2020, including 80 GW small hydropower. The annual electricity generation will be 1,322 TWh (Chen *et al.*, 2013; Department of Energy Statistics, 2015). For the east and north part of China, including Beijing, Tianjin, Hebei, Shandong, Shanghai, Jiangsu, Zhejiang, the total installed capacity will be 35.2 GW, about 10% of the national total amount; the exploitation of hydropower almost has been done. For the middle part of China, including Anhui, Jiangxi, Hunan, Hubei, etc., the installed capacity will be 61.5 GW, about 17.5% of the national total amount; the proportion of exploitation will be above 90%. For the west part of China, the installed capacity will be 254 GW, about 72.5% of the national total amount. By the end of 2020, the installed capacity of pumped-storage power stations is planned to be 70 GW.

By the end of 2030, the conventional installed capacity of the hydropower will be 430 GW, including 340 GW normal hydropower and 90 GW small hydropower (Research Group of Energy Medium and Long Term Development Strategy, 2011; The National Development and Reform Committee, The People's Republic of China, 2017). The annual electricity generation will be 1,853 TWh. The total installed capacity of the east part of China will be 35.5 GW, about 8% of the national total amount. The total installed capacity of the middle part of China will be 68 GW, about 16% of the national total amount. The total installed capacity of the west part of China will be 326 GW, about 76% of the national total amount. The proportion of the exploitation for the west part will be 69%. By the end of 2030, the installed capacity of pumped-storage power stations will be 120 to 140 GW.

According to the Study of China Energy Medium and Long Term (2030, 2050) Development Strategy, by the end of 2050, the conventional installed capacity of hydropower will be 510 GW, including 410 GW normal hydropower and 100 GW small hydropower (Yan & Qian, 2011). The annual electricity generation will be 1,405 TWh. The total installed capacity of the east part of China will be 35.5 GW, about 7% of the national total amount. The total installed capacity of the middle part of China will be 70 GW, about 14% of the national total amount. The total installed capacity of the west part of China will be 406 GW, about 79% of the national total amount. The proportion of exploitation for the west part will be 86%. The new added capacity is mainly from Xizang Province. The objective of China's hydropower development is summarized in Table 11.

Table 11. China's hydropower development objective.

Year		2020	2030	2050
Installed capacity (GW)	Total	350	430	510
	Large- and medium-sized hydropower	270	340	410
	Small hydropower	80	90	100

Restrictive issues for hydropower development in China

Hydropower is well-known as an economic, clean, and renewable energy source, and it has been touted as one of the prioritized clean and renewable energy sources in China. Driven by the strong political willingness of energy sector decarburization and stressed air pollution, China has speeded up the development of clean and renewable energy sources, among which, hydropower is prioritized. The Action Plan for Energy Development Strategy (2014–2020) issued by the State Council in 2014 highlights the importance of increasing the share of clean energy in China's energy mix. However, hydropower development, in particular the constructions of large dams, have had some environmental and ecological impacts on the areas surrounding dam reservoirs. The historical exploration of hydropower in China was simple and did not fully take into account the impacts on the environment and ecosystem. There are some problems that may hinder the development of hydropower in China.

Negative impacts on ecological system and environment

When hydropower is touted as a solution to reduce carbon emissions, the fact that large-scale dams may result in some ecosystem damage on the areas surrounding dam reservoirs is often masked. For instance, dam construction may cause sediment accumulation in reservoirs, change the characteristics of soil surrounding reservoirs, flood unearthed cultural relics, change the water temperature and water quality, influence the habitats of fishes and affect local biodiversity. Dams and associated hydropower stations can also change the amount of river flow and influence the downstream water supply (Zhang, 2010).

The hydropower development of Hongshui River has an impact on water temperature. It includes ten cascades. The tier 1 cascade of Tianshengqiao reservoir results in a reduction in water temperature by 3.9 °C to 6.3 °C of inflow to the downstream Longtan reservoir, impacting crops and fish.

Siltation and potential algal bloom could be a problem for the Three Gorges Dam. When water flows, it has the ability to transport particles heavier than itself downstream. This has a negative effect on dams, and subsequently, their power stations, particularly those on rivers or within catchment areas with high siltation. There are large amounts of sediment in the rivers since the Three Gorges Dam started to impound water in June 2003. Concentrations of nitrogen and phosphorus of rivers have increased as well. For instance, the TN (total nitrogen) and TP (total phosphorus) of Wu River has exceeded the limits that implicate a high likelihood for algal bloom.

China has prioritized the ecosystem health issue as the highest political strategy. It is critical for China to address the environmental and ecosystem challenges associated with hydropower development.

Challenges for resettlement of displaced indigenous

Most hydropower projects are in remote and underdeveloped areas where the indigenous people are often uneducated and have the lack of skills to live well in a new place. China has issued a variety of policies for resettlement associated with dams and reservoirs' construction since the 1980s; however, it is not just a simple relocation of people and the displaced persons need more help to resettle.

Weak management of hydropower investors and developers

Currently, China has assigned private investors to develop and manage all hydropower infrastructures along a specific river and allowed different investors to participate in various cascade developments of a river. However, hydropower developments require good collaboration between various cascades, between upstream and downstream, and between various water users and stakeholders within the basin. China needs a better basin-wide management to coordinate and manage the hydropower investors and developers.

Unmatched distribution infrastructure for hydropower production

The distribution system of hydropower has lagged behind the construction of hydropower stations (Ma & Chen, 2017). China has planned and constructed many large-scale hydropower projects in western China in the 10th Five-Year-Plan, which are expected to serve themselves and eastern provinces in the 12th Five-Year-Plan (referred to as the strategy of 'Western Electricity to East'). The unmatched distribution system will result in the surplus of electricity production in western areas.

Conclusion

Hydropower is a renewable clean energy, which can improve the environment and protect it. At present, global power production is still dominated by mineral fuels that results in higher CO_2 emissions and air pollution. Developing hydropower energy instead of mineral power generation as far as possible may promote energy sustainable development, reduce CO_2 and pollutant emissions, and accelerate social and economic development. Hydropower construction can also prevent floods and droughts, reducing natural disasters.

China has abundant hydropower resources. After the efforts of 70 years, especially in the latest 20 years, hydropower in China has been greatly developed. China Energy Medium and Long Term (2030, 2050) Development Strategy indicates that China's hydropower will continue to develop rapidly in the next 30 years. By 2050, China's installed capacity of hydropower will be close to the technical exploitable capacity. China's hydropower will play an important role in national economic development, environmental protection, and energy sustainable development.

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